Out of date

This report has been withdrawn because it is out of date.

For a copy of the updated River Severn drought order environmental report please contact the Environment Agency.

River Severn Drought Order Environmental Report

APPENDICES

(Working Draft)

Version 7 - December 2013

APPENDICES CONTENTS

Appendix A

Designated sites in Hydrological continuity with the River Severn

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
Upper Severn					
1	Plynlimon	SN 790870 SN 830950	SSSI	An important upland area with extensive areas of blanket bog where the River Severn rises. As it's the source of the river is above the regulated stretches therefore the Drought Order will not have any impact on this site..	All Flows
2	Dol-llys, Llanidloes	SN 9608 8576	County Wildlife Site	An old in-filled oxbow lake. Great crested newts present. Possibly fed by gravels since mimics river levels.	All Flows
3	River Severn, Dolwen (including Llandinam gravels)	SO 0219 8804	Montgomery Wildlife Trust Reserve Proposed geological/ geomorphological SSSI. Geological Conservation Review (GCR) site	Braided river channel with gravel beds and associated shingle banks (including Llandinam gravels), also contains old oxbows. Conservation importance for invertebrates on shingle banks, birds including little ringed plover, and spawning salmonids. It is more likely to be affected by flooding and especially a prolonged rainfall event following a drought Still not yet designated as a SSSI however is included as one of 19 GCR sites included in the Fluvial Geomorphology of Wales. There is no individual site report available giving further details.	All Flows
4	Red House, Abermule	SO 1499 9398 (EA report SJ 170967)	Montgomery Wildlife Trust Reserve	A large wet meadow including oxbow, river terraces, reed swamp and carr (wet) woodland. This is connected to the river but also gets flooded. The biggest issue affecting this site is the loss of water supply from the canal via leakage due to canal repairs.	All Flows
5	Montgomery Canal	SO 139 925 (EA report SJ 245100!)	SSSI and SAC all along its length to Llanymynech for floating water plantain Luronium natans	The canal runs adjacent to River Severn to Buttington. It is fed by water taken from the Severn at Newtown, and the River Tanat at Carreghofa. All water abstracted is returned to the River Severn. This site is at risk from low flows in the river particularly since the abstractions which feed the canal are firmly tied into river regulation. **This site will be addressed in more detail in the**	All Flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				Habitats Directive Assessment.	
6	Dolydd Hafren, Forden	SJ 2083 0106	Montgomery Wildlife Trust Reserve	100 acres flood plain, old oxbows, shingle, arable and grassland. Marsh vegetation including Welsh mudwort Limosella australis. Invertebrates associated with shingle and bird interest – little ringed plovers, barn owls. Thought to be connected to the River Severn.	Flood primarily
7	River Severn, Leighton	SJ 610 048	Not designated but mentioned in County Flora.	Welsh mudwort Limosella australis found along the banks of the River Severn near Leighton. More related to flooding	Flood primarily
9	Severn-Vyrnwy confluence	SJ 327 158	No designation but Countryside Agency Land Management Initiative area	Severn Vyrnwy Project was an initiative which created additional wetlands through land management measures such as CSS and HLS. The Agency has also created numerous additional ponds and wetland sites within this area.	Flood primarily
10	Loton Loop	SJ 3640 1590 (EA report SJ349167)	County Wildlife Site	Area used for flooding. High wildlife value including botany and wintering waterfowl. Ditch feeds to and from River Severn therefore is linked hydraulically.	Flood primarily
11	Military training area at Nesscliff	SJ 3700 1600	Potential County Wildlife Site but not designated at present.	Waterfowl and BAP species use site. Southern section definitely hydraulically linked.	All Flows
Middle Severn					
12	Attingham Park, Shrewsbury	SJ 552 091	SSSI	Wetland habitats including wet woodland. Monitoring already in place but very basic and only checked once a week. The Agency is working closely with the National Trust (estate owners) to effect on-going wetland and flood plain habitat improvements associated with the Rivers Tern and Severn.	Flood primarily
13	Cound Brook	SJ 565 062	County wildlife site	Rich biota.	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
14	Cressage	SJ 591 051	County Wildlife Site	Siltbed of River Severn with willow carr.	All flows
15	Severn Meadow (W. Bank)	SO 743 854	County Wildlife Site	Woodlands and wet meadows, only meadow in hydrological continuity.	All flows but flood primarily
16	Borle Brook	SO 751 817	County Wildlife Site	Dingle woodlands, steep sides, wet at bottom. Stream is in continuity with River Severn.	All flows
17	Dowles Brook	SO 778 763	Included in Wyre Forest SSSI	The brook provides varied habitat, with the banks being good for bryophytes. White-clawed crayfish, salmon, bullhead, and brook lamprey present in stream.	All flows
18	Grimley Brick pits.	SO 840 605	SSSI	This site consists of a number of old clay workings on the banks of the River Severn. Wide range of wetland habitats and important for specialised aquatic plants, wintering wildfowl and breeding bird assemblages as well as a varied invertebrate fauna. They remain wet because of seasonal flooding and impeded drainage.	Flood primarily
19	Northwick Marsh	SO 835 579	SSSI and Special Wildlife Site	Species-rich marsh occupying disused brick-pits, used for grazing. Site also includes part of the river bank. Marsh is extensively flooded in winter and spring.	All flows but primarily flooding
20	River Teme	SO 121 848 to SO 850 525	SSSI (also supports Habitat Directive species)	Second largest tributary of the River Severn. Represents near-natural biologically rich river type associated with seashore and mudstone. Supports significant river plant, fish, bird and invertebrate communities. Also otters. EC Habitats Directive Species: twaite shad; sea lamprey; salmon; bullhead, grayling and Atlantic stream crayfish.	All flows
21	River Clun	SO 395 767 to SO 402 738	SSSI and SAC	Stream, floodplain, grassland and woodland of 14.93 ha. Designated a SAC due to presence of Freshwater Pearl Margaritifera margaritifera which are dependent on low sediment and nitrate levels, fast flows of cool water and clean gravels. It also relies on the presence of trout and Atlantic salmon for part of its breeding cycle therefore the river's hydrological continuity with the River Severn and the estuary is important. Also supports white-clawed crayfish, brook lamprey, bullhead and otter. **This site will be addressed in more detail in the**	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				Habitats Directive Assessment	
22	Droitwich Canal	SO883625, SO922630, SO848599	Special Wildlife Site	Canal supporting salt loving flora. Tributary of River Severn.	All flows
23	Staffordshire & Worcestershire Canal	SO830763 SO853819 SO810710	Special Wildlife Site	Canal supporting wildlife. Tributary of River Severn.	All flows
24	The Werps, Banks of River Severn	SO 670 040	County Wildlife Site	River bank.	All flows
25	Shrawley Wood	SO 808660	SSSI	A large tract of ancient woodland with streams & pools in connectivity with River Severn which add to the site's conservation interest	All flows
26	Redstone LNR (The Bogs)	SO 811703	LNR and Special Wildlife Site	Marshland and flood plain adjacent to River Severn.	Flood primarily
27	Bournes Dingle and Turnmill Pond Complex	SO841618	Special Wildlife Site	Mosaic of habitats including wetlands adjacent to the River Severn.	Flood primarily
Lower Severn					
28	Upton Ham	SO 860 400	SSSI	Unimproved flood meadow, regularly flooded during the winter. Good for waders. White-legged damselfly and club-tailed dragonfly breed along this section of river.	Flood primarily
29	Severn Ham	SO 885 325	SSSI	Traditionally managed flood meadow subject to annual winter flooding	Flood primarily
30	Old River Severn, Upper Lode	SO 880 331	SSSI, Special Wildlife Site	Old meander in the River Severn cut off from the main river when the Upper Lode lock was constructed; it now forms a quiet backwater; only linked to the Severn at its southern end.	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
31	Mythe Composite Site	SO 886 343	Key Wildlife Site	Lakes, gravel pits, reservoirs & Mythe Brook. Directly adjacent to River Severn	All flows
32	Ripple Meadow	SO 869 362	Special Wildlife Site	Improved flood meadow.	Flood primarily
33	Queenhill Brickpit and Uckingham Pool	SO 863 374	Special Wildlife Site	Pool on western bank of River Severn supporting rich flora	All flows
34	Brickpits Plantation & Sandford Pits	SO 846 446	Special Wildlife Site	Disused brickpits with a carr fringe; adjacent to River Severn.	All flows
35	Clifton Arles Complex	SO 847 455	Special Wildlife Site	Wet woodland on flood plain of River Severn.	Flood primarily
36	Ashmoor Common	SO 854 464	SSSI	Marshy grassland floodplain with wetland bird interest. Site is important for studies of river landform and history of the River Severn	Flood primarily
37	Kempsey Upper Ham and Lower Ham	SO 849 498, SO 845 484	Special Wildlife Sites	Improved River Severn meadow. Improved alluvial hay meadow adjacent to the River Severn	Flood primarily
38	Gloucester & Sharpness Canal	SO 750 088	Key Wildlife Site	Canal; tributary of River Severn.	All flows
39	Severn Stoke Meadow	SO 851 443	Special Wildlife Site	Alluvial flood meadow; now arable	Flood primarily
40	Ripple Lake & Napps	SO 874 364	Special Wildlife Site	Wet woodland; close to River Severn	All flows
41	Coombe Hill Canal	SO 870 269	SSSI	Disused canal with a range of flanking habitats. Supports a variety of rare plants and invertebrates, particularly beetles. Situated in a low lying area of the River Severn floodplain and whole area subject to extreme winter flooding.	All flows but flood primarily
42	Ashleworth Ham	SO 833 263	SSSI	Grassland of the Severn floodplain. Important refuge for wintering	Flood primarily

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				wildfowl. Floods annually.	
43	Chaceley Meadow	SO 857306	SSSI	Unimproved herb-rich neutral grassland occasionally flooded in winter.	Flood primarily
44	Sud Meadow	SO817187	Key Wildlife Site	Semi-natural grassland classified as grazing marsh. Directly adjacent to River Severn.	Flood primarily
45	Alney Island	SO 820 190	LNR	Flood meadows adjacent to River Severn.	Flood primarily
46	Over Ponds & Osier Bed	SO 820193, SO 817194	Key Wildlife Site	Ponds and willow carr; part of Alney Island Local Nature Reserve; in the middle of River Severn.	All flows
47	Walham Ponds (Maisemore) Brickpits	SO 825204	Key Wildlife Site	Wet woodland directly adjacent to River Severn.	All Flows
48	Longford Brickpits	SO 826210	Key Wildlife Site	Lakes, gravel pits and reservoirs with bird and invertebrate interest. Adjacent to River Severn.	All flows
49	Ashleworth Quay Brickpits	SO 819249	Key Wildlife Site	Wet woodland directly adjacent to River Severn.	All flows
50	Sandhurst Brickpits	SO 817233	Key Wildlife Site	Wet woodland directly adjacent to River Severn.	All flows
51	Groundless Pool	SO 791161	Key Wildlife Site	Pond directly adjacent to River Severn; designated for plant interest.	All flows
52	Small Reserve	SO 855287	Key Wildlife Site Gloucestershire Wildlife Trust	Mud-flat of River Severn; bird interest.	All flows
53	Walmore Common	SO 753 154	SSSI, SPA and Ramsar.	Unimproved and improved neutral grassland, marshy grassland and open water ditches. Holds internationally important numbers of Berwick's Swans over winter. **This site will be addressed in more detail in the Habitats Directive Assessment**	All flows
54	Severn & Avon Vale Project		No designation but Countryside Agency Land	The Severn Avon Vale Project was an initiative which created additional wetlands through land management measures eg CSS and HLS and the Agency has created numerous additional ponds and	Flood primarily

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
			Management Initiative area	wetland sites within this area.	
Severn Estuary					
55	Beachley & Sedbury Saltmarshes	Key Wildlife Site	ST 546906	Saltmarsh with plant and invertebrate interest; on banks of the River Severn.	All flows
56	Purton Timber Ponds	Key Wildlife Site	SO683038	Lakes, gravel pits and reservoirs; part of Gloucester and Sharpness Canal, near to canal mouth.	All flows
57	Beachley Grassland	Key Wildlife Site	ST 545922	Grazing marsh & ditches adjacent to the River Severn.	All flows
58	Sharpness Docks	Key Wildlife Site	SO 675025	Quay and dismantled railway designated for plant interest. Quay only (small proportion of the site) could be affected.	All flows
59	Severn Estuary	SSSI, SPA, Ramsar & cSAC	ST 480830	The Severn Estuary forms part of a larger area which includes the Upper Severn Estuary SSSI, Taf/Ely Estuary SSSI and Birdgewater Bay NNR and proposed SSSI. This larger area is also a Special Protection Area and part is a Special Area of Conservation and Ramsar site. The Severn Estuary lies on the south west coast of Britain at the mouth of four major rivers (the Severn, Wye, Usk and Avon) and many lesser rivers. The immense tidal range (the second highest in the world) and classic funnel shape make the Severn Estuary unique in Britain and very rare worldwide. The intertidal zone of mudflats, sand banks, rocky platforms and saltmarsh is one of the largest and most important in Britain. The estuarine fauna includes: internationally important populations of waterfowl; invertebrate populations of considerable interest; and large populations of migratory fish,	All flows

Site No.	Site Name	Grid Reference	Designation	Description	Main flow parameter (including GW); all flows or Flood primarily?
				including the nationally rare and endangered Allis Shad Alosa alosa. **This site will be addressed in more detail in the Habitats Directive Assessment**	

Appendix B

Historic Droughts; River Severn Drought Order operation 1976, 1984 and 1989

1975-1976 Drought[1]

Two Severn Drought Order applications;

- **29 July: Lower Bewdley prescribed flow from 727Ml/d to 545Ml/d & remove the compensation release obligation (18 Ml/d) from Llyn Clywedog for 6 months. Granted 6 August and operated.**
- **20 August: Abandon prescribed flow at Bewdley and move to releasing 2% of remaining storage per day subject to Bewdley not exceeding 545Ml/d. Granted 3 September but never operated, rainfall arrived.**

Flow gauging stations were not common or widespread at the time, however current analysis still shows 1976 as the most widespread and severe hydrological event for the majority of England and Wales, with subsequent droughts recording annual flows more than 30% higher than experienced in 1976 (Rodda, J.C, & Marsh, T.J. 2011 (CEH)). Estimates for the rainfall return period of England and Wales for this event vary; estimates from a 1 in 250 year to over a 1 in 1000 year (Wright, 1976) event over a 16 month period have been quoted. Local variations and different time periods make it hard to compare results. Using the Tabony technique a 1 in 200 year return period was calculated for the Severn catchment as a whole, over the 11 month period leading up to the end of August 1976, although some sub catchments experienced up to 1 in 500 year events over 3 months.

1975 had the lowest overall rainfall totals but baseflows were sufficient to maintain River Severn flows. The continuing low rainfall over winter 1975/1976 did not recharge groundwater and despite higher rainfall in 1976, a worse drought occurred. Within the Severn catchment, 1976 flows remain the lowest daily mean flows on record (e.g. Tanat, Teme and majority of the main River Severn) and many rivers in Wales were reported to have dried up or flowed through gravels below the river bed.

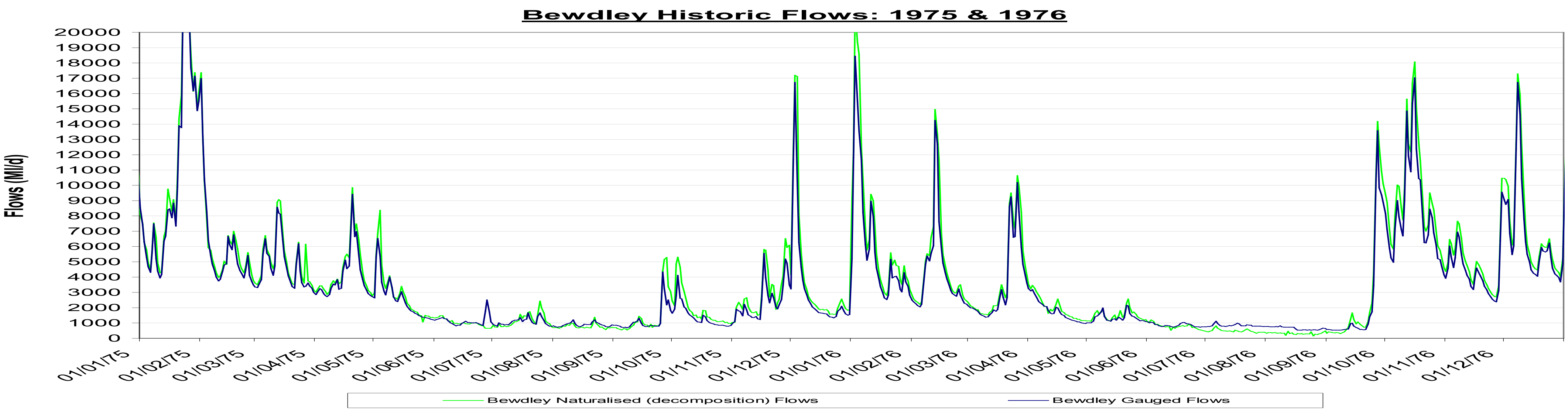
In 1976, a dry April occurred for the second consecutive year; Llyn Clywedog was at 97.6% storage when the regulation alert was issued on 22 April. High rainfall in May masked the underlying state of groundwater baseflows and hydroelectric power releases were made from Llyn Clywedog to prevent spill from the reservoir. June turned very hot and flows quickly receded with high regulation releases being needed. Thunderstorms produced brief support to the River Severn, but flows rapidly declined once the rain had passed.

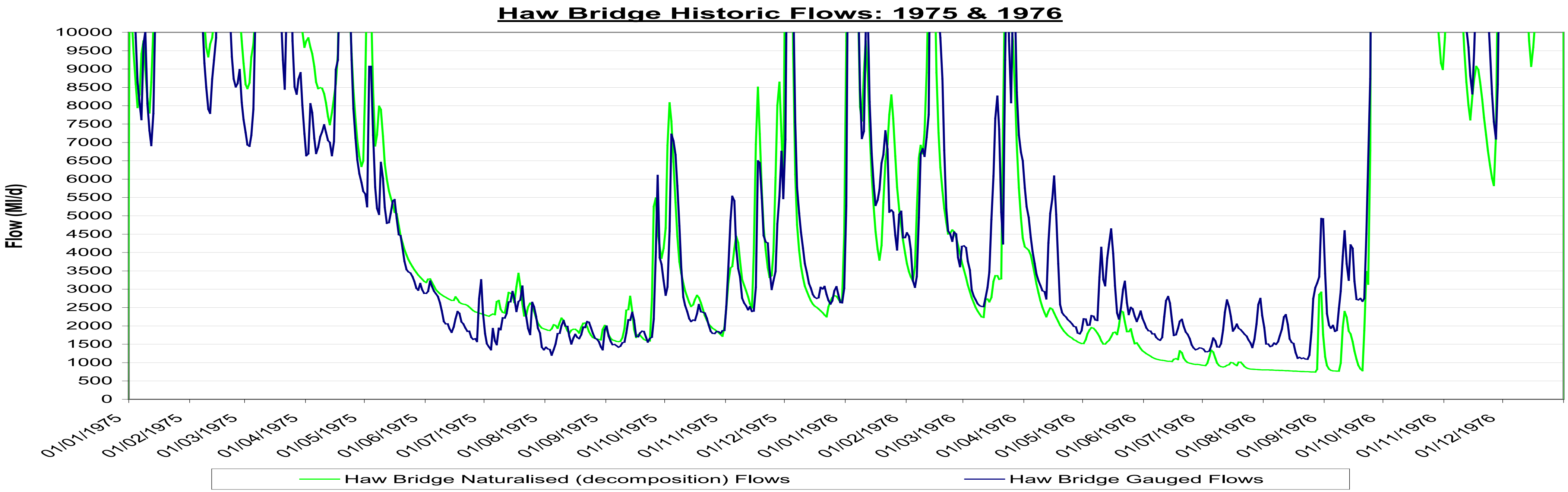
Extensive low flow gauging surveys were carried out 8-9 July and restrictions were imposed mid month on surface water abstractions from tributaries where difficulties were being experienced. On 22 July the need for a River Severn Drought Order was confirmed and an application was made on 29 July, Chelmarsh reservoir was used to balance flows at Bewdley until the drought order was granted on 6 August.

In accordance with the drought order, prescribed flows at Bewdley were lowered by 182 Ml/d, from the normal 727 Ml/d down to 545 Ml/d. August continued to be hot and dry, with more rivers drying up and abstraction demands increasing as small reservoirs and shallow groundwater wells dried up. By mid August the Authority realised the drought event was exceeding Llyn Clywedog's original design and applied for a second drought order on 20 August as projections showed only 42 days

[1] Information from reports;
Severn Trent Water Authority, Directorate of Operations. December 1977. Regulation of the River Severn – 1975 and 1976.
Severn Trent Water Authority, Report of the River Severn Basin Steering Group. October 1977. A Prescribed Flow Policy for the River Severn.
Environment Agency, Regional Scientific Department. April 1997. Low Flow Data for the Midlands Region 1975-1995.

of storage remained. The drought order granted on 3 September would have abandoned prescribed flows at Bewdley, moving to releases 2% of the remaining storage per day, subject to Bewdley not exceeding 545 Ml/d. Although the second drought order was granted, it was never operated as sufficient rainfall returned.


Bewdley Historic Flows: 1975 & 1976
Flows (Ml/d)
20000
19000
18000
17000
16000
15000
14000
13000
12000
11000
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
01/01/75
01/02/75
01/03/75
01/04/75
01/05/75
01/06/75
01/07/75
01/08/75
01/09/75
01/10/75
01/11/75
01/12/75
01/01/76
01/02/76
01/03/76
01/04/76
01/05/76
01/06/76
01/07/76
01/08/76
01/09/76
01/10/76
01/11/76
01/12/76
Bewdley Naturalised (decomposition) Flows
Bewdley Gauged Flows


Haw Bridge Historic Flows: 1975 & 1976
Flow (Ml/d)
10000
9500
9000
8500
8000
7500
7000
6500
6000
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
01/01/1975
01/02/1975
01/03/1975
01/04/1975
01/05/1975
01/06/1975
01/07/1975
01/08/1975
01/09/1975
01/10/1975
01/11/1975
01/12/1975
01/01/1976
01/02/1976
01/03/1976
01/04/1976
01/05/1976
01/06/1976
01/07/1976
01/08/1976
01/09/1976
01/10/1976
01/11/1976
01/12/1976
Haw Bridge Naturalised (decomposition) Flows
Haw Bridge Gauged Flows

The 1975/76 graphs above contain the gauged flows during 1975 and 1976, with the naturalised (decomposition method) flows at Bewdley. The minimum daily mean flow recorded at Bewdley was 517.54 Ml/d on 4 September 1976, and 1088.64 Ml/d at Haw Bridge on 23 August 1976, instantaneous values would have fallen lower than these daily averages. The most important observation from the 1975/76 graphs is the naturalised flow clearly indicates that without Severn Regulation support, flows would have been significantly lower than experienced. Even when the drought order is operated and prescribed flows reduced, the graph illustrates flows could have been up to 300 Ml/d lower still without the artificial support of the Severn Regulation system.

Environmental impacts were widespread with low flows coinciding with high ambient temperatures. Water quality did not create a major issue as the temperature promoted high biological activity both in the effluent treatment plants and the river with a consequent reduction in pollution loads. Any significant reduction in biological activity could have increased concentrations of ammonia and BOD in the river. The River Stour was commonly documented as being a ‘polluted’ river during this period, and reports acknowledged a decline in water quality on the Severn downstream of the confluence with the Stour. No major problems were encountered at the major public water supply intakes and treated water standards were maintained. Thunderstorms and high rainfall events that ended the drought did cause a drop in water quality across the catchment, but nothing could be done to prevent this.

There were concerns about saline intrusion from the Severn Estuary at the Gloucester Docks during high tides in late August. Saline water can enter the Sharpness canal and eventually cause Bristol Waterworks to shut down the intake (abstraction) at Purton. Pumping continued during the period although the total abstraction was reduced as saline levels at Purton slightly exceeded EEC guidance for surface water abstraction, however the drought ended abruptly and no further action was required.

Impacts on the Gloucester and Sharpness canal and Severn Estuary inflows seem to have been the most obvious issue, although severe problems were occurring before the Severn Drought Order was operated. High abstraction demands for the canal (lockage purposes and Bristol Waterworks Company abstraction at Purton) during low flows resulted in residual flows to the estuary being reduced to nearly zero for short periods. During peak pumping, flow in the River Severn dried up over Maisemore Weir and reduced to only a few centimetres over Llanthony Weir (lower level), shown in the photo’s below. Prior to the Severn Drought Order being operated; during June the western channel downstream of Upper Parting became choked with silt while little fresh water flow was reported in the east channel. Combined with high temperatures the result was salmon mortality and the delay of migration.

RIVER SEVERN. – LLANTHONY WEIR and EAST CHANNEL.
20th AUGUST 1976.

RIVER SEVERN. – MAISEMORE WEIR and WEST CHANNEL.
20th AUGUST 1976.

The 1976 meteorological drought officially broke at the end of August with the return of rainfall, the wettest autumn in 73 years followed. Regulation releases from Llyn Clywedog ended on 15 September although compensation releases (18.2 Ml/d) were withheld (from 6 August) until 30 November, when Llyn Clywedog reached 50% storage. Surface water abstraction restrictions were lifted on 5 October. Llyn Clywedog reached a minimum storage of 22-23% in mid September, recharging to 60% by 1 January 1977 (Elan & Lake Vyrnwy at 83%) and over 95% by February. A total 39,000 Ml was released for regulation during 1976. Between June and September 40% of releases were made for abstraction upstream of Bewdley and 42.5% were made to support the prescribed flow and therefore protect the environment (remaining releases forecasting difficulties/errors).

In 1976 reports concluded “moderate increases or decreases in the regulated flow at Bewdley would have little effect on the river or estuary” and the “circumstances [experienced] were acceptable on the basis that such “emergency” conditions were not to be expected more than once or twice in a lifetime” (River Severn Basin Steering Group (Severn Trent Water Authority), 1977). As a result of the 1975-1976 drought event, several steps were taken in water resource planning and drought management over subsequent years to increase the Severn catchments robustness. Operational drought curves for Llyn Clywedog were updated, the prescribed flow at Bewdley was raised to 850 Ml/d to buffer abstraction and improve environmental protection downstream of Bewdley, Lake Vyrnwy bank operation was formalised and further resources were developed in the Shropshire Groundwater Scheme.

The impacts observed in 1976 were largely a natural consequence of drought and would be expected to reoccur during similar events. Evidence enables the conclusion that under 1976 conditions, the Severn Drought Order alone did not cause significant adverse impacts on the environment because it continued to elevate flows above what would have naturally occurred. The potential in combination impact appears largely related to water quality and insufficient dilution for sewage treatment works. Maximum pumping into the Gloucester and Sharpness canal reduced Severn Estuary inflows to nearly zero, exacerbating saline intrusion and silt deposition, which resulted in fish mortality and migration issues.

1984 Drought[2]

One Severn Drought Order application;

- **1 August: Cap Llyn Clywedog releases to 2% of storage (no reference to prescribed flow reduction at Bewdley and flows do not consistently fall below 850Ml/d). Granted 18 August and operated.**

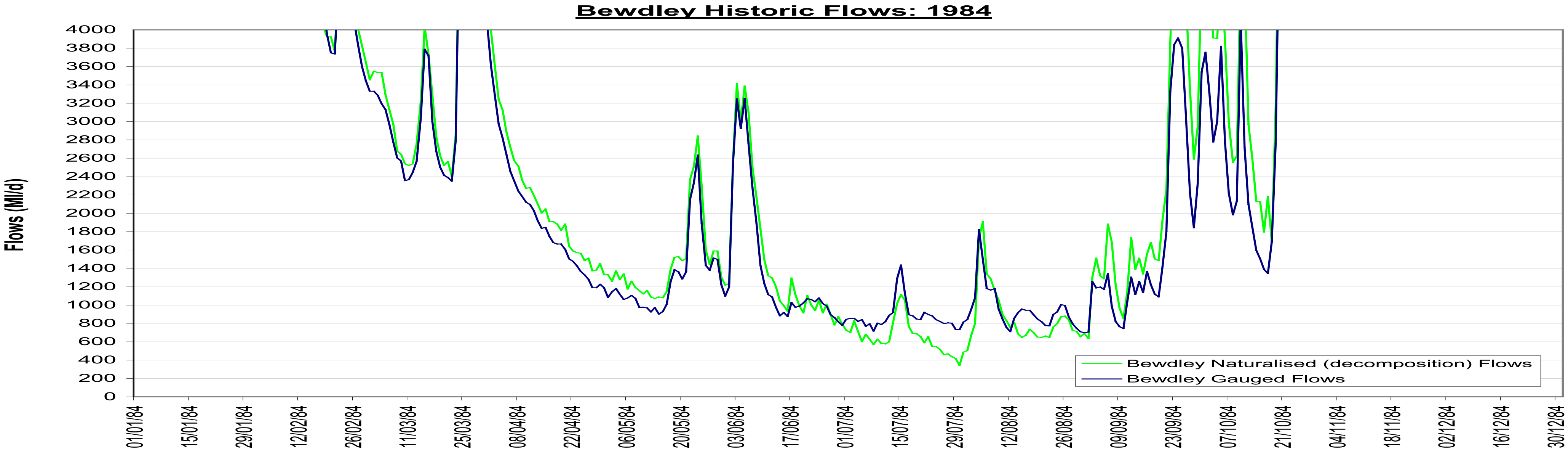
"As a whole 1984 was not an exceptionally dry year. Overall rainfall totals were not significantly below long term averages" (Hobbs, 1985). The important drivers for the Severn catchment were consistently below average rainfall over the Welsh Mountains from March to July (only 9mm in April, lowest since 1938), combined with essential maintenance work leaving Llyn Clywedog at only 85% storage when regulation began on 15 June. Flows did not reach the 1976 recorded minimums.

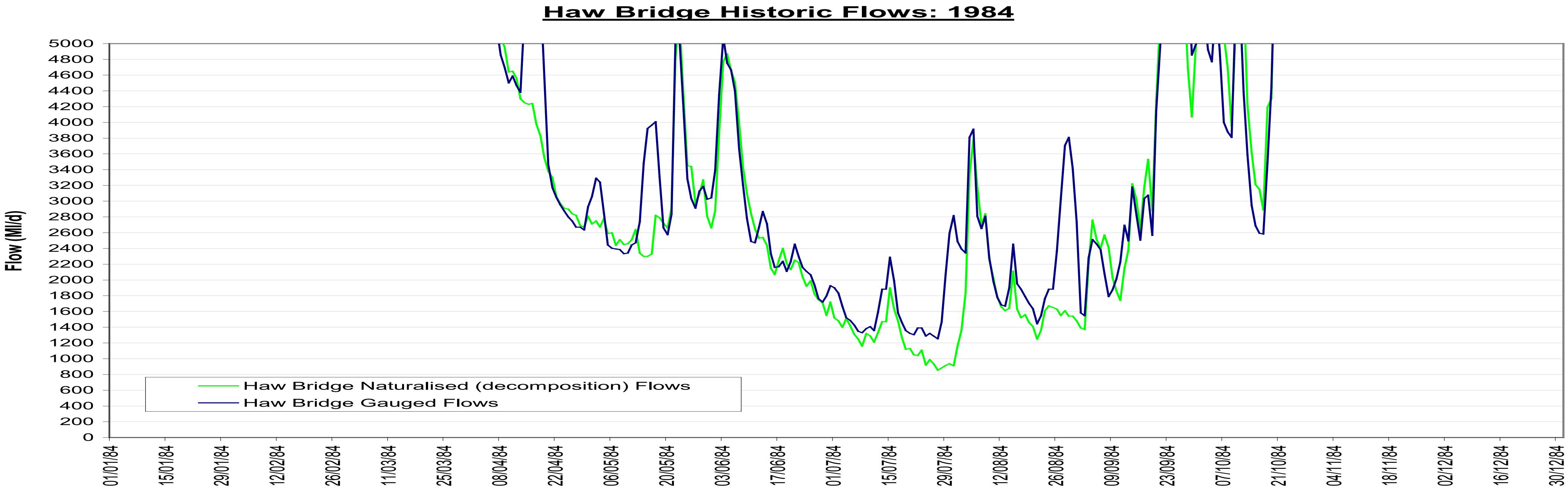
Maximum regulation was in place by 11 July and high rainfall events provided only short term relief to the River Severn. Hosepipe bans were implemented across the Severn and Trent catchments and in some areas the National Farmers Union (NFU) organised voluntary rotas for abstractors to ration the remaining resources and reduce the likelihood of further restrictions being applied. During August, drought order applications were made for Elan Valley reservoir compensation flow reductions, and for Bristol Waterworks Company to increase abstraction at Purton.

The Severn Drought Order application to cap releases from Llyn Clywedog was made on 1 August, and operated from 18 August for 2 months between 4 October and 4 December, releases from Llyn Clywedog were below the 18.2 Ml/d compensation threshold. Minimum flows of less than 2 Ml/d were recorded at Bryntail by the end of October.

No reference is made to prescribed flow alterations at Bewdley and flows did not fall below 850 Ml/d consistently enough to suspect they were altered significantly. Consequently this event does not provide information on the effects of operating a 730 Ml/d prescribed flow at Bewdley, however the 1984 graphs (next page) do again illustrate that regulation supported flows significantly higher than would have naturally occurred during a drought. Over 300 Ml/d of additional flow (above natural) was provided to the River Severn at both Bewdley and Haw Bridge. The minimum daily mean flows recorded were 707 Ml/d at Bewdley on 1 September and 1253 Ml/d at Haw Bridge on 27 July (flows in August were all above 1400 Ml/d).

2 Information collated from reports;
Hobbs, K. Date unknown. 1984 Drought – A Perspective Comparison.
Environment Agency, Regional Scientific Department. April 1997. Low Flow Data for the Midlands Region 1975-1995.


Bewdley Historic Flows: 1984
Flows (Ml/d)
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
01/01/84
15/01/84
29/01/84
12/02/84
26/02/84
11/03/84
25/03/84
08/04/84
22/04/84
06/05/84
20/05/84
03/06/84
17/06/84
01/07/84
15/07/84
29/07/84
12/08/84
26/08/84
09/09/84
23/09/84
07/10/84
21/10/84
04/11/84
18/11/84
02/12/84
16/12/84
30/12/84
Bewdley Naturalised (decomposition) Flows
Bewdley Gauged Flows


Haw Bridge Historic Flows: 1984
Flow (Ml/d)
5000
4800
4600
4400
4200
4000
3800
3600
3400
3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000
800
600
400
200
0
01/01/84
15/01/84
29/01/84
12/02/84
26/02/84
11/03/84
25/03/84
08/04/84
22/04/84
06/05/84
20/05/84
03/06/84
17/06/84
01/07/84
15/07/84
29/07/84
12/08/84
26/08/84
09/09/84
23/09/84
07/10/84
21/10/84
04/11/84
18/11/84
02/12/84
16/12/84
30/12/84
Haw Bridge Naturalised (decomposition) Flows
Haw Bridge Gauged Flows

Specific records for the environmental impacts on the River Severn during 1984 have not been found. Severn regulation stopped on 16 September with the return of substantial rainfall, Llyn Clywedog reached a minimum storage of 29% on 17 September but no record of the total regulation releases has been found. Restrictions applied on abstractors saved approximately 42 Ml/d, of which 39 Ml/d was located upstream of Bewdley.

1989 Drought [3]

One Severn Drought Order application;

- **31 August details agreed, application made on 11 September. Lower Bewdley prescribed flow reduced from 850Ml/d to 730 Ml/d over a 5 day mean. Granted 30 September.**

The National Rivers Authority (NRA) was formed in 1989, with work still transferring from Regional Water Authorities as the drought developed. The change in roles and responsibilities did impact staff resources and operations on the ground.

Meteorologically 1989 and 1990 were persistently warm and dry years. In the West (River Severn catchment), 1989 was more severe owing to longer term rainfall shortages impacting on groundwater levels and subsequently reducing baseflow to the rivers. In the East (River Trent), 1990 developed into a more critical drought year. For the Severn catchment, groundwater recharge into spring 1988 was above average, with North Shropshire recording the highest levels since 1971. Rainfall shortages began during August 1988 and extended over the winter, resulting in virtually no groundwater recharge by the end of January 1989. February to mid April saw rainfall return, but only modest recharge was recorded with the majority of groundwater sites only experiencing a slackening in the overall decline. In North Shropshire groundwater levels were lower than those recorded prior to the 1984 drought, but higher than pre 1975-1976 events. From mid April persistently dry weather returned and river recessions began.

The regulation alert was issued on 22 May 1989 and the first day considered as regulation was 30 May, however hydroelectric power releases were made from 26 May to aid with local equipment replacement. Rainfall was periodic and heavy from June into September, causing releases to be constantly changed. River flows rapidly receded once rainfall events ended, with releases primarily from Llyn Clywedog and Lake Vyrnwy. The Shropshire Groundwater Scheme alert was issued on 22 June and activated on 17 July, with bankside storage and abstraction cutbacks needed at Hampton Loade and Trimpley during August and September when recessions exceeded predictions.

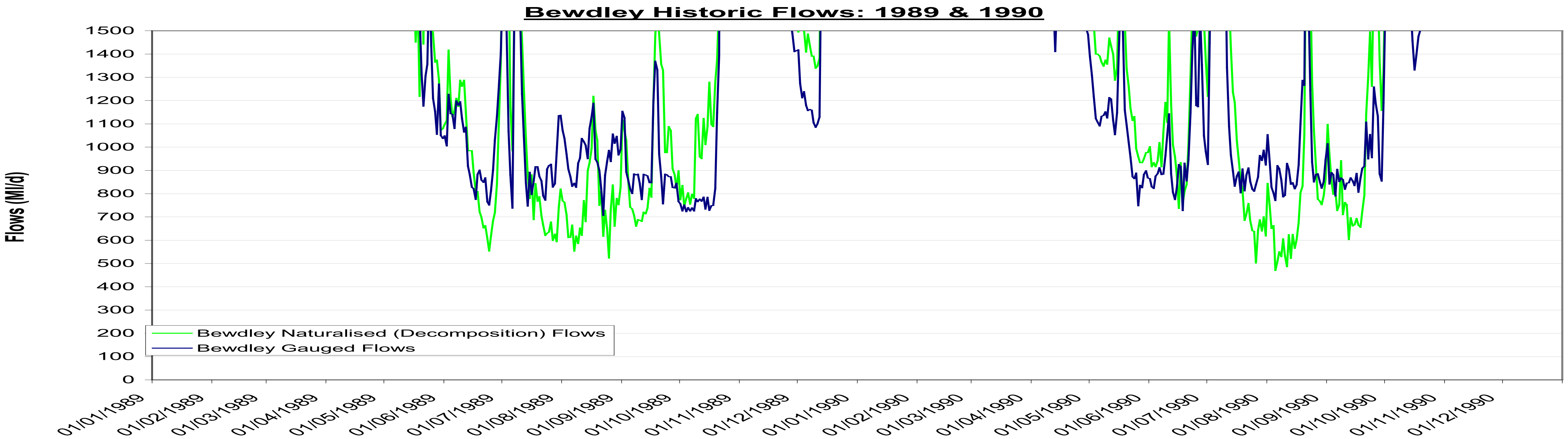
Baseflows at Bewdley dropped down to 500 Ml/d (flows to be expected without Severn regulation support), requiring high regulation support to achieve the prescribed flow. By 31 August Llyn Clywedog storage was down to 40% and a meeting was held to agree the River Severn Drought Order application. The Drought Order came into force on 30 September 1989, lowering prescribed flows at Bewdley to 730 Ml/d.

3 Information collated from reports;

NRA. Date unknown. Drought Report 1989.

Johnson, P. December 1991. NRA Management of 1989/90 Drought. (Internal Distribution only).

Environment Agency, Regional Scientific Department. April 1997. Low Flow Data for the Midlands Region 1975-1995.


Bewdley Historic Flows: 1989 & 1990
Flows (Ml/d)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300
1400
1500
Bewdley Naturalised (Decomposition) Flows
Bewdley Gauged Flows
01/01/1989
01/02/1989
01/03/1989
01/04/1989
01/05/1989
01/06/1989
01/07/1989
01/08/1989
01/09/1989
01/10/1989
01/11/1989
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01/04/1990
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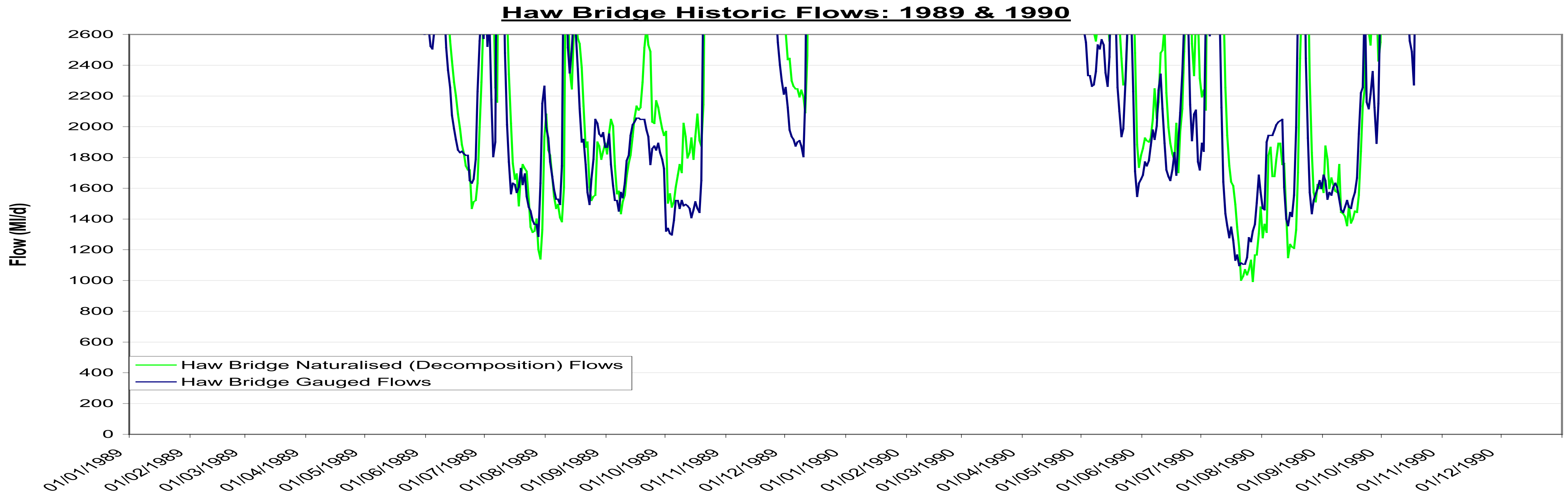
01/11/1990
01/12/1990


Haw Bridge Historic Flows: 1989 & 1990
Flow (Ml/d)
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400
2600
Haw Bridge Naturalised (Decomposition) Flows
Haw Bridge Gauged Flows
01/01/1989
01/02/1989
01/03/1989
01/04/1989
01/05/1989
01/06/1989
01/07/1989
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01/04/1990
01/05/1990
01/06/1990
01/07/1990
01/08/1990
01/09/1990
01/10/1990
01/11/1990
01/12/1990

The 1989/90 graphs contain the gauged flows during 1989 and 1990, with the naturalised (decomposition method) flows at Bewdley. Compared to previous drought event hydrographs, the River Severn Drought Order is less clear to identify (30 September) due to the short length of time it was active before significant rainfall returned and masked the effects, a total of 11 days. The Bewdley hydrograph does still clearly show flows were maintained higher than the expected natural, however by Haw Bridge the difference in flows is only marginal. For Haw Bridge more flow benefits are seen during August and September 1990, the following year.

During July and August the combined flows at Gloucester (East and West channel combined) receded to a minimum 1400-1500 Ml/d, with residual flows to the Severn Estuary (excluding Netheridge discharge) dropping to 1100-1200 Ml/d on The Canal and River Trust large abstraction days. After 1 September The Canal and River trust pumped 680 Ml/d for brief periods, reducing Estuary inflows occasionally to 800 Ml/d. On 18 October the mean daily flow after abstraction was estimated as 1130 Ml/d with an instantaneous value of 780 Ml/d. It was concluded that residual outflows into the Severn Estuary are highly sensitive to the Canal and River Trust pumping rate during periods of low river flow. However it is important to note large Salmon kills were only recorded on days when inflows were no lower 1300 Ml/d, and mainly higher than 1400 Ml/d, which did not correlate with the highest abstractions from The Canal and River Trust.

Fish kills in the Severn Estuary were recorded on 25 June (114 adult Salmon), 13 July (92 adult Salmon) and 22 July (61 Salomon). The cause was attributed to sudden oxygen depletion, with large numbers of Salmon spending long periods in the Estuary awaiting higher flows to begin migration. All significant fish kills were prior to the River Severn Drought Order application or operation.

Section 45 irrigation bans were implemented (Licences of Right not encompassed) in several regions although conflict arose with public perception as some water companies resisted implementing hose pipe bans. Across the Midlands region 4 other Drought Order applications were made by the Water Companies. In total, spray irrigation from the Severn averaged over 100 days equated to 70 Ml/d. A total of 222 licences were restricted through normal Hands off Flow (HoF) restrictions.

Problems were experienced in meeting the statutory flows at Bewdley due to the new practise of enhanced overnight abstraction at Hampton loade and Trimpley to take advantage of lower electricity tariffs. Flows fell below the minimum 650 Ml/d on a number of occasions over 6 hour periods, resulting in diurnal deterioration in water quality (ammonia and other parameters). Other problems related to excessive plant growth, particularly phytoplankton in the Severn and Avon, benefiting from the slower flows and increased nutrient, temperature and light. Major problems were also recorded for excessive blue-green algal growth (particularly Microcystis) affecting public health, water supply reservoirs and even causing livestock fatalities.

Storage in Llyn Clywedog reached a minimum 30% on 10 October, but widespread heavy rainfall between 19-20 October brought an end to the drought and River Severn regulation for 1989. Storage increased by almost 30% by mid November, with limited hydropower releases being made. Mid November to mid December saw another dry period, however above average rainfall until February brought widespread flooding across the Severn basin, and both Lake Vyrnwy and Llyn Clywedog began spilling.

Appendix C

Tabony Tables explained

Tabony tables and graphs (Tabony, 1977)

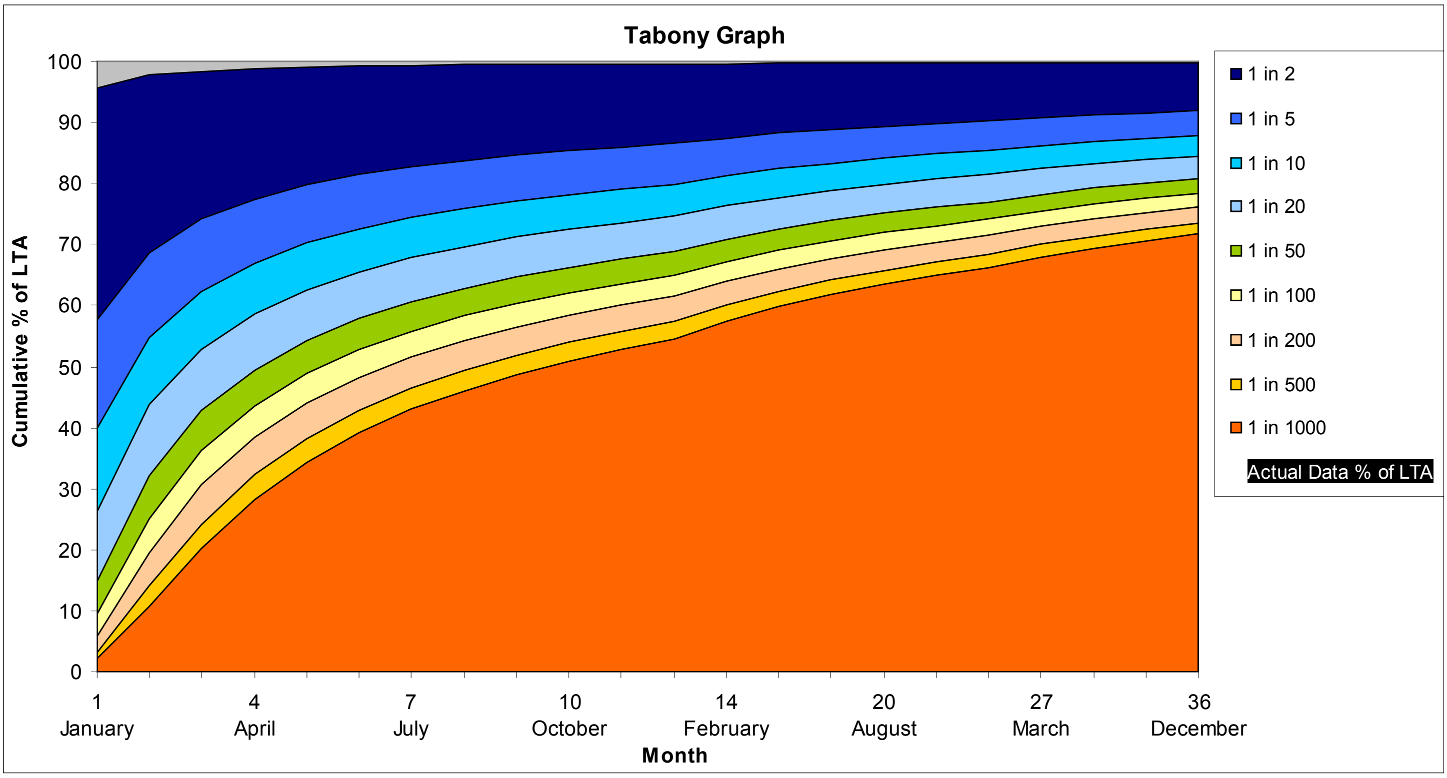
Introduction

Tabony tables were developed by Mr Tabony at the Met. Office in 1977, and remain the standard way for estimating return periods of monthly rainfall totals. They relate monthly catchment rainfall to long term average data to calculate the deficit (or excess) received and produce a return period. This information can be used as an aid in assessing the severity of drought.

The method is a combination of parametric distributions and empirical formulae that are used to define regional parameters for estimated frequency distributions for rainfall accumulations of a specific duration and starting month (from 1 to 120 months). These estimates are expressed as a percentage of a long-term average; the original tables were derived from records from 90 rain gauges across Britain, using the long term average from 1911 to 1970.

Tabony Tables are calculated locally or derived from regional estimates to provide catchment or regional tables. The results are plotted on the corresponding graph (e.g. Figure 1), which contains the return period curves and ranges, calculated from the long term data at each site/area/region etc. The return period for a given duration (i.e. whether 1 to 120 months of data is included) and date is then taken from the graph, indicating the rarity of either excess or deficit rainfall totals.

Figure 1: Example tabony Graph for the Shropshire Plains.



Methodology in more detail

The method, as described by Tabony (1977), adheres to the following assumptions:

(i) The rainfall deficit/excess (compared to the long-term mean) of d-month duration starting month m follows a modified log-normal distribution;

(ii) The parameters of the distribution can be defined using regional estimates of the coefficient of variation (Cv) and coefficient of skewness (Cs) of the series of d-month total rainfall starting month m;

(iii) (iii) Regional estimates of Cv and Cs for any d-month can be deduced from local estimates of Cv and Cs for one month using areal reduction coefficients and averaging. These are dependent on the region and on the season, but are independent of the duration.

Using various empirical formulae and data for the 90 sites over the UK for the 60-year period 1911-1970, Tabony produced maps of Cv, Cs and areal reduction factors for Britain. These were later used to produce the tables consisting of anomalies (in percentage of the long-term average rainfall) associated with their return periods.

Main Limitation

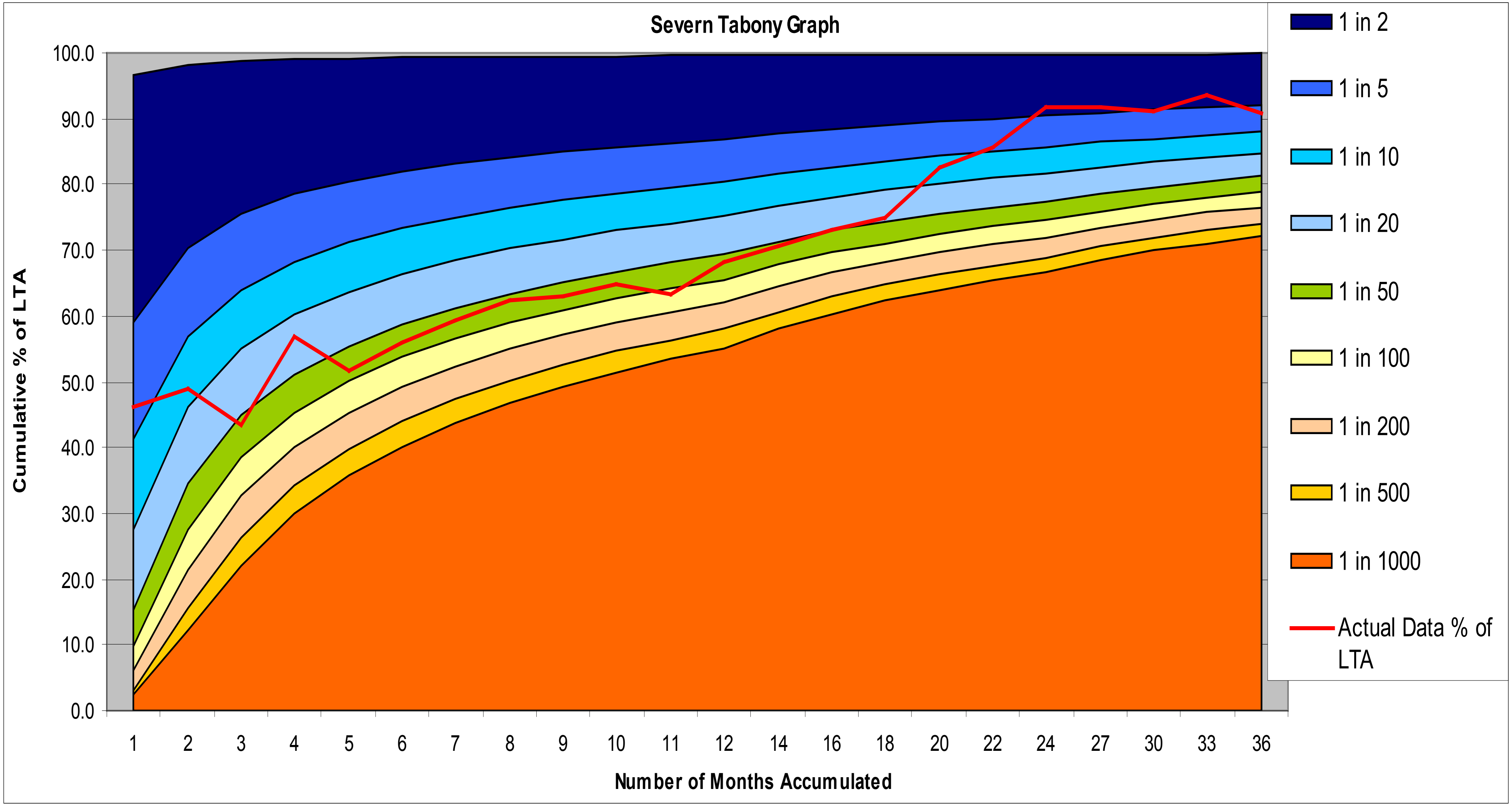
While providing adequate estimates for the majority of rare events, at present its use in the analysis of very extreme events (drought or flood) is being called into question (Hollis, personal communication).

The method described by Tabony considers accumulated rainfall over certain durations, mixing both periods of wetness and dryness. When extreme rainfall totals or deficits occur, there is a risk of bias in the estimation of the frequency.

Appendix D

1976 Tabony Graphs

Figure 1: Severn Catchment – August 1976 (River Severn Drought Order activated)



Appendix E

Water Resources Aquator Modelling – River Severn Drought Order

Severn Drought Order
Aquator Modelling Work

Environment Agency
Paul Clark (August 2011-2012)
Midlands Environment Planning

1. Introduction

The Environment Agency oversees regulation of the River Severn to maintain the prescribed flow conditions at Bewdley via release of water from Clywedog and Vyrnwy reservoirs and the Shropshire Groundwater Scheme (SGS). Our drought plan identifies that in an extreme drought additional measures may be required. The River Severn drought order includes a series of actions to preserve supplies and reduce demand during an extreme drought to maintain flows. The aim of this project was to analyse the impact of the Severn drought order and the in combination effect of water company drought permits on river flows. This information will then be used in the production of an environmental assessment of the potential impacts of the order. Further background on the River Severn drought order are included within the scoping report (Environment Agency, 2011).

The Aquator water resources model for the Severn and Wye system was used to model the drought order on the River Severn and in-combination of water company drought permits. Two rainfall scenarios were applied to assess the potential use of the drought order. The simulations were more prolonged and severe than anything previously experienced .

1.1 Overview of the model

Severn Trent Water's (STWL) Aquator model of the River Severn and Wye system was used to assess the potential changes in flow resulting from enforcing the Environment Agency drought order under different climate scenarios. The model uses a 88 year record of inflow sequences into the Severn catchment to assess water availability. Current supply and demand constraints have been built in so that all major licensed abstractions and discharges are accounted for. Major urban areas are presented as a series of demand centres, each contains a demand profiles and will try to draw water from the surrounding area to meet the required need. River Severn Regulation is also included within the model. During regulation periods the primary river channel flow is maintained by releases from Clywedog & Vyrnwy reservoirs and SGS.

The model used was that produced by STWL for the 2010 final water resources management plan (WRMP). It is worth noting that some minor improvements by STWL have been undertaken since the final water resources management plan. The current version, includes the most update version (spring 2011) inflow sequences and the parameter sets available.

1.2 Rainfall scenarios

Climate change is recognised as one of the most pressing environmental challenges. There is strong evidence for changes in the amount and distribution of rainfall and an increase in temperature. In the Midlands we can expect hotter, drier summers with more extreme weather events such as droughts.

A comparison of the 1976 drought monthly rainfall totals relative to Long Term Average (LTA) is presented in Figure 1.1 for Hampton Loade (Shropshire). The figure shows an extensive dry period between summer 75 to Sept 76, with rainfall totals typically less than the Long Term Average (LTA). Warm summers and comparatively little runoff or aquifer recharge during the 1975/76 winter caused river levels to fall to lower than previously recorded.

The drought 1975-76 abruptly ended in September 1976. If September and October rainfall had not occurred river levels would have continued to decline with increasing pressure on wildlife and water supplies. This study seeks to simulate such an 'acute' scenario. In addition we will model an even more severe 'chronic' scenario with the occurrence of a further dry winter (1976-77) designed to severely test the environmental impact of such a dry period.

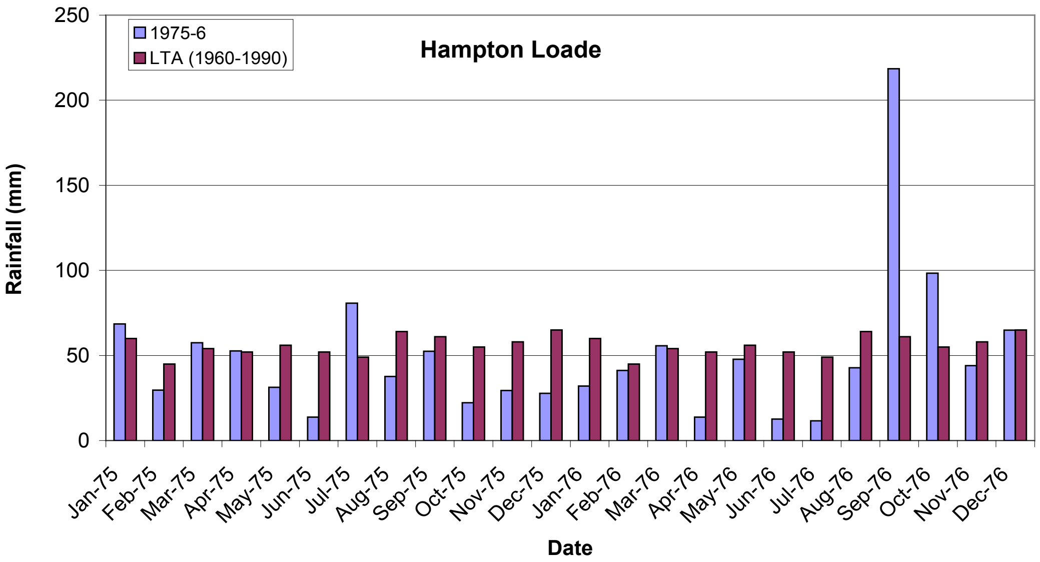


Figure 1 Daily Rainfall totals at Hampton Loade (Shropshire) during 1975-76. Data supplied by the Met Office (site: 436697)

Before Aquator modelling can be conducted, background flows needed to be calculated. Background flows are the amount of water that enters the river channel via surface runoff, interflow and baseflow. The flow in minor channels was calculated and routed/combined to determine flow in the R. Severn's individual sub catchments. These sub catchments were then imported into Aquator and added to the main river channel.

Background flow estimates were calculated by a rainfall runoff model called HYSIM. HYSIM simulates the complex system of hydrological processes involved as rainfall moves from the ground and vegetation, through or over the soil, through the aquifers and to the river allowing for evaporation and transpiration. The original HYSIM background flow set were created by consultants Mott MacDonald in 2008. These original flows were then modified by the EA to include the Acute and Chronic scenarios using the method outlined in Section 2.1 The HYSIM background flows are based on so called 'naturalised flows' although do contain irrigation and sewage discharges.

1.3 Overview of Severn Regulation

It is a statutory requirement for the Environment Agency (EA) to ensure the average flow in the River Severn at Bewdley in any period of five consecutive days is not less than 850Ml/d. This regulation of the river is conducted with the release of water from two impounding reservoirs (Llyn Clywedog and Lake Vyrnwy) and the Shropshire groundwater scheme (SGS). The order that the sources are implemented is determined by the EA Flood Forecasting Team, using hydrological data to evaluate the 'Drought Potential Indicator' (low/medium/high). The quantity of water released is then determined by: weather forecasts, current flow conditions and abstraction rates. Details of the scheme are beyond this report but can be found in EA documents:

- Operating Rules for the River Severn Resource/Supply System (2011)
- Design of Operating Rules for the Shropshire Groundwater Scheme

The Severn & Wye Aquator model has been customised by consultant Oxford Scientific Software to include Severn Regulation. The customisation uses visual basic for applications (VBA) computer language and was included in the original STWL WRMP 2010 model. The code seeks to maintain the prescribed flow at Bewdley by making regulation releases. The time of travel that the water takes between release and arrival at Bewdley has been included. For regulation water to reach Bewdley, it must be released 4 days in advance from Clywedog and Vyrnwy reservoirs and 3 days from SGS. Consequently, the model forecasts Bewdley flows several days in advance in order to calculate the required releases.

2. Methods

2.1 The River Severn Drought Order

The Environment Agency River Severn Drought Order was included in the original STWL WRMP 2010 model. The drought order in the model is instigated by the crossing of trigger control lines on Clywedog, Draycote or Elan Valley reservoir group. The curve which switches on the drought order is labelled 'level 2 demand saving curve' within Aquator. The drought order implementation occurs immediately upon reaching the trigger level, with no time delay. Once implemented the drought order will remain on for at least 100days and will not cease until 100days after trigger reservoirs have storage exceeding the level 2 demand saving curve. The hold period prevents the drought order from switching on and off in quick procession (technically termed 'hunting') and also reflects the lag time expected in its actual removal.

During regulation conditions releases can be made from Clywedog, usually up to a maximum of 500 Ml/d. Under a drought order these are capped at 300 Ml/d. The drought order reduces the prescribed flow at Bewdley to 730 Ml/d from 850 Ml/d and results in a 5% reduction in demand on non-spray irrigation licences. Combined regulation release for Clywedog, Vyrnwy and Shropshire Groundwater is also reduced to 700Mld. Once Clywedog reservoir falls to below 17.8% storage, maximum releases are then capped at 1.5% of remaining storage.

2.2 Demand

Demands at each 'Demand centre' are set using:

* Demand centre 'parameter' (demand denominator)
* Demand centre 'sequence' (provides seasonal variations in demand by a specified profile of monthly values repeated each year).
*Parameter toolbar button (commonly used to calculate 'deployable output')
The overall demand on a given day is calculated by multiplying the three inputted values (parameter, sequence, toolbar button) described above.

Demand was set based on the original demands in Aquator as used by STWL to calculate Deployable Output. The demand profile for each demand centre is based on actual demands seen during the summer of 1995 and the winter of 2001 for the summer and winter months respectively. This provides a duel peak in the profile- a peak demand in the summer due to drought conditions and a peak in the winter due to leakage. For the purpose of this project the 'demand factor' was set as 1 to reflect drought demands with the exceptions of:

- South Staffs demand centre (SSW) was kept slightly below 1995 dry year levels at 98.6% of dry year demand. The value was set in the original STWL model and not modified due to additional modelling complexities within the South Staffs Water Resource Zone (Section Limitations 2.10)
- The Forest of Dean and Stroud demand centres (STWL) were set at 89%. The value was set in the original STWL model and not modified due to additional model complexity within water resource zone.

The model has been set up to implement a hosepipe ban when reservoir storage at Clywedog, Draycote or Elan Valley reservoir group drops below the level 2 demand saving curve. This is the same curve used for drought order implementation, however unlike drought order, use of the hosepipe ban will be available in all model runs and not limited to particular scenarios. When in force a hosepipe ban reduces demand by 5%. A hosepipe ban will remain on for at least 100days and will not cease until 100days after both reservoirs have storage exceeding the level 2 demand saving curve.

2.3 Scenarios Acute/Chronic

Aquator background flow datasets for the period 1976-77 were modified in order to create two scenarios of varying drought severity. The scenarios include:

- Acute; a dry winter followed by a prolonged dry summer
- Chronic; a dry winter, a prolonged dry summer, followed by another dry winter and dry summer. The chronic scenario is more severe than acute, however, occurs less frequently.

Acute

In the Acute scenario the dry weather of 1976 summer was extended through to the end of October. September, October rainfall (Figure 1.1) was assumed to be zero and river flows allowed to continue to recess. This was conducted by exporting the original background flow data from the model, recessing the flows using regression (log linear) analysis and then importing the modified data back into Aquator.

The background flows were :

- July, Aug normal 1976 flows
- Sept, Oct flow recession continued

Reservoir rainfall time series were also exported, edited and then re-imported. The Aquator rainfall time series is used purely as a direct input over the reservoir surface area. Changing the rainfall time series is expected to have relatively small impact on modelled river flows. The majority of the modelled in-channel flow resulting from the routing of the background river flow time-series along the river.

Chronic

The Chronic scenario illustrates a dry winter, prolonged dry summer of 1976 followed by a dry winter and repeated dry summer. The scenario tests a situation where recovery of the regions water resources is hampered by low winter flows. Reservoir refill during autumn-spring 76/77 is reduced and several resources fail to reach healthy conditions before summer. Pressure on water resources steadily increases during the summer and autumn. River flows return to 1976 acute levels, reservoir levels become depleted and numerous groundwater and surface licences reach their abstraction restrictions. This has been designed to reflect a very possible, but extreme scenario using the Aquator catchment inflows:

- July, Aug normal 1976 flows
- 1/9/76 to 14/9/76 no rainfall period, flows recessed following acute methodology
- 15/9/76 to 31/5/77 repeated winter of 1975 but with 10% reduction in flow
- 1/6/77 to 31/10/77 repeat of Summer 1976, with flows September and October recessed following acute methodology

2.4 Drought Risk Indicator

Each April the Environment Agency assess the risk of failure of River Severn Regulation from drought. This forecast of the forthcoming season uses the latest groundwater levels and rainfall totals to determine the ‘Drought Risk Indicator’ (DRI). This indicator is used to determine the order which regulation sources (Clywedog, Vyrnwy reservoirs, and Shropshire Groundwater) are used. If the risk of drought is perceived ‘low’, reservoir releases are favoured. Reservoir releases do not require pumping and are hence cheaper than groundwater abstraction in terms of monetary and carbon emission. However, if drought risk is perceived ‘high’ early use of SGS is necessary. The rate of groundwater abstraction is limited by pump capacity and prolonged use of pumping is necessary to maximize the total amount of water available for regulation. Groundwater abstraction is favoured and used to its maximum capacity before reservoir releases. This preserves reservoir storage, which can be used later in the season. Medium drought risk seeks to use a mix of reservoir and groundwater release.

Aquator can not calculate the DRI and instead relies on a predefined time series supplied prior to the model run. Table 1 shows the DRI used for both acute and chronic scenarios. The DRI has been chosen to reflect the drier conditions experienced in 1975 and 1977. The current procedure of using the index to determine operation releases from the various sources was devised in 1999. It is important to note that Aquator simulates how the current operational control rules and infrastructure would deal with the hydrological conditions of the past. It does not simulate the operations/infrastructure of the past and therefore differs to those that occurred during the actual event.

Table 1 Drought risk indicator used in model runs

Year	Drought Risk Indicator
1970	Low
1971	Low
1972	Low
1973	Low
1974	Low
1975	Medium
1976	High
1977	High
1978	Low
1979	Low

2.5 Regulations components

Severn Regulation in Aquator is designed to follow operational rules set out in the Environment Agency report 'Operating rules for the River Severn Resource/Supply System (2011).' This section seeks to provide a brief high level overview of how the regulation sources are characterised within the model.

Clywedog
At 49924 ML storage capacity and only 5% dead water, Clywedog reservoir is the largest available source for Severn regulation water. Clywedog appears in Aquator as an off-the-shelf component including characteristics of: parameters, states and sequences. The component has been further customised with VBA to aid river regulation and drought order.

Releases from the reservoir incorporate :

- Severn Regulation release
- Compensation releases
- Flood drawdown releases
- Hydropower releases

Vyrnwy
Vyrnwy is mainly used by United Utilities to supply Liverpool and the North West of England, with some water available for river regulation. Vyrnwy appears in Aquator as an off-the-shelf component including characteristics of: parameters, states and sequences. The component has been further customised with VBA in order to calculate Vyrnwy Bank. The bank is the amount of water available in Lake Vyrnwy for use by the Environment Agency. It is accumulated by the storing of compensation water and an allocation from the Resident Agent. The reservoir component also includes VBA that interacts with the wider River Severn Regulation programming and to determine discharge to Unities Utilities. Releases from the reservoir incorporate :

- Transfer to Liverpool and the North West of England
- Flood drawdown releases
- Severn regulation release

The bank accumulated by storing compensation water and addition of 725ML each month (March-October) by the reservoir Resident Agent

Shropshire groundwater Scheme (SGS)
The Shropshire Groundwater scheme is made up of groups of boreholes, which draw water from groundwater reserves stored within the sandstone aquifers underlying much of North Shropshire.

Although all 8 phases of the Shropshire groundwater scheme are included within the STWL Aquator model, only four were enabled in the modelling. This reflects the current phases that could be fully operationally utilised during a drought.

Phase 5 is complete, however, groundwater contamination has reduced its potential target yield. The future operational contribution of Phase 5 is subject to the outcome of a recovery strategy and final commissioning tests. Until such a time Phase 5 will not form part of the commissioned operational Shropshire Groundwater scheme and thus has not been included in the modelling work.

2.6 Model calculations

It is beyond the scope of this document to fully detail how Aquator performs its calculations. Such information can be obtained from the Aquator user manual: A Guide to Aquator By Oxford Scientific Software Ltd (2004) http://www.oxscisoft.com/aquator/manual/01Aquator.pdf. This short section aims to provide a brief overview of the 'How does it work'.

Aquator works by moving water on a daily timestep according to the input data, operating rules built into each component, and the connectivity (the *network*) of the model.
During each day the model conducts a multi-pass calculation with five phases in which the water moves:

1. Catchments add water to river flows at the start of the day. These (background) inflows are inputted as a simple time series values.
2. River regulators augment flows in order to satisfy flow constraints and today's expected abstractions. This is further complicated by river travel lag times between abstraction and constraint, which necessitate use of flow forecasting. The flow forecasting ensures releases may also be made to satisfy flow constraints and predicted abstractions on future days.
3. Demand centres try to satisfy their demands by drawing water from available supplies, such as river/groundwater abstractions and reservoirs.
4. Reservoirs refill as necessary from their available supplies according to built-in rules governing refilling.
5. If necessary reservoirs spill into their attached river spillways.

In phases 3 and 4 water is *pulled* from supplies to demands. Components between the demand and the supply can control, disallow, decrease, or even increase, the amount requested by the demand. In the other phases water is *pushed* into the *river* part of the network.

2.7 Model output

The Severn & Wye Aquator model calculates several thousand variables on a daily basis. Much of this data is not stored as it would require massive amounts of memory and thus impractical. A set of a few hundred variables were selected for capture and investigated within Aquator. Captured variables were used throughout the project for model validation purposes and included various:

- River flows
- Pipe flows
- Pipe flow direction
- Reservoir storage
- Reservoir releases
- Regulation amount
- Demand
- Demand savings
- Licence conditions
- Groundwater releases

A subset of these were selected for export outside Aquator and into MS Excel. These exported variables have been analysed and the findings are considered here (Section 3). This subset included: flows, reservoir storage, reservoir/groundwater releases.

Flows

River gauging stations were added to Aquator to capture daily flow at:

- Immediately downstream of Clywedog Reservoir
- Immediately downstream of Vyrnwy Reservoir
- Buildwas (located immediate upstream of Ironbridge Power Station)
- Bewdley
- Saxons Loade (below catchment 'Severn to Saxons Loade' & Strensham WTW)
- Deerhurst (immediately downstream of Severn Avon confluence)
- Lower Parting (immediately below the The Canals and Rivers trust and Bristol Water abstraction). This is the lowest section of the river modelled within the Severn & Wye Aquator model.

Reservoir Storage

Reservoir storage was captured at:

- Clywedog
- Vyrnwy

Reservoir/groundwater release

Reservoir release was captured at:

- Clywedog
- Vyrnwy
- Shropshire groundwater

Model Log

A model log is also produced at the end of each run. This acts as an overall summary assessment of the water resource situation. The log includes information on:

- Total water successfully supplied to each demand centre
- Total demand centre failures (model unable to supply a demand centre with the required amount of water)
- Total of regulation releases
- Total number of days demand savings occurred
- Supply results summary

The log and the selected captured variables are saved within the model database for future use.

2.8 Water Quality SIMCAT calibration using headwater adjustment

Aquator HYSIM 'catchment' inflows series were exported.

- Acute (1970-79)
- Chronic (1970-79)
- The 'Original' STWL model, no modification (1920 to 2007)

HYSIM catchment boundaries are defined in the technical report: Beskeen, T (2008) Extension of Aquator Flow Database Motts STWL. The catchments are the summation of water that enters the main channel within a defined boundary. They do not include water routed from upstream catchments.

Acute and Chronic scenarios datasets were cropped: Acute 1/9/76 to 31/10/76 and Chronic 27/5/77 (start of regulation 2nd year) to 2/11/77. The means and Q95s were calculated for each dataset and results shown in Table 2.

From the Means and Q95s data, ratios were created of:

- o 'Original' mean/Acute mean
- o 'Original' mean/Chronic mean
- o 'Original' Q95/Acute Q95
- o 'Original' Q95/ Chronic Q95

Catchments were grouped (Table 3) and medians calculated. These medians are the final adjustments required by the SIMCAT model, the results shown in Table 4.

	Original STWL model 1920-2007 (Ml/d)		Acute Source: File: Platinum5 1/9/76-31/10/76 (Ml/d)		Chronic File: Platinum8 27/5/77-2/11/77 (Ml/d)		SIMCAT Ratio Calculations Mean		Q95	
HYSIM Catchment	**Mean**	**Q95**	**Mean**	**Q95**	**Mean**	**Q95**	**ori/acu**	**ori/chr**	**ori/acute**	**ori/chr**
Clywedog Reservoir	199.8	27.34	12.11	9.14	20.26	9.4665	16.50	9.86	2.99	2.89
Severn at Abermule	1242.92	79.7	20.59	11.38	61.34	12.2705	60.37	20.26	7.00	6.50
Vyrnwy Reservoir	382.4	60.4	25.66	19.37	43	20.073	14.90	8.89	3.12	3.01
Cownwy at Cownwy Weir	49.5	3.4	0.63	0.38	1.7	0.4	78.57	29.12	8.95	8.50
MS Vyryny Llannymynech	1714.9	57.2	5.89	2.2	35.87	2.497	291.15	47.81	26.00	22.91
Severn at Montford	893.46	154.6	64.49	54.15	88.35	55.3675	13.85	10.11	2.86	2.79
Perry at Yeaton	184.8	43.4	26.12	24.55	28	24.748	7.08	6.60	1.77	1.75
Tern at Walcott	931.2	308.34	325.44	321.6	328.63	321.5955	2.86	2.83	0.96	0.96
Severn at Buildwas	884.66	122.54	41.71	37.57	49.46	38.075	21.21	17.89	3.26	3.22
Worfe at Burcote	105.8	26.6	17.29	16.2	18.5	16.329	6.12	5.72	1.64	1.63
Severn at Bewdley	81	11.5	12.29	11.09	11.849	9.8	6.59	6.84	1.04	1.17
Stour at Kidderminster	201.1	98.1	85.32	84.57	86.1	84.669	2.36	2.34	1.16	1.16
Teme at Knightsford Brid.	1731.36	195.7	7.25	3.5	27.96	3.8465	238.81	61.92	55.91	50.88
Severn at Saxon's Lode	1140.36	260.2	92.87	86.34	107.66	87.1515	12.28	10.59	3.01	2.99
Severn at Haw Bridge	559.76	70.14	22.41	20.09	27.03	20.367	24.98	20.71	3.49	3.44
Avon at Stanford Reservoir	28.1	5.5	3.99	3.8	4.33	3.8	7.04	6.49	1.45	1.45
Avon at Stareton	166.4	32.4	24.87	23.84	27.2	23.9685	6.69	6.12	1.36	1.35
Leam at Princes Drive Wr	17.5	3.4	3.57	2.31	3.106	1.3	4.90	5.63	1.47	2.62
Leam at Eathorpe	84.6	16.3	9.04	8.73	9.3	6.5	9.36	9.10	1.87	2.51
Sowe at Stoneleigh	249.2	116.7	97.05	95.6	98.9	95.778	2.57	2.52	1.22	1.22
Avon at Evesham	718.7	144.1	106.51	104.78	109.4	104.9975	6.75	6.57	1.38	1.37
Severn at Gloucester Dks	693.16	76.54	34.12	32.09	38.43	32.3475	20.32	18.04	2.39	2.37
Lugg at Lugwardine	923.4	222.54	93.84	84.08	122.97	85.258	9.84	7.51	2.65	2.61

Table 2 Analysis of Aquator catchment flow series (file:raw flows used combined WQ, July/11)

Table 3 Combined catchments

Headwater	Catchments
Buildwas H	Severn at Abermule
	Clywedog Reservoir
	Severn at Montford
	MS Vyryny at Llannymynech
	Vyrnwy Reservoir
	Cownwy at Cownwy Weir
	Perry at Yeaton
	Tern at Walcott
	Severn at Buildwas
Buildwas S	Perry at Yeaton
Bewdley Saxon L	Worfe at Burcote
	Severn at Bewdley
	Stour at Kidderminster
	Teme at Knightsford Bridge
	Severn at Saxon's Lode
Haw B Deer Hurst Hook Cliffe	Severn at Haw Bridge
	Avon at Evesham
	Avon at Stanford Reservoir
	Avon at Stareton
	Leam at Eathorpe
	Leam at Princes Drive Weir
	Lugg at Lugwardine
	Sowe at Stoneleigh

Table 4 SIMCAT calibration values (File:raw flows used combined WQ, July/11)

Headwater reference location			Flow headwater adjustments (SIMCAT ratios)			
			Acute		Chronic	
			/mean	/95%	/mean	/95%
2001	Bewdley	R.Severn_13	6.59	1.64	6.84	1.63
2003	Vyrnwy Weir	R.Vyrnwy	see below			
2032	Saxon's Lode	R.Severn6.59	6.59	1.64	6.84	1.63
2057	Haw Bridge	R.Severn	6.90	1.46	6.53	1.98
2109	Bryntail	R.Clywedog	see below			
2134	Buildwas H	R Severn	16.50	3.12	10.11	3.01
2134	Buildwas S	R. Severn	7.08	1.77	6.60	1.75
2606	Deerhurst	R.Severn	6.90	1.46	6.53	1.98
n/a	Hook Cliffe	R. Severn	6.90	1.46	6.53	1.98

2.9 Drought permits

Severn Trent's WRMP2010 Severn & Wye model was modified to include permits/orders in order to assess their impact on flows. This customisation of the model was programmed using Visual Basic for Applications computer language, a task undertaken in-house by the Environment Agency.

Permits/orders were added following the specifications published in current water company drought plans, with the exception of DCWW (currently in draft form). Small permits/orders (typically <3Mld) on the R.Wye were omitted due to limitations in model accuracy and the decision to focus effort to produce a good representation of the larger permits/orders.

Drought permits were implemented immediately upon meeting trigger conditions. No lag time delays have been added as administrative applications for the permits were assumed complete prior to the trigger. Once triggered the drought permit will remain on for at least 150 days minimum period. Removal of the permit will only occur 150 days after the trigger conditions are no longer true. This use of 'hold periods' prevent the drought permit switching on and off in quick procession ('hunting') and reflects the lag time expected in permit removal. Permit removal is further complicated by the order that the model executes the code. If abstraction constraints have been modified, the licence states need to be saved prior to the permits implementation. These saved states can then be reloaded when the drought permit is removed. Saved states are only used for the transitional day as licences will be recalculated the following day.

This is believed to be the most detailed study of permits/orders in-combination on the River Severn. Previous studies have predominantly considered drought permits/orders in isolation and ignored the interaction between companies. In addition water company permits are often in conflict with the Environment Agency Drought Order. The company permits/orders often seek to relax restrictions on abstraction licences which would be in conflict with EA's Drought Order. The in-combination study aims to provide a more holistic approach including the combined effect of permits/order along with the Environment Agency Drought Order.

Water company drought permits for SSW, Unities Utilities (UU), STWL and DCWW have been included in the investigation. These permits/order are considered here:

2.9.1 South Staffs Water

South Staffs Water have proposed two options for a drought permit at Hampton Loade. Scenario 1 is believed more likely and therefore selected for use in the in-combination study.

Hampton Loade Drought permit Scenario 1

Trigger: The need for the drought permit at Hampton Loade could occur if storage level at Blithfield was below the Implement Drought Permit trigger curve and the EA had implemented the River Severn Drought Order. The EA drought order resulting in a 5% reduction in abstraction restriction at Hampton Loade.

Implemented: Under this scenario the company would consider applying for a drought permit which would enable a 5% increase in abstraction licence (i.e. back up to the level of abstraction permitted prior to the EA's drought order).

Source of information: Drought Plan (2007)

2.9.2 United Utilities

Lake Vyrnwy

Trigger: The earliest the permit would be implemented is when trigger 4b for the 'Integrated Resource Zone' (Haweswater and Dee reservoirs storage) is reached. However, the UU 'Integrated Resource Zone' is not included in the STWL Aquator model. Consequently the Elan Valley Group has been used as a surrogate in order to trigger the permit.

Implemented: On implementation the drought permit would reduce compensation flow from Lake Vyrnwy from 45 to 25.0 Ml/d. The difference would not be credited to the EA Water Bank for River Severn Regulation but instead left in the reservoir for UU abstraction.

Source of information: Final Statutory Drought Plan (2008). UU are currently revising their Drought Plan and slight variations in the actual trigger are expected.

2.9.3 Severn Trent Water

2.9.3a River Wye at Wyelands

Trigger: When the flow in the River Wye at Redbrook is less than 1209 Ml/d and Elan Reservoir storage is below the Elan storage licence rule trigger curve the permit will be implemented.

Implemented: The drought permit authorises the abstraction up to 45.5 Ml/d at Wyeland.

This Drought Permit will authorise additional abstraction from the River Wye.

Source of information: Drought Plan (2009)

2.9.3b Trimpley

Trigger: Elan Valley Reservoirs storage is below the Elan Valley Licence Rule curve and flow to Frankley has been reduced to 327Ml/d.

Implemented: The drought permit seeks to:

- Suspend the daily abstraction restriction under maximum regulation
- Suspend the constraint limiting abstraction over the first 100 days of river regulation. This will enable the abstraction up to 180Ml/d at Trimpley (200Ml/d with the 20 Ml/d transfer from Hampton Loade).

- Suspend the joint licence constraints after 100 days of regulation at Trimpley and Hampton Loade . The daily maximum of 272Ml/d (max reg.) will revert back to 400Ml/d and the seasonal limit removed.

- suspend the daily abstraction restriction under maximum regulation;
- suspend the joint licence constraints at Trimpley and Hampton Loade WTW.

Source of information: Drought Plan (2009)

2.9.3c River Leam at Eathorpe and Avon at Stareton: Draycote

Trigger: According to the STWL drought plan the Draycote triggers are:
Trigger 1: "We are currently liaising with the Agency to agree the best way forward to manage a drought in the highly regulated river catchment."
Trigger 2. A drought alert line for action has been developed for Draycote Reservoir. For the purposes of this study only trigger 2 has been included as trigger 1 does not have a quantitive value.

The drought permits seeks to:

- Authorise abstraction at Eathorpe on the River Leam to Draycote at any time of year when the storage condition at Draycote Reservoir would normally prohibit such abstraction.
- Relax the prescribed flow in the River Leam at Princes Drive Weir in Leamington from 18Ml/d to 12Ml/d.
- Reduce the hands-off flow in the River Avon at Stareton of 45Ml/d to 35Ml/d.

Source of information: Drought Plan (2009)

2.9.4 Dŵr Cymru Welsh Water

Details of DCWW's drought permit/orders will not be included until their Drought Plan is officially published. Two drought permit/orders have been considered within the modelling for the River Severn Drought Order.

Source of information: Draft Drought Plan (Not Published).

2.10 Limitations

Whilst the current Severn & Wye model is believed the most complete water resource planning model available for the River Severn, there are limitations to its ability to simulate a drought.

Aquator makes decisions using strict operational rules. The model cannot account for human modification/intervention producing deviations in these rules. For example:
The EA modifying the order in which it uses regulation sources (Clywedog, Vyrnwy and Shropshire groundwater). In addition during a drought, water companies would make several supply and demand side drought management options, not included within the model. These include:

Supply Side
*Water routing is expected to change as reservoir storage alert lines are crossed, switching to alternative sources may be needed to meet demand.

* Re-commissioning of sources. There are a number of licensed sources which are theoretically capable of being re-commissioned into supply and hence increase the deployable output.
* Increased use of unsupported river abstractions in spring and early summer to reduce the rate of drawdown at surface water storage reservoirs if drought risk is predicted to be high.
* Increase imports from other catchments or water companies in order to relax pressure on local water resources.
* Reduce exports to other catchments and water companies in order to protect local water resources.
* Introduction of temporary pipelines, pumps and tankering.

Demand Side
Demand side saving beyond hosepipe ban

- A water efficiency campaign,
- Targeted increased leakage reduction,
- Increased metering,
- Appeals for constraint,
- In the most severe drought conditions, restrictions on non-essential use
- Use of Standpipes and water bowsers

The majority of demands set within the model were based on drought summer profile combined with high demand winter. Estimations of demand saving and extreme drought demands were not calculated due to required information not being held in the EA and the project's time limitation.

It is acknowledged that 'false failures' within the Severn and Wye model are a limitation to modelling conducted. False failures occur when the model fails to route water correctly through the supply pipe network due to the autonomous nature of sources. This tends to be more significant during extreme droughts as cheap sources become exhausted and water has to be transported over longer distances. The modelling has been conducted on Aquator version 3. A newer version of Aquator (version 4) is now available, however, there is compatibility problems with the current River Severn & Wye model. In addition network costs need to be added. Oxford Scientific and STWL are currently rebuilding the Severn & Wye model to incorporate new water resources zones, version 4 compatible and include costing information. The model is expected to be released September 2011.

Aquator uses modelled (HYSIM) background flow series to determine the amount of water entering sub catchments. Aquator then routes this water down the main channel and into supply. Rainfall runoff modelling is necessary to provide flow records from climate data and river basin hydraulics. Measured flows could not be used as available gauging station data of the period is limited to a few catchments. The EA acknowledges errors associated with rainfall runoff modelling and seeks to improve the ability to represent the natural environment.

Irrigation and sewage effluent discharge have been incorporated within the background sub catchment inflows. Although Irrigation and effluent have specified profiles of monthly values repeated each year, there is no consideration of annual variations. However, drought could be expected to significantly impact on Irrigation and effluent discharge, for example the increased use of Spray irrigation S57 bans.

The Severn & Wye Aquator model was originally designed and created to represent the STWL network. South Staffs network is not truly characterised and consequently the quantity of abstraction at Hampton Loade is likely to contain some inaccuracies. The Environment Agency is seeking to improve the representation of SSW within the model, however, these improvements will not be available for the current study.

River Severn regulation requires flows to be predicted at Bewdley 5 days in advance in order to determine the required releases upstream at Clywedog, Vyrnwy and Shropshire groundwater. In the Environment Agency this is conducted by the Flood Forecasting Team using Met Office weather forecasts and knowledge of predicted abstraction. Uncertainty in rainfall prediction and hydrological catchment response can result in over release and Bewdley flow increasing above its 850Ml/d (normal)/730Ml/d (drought order) maintained level. In Aquator forecasting error has been accounted for by regulating to a slightly greater flow (890Mld/740Mld) and use of an additional variable termed 'forecasting error'. The 'predicted' flow was calculated based on the 'forecasting error variable' and 'Bewdley observed flow series'.

Aquator also does not include unforeseen losses of supply due to circumstances such bacteriological/algal activity leading to potential lose of some sources.

2.11 Further recommendations

- Drought permit VBA code should be added to the new STWL Severn & Wye model upon its release. The new model is expected to contain improvements in water routing and resource zone characterisation.
- Mott MacDonald and STWL are currently working on a project to improve the original HYSIM Aquator background flows using new rainfall data and a longer calibration period. The impact on the current project results is expected to be restricted due to the data processing to create the acute and chronic scenarios.

Future modelling should be based on the new Severn & Wye model and background data sets. In addition the current project methodology should be repeated using the new model and background flows in order to confirm our results. Any significant variation between new and old models should be investigated.

- The Severn & Wye model was originally created for STWL. Abstractions by SSW, and DCWW are included in the model, but their supply networks has been dramatically simplified. With the permission from both water companies and access to the necessary data the Environment Agency could improve the Severn & Wye characterisation. Commercial confidentiality must be a key priority in any such improvement.
- Extension of the model further downstream of lower parting (R. Severn) & Redbrook (R. Wye).
- Additional demand saving levels could be added to the model (Section 2.10 Limitations).
- New additional climate change scenarios should be conducted based on UKCP09 flow predictions. This could adopt the EA's methodology used by water companies in their 'Water Resources Management Plans'.

Appendix F

Environmental Flow Indicators explained

Environment Agency

Environmental Flow Indicator

What it is and what it does

April 2013

The Environmental Flow Indicator (EFI) plays a crucial role in the management of Water Resources in England and Wales. This factsheet sets out how the EFI was developed, how it is used and what assumptions can be drawn from its application.

- **EFIs are used to indicate where abstraction pressure may start to cause an undesirable effect on river habitats and species. They don't indicate where the environment is damaged from abstraction.**
- **Compliance or non-compliance with the EFI helps to indicate where flow may or may not support Good Ecological Status.**
- **The EFI is not a target or objective for resolving unsustainable abstractions. It is an indicator of where water may need to be recovered. The decision to recover water in water bodies that are non-compliant with the EFIs should only occur when supported by additional evidence to provide ecological justification.**
- **In Catchment Abstraction Management Strategies (CAMS) EFIs help to indicate where water may be available for future abstraction without causing unacceptable risk to the environment.**

What is the EFI?

The Environmental Flow Indicator (EFI) is a percentage deviation from the natural river flow represented using a flow duration curve. This percentage deviation is different at different flows. It is also dependant on the ecological sensitivity of the river to changes in flow.

The EFI is calculated within the Resource Assessment and Management (RAM) framework. This assessment gives an indication of where and when water is available for new abstractions. Where the assessment fails a more detailed assessment is required to understand if current abstractions and use of full licensed quantities are threatening the long term health of the river ecology.

Development

Flow standards for the Water Framework Directive (WFD) developed by the UK Technical Advisory Group (TAG) have been adapted to set the EFI. The EFI is set through expert opinion and at a level to support good ecological status. The adaptation was necessary for the Environment Agency to use it within the existing abstraction regulatory regime.

UK TAG (2008) identified the percentage deviation from natural flow (that supports GES) for differing river ‘types’ and at different flows: low flows (Q95) and flows above Q95. A summary of the outputs from this report is given in Table 1. This was translated for use within the Resource Assessment Methodology to be used in the Environment Agency's Water Resources work.

River type	**Flow > Q95**		**Flow < Q95**	
	Mar - Jun	*Jul - Feb*	*Mar - Jun*	*Jul - Feb*
Predominantly clay. South East England, East Anglia and Cheshire plain	25%	30%	15%	20%
Chalk catchments; predominantly gravel beds; base-rich	15%	20%	10%	15%
Hard limestone and sandstone; low-medium altitude; some oligotrophic hard rock	20%	25%	15%	20%
Non-calcareous shales; pebble bedrock; Oligomeso-trophic; Stream order 1 and 2 bed rock and boulder; ultra-oligo trophic torrential	15%	20%	10%	15%
	Oct – Apr	*May – Sep*	*Oct - Apr*	*May - Sep*
Salmon spawning & nursery (not chalk rivers)	15%	20%	10%	15%

Table 1: Flow standards for UK river types for supporting good ecological status given as the percentage allowable abstraction of natural flow (UKTAG, 2008).

Use in Catchment Abstraction Management Strategies

The Catchment Abstraction Management Strategy (CAMS) process has 3 main stages to it:

- Water resource availability assessed using our Resource Assessment Methodology (RAM),
- The licensing strategy,
- ‘Measures’ appraisal process – that is identifying and delivering things we want to change

Resource availability is expressed as a surplus or deficit of water resources in relation to the EFI. This is calculated by taking the natural flow of a river, adding back in discharges and taking away existing abstractions. This results in a scenario showing both a recent actual and fully licensed river flow. The difference between the fully licensed scenario flow and EFI gives us the amount of water which is available for abstraction and when it is available.

The Environment Agency abstraction regime uses fixed ‘hands-off flows’. These give a more effective use of water from the environment by enabling abstraction to cease at set flows, but also enable abstraction from periods of time when more water is available. The EFI is defined for four conditions, ranging from naturally low (Q95) to naturally higher (Q30) flows. To help manage abstraction at higher flows and protect flow variation greater percentages of flow is allowed to be abstracted. Table 2 shows the percentages of flow to be abstracted at three different sensitivities to abstraction (abstraction sensitivity bands) at different flows.

	high flow	→	→	low flow
Abstraction Sensitivity Band	**Q30**	**Q50**	**Q70**	**Q95**
ASB3. high sensitivity	24%	20%	15%	10%
ASB2. moderate sensitivity	26%	24%	20%	15%
ASB1. low sensitivity	30%	26%	24%	20%

Table 2: Percentage allowable abstraction from natural flows at different abstraction sensitivity bands.

Details of all the abstraction licences are recorded in CAMS ledgers (volumes and location and discharges). The ledgers are updated every time a new licence is issued, changed or revoked and are updated to inform future licensing decisions.

The EFI is a fundamental component of how we set out clearly what water is available where and when for potential abstractors. This is detailed in licensing strategies that are developed for each CAMS catchment and are available on the Environment Agency's internet site. The strategies set out the hands off flow and other conditions that will be applied to licence applications. They also include any local constraints that potential abstractors will need to be aware of such as higher levels of environmental protection for designated conservation sites, or where local information has shown that different amounts of water are available in the catchment.

Use in Water Framework Directive

The EFI is used in the hydrological classification for WFD to identify the water bodies where reduced river flows may be causing or contributing to a failure of good ecological status. This is called the compliance assessment. Compliance has been assessed at low flows (Q95) using recent actual scenario.

The compliance assessment shows where specific scenario flows are below the EFI, and indicates by how much. This is used to identify areas where flows may not be supporting good ecological status and target further investigation of what measures are needed to achieve good ecological status.

The degree of non-compliance has been split into three compliance bands, each band indicating the certainty that flow conditions does not support good ecological status. The compliance bands help to prioritise action where the abstraction pressure, and therefore the risk of not supporting good ecological status are greatest. The percentage below natural flow for each compliance band is shown in Table 3.

	Flow adequate to support GES	**Flow not adequate to support GES: Low to Moderate Confidence (uncertain)**		**Not adequate to support GES: High Confidence (quite certain)**
Abstraction Sensitivity Band	***Compliant with EFI***	***Non-compliant Band 1*** (up to 25% below the EFI at Q95)	***Non-compliant Band 2*** (25-50% below the EFI at Q95)	***Non-compliant Band 3*** (more than 50% below the EFI at Q95)
ASB3. high sensitivity	<10%	<35%	<60%	>60%
ASB2. moderate sensitivity	<15%	<40%	<65%	>65%
ASB1. low sensitivity	<20%	<45%	<70%	>70%

Table 3: The percentage difference from natural flows for each compliance band and how this relates to supporting good ecological status (GES). Percentages given are the range below natural flow for the relevant abstraction sensitivity band.

Glossary

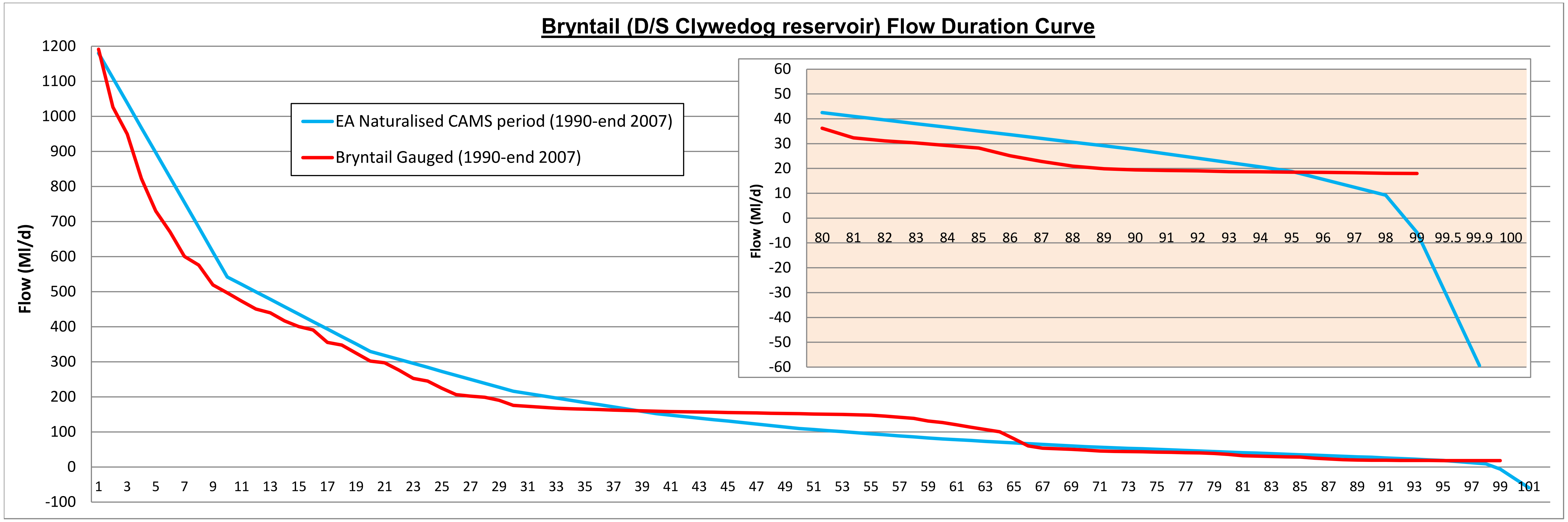
Abstraction Sensitivity Bands (ASB)	There are three abstraction sensitivity bands assigned to each water body in England and Wales: ASB1 – low sensitivity; ASB2 – moderate sensitivity and ASB3 – high sensitivity. Each of the ASB has a different EFI associated with it allowing less abstraction in high sensitive sites and more in sites with lower sensitivity. Each of these sensitivity bands was developed from assessment of 3 components: – Physical typology – using river 'types'. – Macroinvertebrate typology – using expected Lotic index for Flow Evaluation (LIFE) scores – Fish typology – using identification of a fish 'guild' expected under particular physical parameters. – Scores and confidence ratings from each component are combined to give the overall ASB for the waterbody.
Good Ecological Status	Good Ecological Status (GES) defines a water body as only being a little way from being in its totally natural state. It is the main objective of the WFD to return all water bodies to this near natural condition, although it does recognise that this will not always be possible. GES covers a variety of elements that give an indication of the health of a water body and its ability to support life. Hydrology is a supporting element for good ecological status - but in some situations, flow may be the limiting element for biology and for achieving good ecological status.
Natural Flows	The river flow that would have occurred without any human influences. This is calculated by starting with a gauged flow/recent actual flow and adding back in the abstractions and taking out the discharges. It can also be calculated from other surface water or groundwater models.
Scenario Flow	The scenario flow that is generated by denaturalising the natural flow taking into account abstractions and discharges operating at their recent actual rate (**recent actual scenario**) or abstractions operating at their full licensed limit and discharges operating at their recent actual rate (**fully licensed scenario**).
Waterbody	A manageable unit of surface water, being the whole (or part) of a stream, river or canal, lake or reservoir, transitional water (estuary) or stretch of coastal water. A 'body of groundwater' is a distinct volume of underground water within an aquifer.
WR GIS	The WR GIS uses ArcView. The abstraction, discharge, natural flows and complex impacts information from the CAMS ledgers is uploaded onto this central system. The WRGIS uses this information to calculate the current resource availability for each water body at four flow percentiles.

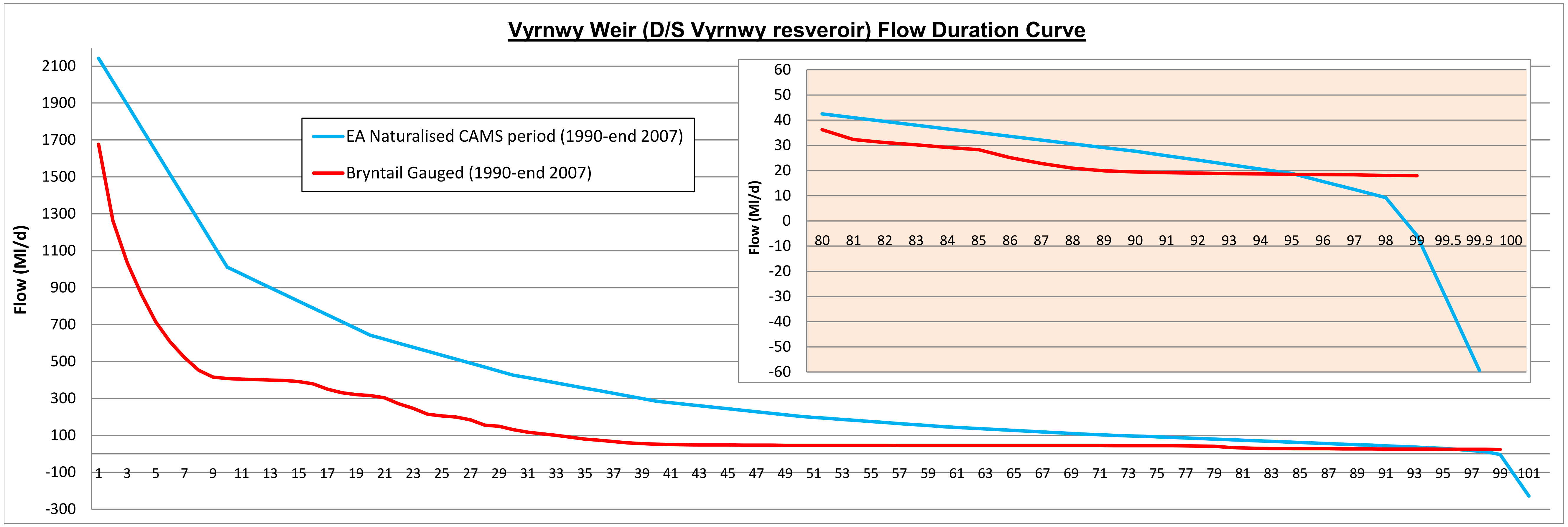
External References

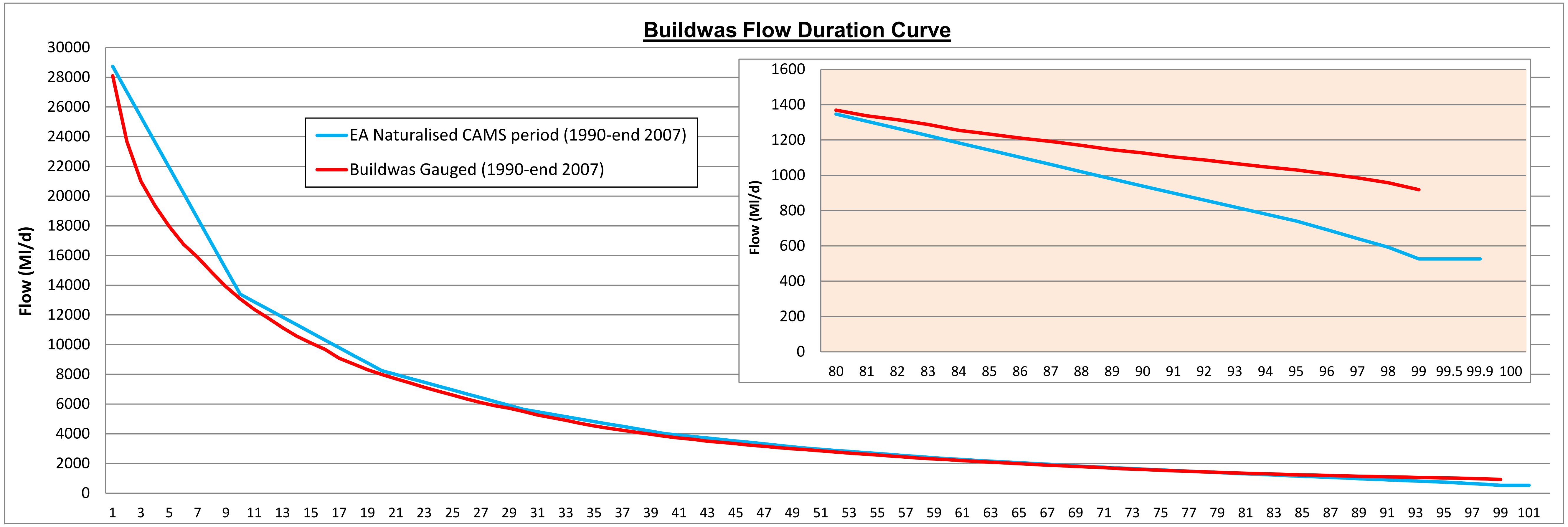
– UKTAG (2008) UK environmental standards and conditions. Report of the UK Technical Advisory Group on the Water Framework Directive.

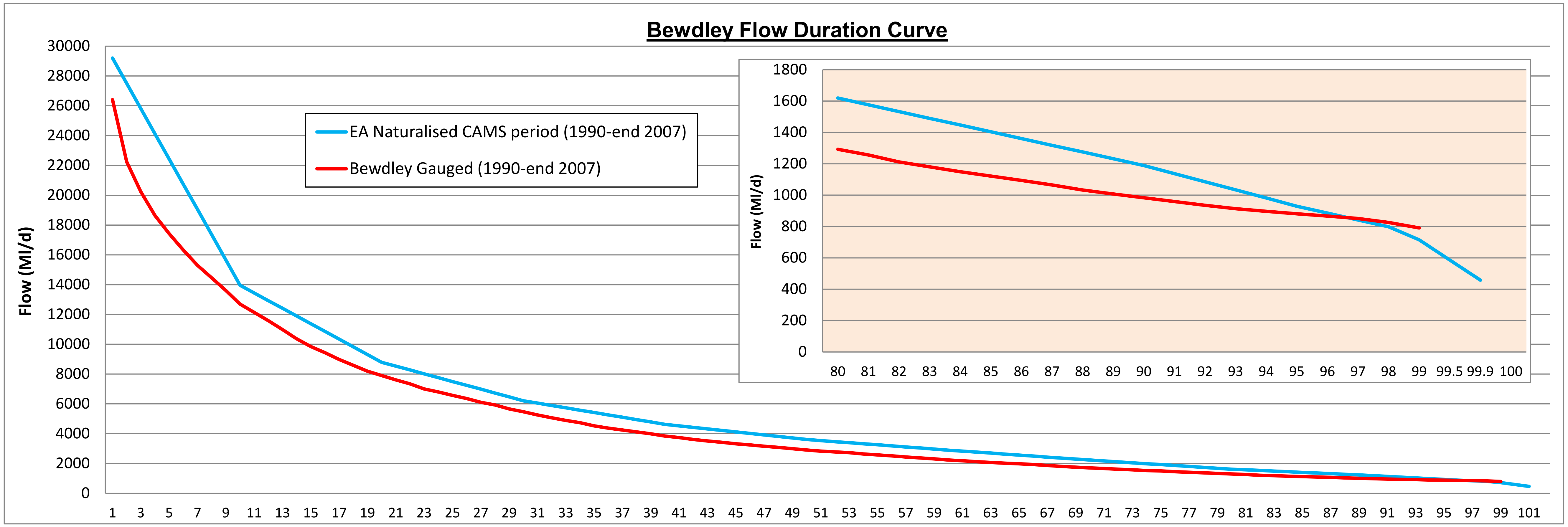
Appendix G

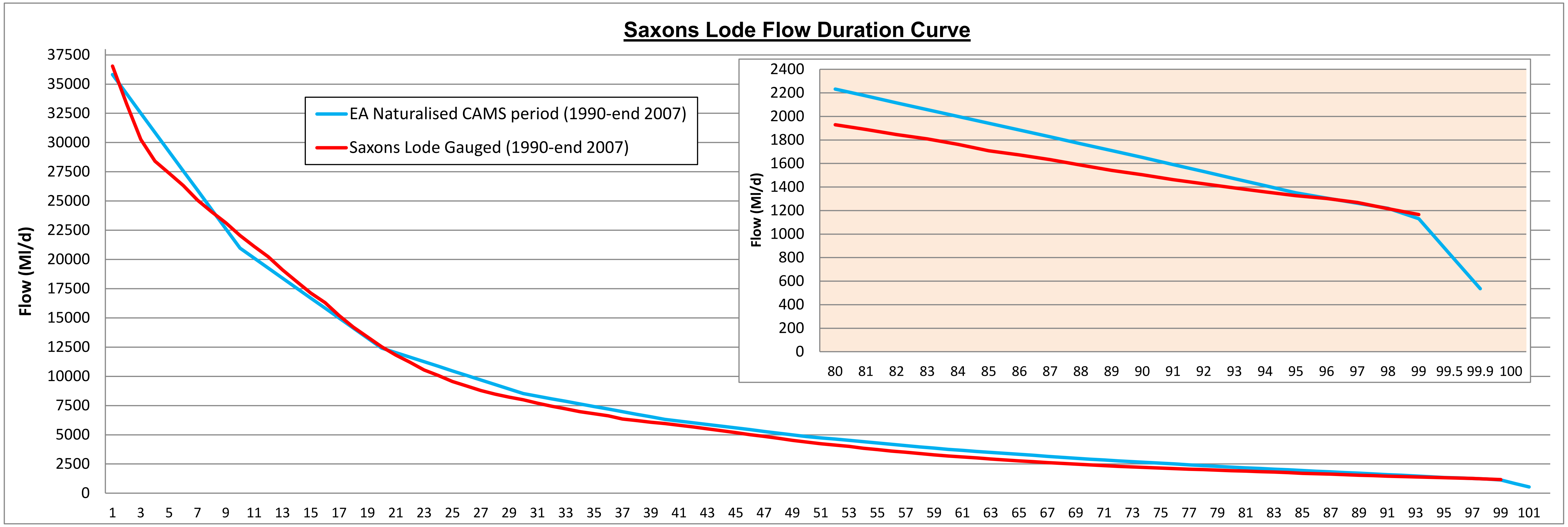
Flow Duration Curves (complete flow regime)


Bryntail (D/S Clywedog reservoir) Flow Duration Curve
EA Naturalised CAMS period (1990-end 2007)
Bryntail Gauged (1990-end 2007)
Flow (Ml/d)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
-100
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 99.5 99.9 100
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101


Vyrnwy Weir (D/S Vyrnwy resveroir) Flow Duration Curve
EA Naturalised CAMS period (1990-end 2007)
Bryntail Gauged (1990-end 2007)
Flow (Ml/d)
2100
1900
1700
1500
1300
1100
900
700
500
300
100
-100
-300
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
-60
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 99.5 99.9 100
1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101


Buildwas Flow Duration Curve
Flow (Ml/d)
EA Naturalised CAMS period (1990-end 2007)
Buildwas Gauged (1990-end 2007)
Flow (Ml/d)


Bewdley Flow Duration Curve
Flow (Ml/d)
EA Naturalised CAMS period (1990-end 2007)
Bewdley Gauged (1990-end 2007)
Flow (Ml/d)


Saxons Lode Flow Duration Curve
EA Naturalised CAMS period (1990-end 2007)
Saxons Lode Gauged (1990-end 2007)
Flow (Ml/d)
37500
35000
32500
30000
27500
25000
22500
20000
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1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101
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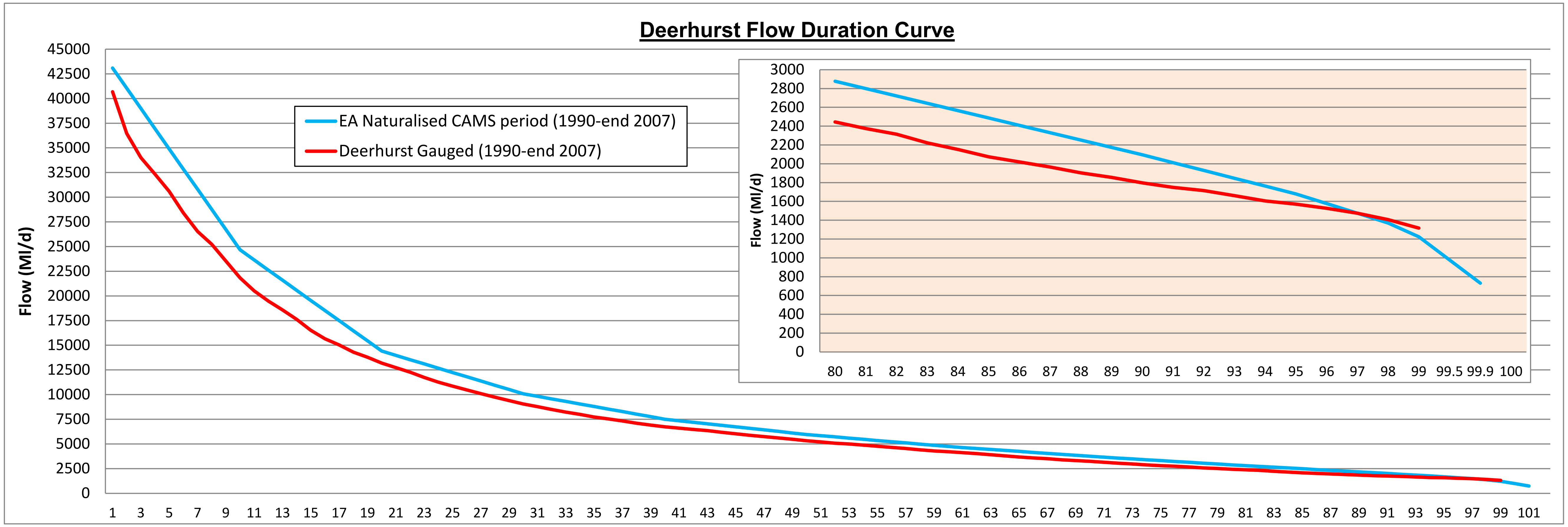
Deerhurst Flow Duration Curve
EA Naturalised CAMS period (1990-end 2007)
Deerhurst Gauged (1990-end 2007)
Flow (Ml/d)
45000
42500
40000
37500
35000
32500
30000
27500
25000
22500
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1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101
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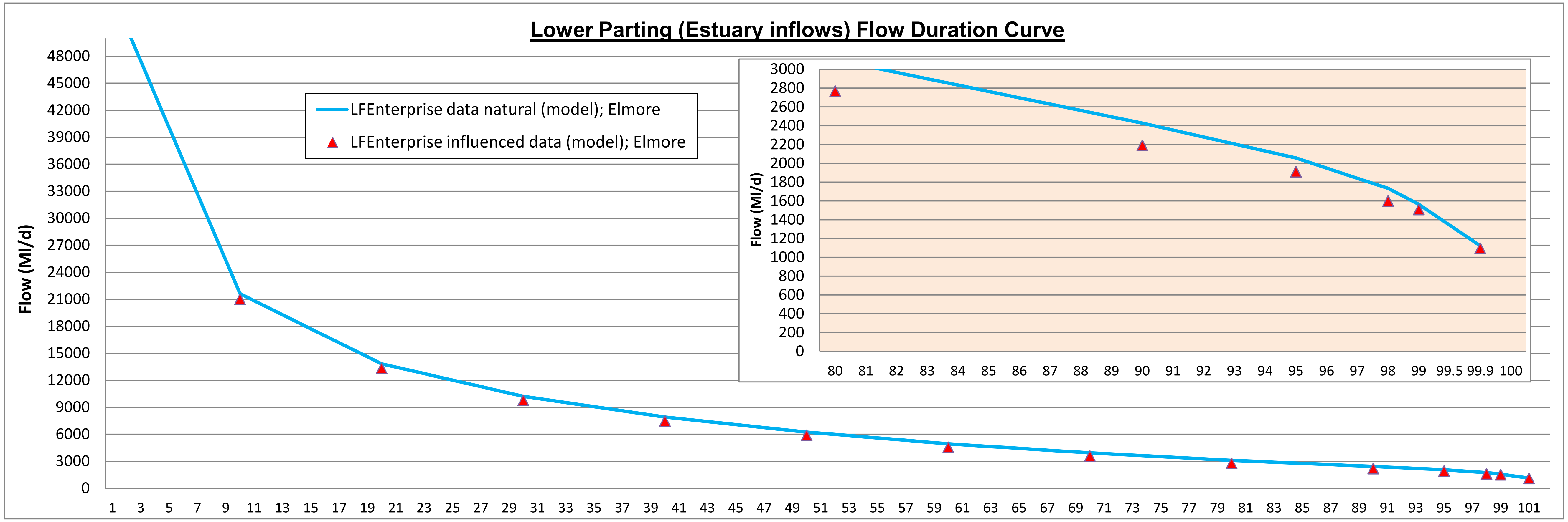
Lower Parting (Estuary inflows) Flow Duration Curve
LFEnterprise data natural (model); Elmore
LFEnterprise influenced data (model); Elmore
Flow (Ml/d)
48000
45000
42000
39000
36000
33000
30000
27000
24000
21000
18000
15000
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1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101
Flow (Ml/d)
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2800
2600
2400
2200
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1200
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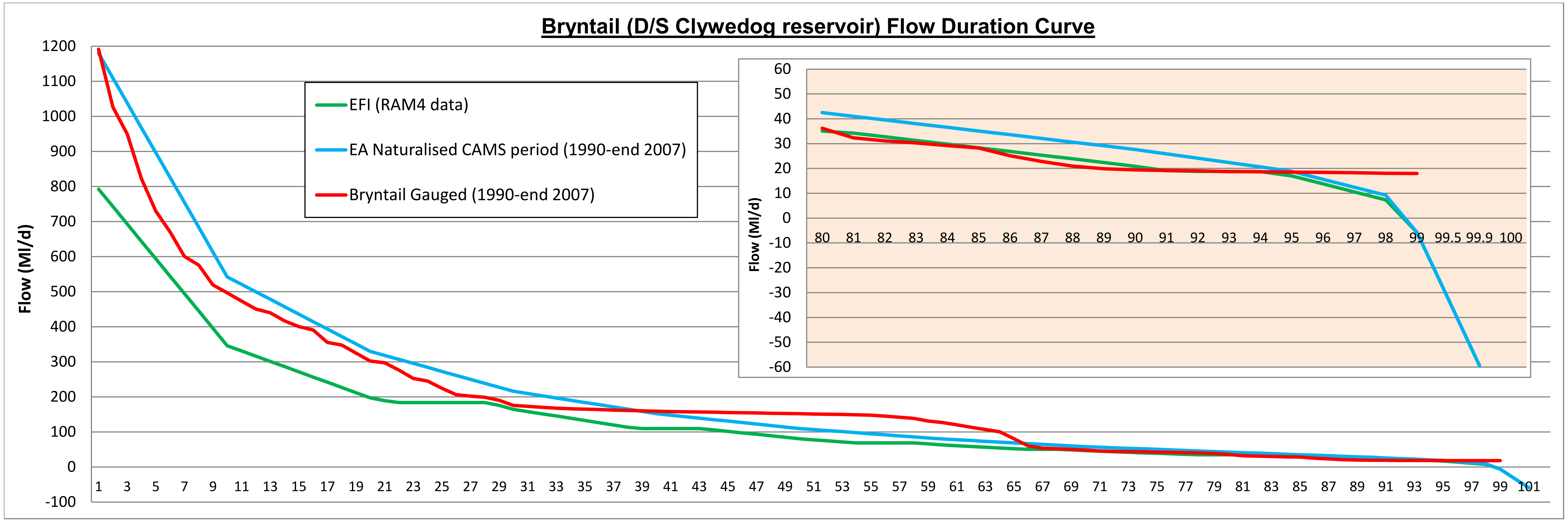
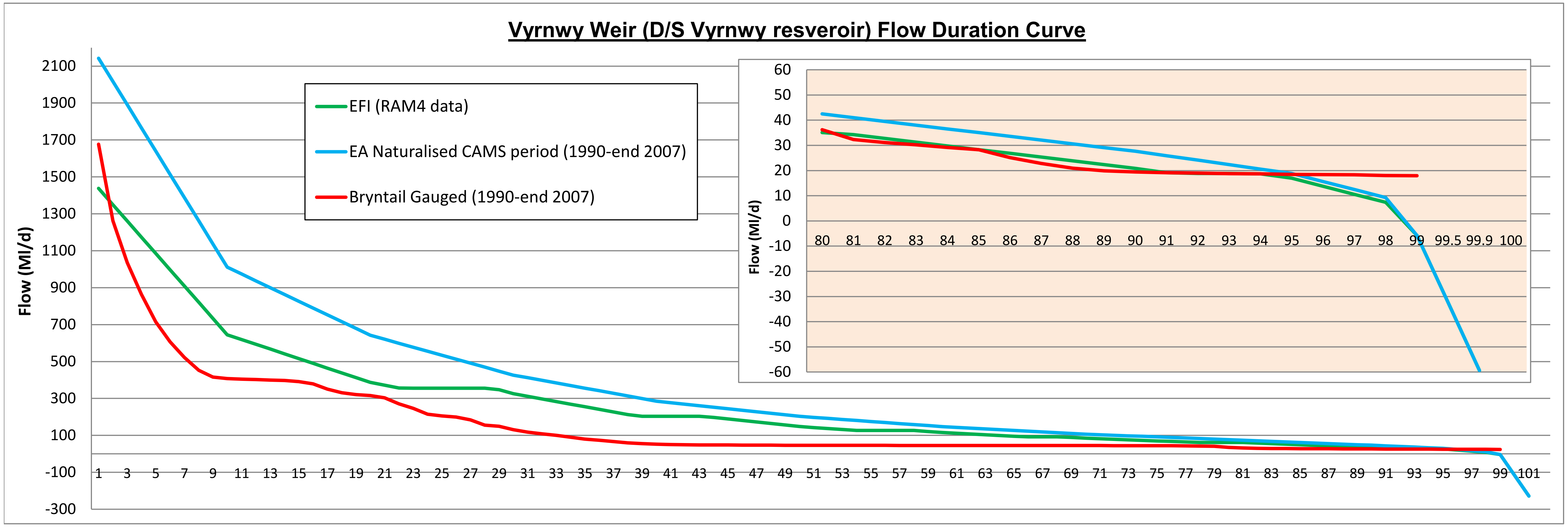
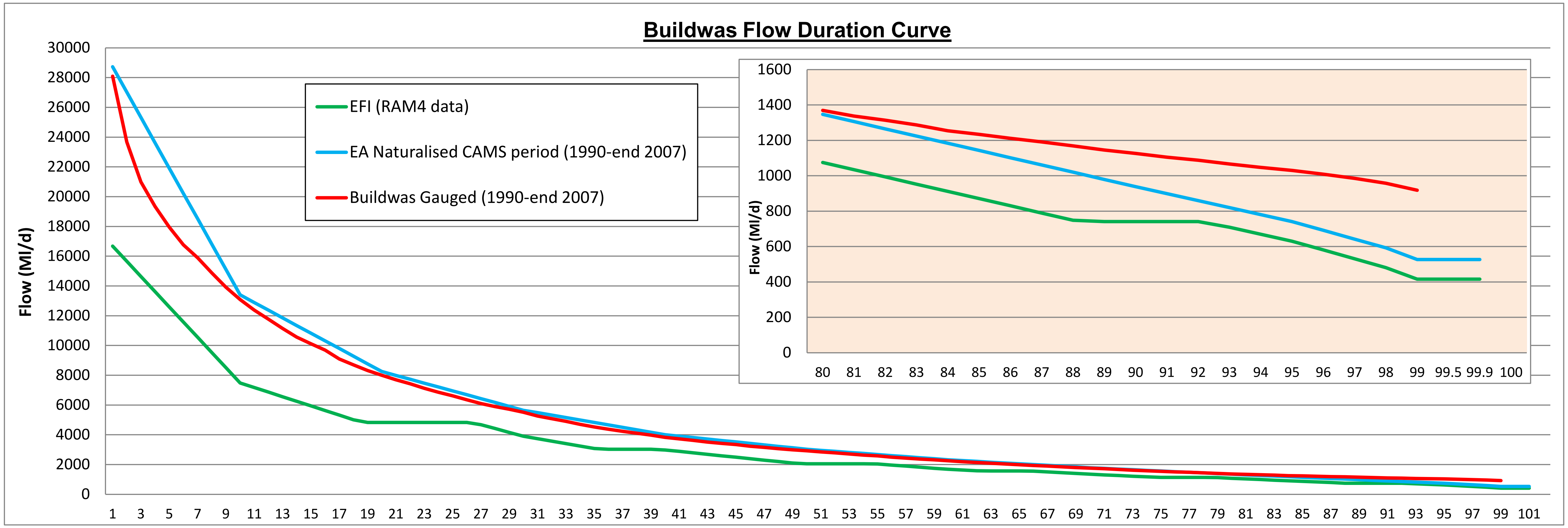
80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 99.5 99.9 100

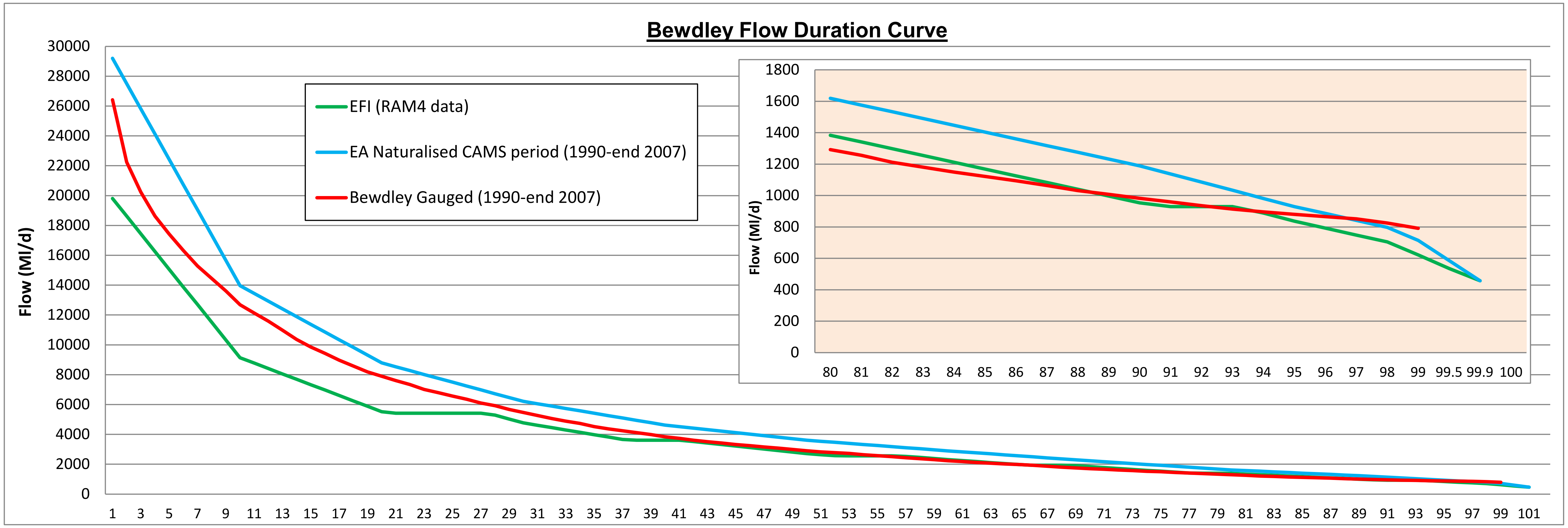
Appendix H

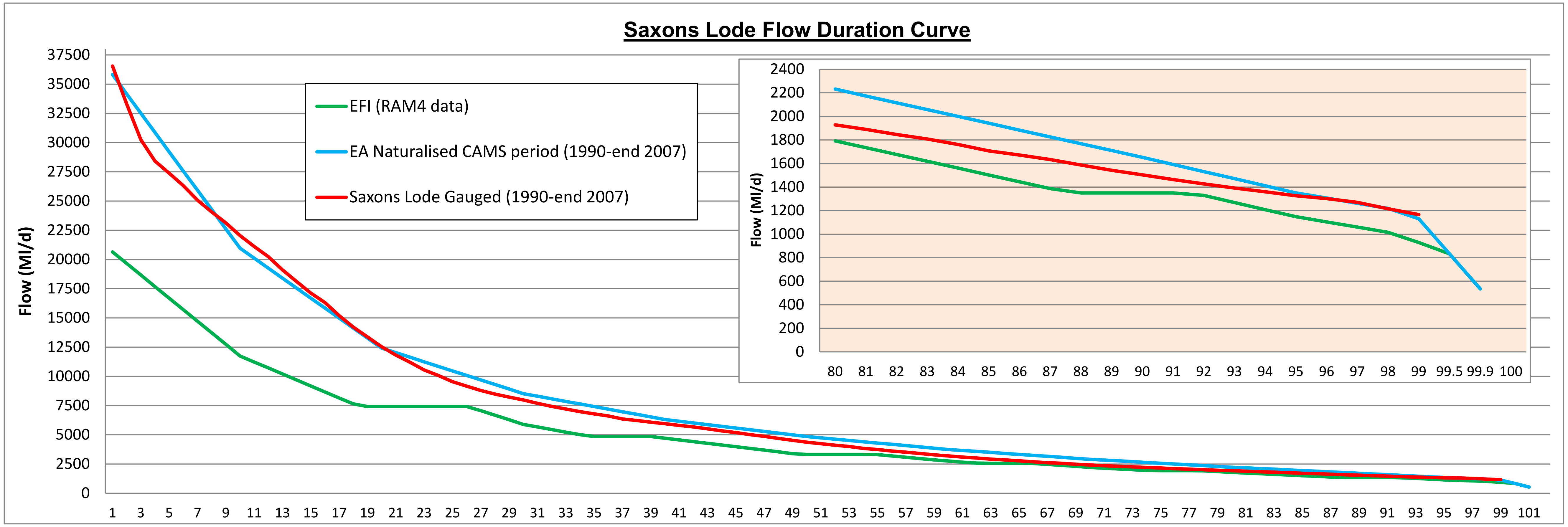
Flow Duration Curves (for comparison)


Bryntail (D/S Clywedog reservoir) Flow Duration Curve
Flow (Ml/d)
EFI (RAM4 data)
EA Naturalised CAMS period (1990-end 2007)
Bryntail Gauged (1990-end 2007)


Vyrnwy Weir (D/S Vyrnwy resveroir) Flow Duration Curve
Flow (Ml/d)
EFI (RAM4 data)
EA Naturalised CAMS period (1990-end 2007)
Bryntail Gauged (1990-end 2007)


Buildwas Flow Duration Curve
EFI (RAM4 data)
EA Naturalised CAMS period (1990-end 2007)
Buildwas Gauged (1990-end 2007)
Flow (Ml/d)


Bewdley Flow Duration Curve
EFI (RAM4 data)
EA Naturalised CAMS period (1990-end 2007)
Bewdley Gauged (1990-end 2007)
Flow (Ml/d)


Saxons Lode Flow Duration Curve
Flow (Ml/d)
EFI (RAM4 data)
EA Naturalised CAMS period (1990-end 2007)
Saxons Lode Gauged (1990-end 2007)
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35000
32500
30000
27500
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1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101
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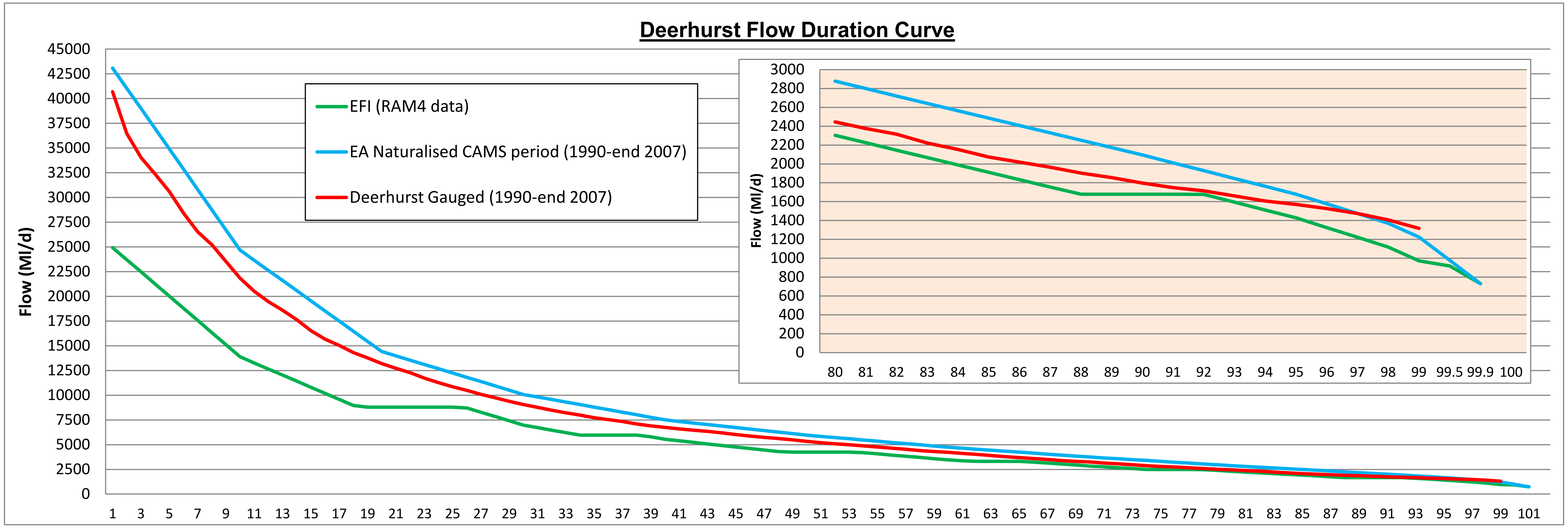
Deerhurst Flow Duration Curve
Flow (Ml/d)
EFI (RAM4 data)
EA Naturalised CAMS period (1990-end 2007)
Deerhurst Gauged (1990-end 2007)
45000
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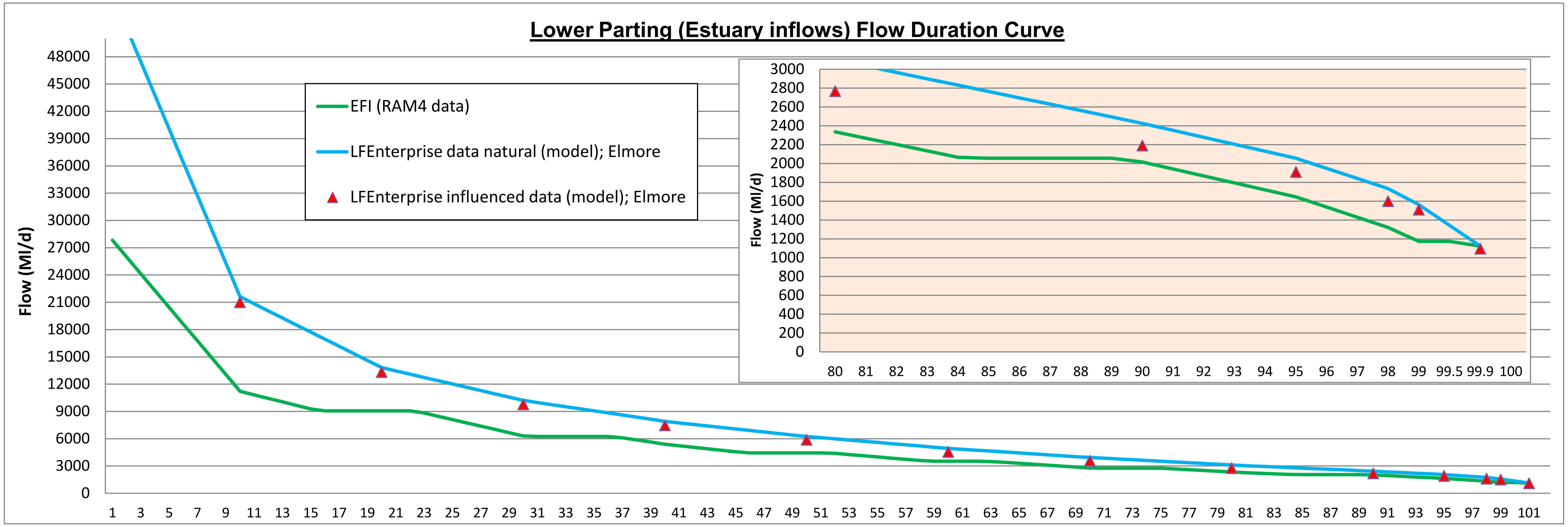
Lower Parting (Estuary inflows) Flow Duration Curve
Flow (Ml/d)
48000
45000
42000
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36000
33000
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21000
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1 3 5 7 9 11 13 15 17 19 21 23 25 27 29 31 33 35 37 39 41 43 45 47 49 51 53 55 57 59 61 63 65 67 69 71 73 75 77 79 81 83 85 87 89 91 93 95 97 99 101
EFI (RAM4 data)
LFEnterprise data natural (model); Elmore
LFEnterprise influenced data (model); Elmore
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Appendix I

Hydrology Technical Report – River Severn Drought Order

RIVER SEVERN DROUGHT ORDER: HYDROLOGY ASSESSMENT

Environment Agency
Kate Evans (2011-2012)
Hydrologist, West Area Environment Planning team

SUMMARY

The River Severn Drought Order is the Environment Agency's last resort option to manage the ongoing development of a critical drought event, encompassing a dual purpose of maintaining public water supply and supporting the environment along the main River Severn. It aims to extend the length of time regulation releases can be made in the absence of significant rainfall by carefully managing remaining storage in Llyn Clywedog reservoir. The River Severn Drought Order primarily lowers River Severn flows in the short term in order to protect against the magnitude of potential regulation failure should the drought persist beyond the systems design capabilities, and protecting against a subsequent dry winter and lack of recharge to safe guard the following years water resources.

The River Severn Drought Order has been operated in different forms during 1976, 1984 and 1989. Conditions along the River Severn have altered significantly since the last operation, with increased abstraction demands, higher prescribed flows at Bewdley (as part of the regulation operation), improved water quality, greater emphasis on environment protection and changing organisations and responsibilities amongst the core regulation group.

Adopting the worse case precautionary approach, if the Severn Drought Order were not operated (Do Nothing scenario) and a drought continued long enough, water in Clywedog could be exhausted and subsequently the Regulation System would quickly fail (failure to meet prescribed flows at Bewdley) causing significant flow crashes. The upper River Severn is likely to dry up as reservoir releases fail, the whole River Severn would experience record minimum low flows and sections of the lower River Severn (upper Estuary outside the Natura 2000 site) could also be at risk of drying up, depending on the operations of the Gloucester and Sharpness canal and remaining baseflow. Water levels would be significantly depleted, causing localised loss of habitat, higher sediment deposition, dissolved oxygen problems and creating extensive barriers for fish migration and boat navigation.

Alternatively, during a 'Do Nothing' Acute (one summer impact) event, if the drought did not continue long enough to reach regulation failure then flows would be maintained at normal statutory requirements, which would be more beneficial to the environment and water users than operating the River Severn Drought Order. However, this option would be a game of chance, if a drought continued the consequences of not managing remaining water resources could be serious and impact subsequent years, shown by the lower minimum flows under the Chronic 'Do Nothing' scenario. The Severn Drought Order is only activated once storage in Llyn Clywedog has already reached critically low levels, conditions not experienced since 1989, with non regulated rivers likely to be already seriously impacted.

Modelling operation of the River Severn Drought Order under an Acute and Chronic drought scenario, indicated regulation failure cannot be prevented but the impacts can be reduced. Flows under the River Severn Drought Order operation in all scenario's were maintained above the modelled 'Do Nothing' scenario after regulation failure began, supporting the need for the Severn Drought Order to limit the severity of prolonged droughts. In the case of the Chronic scenario, operating the Severn Drought Order in the first year safeguards enough water to potentially protect against regulation failure and significantly increase minimum

flows in a subsequent year. Also restoring more varied flows in the upper reaches of the River Severn earlier than the ‘Do Nothing’ scenario.

The actual impact of the River Severn Drought Order alone (up until regulation failure) would be a reduction in flows along the whole River Severn by a minimum 120 Ml/d during the peak of a drought, modelled at an average 140 Ml/d to counter in human tolerance (forecast errors, public water supply abstraction changes etc). The actual impacts on the environment and water users would be limited and localised if this were the only alteration. If regulation failure were reached, the Severn Drought Order maintained higher flows, benefiting the environment and water users. The additional volume provided per day would be dependent on factors at the time, such as baseflow, remaining Regulation resources and length of the drought.

In reality droughts of these severities will involve a full range of in-combination impacts to consider, the true magnitude and duration of which cannot be predicted with certainty until a real event. Modelling full in-combination has suggested the sections most at risk would be largely downstream of Bewdley. The worst affected reach would be the Lower Tidal Severn, and particularly around the channel split in Gloucester. The degree of impact will vary significantly according to the Gloucester and Sharpness canal abstraction volumes, which is currently exempt from licensing. Close liaison and cooperation between all the partners involved would be required and all options to mitigate the impacts discussed. Once again, if regulation failure were reached, the Severn Drought Order could maintain higher flows than ‘Do Nothing’ and help safeguard some flows into the Severn Estuary.

River Severn Hydrology: Current Environment

Flow gauge information			Flow gauge statistics 1990-2007 (Ml/d)*				Notes on data quality
Gauge name	River	Record start date	Q95	Q50	Q5	BFI	
Bryntail (2109)	Clywedog	01/06/1977	19	152	730	0.48	Data quality good at all ranges, perhaps lacking more low flow spot flow gauging verification.
Dolwen (2118)	Severn	13/06/2000	85	355	1916	0.44	Site can suffer from silt build up and drowns out at highest flows.
Abermule (2014)	Severn	01/06/1962	170	677	4574	0.44	Good gauge for all flows. Some problems associated with weed growth along banks. Some evidence that flows occur through the gravel bed.
Vyrnwy Weir (2003)	Vyrnwy	01/01/1920	25	47	715	0.36	Reliable gauge producing good quality data at most flows. Not prone to drown out.
Llanyblodwel (3038)	Tanat	11/05/1973	48	314	2115	0.48	Good reliable gauge with slight over estimation at highest flows.
Llanymnech (2028)	Vyrnwy	17/12/1969	232	958	6707	0.44	Reasonable gauge although not all high flows can be measured. Site has become unstable since gravel removed from bed.
Montford (2005)	Severn	01/10/1953	643	2084	14066	0.48	Site rated as fair. Reliable but very prone to weed growth.
Buildwas (2134)	Severn	01/03/1984	1030	2927	17955	0.56	Reliable gauge producing good quality data at most flows.
Bewdley (2001)	Severn	01/04/1921	881	2904	17424	0.53	Reliable gauge producing good quality data at most flows.
Saxons Lode (2032)	Severn	05/06/1970	1327	4372	27381	0.57	Good at low flows with a fall in quality towards higher flows, still rated as fair. Site affected by high tides and tidal gates on the Avon.
Deerhurst (2606)	Severn	01/12/1995	1571	5327	30600	0.57	Caution needed at the high flow end but low flow recording of good quality. Can cope with tides/reverse flows.
Haw Bridge	Severn						Caution needed due to tidal impacts and substantial bed movement.

River Severn Catchment

The River Severn is the longest in Great Britain at 354km, with the second greatest tidal range in the world (14.5 meters). It rises on the slopes of Plynlimmon in the Cambrian Mountains of Wales and flows first southwards through the Hafren Forest to Llanidloes, where the River Clywedog joins. It then flows north-eastwards, meandering through a broad valley before emerging onto the Shropshire floodplain, at its confluence with the River Vyrnwy. From here it flows eastwards to Shrewsbury, enclosing the town in a large loop, before turning to flow south-westwards through the narrow Ironbridge Gorge and onwards to Bridgnorth. The River Severn then passes from Shropshire into Hereford and Worcester in a southerly direction where it deepens and widens, and continues over the Gloucestershire border to Tewkesbury and Gloucester. At this point the river is subject to a tidal influence from the Severn Estuary. It then flows in a south-westerly direction and begins to widen out into the upper estuary downstream of Longley, before discharging into the sea in the Bristol Channel.

It’s highly artificial, covers various geologies and topographies, and particularly around the Estuary remains highly dynamic. The River Severn provides countless micro habitat’s and flow niches; attempting to model and assess the impacts on every reach and niche would be inappropriate and without baseline data, highly inaccurate.

Rainfall

Within the Severn catchment, rainfall generally decreases from north to south and from west to east. Superimposed upon this pattern is a marked increase in rainfall totals with altitude. Annual totals average up to 2400 mm on the high ground around the headwaters of the Severn, decreasing to below 700 mm on the North Shropshire Plain and to less than 600 mm around the head of the Severn Estuary. When compared to population density, the highest water demand is located in the area’s receiving lower rainfalls. Annual variability can be large with a standard deviation of 100 mm being common for mean annual totals of 600 to 700 mm.

The Environment Agency use Long Term Average (LTA) rainfall figures based on the 1961-1990 period to assess whether a shortage or abundance of rainfall has been received over a catchment each month. This helps predicts the onset of drought (or flood) conditions and enables planning to help prepare and mitigate against the worst impacts. The Severn catchment is split into 6 rainfall catchment areas for reporting, shown in the wider context of the Midlands region in Figure 4;

- Welsh Uplands
- Shropshire Plains
- Mid Severn/Teme
- Avon
- Lower Severn
- Lower Wye

Figure 4: Midlands Region Rainfall Catchments

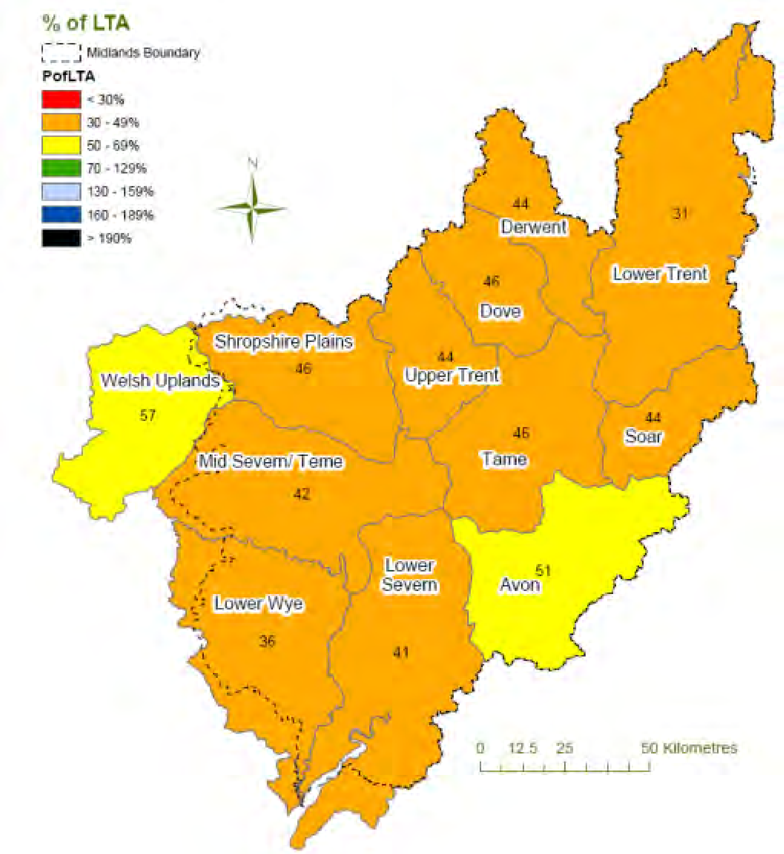


Figure 4 is taken from the February 2012 Midlands Water Situation Report, produced by the Environment Agency.

Winter rainfall and associated run off normally generates sufficient flows to meet the seasonal abstraction and environmental demands placed on the River Severn. However, during most summers flows have to be augmented by releasing water from the River Severn Regulation System. The combination of complex abstractions and Severn Regulation makes the River Severn a heavily influenced and artificial watercourse.

Flows

Flows downstream of both Llyn Clywedog and Lake Vyrnwy are subject to large and often sudden variations in flows, as releases are altered to satisfy downstream need. Both sites conform to minimum flow requirements to protect the environment as much as possible; Llyn Clywedog requires 18.2 Ml/d be maintained while Lake Vyrnwy requires 45 Ml/d, although currently if Cownwy Weir (parallel tributary) flows exceed 20 Ml/d then releases directly from Lake Vyrnwy can be reduced to 25 Ml/d.

Regulation releases can be seen through steps in the flow duration curves for some distance downstream of the major reservoirs, increasing flows significantly above what would naturally occur. Releases have largely smoothed out or been removed (abstracted) by Bewdley, although volumes at low flows remain elevated above natural downstream of Bewdley (see appendix G). This artificial elevation in flows, particularly low flows, illustrates what the Severn Regulation system is designed to achieve, balancing abstraction needs with environmental protection.

Assessment Points: Hydrology current environment

Bryntail is a heavily artificial flow site, the flat V weir is constructed directly downstream of Llyn Clywedog on rock immediately downstream of the Van Lode fault. The 49km^2 catchment is largely afforested and steep, draining Ordovician and Silurian shales and slates whist being substantially Drift free. The steep topography and geology combine with the high rainfall to make the catchment naturally flashy, although the reservoir storage smoothes the affects.

Flows at Bryntail are constantly impacted by regulation, Hydropower, flood and other releases from the reservoir. Appendix H contains the naturalised and gauged flow duration curves and illustrates how the high to mean flows are reduced and then returned to the system in a stepped approach from mid to low flows. The flow regime is affected and some flow variation lost, but Q95 (flow exceeded for 95% of time) and lower flows (often dry weather/drought related) are protected and raised above what would naturally occur. Subsequently, the environment and ecology is prevented from experiencing drought conditions, as the compensation flow of 18.2 Ml/d is maintained.

Vyrnwy Weir is a rectangular notch weir located directly downstream of Lake Vyrnwy, a reservoir built to provide water supply to Liverpool. The catchment artificially incorporates nearly all the flows from the Cownwy and Marnant tributaries, which have been largely re-diverted to flow into Vyrnwy reservoir rather than naturally joining the River Vyrnwy downstream of the gauging station. The 94.3km^2 (natural catchment size excluding the Cownwy and Marnant) catchment is steep and notably wet, draining Drift free Silurian and Ordovician slates and shales. The topography and geology make the catchment very responsive to rainfall.

Flow is artificial, particularly dominated by controlled releases from the reservoir during low flows. Appendix H contains the naturalised and gauged flow duration curves, and also illustrates how the high to mean flows are reduced. However, unlike Clywedog, due to the large public water supply abstractions from Vyrnwy, the mid to lower flows do not display the same stepped return of flows to the system, as the majority of this water is transferred directly out of the catchment. The benefits from the compensation flow are displayed in the more infrequent percentiles, Q95 flows are protected and raised above what would naturally occur.

Buildwas is a multiple ultra sonic cross-configuration gauging station, just upstream of Ironbridge gorge in Shropshire. The 3723.7km^2 catchment is a diverse mixture of moorland and forestry in the upper reaches and predominantly mixed farming in the lower lying reaches. Mixed Palaeozoic formations underlie the headwaters and Permian Sandstones dominate the lower reaches with extensive Drift cover of Boulder Clay, sand and gravels.

The flow regime at Buildwas remains close to natural behaviour under normal conditions (Appendix H), until Q80 onwards when regulation releases can be seen to elevate flows above what could naturally be expected. The site is therefore behaving relatively naturally with flow variation and volumes until dry/summer periods, illustrating how the stepped nature of flows immediately downstream of the reservoirs is gradually smoothed out as it travels downstream.

Once baseflows naturally begin declining, the regulation releases artificially prevent flows at this site from ever dropping to what would have naturally occurred. In effect, when tributaries of the River Severn are beginning to display natural summer/low flow effects, flows at Buildwas are artificially protected (increased) under normal regulation operation. This can be confusing when trying to understand the impacts of drought on the flow dependant environment, as the lowest flows are less likely to occur at the peak of a dry period because the highest regulation releases will be made during these times.

Bewdley is a 20-path unltrasonic gauging station, used as the flow trigger site where the five day rolling mean of 850Ml/d (minimum flow target) is maintained for Severn Regulation. The 4334km^2 catchment is a combination of moorland, forestry and mixed farming, consisting of impermeable Palaeozoic rocks and river gravels in the west and Drift covered Carboniferous to Liassic sandstones and marls in the north.

Flows this far down the main river are largely artificial. Significant public water supply and power generation abstractions take place upstream, removing significant portions of the regulation releases which taken between 3 and 4 days travel time from Clywedog reservoir. Although flows are artificial, they do mirror the naturalised FDC (Appendix H). The gauged FDC (1990-2007) shows the EFI is normally achieved (minor deviations due to stepped representation of the EFI) and from Q97 regulation releases elevate flows above what would naturally occur.
Saxons Lode is a Multipath ultrasonic gauging station that can be affected by high tides travelling up the estuary, and operation of tidal gates on the Avon at Tewkesbury. The 6860.6km2 catchment is diverse, mainly agriculture and forestry with some industrial development in the East. Broad flood peaks are experienced, and geology is largely Triassic Mudstone (Mercia) including Keuper Marl, Dolomitic Conglomerate and Rhaetic.

Saxon’s Lode flows incorporate inputs from the River Teme and River Stour (large effluent returns), whilst including further significant public water supply abstraction. Low flows remain artificially supported by regulation, although to a lesser degree as major abstractions have already removed the majority of additional water. Appendix H) shows the affect is to return flows from Q95 back towards the natural flow, rather than notably elevating it. The graph also shows the current flow regime (gauged FDC) satisfies the EFI at all times.

Deerhurst is a cross path ultrasonic gauging station commissioned in 1995, designed to measure low to medium flows affected by tides. The older Haw Bridge gauge is located downstream, a velocity-area station affected by substantial bed movement and unable to adjust flows to account for tidal action. The sites are often used interchangeably, as Haw Bridge provides a much longer record and includes important historic drought events. Deerhurst and Haw Bridge are the furthest downstream continuous flow gauging stations on the River Severn.

The Deerhurst catchment is 9866.3km2 and greatly diverse due to it’s size. The geology is predominantly Paleozoic slates in the welsh headwaters, Permo-Triassic sediments in the middle reaches and Jurassic and Liassic clays from the Avon catchment down. Flows are substantially modified by this point, with further public water supply abstractions and effluent returns (additional effluent received from the Avon and Thames). Low flows are artificially supported by regulation but to a lesser degree than Bewdley.

Appendix H shows how flows from around Q96 onwards are elevated back to what would naturally have occurred. The current flow regime (gauged FDC) meets the EFI requirements at all times and therefore demonstrates that inflows to the Severn Estuary are still protected at this location.

In order to assess flows further downstream, and represent inflows to the Severn Estuary more accurately, further sites were selected and Low Flows Enterprise data used to represent expected normal and/or natural conditions for comparison. This does represent a change away from the techniques used to assess all the upstream assessment points so greater caution needs to be applied.

One of the largest potential abstractions between Deerhurst and the Severn Estuary is The Canals and Rivers trust abstraction to the Gloucester and Sharpness canal, taken from the East channel where the River Severn splits. Bristol Water then abstract directly from the canal, for which The Canals and Rivers trust have a Commercial Agreement to make best endeavours to meet the public water supply needs, and hold an abstraction licence from the canal itself on their behalf. The Canals and Rivers trust are currently exempt from abstraction licensing under the Water Act 2001 but do work in accordance with an Operating Agreement (1998) with the Environment Agency, which acts to safeguard the Severn Estuary inflows under routine flow regimes (supported by RoC stage 3 assessment). There is however an understanding that severe droughts represent exceptional circumstances and operations may fail to meet the Operating Agreement, close liaison between the Environment Agency and The Canals and Rivers trust will be required, with the option to close the canal to navigation being considered.

The complex interaction and variability of abstraction coupled with a lack of actual flow data downstream of the canal abstraction, make it very difficult to assess with confidence what the true impact on the lower River Severn would be. Abstractions can range from 0Ml/d to >680Ml/d (maximum pump capacity), although high demand abstractions normally average around 300 Ml/d. Drought reports from the 1976 and 1989 event report 680Ml/d was abstracted for brief periods during the lowest flows, causing Estuary inflows to reduce to zero for short periods. At the time this was deemed as acceptable, however with new regulations and the need to safeguard the Natura 2000 Severn Estuary, requirements have changed.

The channel bifurcation (channel split) itself raises additional modelling and impact assessment challenges. Monitoring (between 1997-2007) indicates an approximate flow split of 40% down the East channel and 60% down the West channel. Therefore, low flows occurring due to the drought would become further divided and flow velocity decreased. Post drought reports from 1976 highlighted a considerable siltation problem around the channel bifurcation, with no flow passing down the West channel.

Appendix H shows data for Elmore, the furthest downstream point Low Flows Enterprise can model (owing to tidal influences), plotted against modelled data for Lower Parting to focus on the Estuary inflows. The EFI used is in accordance with the WFD guidance for transitional waterbody's and conforms with the Stage 3 Review of Consents. Due to the large tidal range (second largest in the world) of the Estuary, flow requirements are less sensitive than represented by a normal watercourse so will not match those plotted at Deerhurst.

The flow duration curve suggests flows consistently remain below what would have naturally occurred, meeting only at the severest drought. This could involve errors relating to how the regulation system and Gloucester and Sharpness canal abstraction is represented within Low Flows Enterprise.

The current flow regime (influenced FDC) at Elmore/Lower Parting does suggest the EFI requirements are met at all times, with only Q99-Q100 showing marginal results. Appendix H therefore indicates normal flow operation protects the lower River Severn and subsequently inflows to the Severn Estuary. Greater confidence could be achieved by investigating how the Gloucester and Sharpness canal abstraction has been represented (likely to be average abstraction, not accounting for severe droughts) inside Low Flows Enterprise, to verify the results being shown.

Historic Drought events

Baseline - Historic Drought Records

There is no exact definition of what constitutes a drought, and classification is often dependant on meteorological, hydrological (and environment), agricultural or water supply impacts. The Centre for Ecology & Hydrology report notable drought years in England and Wales as being; 1902, 1905, 1921, 1933-1934, 1943-44, 1949, 1953, 1955, 1962-65 (three dry winters), 1971, 1973, 1975-76, 1984, 1989-90, 1991-92, 1995-97, 2003 and 2004-06 (Rodda and Marsh, 2011).

For the Midlands region, owing to the significance of major groundwater aquifers in supporting river base flows, it’s prolonged shortages of rainfall and dry winters, notably over two consecutive years, that have the biggest environmental impact. Table 2 shows the ten highest regulation years (i.e. notably dry years) on record, showing how years are often paired together in significance. Years where regulation exceeded 100 days provide a particularly good indication of drought stress, as additional restrictions come into force in recognition of the need to manage water resources wisely as dry conditions persist.

Table 2

Rank	Year	Period of Regulation alert	First day of Regulation Last day of Regulation	Total No. of Regulation days	Total releases (Ml)
1	**1989**	May - October	30 May -	125	48,600
2	**1995**	5 May - 23 Nov	17 Jun - 11 Nov	124	42,507
3	**1976**	22 Apr - Oct?	18 May - 15 Sep	121	39,000
4	**1975**	9 June - Nov?	10 June - 3 Nov	113	*missing*
5	**1984**	15 May - 1 Oct	15 June - 16 Sep	93	*missing*
6	**1990**	4 May - 3 - Oct	24 May - 30 Sep	*missing*	36,952
7	**2003**	11 Apr - 17 Nov	16 Jun - 28 Oct	88	26,494
8	**2006**	8 Jun - 12 Oct	21 Jun - 30 Sep	82	27,022
9	**1996**	17 Jun - 28 Oct	25 Jun - 15 Oct	73	33,702
10	**2002**	12 Apr - 16 Oct	16 Jul - 13 Oct	70	16,381

Please note, data prior to 1990 is patchy with several years missing, the prescribed flow target at Bewdley was increased in 1979 (from 727Ml/d mean to 850Ml/d 5 day mean), which will have increased the number of days regulation would be required on in subsequent years, and further resources have been developed for River Severn Regulation since it’s original design. All these factors mean the order of ranking does not entirely reflect the order of drought severity.

Records and data become sparse and anecdotal the further back in time searched, as responsibilities and priorities have changed with society and re-organisations. River Severn Regulation was originally managed by Severn Trent Water, followed by the National Rivers Authority which was superseded by the Environment Agency, resulting in knowledge and experience from these historic drought years becoming diluted. It has been possible to identify that variations of the River Severn Drought Order were operated in 1976, 1984 and 1989.

These consisted of;

- **1975-1976 two separate drought order applications**
  29 July: Lower Bewdley prescribed flow from 727Ml/d to 545Ml/d and remove the compensation release obligation (18 Ml/d) from Llyn Clywedog for 6 months. Granted 6 August and operated.
  20 August: Abandon prescribed flow at Bewdley and move to releasing 2% of remaining storage per day subject to Bewdley not exceeding 545Ml/d. Granted 3 September but never operated, significant rainfall returned.
- **1984 one drought order application**
  1 August: Cap Llyn Clywedog releases to 2% of storage (no reference to prescribed flow reduction at Bewdley, flow records do not consistently fall below 850Ml/d). Granted 18 August and operated.
- **1989 one drought order application**
  31 August details agreed, application made on 11 September. Lower Bewdley prescribed flow reduced from 850Ml/d to 730 Ml/d over a 5 day mean. Granted 30 September.

For a drought summary and hydrograph of each of these drought events refer to Appendix B.

In more than 20 years, and most notably during the 1995-96 events, the River Severn Drought Order has not been required. This reflects the current robustness of the system and ongoing development of further resources in the Shropshire Groundwater Scheme.

<u>Conceptualisation of the River Severn</u>

Six assessment points (AP's) were selected along the main River Severn (Figure 7) to assess the impacts on flows at key points along the river system. All sites were located at gauging stations to enable model data to be considered against actual recorded flows and existing Environmental Flow Indictors (CAMS).

Figure 7: Main River Severn Flow Assessment Points

In order to model the potential impacts of the Gloucester and Sharpness canal abstraction on River Severn flows during severe drought, an average abstraction profile was manually inserted into Aquator. Flows were estimated both upstream of the canal abstraction and channel bifurcation (U/S Sharpness) and downstream (Lower Parting). The maximum abstraction represented was 300 Ml/d, it is recognised this could be a significant under estimation, but does represent more likely dry weather operation. Final conclusions will be based around the 'worse case' likely effects (assuming maximum abstraction), with further work suggested to improve the conceptualisation and understanding for drought management.

A number of methods have been used to present and interpret the modelled flow data, and attempt to assess whether flows are significantly impacted. Hydrographs have been produced to assess the daily changes and duration of the event. Data has also been converted into flow duration curves for comparison against actual flow records, and assessment against Catchment Abstraction Management Strategies (CAMS) Environmental Flow Indicators to attempt to quantify the significance of any flow changes.

Flow duration curves are useful for illustrating the duration and magnitude of low flow/drought events (i.e. the rarity), however caution is needed when comparing different time periods as the results will be skewed. The existing data sets are all based around the CAMS period 1990 to 2007 (18 years). The modelled data is a theoretical 1975 to 1977 (only 3 years), a much shorter record and largely low flow biased. Therefore, consideration of adverse impacts will only be taken of the mid to low flows, using a precautionary guidance only principle to the results/conclusions.

The aim of the flow analysis is to identify, with the best certainty possible at this time, what impact the drought order in isolation, and separately in full combination, is having on the modelled drought scenario's. The Do Nothing model runs are used as the baseline prediction of what could happen if no management strategies were undertaken to alleviate the developing conditions, therefore focus will be on the difference between the Do Nothing model and the drought order and full combination models.

Hydrology scenario drought magnitude and setting the scene

The 1975-76 drought remains a primary benchmark for drought planning due to it's hydrological severity and spatial impact.

Owing to the size of the River Severn catchment and complexity of the water demands upon storage at Llyn Clywedog (not local) it is difficult to calculate return periods specifically for the River Severn Drought Order. The nature of the Welsh Mountains is to receive the highest rainfall, however it could be localised groundwater recessions in the Shropshire Plains down to the Severn Estuary that trigger the high regulation need and depletion of Llyn Clywedog storage. The opposite could also be true, with a lack of rainfall over the Welsh Mountains preventing sufficient recharge during a high regulation season primarily triggering the need for a Severn Drought Order. Very different return periods would be produced according to which rainfall catchment area's you include in calculations and what time periods you are using.

For consistency with Environment Agency drought management, Tabony Table* calculations were used to produce return periods based on accumulative rainfall (up to 36 months) compared to expected long term monthly averages (1961-1990).

The drought scenario's created to test the Severn Drought Order were all based on the 1975-1976 drought event as a starting point, therefore rainfall data for this period was used to populate the initial Tabony Tables. Figure 8 and Table 3 and 4 below contain the return periods for the real event which triggered the River Severn Drought Order application in July 1976, and activation in August 1976.

The Severn Drought Order was triggered during July 1976, using the Severn tabony table (at the full catchment scale) a return period of 1 in 20 years is calculated over 6 to 15 months, however the Welsh Uplands clearly received more average winter rainfall compared to the mid to lower catchments which were experiencing up to a 1 in 200 year events over 15 months. This highlights the important geographical split that drives the River Severn Drought Order requirement. During 1976 the Welsh Uplands experienced a shorter term but more acute shortage of rainfall compared to the downstream catchments, which was then sufficient to limit recharge to Llyn Clywedog during the critical demand period. Coupled with the high regulation demand from downstream resulting from the longer term lack of rainfall having reduced baseflows, the River Severn Drought Order requirement threshold was crossed during August 1976. By the end of August, the whole Severn catchment tabony calculates a return period of 1 in 100 year over an accumulated 11 month period.

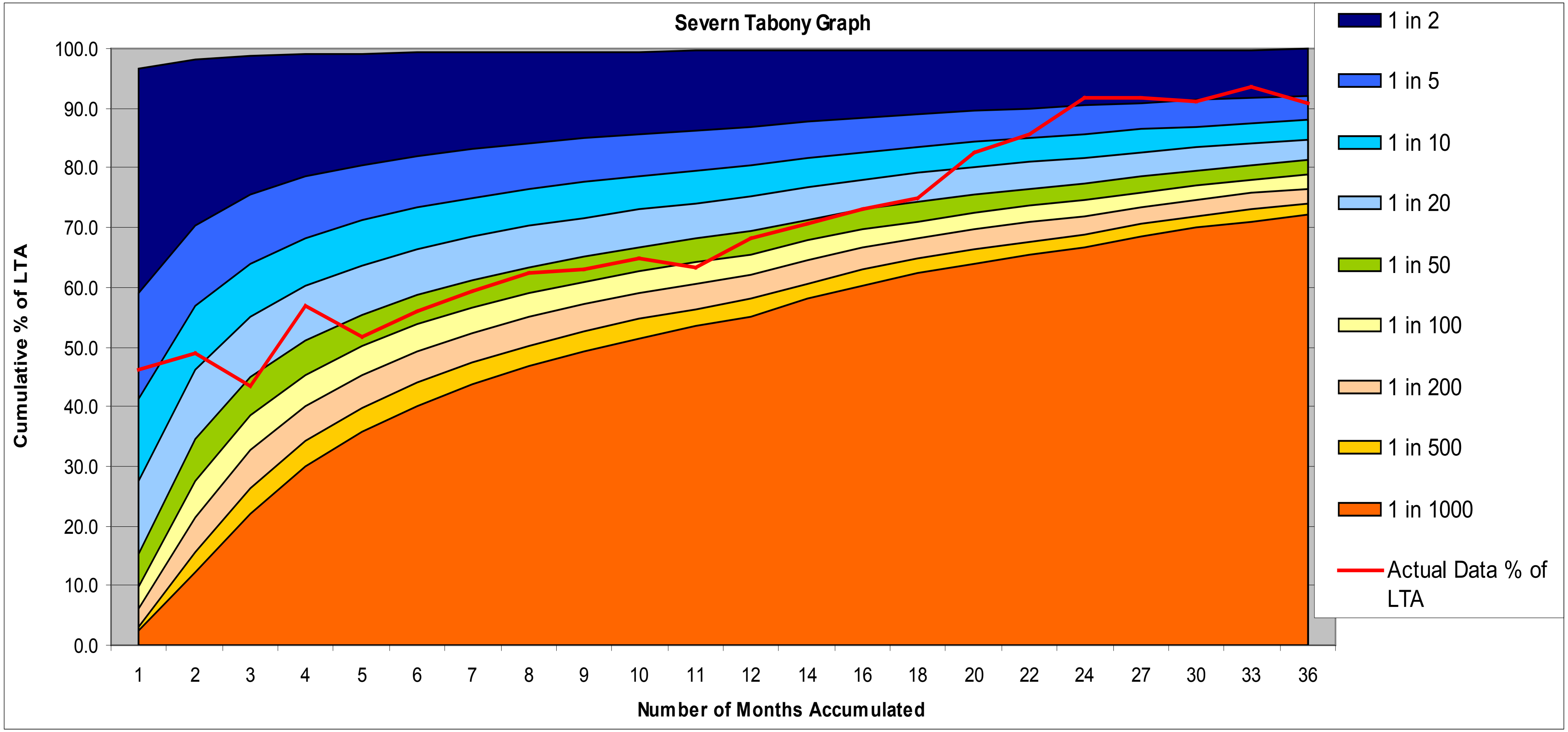
Table 3: July 1976 Tabony Table Accumulative Return Periods

	Accumulative Return Period (1 in x years) - from July 1976 (going back 36 months)							
Tabony catchment	**1 month**	**3 month**	**6 month**	**9 month**	**11 month**	**12 month**	**15 month**	**18 month**
Severn Tabony	**5**	**10**	**20**	**20**	**20**	**20**	**20**	**10**
Welsh Mountains	5	20	20	2	2	5	10	2
Shropshire Plains	5	10	10	50	100	100	200	50
Middle Severn	5	10	20	50	50	50	50	20
Avon	10	10	100	200	200	200	200	50
Lower Severn	10	20	50	100	100	200	200	50

Table 4: August 1976 Tabony Table Accumulative Return Periods

	Accumulative Return Period (1 in x years) - from August 1976 (going back 36 months)							
Tabony catchment	**1 month**	**3 month**	**6 month**	**9 month**	**11 month**	**12 month**	**15 month**	**18 month**
Severn Tabony	**5**	**50**	**50**	**50**	**100**	**50**	**50**	**20**
Welsh Mountains	100	500	200	10	10	10	10	20
Shropshire Plains	20	100	100	100	200	200	200	200
Middle Severn	10	50	50	50	200	100	50	50
Avon	1	10	20	100	200	100	100	50
Lower Severn	2	20	50	100	200	100	200	100

Figure 8: Severn Catchment – August 1976 (Drought Order activated)



It is important to note from Table 4, that by the end of August individual rainfall area's within the Severn basin experienced up to 1 in 500 year return periods over 3 months, and the majority experienced a 1 in 200 year event over 11 months. The difference in return periods between the rainfall area's demonstrates the difficulty already highlighted in determining an overall River Severn Drought Order estimate.

River Severn Drought Order Return Periods
The Aquator flow modelling assumed rainfall and flows to mimic the real event into August 1976, from September onwards inflows were reduced to prolong the drought impacts to test the Severn Drought Order. Rainfall cannot be directly altered within Aquator, so flow reductions were applied across the whole River Severn catchment, to replicate little to no significant runoff.

Assuming no rainfall was received, the Severn catchment Tabony return periods were pushed into extremes of 1 in 1000 year over 1 month, with accumulative return periods averaging between 1 in 200 and 1 in 500 years over 2 to 11 months for the theoretical September (theoretical drought order activated at the end of August). However this is an extreme interpretation of continued flow recessions, some rainfall would be likely even during continued recessions. The 1976 event (Bewdley prescribed flow was 727 Ml/d at this time) highlighted that at the Severn catchment scale, Tabony return periods of 1 in 20 from 6 to 15 months accumulatively were enough to trigger the Severn Drought Order application during July.

Using the 1976 event as a benchmark (noting the improvements within the regulation system since this event), it could be assumed that a River Severn Drought Order 'application' could be triggered for events with Severn catchment scale Tabony returns of greater than 1 in 20 for 6 months and longer accumulatively. A drought order application would depend on the time of year when rainfall shortages occurred. It is important to note that the probability for an application is more likely than a drought continuing long enough for the River Severn Drought Order to actually need to be 'activated.' As discussed, it's the combination of long term rainfall shortages in the middle Severn sub catchments that drives the need for high regulation (owing to significantly reduced baseflows), coupled with a shorter term absence of significant rainfall over the Welsh Uplands, reservoir refill is limited enough to trigger the need for a River Severn Drought Order. Due to the various parameters, timings and sequence of events involved it is unrealistic to predict a return period/probability with high accuracy. Climate change rainfall variations and/or increased abstraction demands on the River Severn will also increase the frequency of need for a River Severn Drought Order.

Limitations with using rainfall and Tabony Tables to determine return periods
Short term high rainfall events do not provide effective recharge to catchments already experiencing long term dry weather/drought impacts (due to soil moisture deficits and depleted groundwater levels), although they can be vital in refilling reservoirs.

Tabony Tables use monthly rainfall totals and make no assumption about rainfall distribution throughout a month, producing return periods based around the expected monthly long term average. This needs to be understood when using Tabony results, as high rainfall/flood events in particular can skew results (for a single month and accumulatively) to suggest normal rainfall which could conflict with environmental evidence in the catchment. For the Midlands we know groundwater levels are a crucial parameter in drought development, so rainfall should be used in context of aquifer recharge and groundwater levels during real events, not in isolation.

Flow Modelling Analysis
'Do Nothing' models were used as the baseline comparison instead of a natural flow series for this investigation. Aquator contains discharges built into the natural background flow of the model, making it difficult to accurately separate and naturalise the flow series for a theoretical event. CAMS period (18 years) naturalised flow duration curves were used for some comparison analysis, but modelled flows were obviously skewed by the theoretical drought, which needs to be understood to ensure the correct context for interpretation.

The River Severn is a highly regulated and artificial watercourse, natural flow regimes can no longer be expected along the main river although flow targets exist to protect the environment. The Severn Corridor CAMS identified current and fully licensed management of water resources along the main river Severn is acceptable to the Environmental Flow Indicators (EFI).

The Review Of Consents (RoC) stage 3 (2009) conducted a Habitat's Directive appropriate assessment into the current flow regime entering the Severn Estuary. Investigations concluded the current licensing policy and operation of the Severn Regulation system protect and maintain a adequate flows (in accordance with WFD transitional waterbody flow targets). The Appropriate Assessment concluded current flow regime was having no significant impact on the Severn Estuary features, with the exception of severe drought conditions, which were not assessed. These findings were signed off by Natural England and the Countryside Council for Wales in 2009.

Building on the foundations of RoC, CAMS and WFD assessments of the River Severn, the River Severn Drought Order investigation focused on a Do Nothing scenario as a baseline instead of a naturalised flow series. Representing a more realistic comparison of likely flows during a severe drought event if no Drought management actions were taken when operating regulation releases from Llyn Clywedog reservoir.

It is important to emphasise that the particular drought order management scenarios being assessed are theoretical. They were developed as a means of assessing the likely worst case environmental impacts associated with managing water resources during a very severe drought, providing a guide on flow trends and likely periods of operation. Models cannot predict to a high level of accuracy exactly what a drought will look like (e.g. timing and duration) until the antecedent conditions are known.

Model Data: Acute Scenario

Severn Regulation impacts

The relevant Appendices contains the graphs illustrating the regulation system operations for the three main scenario's, throughout the theoretical period 1975 to the end of 1979.

Do Nothing Model

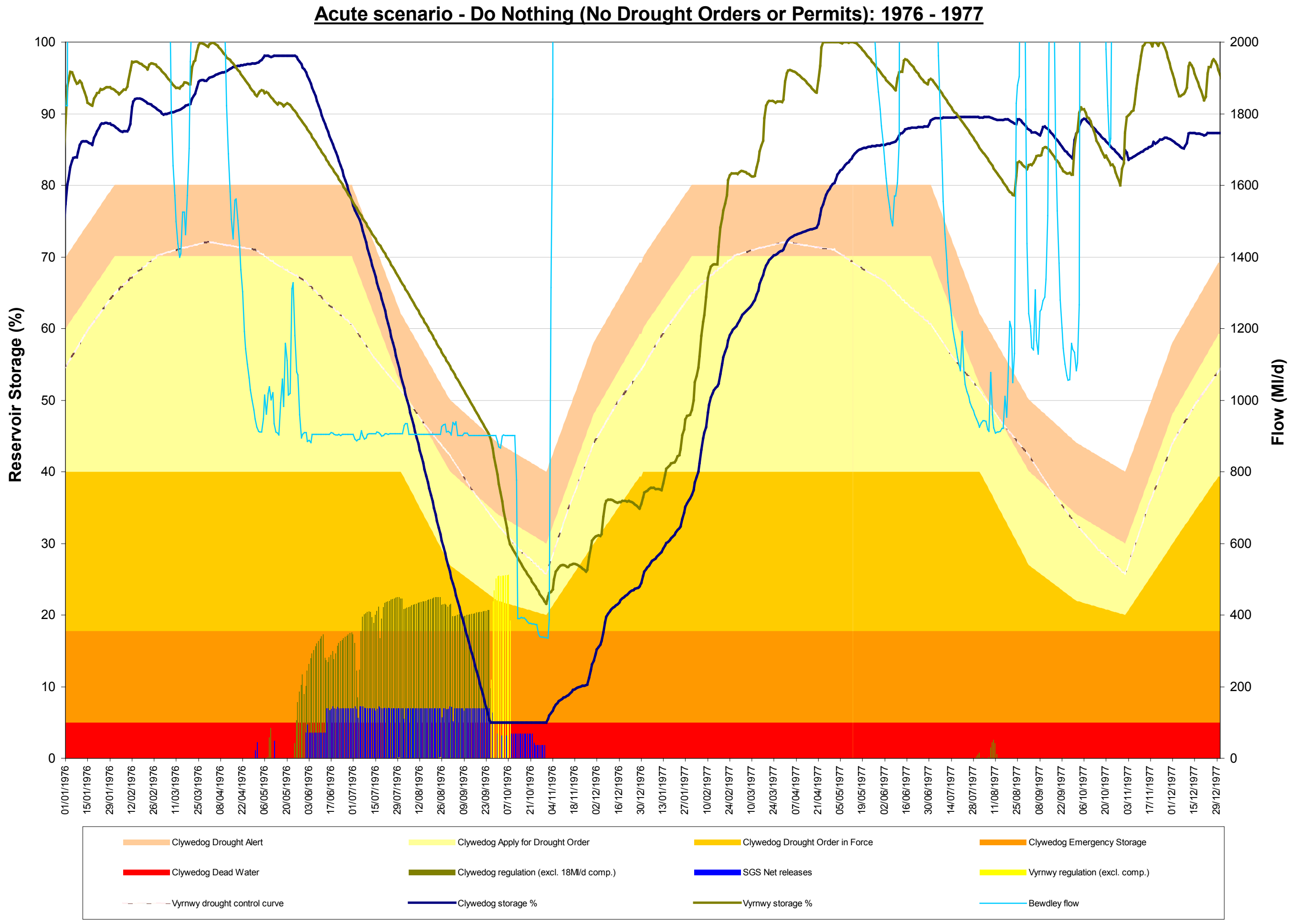


Figure 9 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Do Nothing model.

Figure 9 presents modelled regulation operation if the Severn Drought Order were not operated, and therefore high regulation releases were maintained from Clywedog, regardless of the storage levels. Appendix J.6 contains a breakdown of key dates and timings for this model run.

The graph shows operationally, Clywedog provides the primary support with over 400 Ml/d up until dead water (5%) is reached; SGS runs in parallel at the current maximum net release of 140 Ml/d. Therefore once Clywedog fails only Vyrnwy bank can be utilised to meet the 850 Ml/d flow target at Bewdley, with regulation releases peaking at 513 Ml/d. The regulation system fails 16 days after Clywedog, a combined consequence of Vyrnwy regulation ceasing as the bank is exhausted and SGS individual licence maximum's being reached causing significant reductions in releases. In a real event, the operation of these sources is likely to be different, but the model does allow system failure and worse case to be tested.

Continuous regulation releases begin on the 25 May 1976, and continue for 152 days until 30 October. A total of 166 regulation days and 70,220 Ml combined releases were modelled during 1976, with Clywedog providing 66% of the resource, SGS providing 25% and Vyrnwy providing 9%. For context, during the real 1976 event

39,000 Ml were released over 121 days of regulation. The highest regulation year on record was 1989 with 48,600 Ml being released over 125 days. More regulation resources have been developed since both these drought events, so the number of regulation days is more representative for comparison of severity, with modelling indicating an increase in regulation days of 41-45 days.

Clywedog provides 125 days regulation support before failure on 29 September. From continuous activation on 25 May at 98% full, it takes 33 days of >300 Ml/d releases to cross the Drought Alert curve (27 June), 70 days to cross the Drought Order application curve (3 August), 96 days before crossing the Drought Order in force (29 August) curve and 108 days before crossing the emergency storage (10 September) curve. Clywedog storage remains in dead water for 36 days, during which no regulation or compensation flow releases would be possible.

Vyrnwy reservoir provided 13 days of regulation support between 26 September and 8 October. The drought control curve is crossed on 8 October at 30% storage, marking the end of regulation support. Minimum storage is reached on 31 October at 22%, but dead water is avoided and minimum compensation flows are maintained throughout.

SGS activates on 1 June and provides 152 days continuous regulation support until 30 October. Maximum 140 Ml/d net discharges are made from 14 June until individual licence maximums are reached on 28 September (Montford licence) and 22 October (Leaton licence), with net discharges halved on both occasions as some phases deactivate. The combined licence annual limit is not exceeded, which could suggest with different operation during a real event, additional discharges (<80 Ml/d) could be maintained for longer. However, the model indicates the spare licence is within the phases that continued to pump at maximum deployable output until regulation was no longer required, so it might not be physically possible to provide more water than is modelled. The final option would be to apply for the SGS drought order, which seeks to exceed the licence quantities.

Clywedog recovers above the emergency storage curve on 7 December 1976 and after almost a year (307 days) crosses above the Drought Alert curve on 30 April 1977. Vyrnwy recovers above the drought control curve on 10 February 1977 and exceeds 90% storage on 19 March 1977, Clywedog takes until 17 July 1977 to exceed 90% storage.

Environment Agency Drought Order in isolation Model

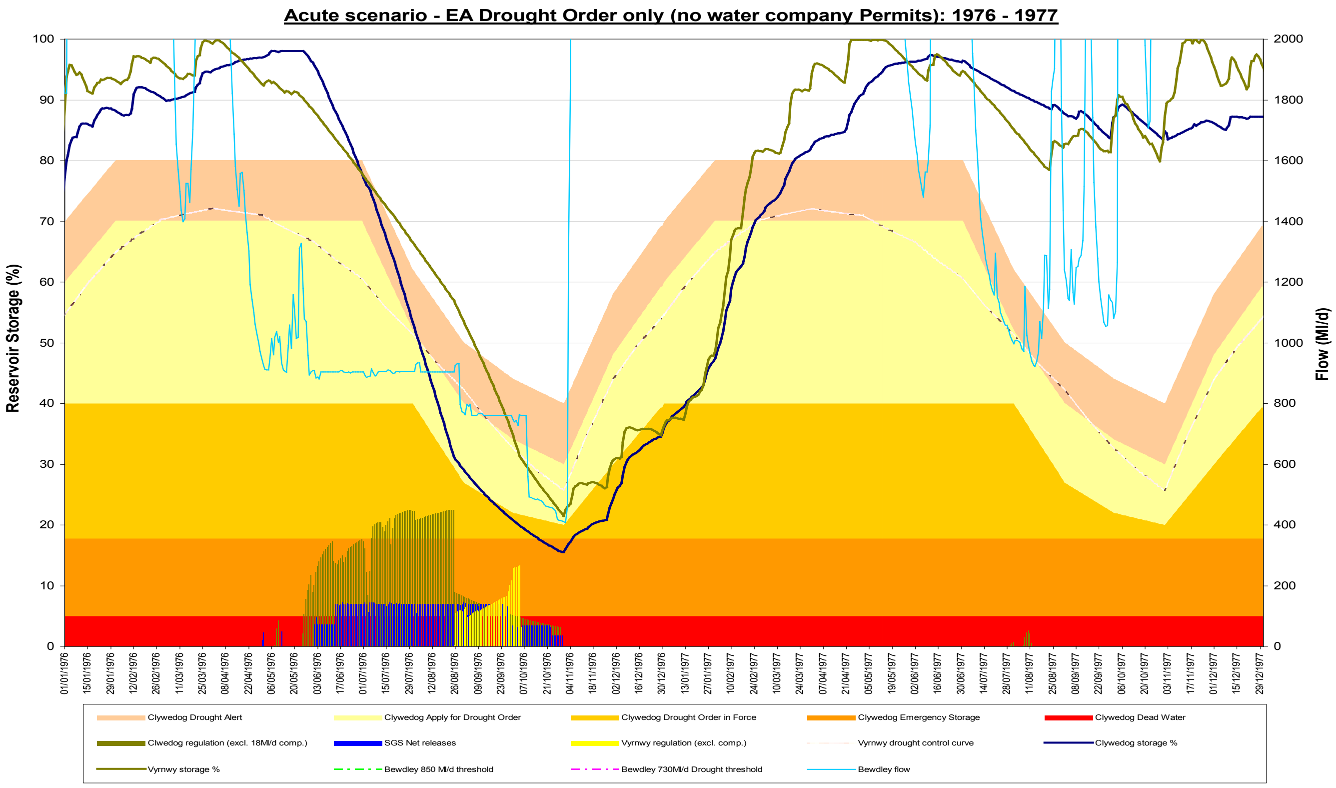


Figure 10 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Environment Agency Drought Order in isolation model..

Figure 10 presents modelled regulation operation if the Severn Drought Order were operated but no other drought permits or orders were active. Appendix J.6 contains a breakdown of key dates and timings for this scenario.

Clywedog provides the primary support until the Drought Order in force curve is approached and the model activates the drought order on 25 August 1976, as storage reaches 31%. SGS operation is very similar to the Do Nothing model, with maximum net discharges already being made. Operationally, the lost Clywedog resource (releases now capped at 300 Ml/d) is again taken from the Vyrnwy bank, although the Bewdley prescribed flow has decreased to 730 Ml/d, reducing the pressure slightly.

The regulation system still fails (failure measured as not achieving Bewdley prescribed flows) with the drought order in operation, again resulting from the combined loss and reductions in Vyrnwy and SGS regulation support. Subsequently flows begin to crash 3 days earlier than under the Do Nothing model. This appears to be caused by moving greater demand to the Vyrnwy bank earlier, as Clywedog releases are capped at 300 Ml/d and SGS is already at maximum deployable output. Vyrnwy bank therefore exhausts faster and again coincides with SGS licence maximums being reached.

The beneficial difference from the Do Nothing model is Clywedog never reaches dead water and therefore continues to make both compensation and regulation releases throughout. The results of this can also be seen down the whole system, with all minimum flows being higher than the Do Nothing model.

A total of 166 regulation days and 64,557 Ml combined releases were modelled during 1976, with Clywedog providing 63% (40748 Ml) of the resource, SGS providing 27% (17708 Ml) and Vyrnwy providing 9% (6102 Ml).

The continuous regulation period is only 1 day longer, but lower prescribed flows at Bewdley result in the combined regulation releases being reduced by 8% to 64,557 Ml during 1976. This equates to a storage saving at Clywedog of 11%, with the minimum storage of 16% being reached on 31 October. By avoiding dead water, regulation support from Clywedog also increases to 158 days.

The initial dates and time periods of Clywedog operation remain the same until the drought order is activated. The saving in storage appears to move key points by about one month. Emergency storage is reached on 15 October instead of the 10 September, recovery back above the emergency storage is achieved on 6 November instead of 7 December, and storage recovers above the Drought Alert curve on 21 March 1977 instead of 30 April. The drought order remains active within the model for 144 days, stopping on 15 January 1977 when storage (41%) crosses above the drought order in force curve.

Vyrnwy reservoir provided 44 days (31 day increase) of regulation support between 23 August and 5 October with releases peaking at 267 Ml/d (246 Ml lower than Do Nothing), almost half the Do Nothing model and therefore more sustainable, explaining the increased time Vyrnwy bank could be utilised. The drought control curve is crossed on 4 October, with the minimum storage remaining the same at 22% (31 October), recovery dates are the same as Do Nothing modelling. SGS again activates on 1 June, providing 1 extra days regulation up to 31 October. Near maximum 140 Ml/d net discharges are still made from 14 June and again step back when individual licence maximums are reached, slightly later on 29 September (Montford licence) and 24 October (Leaton licence). The maximum combined licence is not reached.

Clywedog storage remains below the Drought Alert curve for 267 days in total, with the drought order being active for 144 days of this critical period. Clywedog storage is able to recover faster than the Do nothing, as levels were not drawn down as far. Storage exceeds 90% on 27 April 1977, over two months earlier than under Do Nothing.

Full In-combination Model

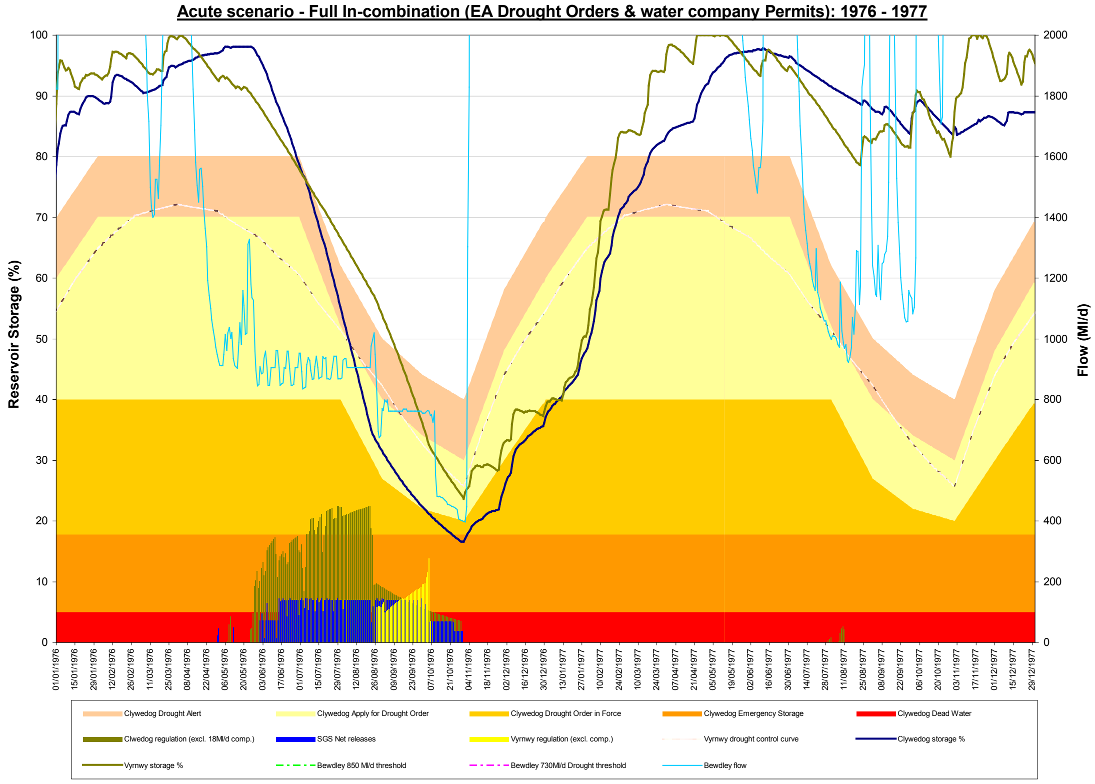


Figure 11 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the full in-combination model, which activates all the possible drought Permits as well as the Environment Agency drought order.

Figure 11 presents modelled regulation operation if the Severn Drought Order were operated alongside all drought permits impacting on the River Severn catchment. Appendix J.6 contains a breakdown of key dates and timings for this scenario.

The full in-combination model results are very similar to the Environment Agency drought order model for regulation operations. A total of 166 regulation days and 64,022 Ml combined releases were modelled during 1976, with Clywedog providing 63% (40248 Ml) of the resource, SGS providing 28% (17672 Ml) and Vyrnwy providing 9% (6102 Ml). The drought order is activated 1 day earlier, 24 August 1976 at 32% storage, but also deactivated 5 days earlier on 10 January 1977, a total of 140 days in operation.

The regulation system fails the Bewdley prescribed flow; 2 days earlier than under the Do Nothing model (1 day later than the Environment Agency drought order model). The reason for failure remains the same, but why the full in-combination model appears to reduce the regulation releases when the abstraction pressure on the system is increased is unclear, although the quantities aren’t significant. Vyrnwy total releases remain the same, but a further 1% storage (499 Ml/d) is saved at Clywedog and SGS releases reduce by 36 Ml. The timings are slightly different, which could attribute some of the resource savings as the modelled drought period itself remains the same (drought order in operation for slightly less time).

Clywedog reaches emergency storage on 21 October and avoids dead water with a minimum storage of 17% reached on 31 October. Storage recovers above the emergency storage curve on 4 November and recovers above the Drought Alert curve on 19 March 1977.

Vyrnwy bank provided 41 days of regulation support between 27 August and 6 October, with releases peaking at 276 Ml/d (237 Ml lower than Do Nothing), almost half the Do Nothing model and therefore more sustainable. The drought control curve is crossed on 11 October, with the minimum storage reaching 24% (31 October), recovery dates remain the same as Do Nothing modelling. SGS operational period is the same as DO nothing, but the initial licence limit is reached slightly later on 5 October (Montford licence), Leaton still reaches the licence limit on 24 October. The maximum combined licence is not reached.

Clywedog storage remains below the Drought Alert curve for 263 days in total, with the drought order being active for 140 days of this critical period. Storage exceeds 90% on 25 April 1977, over two months earlier than under Do Nothing.

Severn Corridor Flow Impacts

This section includes a break down of modelled regulation behaviour, hydrographs for the main River Severn and the main conclusions from the hydrological analysis.

Assessment Point 1, Bryntail

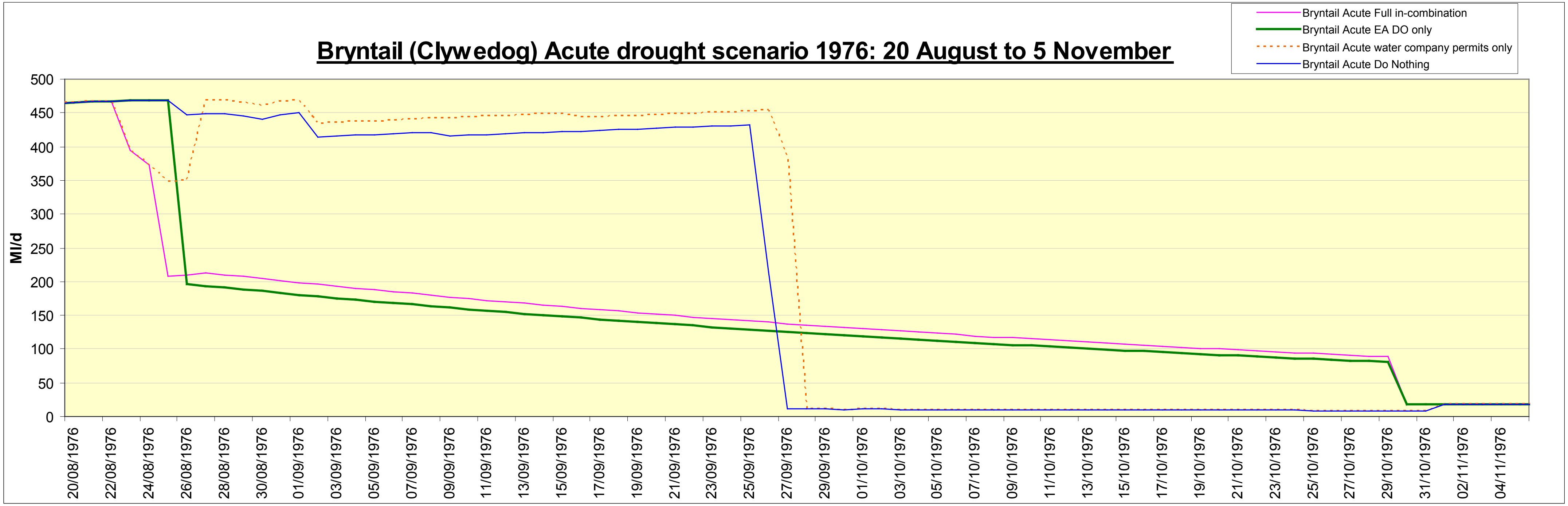


Figure 12 shows the modelled impacts on flows at Bryntail, immediately downstream of Clywedog dam. All models are displayed to illustrate the different impacts on flows caused by varying the regulation operations and drought permits and order. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 12 presents a close up of the hydrographs at Bryntail from 20 August and 5 November 1976, the critical period of low flows. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J.6 contains a breakdown of key dates and timings for each model.

Table 5

	Acute Do Nothing Ml/d	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*163*	*163*	*163*	176	216
Q95	18	18	18	18	19
Q99	9	18	9	18	-6
Q99.9	9	18	9	-	-59

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

The most significant impact of the Do Nothing model is that compensation flow fails on 27 September 1976, crashing from 214 Ml/d to 11 Ml/d in one day. The failure lasts for 35 days with flows consistently <10 Ml/d, a minimum flow of 8.67 Ml/d occurs on 31 October. Compensation flow is restored from 1 November, but flow variation (flows above compensation) does not occur until 30 July 1977. Up until this point, 306 days in total, the reservoir is essentially intercepting all the runoff in order to refill while regulation is not required.

Appendix J.2 plots just the modelled flow duration curves against one another, the significant Q values are contained in Table 5. The graph illustrates how the Do nothing model produces larger high flows (e.g Q5 to Q25); greater regulation (>200 Ml/d) is maintained from Clywedog for longer if the drought order is never applied, as no attempt is made to prolong the resource and plan for a continuing drought. The mid to lower flows (Q52 to Q73) are then reduced compared to the drought order modelling, illustrating how Do Nothing has already caused Clywedog to use up the regulation water in larger but shorter term releases as the drought developed. Once the critical drought flows are reached from Q97 onwards (short term), the Do Nothing model shows lower flows than the drought order models, representing how dead water has been reached at Clywedog and releases are no longer physically possible.

Generally the Do Nothing flow duration curve is lower than the gauged and naturalised record. This is largely due to the different time period used (biased towards low flows), but does illustrate how the modelled drought event itself, Do Nothing, has reduced the natural background flows, regardless of any abstraction activity. This flow response would be expected in a real event. The most significant observation in the modelled data is the failure of the compensation flow.

Appendix J.3 attempts to quantify the significance of flow changes to the Environmental Flow Indicators provided by CAMS. High flows are failed as a result of the time period used, which excludes a balanced portrayal of high/flood flows and can therefore be excluded from assessment. The important failures from Q60 to Q94, the majority of which is high risk (>30% migration from EFI), represent the loss of flow variation which would realistically be caused by a natural drought event, although the duration would vary with each unique drought. It is important to stress these failures would be an unavoidable natural consequence of drought, something that would be normal in the cycle of the natural world regardless of mans intervention.

The failure of the compensation flow is represented from Q97, although no EFI failure is observed, it is likely the ecology and habitat has adapted to rely on the minimum flow of 18.2 Ml/d, so this period would be classed as a significant flow failure.

Environment Agency Drought Order model
The Environment Agency Drought Order model shows no compensation flow failure. Flow variation is lost whilst the reservoir refills, flat lining at compensation flows from 30 October to 11 June 1977. A total of 224 days, an 82 day improvement from the Do nothing model.

Appendix J.2 shows how higher flow occurrences (e.g Q5 to Q25) reduce as regulation releases are capped (<300 Ml/d) through the drought order activation. The mid to lower flows (Q52 to Q73) are increased as the stored water is then released in smaller amounts over a longer period. Once the critical drought flows are reached from Q97 onwards, the drought order model displays higher flows than Do Nothing, representing how dead water is avoided and compensation flows maintained as a minimum.

Generally the Environment Agency drought order flow duration curve is lower than the gauged and naturalised record. However, with the exception of the higher flows (time period has an impact), operating the drought order brings Bryntail flows closer to the gauged and naturalised flow duration curve than the Do Nothing model.

Appendix J.3 shows no significant flow failure beyond the Do Nothing baseline.

Full In-combination model
The Full in-combination model shows no compensation flow failures. Flow variation is again lost whilst the reservoir refills, flat lining at compensation flows from 30 October to 8 June 1977. A total of 221 days, an 85 day improvement from the Do nothing model.

The full in-combination flow duration curve (Appendix J.2) is very similar to the Environment Agency drought order curve, as to be expected. At Bryntail, no other drought permits or orders have a direct impact, however the differences in flows are created by the changes in downstream demand and resource ‘juggling’ within the regulation system to address varying need.

Appendix J.3 shows no significant flow failure beyond the Do Nothing baseline.

Assessment Point 2, Vyrnwy

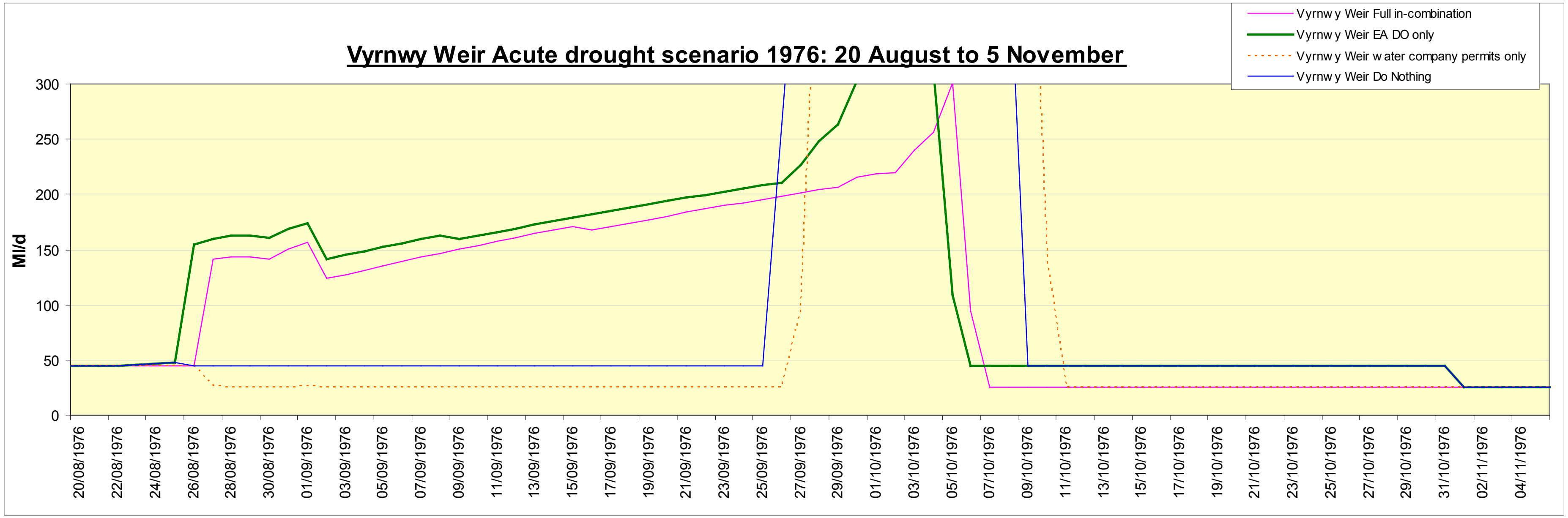


Figure 13 shows the modelled impacts on flows at Vyrnwy, immediately downstream of Reservoir dam. Vyrnwy would not be directly impacted by the operation of an Environment Agency drought order, however changes in the regulation operation would indirectly impact on flows at this AP. All models are displayed to illustrate the different impacts on flows caused by varying the regulation operations and drought permits and order. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 13 presents a close up of the hydrographs at Vyrnwy from 20 August and 5 November 1976, the critical period of low flows. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J.6 contains a breakdown of key dates and timings for each model.

Table 6

	Acute Do Nothing Ml/d	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*45*	*45*	*45*	131	426
Q95	25	25	25	25	30
Q99	25	25	25	24	0
Q99.9	25	25	25	-	0

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model
The Do Nothing model does not cause compensation flow failure (below 25 Ml/d expected at Vyrnwy Weir) at any point. The existing operation rules require a minimum of 45 Ml/d compensation flow be maintained, however if 20 Ml/d is flowing at Cownwy Weir then the flow at Vyrnwy Weir itself is reduced to 25 Ml/d and water added to the Vyrnwy bank. The minimum 25 Ml/d flow value is not failed at any point.

Continuous compensation flows of 25 Ml/d began on 1 November and continued until (flows above 25 Ml/d) 24 April 1977, a total 174 days without flow variation as the reservoir refills.

Appendix J.1 shows the main difference is variations in higher flows (Q18 to Q22) as larger, less sustainable regulation releases are made. These releases occur when Clywedog runs out of water, forcing Vyrnwy to take over primary regulation support until its own resources are exhausted (i.e. Vyrnwy bank). Very little difference is obvious between the mean to low flows.

Generally the Do Nothing flow duration curve is lower than the gauged and naturalised record for higher to mid flows; attributable to the time period used. From Q40 onwards there is little difference between the Do Nothing model and gauged flows, just a slight increase in minimum compensation flows from around Q68 to Q80. With the exception of infrequent low/drought flows (Q98 onwards), the whole gauged and modelled flow duration curves are lower than the naturalised curve.

Appendix J.3 shows that nearly the full flow duration curve creates high risk failures of the EFI, however the gauged flows show a similar failure attributed to the heavily modified nature of the waterbody. As with the gauged flows, from around Q95 onwards flows cross above the EFI and satisfy the recommended flow requirements. These infrequent low flows represent the critical drought impact, concluding no significant impact on flows.

Environment Agency Drought Order model

The Environment Agency Drought Order model also shows no compensation flow failure. Flow variation is lost for the same period, 1 November to 24 April 1977, a total of 174 days. No improvements or deterioration from Do Nothing modelling.

Appendix J.1 shows the main difference is some reductions in higher flows (Q18 to Q22) as regulation releases are made more sustainable at lower volumes for longer periods. Flow trends are very similar to Do Nothing when compared against gauged and naturalised Appendix J.2, as well as the EFI failure Appendix J.3 testing. No significant additional EFI failures are created by the drought order.

Full In-combination model

The Environment Agency Drought Order model also shows no compensation flow failure. Flow variation is lost from 7 October to 23 April 1977, a total of 198 days. The increased loss of flow variation by 24 days is caused by the United utilities Drought Permit operation.

Flow duration curve graphs show very similar results to the Environment Agency drought order model. The increased frequency of minimum compensation flows can be seen from Q64 to Q67. EFI flow failures are already high risk under Do Nothing, the additional short term failure is not caused by the Environment Agency drought order and is unlikely to have any additional significant impact as the minimum 25 Ml/d flow is still maintained.

Assessment Point 3, Buildwas

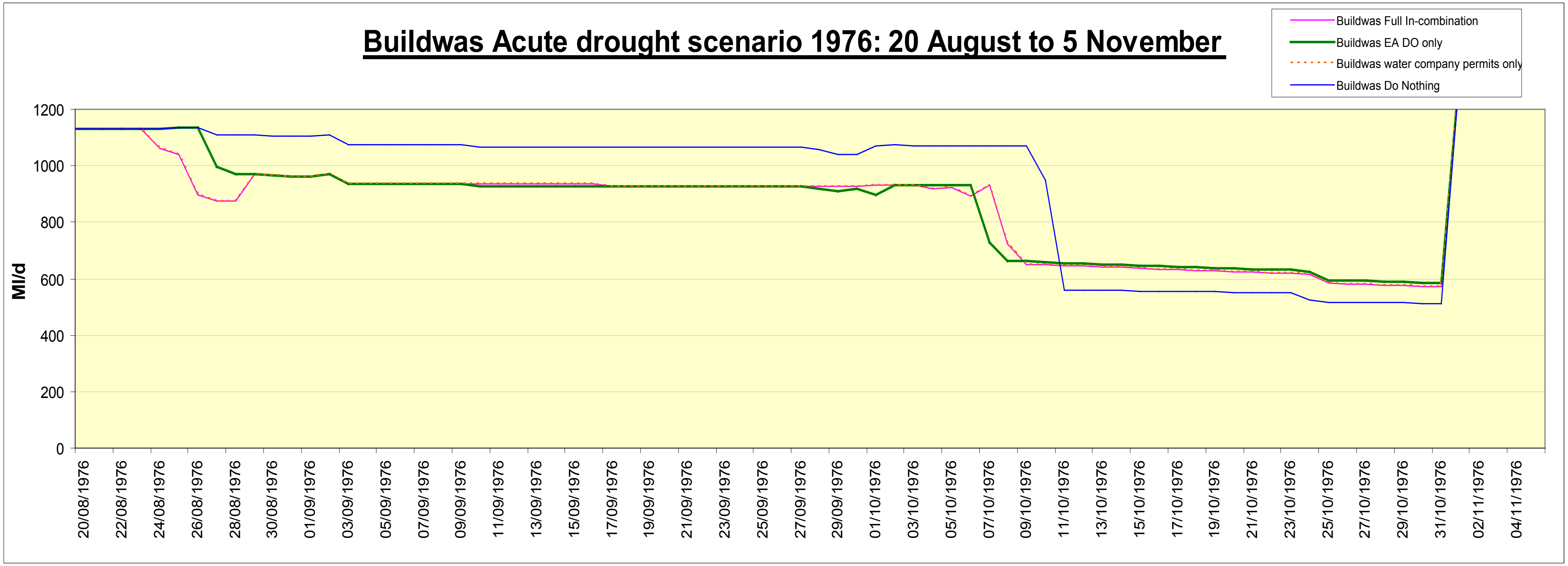


Figure 14 shows all the modelled impacts on flows at Buildwas, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 14 presents a close up of the hydrographs at Buildwas from 20 August and 5 November 1976, the critical period of low flows. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J.6 contains a breakdown of key dates and timings for each model.

Table 7

	Acute Do Nothing Ml/d	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*4978*	*4978*	*4978*	5511	5646
Q95	1068	934	934	1030	742
Q99	551	635	623	919	527
Q99.9	513	586	573	-	527

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Under the Do Nothing model maximum regulation is continued with no management intervention to protect and prolong flow support, subsequently the regulation system beings to fail and flows crash once upstream resources become exhausted. At the most critical point, only 36 Ml/d of regulation support is possible, sourced from SGS.

Prior to the regulation system failure, the Do Nothing model flows at Buildwas average (mathematical average) at 1075 Ml/d. The impacts of regulation failure first impact on Buildwas on 10 October 1976, halving flows to an average of 540 Ml/d. A minimum modelled flow of 512.1 Ml/d occurs on 31 October. The flow depression lasts 22 days in total before rainfall significantly elevates flows from 1 November 1976.

Appendix J.2 shows how the regulation releases have largely smoothed out along the FDC by the location of Buildwas. The first notable difference between the models occurs during low flows (90 percentiles), representing the variations in regulation operations between the models. Initially the Do Nothing FDC shows higher flows being maintained for longer, until flows crash to be the lowest from Q98. Again this represents how under the DO Nothing model, regulation releases are not cut back in order to prolong flow support, therefore higher releases are made until system failure is reached.

Generally the Do Nothing flow duration curve is lower than the gauged and naturalised record up until around Q85, although mid range flows do move closer to the gauged record before drifting away again. The majority of this can be attributed to the different time periods used. From Q90 to Q98 flows are very similar or higher than the gauged record, until the flow crash occurs from Q98. the DO Nothing FDC crosses above the naturalised FDC from Q85, illustrating how regulation support artificially increases low flows. Importantly, even when the flow crash occurs at Q98, the Do Nothing flows are not reduced below the naturalised FDC (1990 to the end of 2007). This suggests even with a drought of significantly higher magnitude than the 1995-1996 event, when the regulation system fails flows still do not exceed the minimum that could have been expected under natural conditions during 1995-1996.

Appendix J.3 shows that nearly the full flow duration curve satisfies the EFI target, only a short period of low risk failure occurs around Q65 to Q71. The low flow period, including the flow crash, meet the EFI objective. Considered with the observation against the naturalised FDC, no significant impact on flow is concluded.

Environment Agency Drought Order model
The first impacts of operating the drought order are picked up at Buildwas on 27 August 1976, 2 days after taking affect at Clywedog. The average (mathematical average) flow maintained is 935 Ml/d, a 140 Ml/d (13%) decrease from the Do Nothing model. The drought order is active for 45 days before benefits from the small but continued regulation releases from Clywedog are observed.

Flows still crash as a result of regulation failure (remaining resource can no longer meet demand), impacts are observed on 7 October, 3 days earlier than Do Nothing. However the benefits from the drought order is evident from 11 October, when modelled flows remain higher than Do Nothing by an average 89 Ml/d (16% increase) until flow recovery on 1 November. Flow depression lasts for a total 25 days, 21 of which are higher than Do nothing.

Appendix J.2 shows the drought order reduces flows below Do Nothing from Q93 until Q98 (5% duration), after which flows are increased using the drought order. No additional EFI failures are observed, therefore no significant flow impact is concluded.

Full In-combination model
Flow impacts are first observed on 26 August 1976, 1 day earlier than the Severn Drought Order in isolation. The average (mathematical average) flow maintained is 930 Ml/d, a 145 Ml/d (13%) decrease from the Do nothing model but only 5 Ml/d difference from the Severn Drought Order model run. Flows crash on 8 October, 2 days earlier than Do Nothing. It takes 48 days for flow benefits to be observed, evident from 11 October when flows remain an average 76 Ml/d (14% increase) higher than Do Nothing. Flow depression lasts 24 days, 21 of which are higher than Do nothing, until recharge again arrives on 1 November.

Appendix J.2 shows full in-combination reduces flows below Do Nothing for slightly longer, from Q91 until Q98, after which flows are increased. No additional EFI failures are observed, therefore no significant flow impact is concluded.

Assessment Point 4, Bewdley

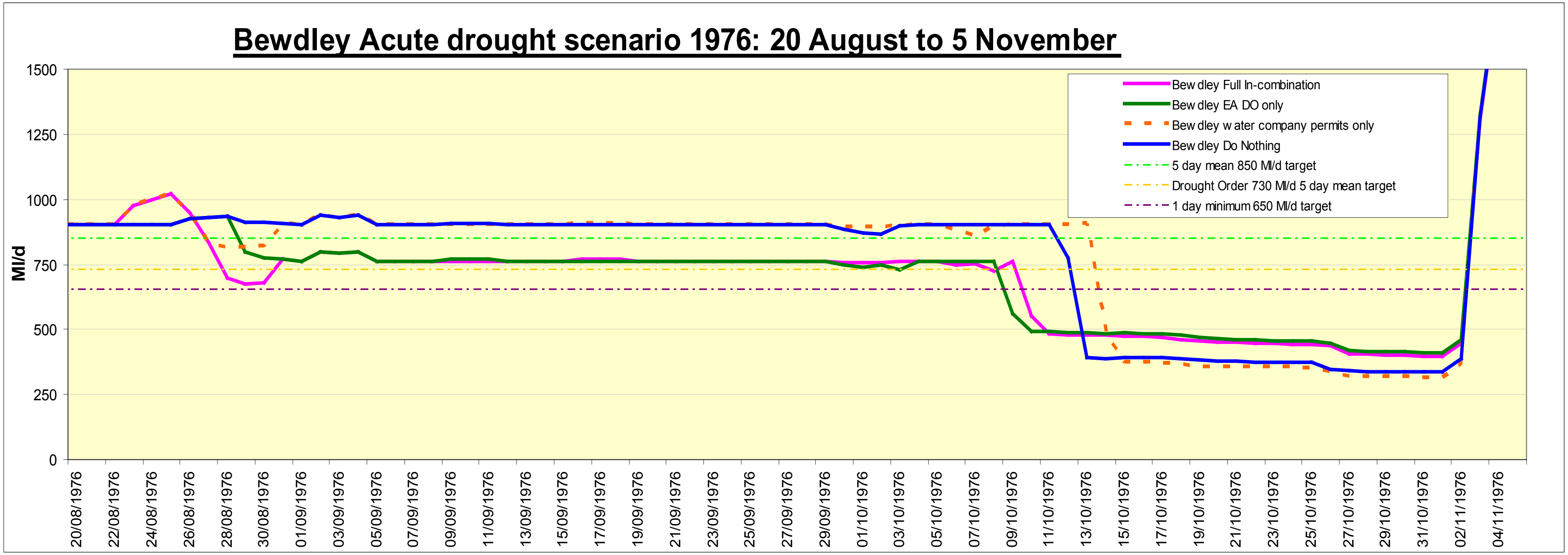


Figure 15 shows all the modelled impacts on flows at Bewdley, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 15 presents a close up of the hydrographs at Bewdley from 20 August and 5 November 1976, the critical period of low flows. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J6 contains a breakdown of key dates and timings for each model.

Table 8

	Acute Do Nothing Ml/d	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30	*4988*	*4982*	*4982*	5470	6211
Q95	901	762	870	881	930
Q99	375	458	355	791	715
Q99.9	337	411	317	-	458

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Due to the lack of runoff entering the system under the Acute scenario, modelled flows show a decline in volume when compared to Buildwas. Under normal conditions you would expect the river to accrete downstream, as the catchment area increases and tributaries enter the system. However, due to the severe shortage of rainfall being modelled, abstractions are removing more than can be naturally replaced or supported by the regulation system. Until regulation failure occurs or the drought order is implemented, this does not prevent the normal regulation flow targets from being maintained and no detrimental impacts would be expected.

Do Nothing model
Leading up to regulation failure, Do Nothing flows at Bewdley average (mathematical average) at 903 Ml/d. The impacts of regulation failure are first observed on 12 October 1976, more than halving flows to an average of 368 Ml/d. Flow depression lasts 22 days with a minimum flow of 336 Ml/d occurring on 1 November, flow recovery begins on 3 November 1976. Flows fell below the critical 1 day 650 Ml/d target for 21 days in total.

Appendix J.2 and Appendix G show the same trends in flow behaviour/response as Buildwas. Once again the Do Nothing model flows appear higher than the gauged record between Q94 and Q98, and from Q97 of the naturalised FDC. Do Nothing flows crash at Q98 as the regulation system begins to fail.

Appendix J.3 shows the whole mid to low flow (Q40-Q90) range fails to meet the EFI. This is due to the unavoidable loss of flow variation expected during a severe drought event, and represents the lack of runoff and reduced baseflow entering the system. Flow variation would be created naturally as thunder storms and rainfall events occurred, but these modelled FDC’s represent only a 3 year period and rainfall has been altered to produce more extreme droughts than we have on our flow records. The range of significance to this analysis is more likely to be Q90 onwards, as the approximately 70 days of impact represent only 6% of the 3 year period used to calculate the FDC, which would also largely be represented within the lowest flows of the FDC.

Applying this principle, between Q90 and Q98 the EFI is not significantly failed under Do Nothing. However, once regulation failure impacts at Q98, flows drop into the

High Risk (>30% lower than EFI) band. Although this banding system is only a guide on whether the impact could be significant, when considered against the 1 day minimum 650 Ml/d flow target at Bewdley and the minimum flow ever recorded at Bewdley of 518 Ml/d (recorded in September 1976), the magnitude becomes apparent. The short term flow crash experienced under Do Nothing is a significant flow impact.

Environment Agency Drought Order model

The first impacts of operating the drought order show on 29 August 1976, 4 days after taking affect at Clywedog. The average (mathematical average) flow maintained is 764 Ml/d, a 139 Ml/d (15%) decrease from the Do Nothing model. Flows crash on 9 October, 3 days earlier than Do Nothing. However the benefits from the drought order is evident from 13 October, when modelled flows remain higher than Do Nothing by an average 90 Ml/d (24% increase) until flow recovery on 3 November. Flow depression lasts for a total 25 days (all below 650 Ml/d), 21 of which are higher than Do nothing, resulting in the drought order having been active for 45 days before a benefit was observed.

Appendix J.2 shows the drought order only reduces flows below Do Nothing from Q94 until Q98, after which flows are higher than Do Nothing. A minor additional EFI failure occurs between Q94 and Q96, however it is within 10% of the EFI and for a very short period. From Q98 the drought order reduces the EFI failure to be within 30% of the EFI.

The aim of this assessment is to identify whether the drought order itself is having a significant detrimental flow impact, separating it's individual impact away from that being naturally caused by the drought event (Do Nothing model). Therefore, no significant flow impact is concluded for the drought order. No significant additional impact is caused and flow benefits are evident during the most critical period.

Full In-combination model

Flow impacts are observed on 28 August 1976, 1 day earlier than the Severn Drought Order in isolation. The average (mathematical average) flow maintained is 757 Ml/d, a 146 Ml/d (19%) decrease from the Do Nothing model but only 7 Ml/d lower than the Severn Drought Order model. Flows crash on 10 October, 2 days earlier than Do Nothing. It takes 46 days for flow benefits to be observed, evident from 13 October when flows remain an average 77 Ml/d (21% increase) higher than Do Nothing. Flow depression lasts 24 days (all below 650 Ml/d), 21 being higher than Do nothing.

Full in-combination (Appendix J.2) reduces flows below Do Nothing for slightly longer, from Q90 until Q98, however the deterioration remains within 10% of the EFI and would not be considered significant. From Q98 flows benefit compared to Do Nothing. No significant flow impact is concluded.

Assessment Point 5, Saxon's Lode

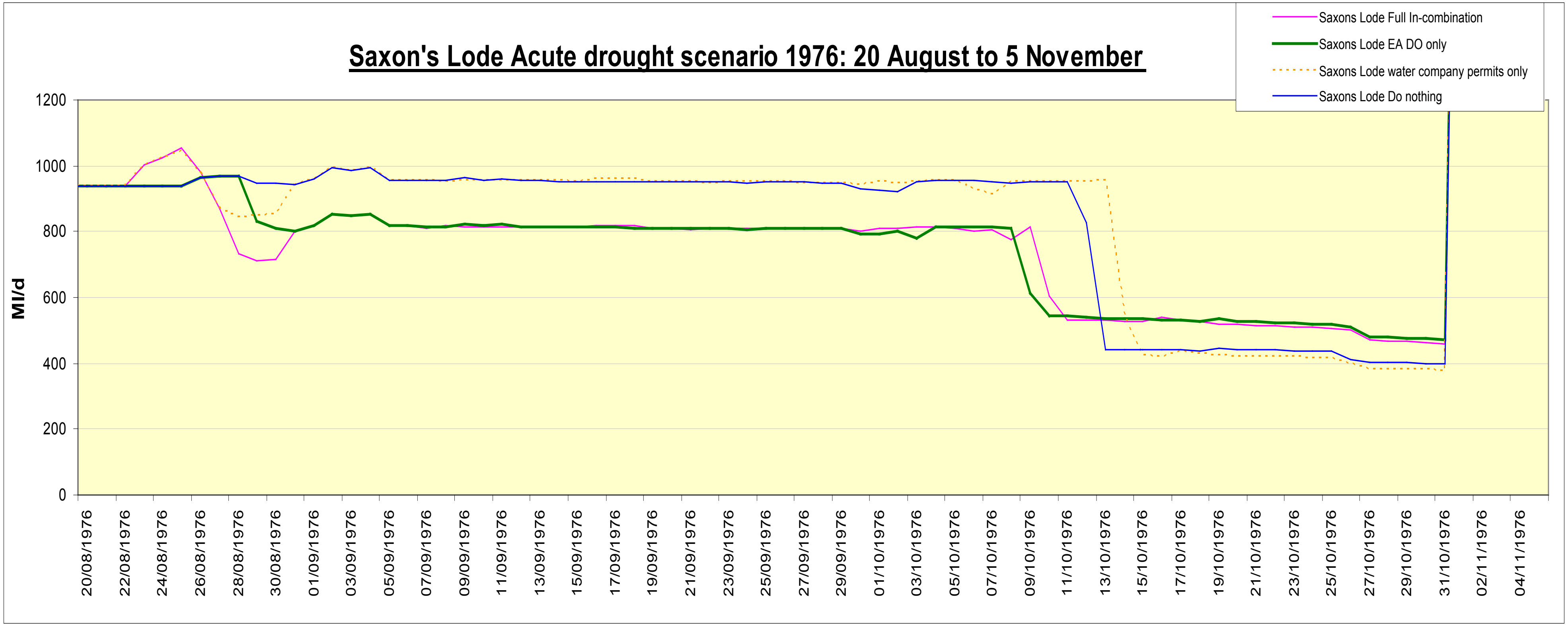


Figure 16 shows all the modelled impacts on flows at Saxon's Lode, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 16 presents a close up of the hydrographs at Saxon's Lode from 20 August to 5 November 1976, the critical period of low flows. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J.6 contains a breakdown of key dates and timings for each model.

Table 9

	Acute Do Nothing Ml/d	Acute EA DO in isolation Ml/d	Acute Full In-combination Ml/d	Gauged Ml/d	Naturalised Ml/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	*7551*	*7551*	*7550*	*7992*	*8523*
Q95	946	817	945	1327	1350
Q99	440	526	421	1167	1131
Q99.9	400	475	380	-	536

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

Prior to regulation failure, Do Nothing flows at Saxon's Lode average (mathematical average) at 954 Ml/d, showing some flow accretion has occurred. Flows crash on 12 October 1976, halving to an average of 428 Ml/d. Flow depression lasts 20 days with a minimum flow of 399 Ml/d occurring on 31 October, flow recovery begins on 1 November 1976. Events are slightly shorter and earlier than at Bewdley and Buildwas. Considering the downstream location, this is likely to be caused by input flows from the Teme and Stour, and could represent earlier rainfall over these catchments reaching Saxon's Lode before flows along the main Severn corridor receive separate recharge.

Appendix J.2 shows the Do Nothing FDC as the highest until Q98. The whole FDC is lower than gauged and naturalised, compared against Buildwas and Bewdley this shows how the major abstractions have removed the main portion of additional regulation releases made under Do Nothing.

Appendix J.3 shows the EFI is failed from Q51 onwards, although the magnitude of failure reduces (improves) from Q90 until the crash at Q98. Due to the low flow biased period (3 years) used to generate the FDC's, only the Q90 to Q100 should be considered for this assessment. The effects of regulation can be observed as the FDC artificially flat lines due to the flow support. EFI failure ranges from High Risk (>30% lower than EFI) to being within less than 10% of the EFI where impact would be unlikely, until flows crash back into the High Risk band after Q98. Although short term and with varying magnitude, overall the underlying drought (Do Nothing) is causing significant flow impacts.

Environment Agency Drought Order model

Impacts of operating the drought order are observed on 29 August 1976, 4 days after taking affect at Clywedog. The average (mathematical average) flow maintained is 814 Ml/d, a 140 Ml/d (15%) decrease from the Do Nothing model. Flows crash on 10 October, 3 days earlier than Do Nothing. Benefits from the drought order are evident from 14 October, when modelled flows remain higher than Do Nothing by an average 90 Ml/d (21% increase) until flow recovery on 1 November. Flow depression lasts for 23 days, 19 of which are higher than Do nothing. The drought order was active for 46 days before a benefit was observed.

Appendix J.2 shows the drought order reduces flows by an additional 15% below Do Nothing from Q94 until Q98, after which flows increase 21% above the Do Nothing. No additional EFI failures are caused, but the magnitude of failure is increased between Q94 and Q98, remaining over the Medium Risk (>20% below the EFI) band for longer than Do Nothing. Flow benefit is evident from Q98. It is important to note the EFI's and risk banding system used only provide a best guide on whether flows are significantly altered, how this translates into environmental impact is largely determined by the ecological assessment.

The modelled drought order does create a short term increase in potentially significant flow impacts. This will need to be carefully considered in context of the duration it occurs for (an extra 4% over 3 years, or 46 days in total) and the resulting flow benefits it subsequently enables (21% increase over 19 days). Whether the increased duration of flow impact translates into adverse impacts on the environment needs to be assessed against the ecology, taking into account whether this could cause more harm than allowing the Do Nothing minimum flows/levels from occurring.

<u>Full In-combination model</u>

Flow impacts begin on 28 August 1976, 1 day earlier than the Severn Drought Order in isolation. The average (mathematical average) flow maintained is 807 Ml/d, a 147 Ml/d (15%) decrease from the Do Nothing model but only 7 Ml/d lower than the Severn Drought Order model. Flows crash on 10 October, 2 days earlier than Do Nothing. It takes 47 days for flow benefits to be observed, evident from 13 October when flows remain an average 80 Ml/d (19% increase) higher than Do Nothing. Flow depression lasts 22 days, 19 being higher than Do nothing.

Full in-combination (Appendix J.2) reduces flows below Do Nothing for slightly longer than the Severn Drought Order in isolation, from Q92 until Q98. When assessed in more detail, the increase in duration represents 1 additional day and an average 7 Ml/d over the 47 day period.

As with the Severn Drought Order model, the Full In-combination model does create a short term increase in potentially significant flow impacts, and will need to be assessed further with the same considerations.

It is also useful to note from the graphs, if the Severn Drought Order were not operated but the water company Drought Permits were, the subsequent flow crash could potentially be greater than the Do Nothing baseline. This illustrates how complicated and interconnected the River Severn system has become, any decisions would need to be made in balance with the whole situation at the time.

Assessment Point 6, Haw bridge/Deerhurst

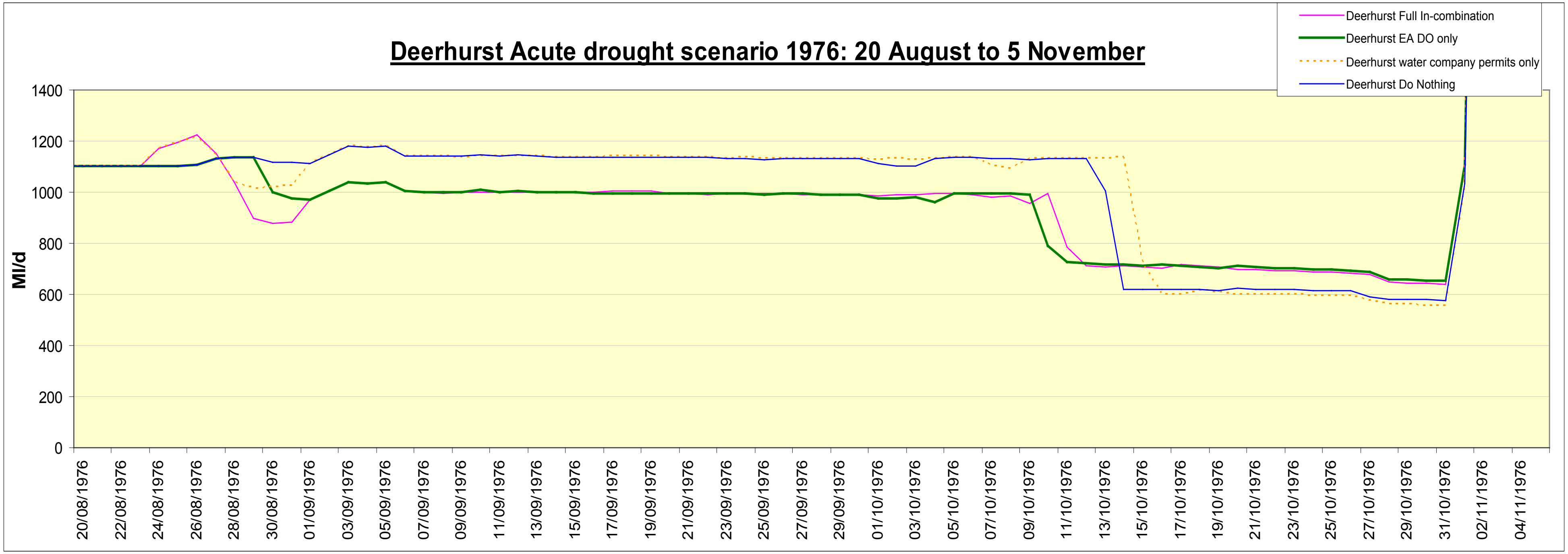


Figure 17 shows all the modelled impacts on flows at Deerhurst, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 17 presents a close up of the hydrographs at Saxon's Lode from 20 August to 5 November 1976. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J.6 contains a breakdown of key dates and timings for each model.

Deerhurst was built closely downstream from the flow gauge Haw Bridge, but designed to cope with the reversed flows created by the tidal movements up the Severn Estuary. Deerhurst is the furthest downstream flow gauge in operation and represents the last location from which flows into the Estuary can be measured and regulated to. Flows at Deerhurst include inputs from the River Avon and public water supply abstractions from Mythe. The channel bifurcation (channel split) and in take for the Sharpness and Gloucester canal are located downstream.

Table 10

	Acute Do Nothing Ml/d	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*9501*	*9501*	*9497*	7992	8523
Q95	946	817	945	1327	1350
Q99	440	526	421	1167	1131
Q99.9	400	475	380	-	536

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model
Leading up to the modelled regulation failure, Do Nothing flows at Deerhurst average (mathematical average) at 1136 Ml/d. Flows crash on 13 October 1976, almost halving to an average of 608 Ml/d. Flow depression lasts 19 days with a minimum flow of 577 Ml/d occurring on 31 October, flow recovery begins on 1 November 1976.

As with all the upstream assessments, Appendix J.2 shows the Do Nothing FDC as the highest until Q98. Between Q24 and Q40 the modelled flows exceed the gauged FDC, but remain below the natural and gauged for at all other flows.

Appendix J.3 shows the EFI is again largely failed from Q51 onwards, although the magnitude of failure reduces (improves) from Q93 until the crash at Q98. Adopting the same principle of focusing on the Q90 onwards, EFI failure ranges from High Risk (>30% lower than EFI) to briefly achieving the EFI at Q98, before flows immediately drop to be just within the High Risk band. The trends are very similar to Saxon's Lode, although the magnitude of EFI failures from Q98 onwards are less. However, the underlying drought conditions (Do Nothing) are causing significant flow impacts.

Environment Agency Drought Order model
Impacts from the drought order are observed on 31 August 1976, 6 days after taking affect at Clywedog (2 days later than observed at Saxon's Lode) although flows still crash on 10 October, 3 days earlier than Do Nothing. The slight discrepancy of 6 days when compared against 4 days at Saxon's Lode is likely to be a buffering affect from the River Avon inflows, as well as the increased travel distance.

The average (mathematical average) flow maintained is 996 Ml/d, a 140 Ml/d (12%) decrease from the Do Nothing model. Flow benefits from the drought order are evident from 14 October, when modelled flows become higher than Do Nothing by an average 90 Ml/d (15% increase) until flow recovery on 1 November. Flow depression lasts for 22 days, 18 of which are higher than Do nothing. The drought order was active for 45 days before a benefit's observed.

Appendix J.2 shows the same trend as Saxon's Lode. The Severn Drought Order reduces flows by an additional 12% below Do Nothing between Q94 and Q98, after which flows increase 15% above the Do Nothing. No additional EFI failures are caused, but the magnitude of failure is increased between Q94 and Q98, remaining over the Medium Risk (>20% below the EFI) band for longer than under Do Nothing. Flow benefit is evident from Q98.

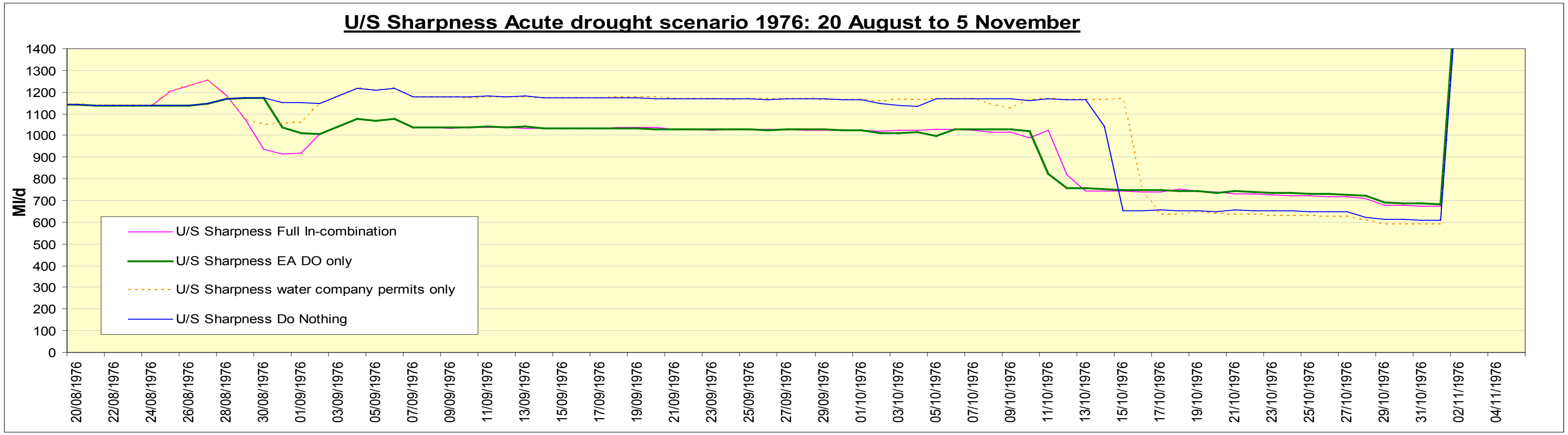
The modelled drought order does create a short term increase in significant flow impacts. To determine whether this creates an adverse environmental impact careful consideration is again needed in context with the duration (an extra 4% over 3 years, 45 days in total) and resulting flow benefits it subsequently enables (15% increase over 18 days).

<u>Full In-combination model</u>
Flow impacts begin on 29 August 1976, 1 day earlier than the Severn Drought Order in isolation. The average (mathematical average) flow maintained is 989 Ml/d, a 147 Ml/d (13%) decrease from Do Nothing but only 7 Ml/d lower than the Severn Drought Order model. Flows crash on 15 October, 2 days earlier than Do Nothing. It takes 46 days for flow benefits to be observed, evident from 14 October when flows remain an average 80 Ml/d (13% increase) higher than Do Nothing. Flow depression lasts 21 days, 18 being higher than Do nothing.

Full in-combination (Appendix J.2) reduces flows below Do Nothing only slightly longer than the Severn Drought Order in isolation, from Q93 until Q98. The same trend as Saxon's Lode is observed; the increase in duration represents 1 additional day and an average 7 Ml/d over a 46 day period.

As with the Severn Drought Order model, the Full In-combination model creates a short term increase in significant flow impacts, and will need to be assessed with the same considerations.

Assessment Point 7 U/S Sharpness and Assessment Point 8 Lower Parting



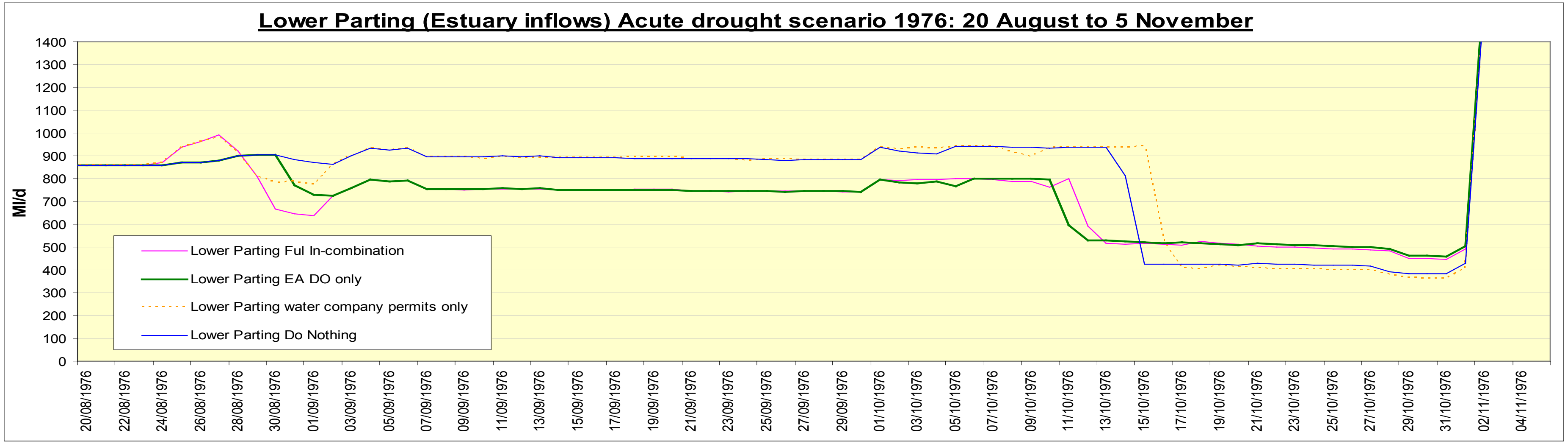


Figure 18 shows all the modelled impacts on flows at U/S Sharpness and Lower parting. Both are downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS) but U/S Sharpness is located upstream of the Gloucester and Sharpness canal abstraction while Lower Parting is downstream. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 18 presents two close up hydrographs, U/S Sharpness and Lower Parting from 20 August to 5 November 1976. Appendix J.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix J.6 contains a breakdown of key dates and timings for each model.

Deerhurst is the furthest downstream flow gauge from which to calibrate data, all downstream flows are estimated from models, previous analysis and observations and need to be considered with greater caution.

One of the potentially largest abstractions between Deerhurst and the Severn Estuary is The Canals and Rivers trust abstraction to the Gloucester and Sharpness canal, taken from the East channel where the River Severn splits. The variability of abstraction coupled with a lack of actual flow data downstream of the canal abstraction make it very difficult to assess with confidence what the true impact on the lower River Severn would be.

In order to model the potential impacts of the Gloucester and Sharpness canal abstraction on River Severn flows during severe drought, an average abstraction profile was manually inserted into Aquator. Flows were estimated both upstream of the canal abstraction and channel bifurcation (U/S Sharpness) and downstream (Lower Parting). The maximum abstraction represented was 300 Ml/d, although it is recognised this could be a significant under estimation and final conclusions will be based around the ‘worse case’ likely effects (assuming maximum abstraction), with further work suggested to improve the conceptualisation and understanding for drought management.

Table 11

	U/S Sharpness			**Lower Parting**			**Low Flows Enterprise**	
	Acute Do Nothing Ml/d	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Acute Do Nothing Ml/d**	**Acute EA DO in isolation Ml/d**	**Acute Full In-combination Ml/d**	**Modelled Influenced Ml/d**	**Modelled Natural Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1975-1977)**	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*1170*	*1033*	*1033*	*983*	*893*	*914*	9772	10213
Q95	648	732	721	370	735	729	1910	2056
Q99	616	706	695	319	729	718	1509	1564
Q99.9	609	684	672	304	528	523	1096	1123

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

<u>Do Nothing model</u>
Leading up to the modelled regulation failure, Do Nothing flows average (mathematical average) at 1170 Ml/d for U/S Sharpness and 904 Ml/d at Lower Parting. Flows crash on 14 October 1976, down to an average of 640 Ml/d at U/S Sharpness and significantly lower to 415 Ml/d at Lower Parting. Flow depression lasts 19 days with minimum flows of 609 Ml/d and 382 Ml/d occurring on 1 November, flow recovery begins on 2 November 1976.

As with all the upstream assessments, Appendix J.1 shows the Do Nothing FDC as the highest until Q98. Appendix J.3 shows the EFI at lower Parting is failed from Q50 onwards, crossing into High Risk failure from Q83 with marginal improvement between Q96 and Q98 until flows crash. Bearing in mind EFI's provide a guide only and the short time period used to generate the scenario FDC's, it is still likely the natural drought event would have detrimental impacts on the lower River Severn. Even more so when considered against the unknown abstraction maximum's for the Gloucester and Sharpness canal, and the natural channel bifurcation splitting flows through Gloucester.

Likely significant effects concluded.

Environment Agency Drought Order model
Impacts from the drought order are first observed on 31 August 1976, 6 days after taking affect at Clywedog. Flows crash on 11 October, 3 days earlier than Do Nothing.

The average (mathematical average) flow maintained is 1031Ml/d at U/S Sharpness and 762Ml/d at Lower Parting, between 139-142 Ml/d (12-16%) decrease from the Do Nothing model. Flow benefits from the drought order are evident from 15 October, when modelled flows become higher than Do Nothing by an average 90-91 Ml/d (12-18% increase) until flow recovery on 2 November. Flow depression lasts for 22 days, 18 of which are higher than Do nothing. The drought order was active for 46 days before a benefit's observed.

Appendix J.1 again shows the Severn Drought Order reduces flows further below Do Nothing largely between Q94 and Q98, after which obvious flow gains are achieved above the Do Nothing. No additional EFI failures are caused and despite the minor extension of High Risk (>30% below the EFI) failure, results show the Do Nothing drought baseline would already be causing likely significant effects. The additional failure is assessed as minor in context, and flow benefits are evident from Q98.

Full In-combination model
Flow impacts begin on 30 August 1976, 1 day earlier than the Severn Drought Order in isolation. The average (mathematical average) flow maintained is 1023 Ml/d at U/S Sharpness and 757Ml/d at Lower Parting, between, a 147 Ml/d (13-16%) decrease from Do Nothing but only 5-8 Ml/d lower than the Severn Drought Order model. Flows crash on 12 October, 2 days earlier than Do Nothing. It takes 48 days for flow benefits to be observed, evident from 15 October when flows remain an average 81 Ml/d (13-20% increase) higher than Do Nothing. Flow depression lasts 21 days, 18 being higher than Do nothing.

Full in-combination (Appendix J.1) reduces flows below Do Nothing only slightly longer than the Severn Drought Order in isolation. The same trend as Deerhurst is observed; the increase in duration represents 1 additional day and an average 5-8 Ml/d over a 48 day period.

The biggest unknown in context of the full in-combination assessment is the abstraction activities of The Canals and Rivers trust for the Gloucester and Sharpness canal. Results assume a maximum 300 Ml/d abstraction, however in the likely circumstances larger abstraction would be required to support the canal and Bristol Waters public water supply needs, flows in the lower River Severn could be significantly reduced further.

CONCLUSIONS: ACUTE SCENARIO

The Acute drought scenario represents a dry summer and winter (1975) preceding the summer drought (theoretical 1976) event. The modelled drought is broken in November with the return of high rainfall. It is important to note the rainfall creates significant flow recovery, and if the drought period continued the duration of flow gain would also increase until complete regulation system failure (all three sources exhausted) was reached. Similarly, if rainfall was to return earlier than modelled then regulation failure would be avoided and flow benefits of the Severn Drought Order may not be observed (refer to the Chronic scenario).

The most difficult stretch to assess with confidence is the lower Severn, from the channel bifurcation down to the Severn Estuary. Owing to the proximity to the Natura 2000 site and its importance for migratory fish and navigation, impacts could have the greatest significance to the catchment as a whole. The Canals and Rivers Trust are currently exempt from needing an abstraction licence to operate the canal; therefore the Environment Agency has no legal powers to regulate abstraction. Post drought reports from 1976 and 1989 indicate large abstractions to the canal were taken during the peak of the droughts, in 1989 drying up flows down the West channel and allowing only a few centimetres to pass over the Llanthony Weir. An Operating Agreement was created in 1998 to help safeguard the Severn Estuary, and assessments have shown that under routine flow regimes there is sufficient flow reaching the Estuary. The difficulty is managing a severe drought, which falls outside normal operation and would require close liaison and management between interested parties.

Baseline, Do Nothing

The Do Nothing model represents the baseline drought conditions if all routine abstractions and discharges were operating but no Environment Agency actions were taken to prolong Clywedog storage and therefore extend the potential regulation period. The model represents the unavoidable drought conditions and impacts that would occur if the Severn Drought Order was not operated. It clearly illustrates how critical Clywedog's role is in the Severn regulation system, providing the largest portion of water of the three regulation sources.

An annual total of 166 regulation days and 70,220 Ml combined releases were modelled during the Acute Do Nothing drought scenario, with 152 days of continuous regulation; Clywedog provided 66% (46374 Ml), SGS 25% (17744 Ml) and Vyrnwy 9% (6102 Ml) of the total resource.

SGS provides a steady and continuous support, currently limited to a net of approximately 140 Ml/d. Therefore, once Clywedog is exhausted only Vyrnwy bank contains large enough volumes to replace the 500+ Ml/d regulation can require. However, the Vyrnwy bank is a short term resource when large releases are required and can only provide a temporary replacement to Clywedog. Modelling has shown during high regulation requirements, if Clywedog is exhausted and significant rainfall does not arrive, the regulation system will begin to fail and flows decline. The speed and degree of failure and resultant flow crashes will vary according to the climatic conditions, abstraction demand and how much resource remains individually in the Vyrnwy bank and SGS licence.

Do Nothing models regulation failure to begin on 29 September, 16 days after Clywedog reached dead water. Once Vyrnwy bank became exhausted, SGS also began to reach its 'individual' licence limits. In reality, SGS could be operated differently to utilise the group licence surplus (7756 Ml) more effectively, and/or the Environment Agency could consider applying the SGS Drought Order (separate report). It is important to note the additional daily quantities from SGS would be too small to prevent the eventual regulation failure, but early optimisation of the scheme could help delay a River Severn Drought Order application and exhausting Llyn Clywedog.

Significant flow impacts are observed under Do Nothing at Bryntail, Bewdley, Saxon's Lode, Deerhurst and the lower River Severn (most notably Lower Parting, downstream of the Gloucester and Sharpness canal abstraction). It can therefore be assumed a drought of this severity is going to put the most flow stress on the Upper Severn (dependant on reservoir operation), and from around Bewdley downstream. Flows around Bewdley are likely to be most affected at and downstream of the major abstractions points.

Bryntail identified significant flow impact; although the EFI (derived from natural flow) is not failed the local habitat and ecosystems will have adapted to rely on this residual flow. As Clywedog reaches dead water the 18.2 Ml/d compensation flow requirement can no longer be made between 27 September and 1 November, a total of 35 days. The model does not show flows drying up entirely at Bryntail, however in reality this is likely to occur immediately downstream of the dam under such a severe drought (i.e. little/no baseflow expected). It is unclear where flows would begin to buffer from tributary inputs, but with such a severe drought affecting the whole catchment it could be some distance downstream before significant flow returns.

Another consideration at Bryntail and downstream is the longer term affect on flow variation. Under Do Nothing, including the 35 days of little/no flow, there is a total of 306 continuous days (almost a full year) when only the compensation flow is released. The minimum flow occurs because the reservoir is intercepting all upstream runoff to refill, a vital process to prepare for the year ahead. The model shows September right through to the following July as being affected, in reality this period will vary according to how much recharge is received over what duration.

From Bewdley, it can be expected the whole River Severn downstream would be affected to varying degrees by the natural drought event. As a result of the regulation system failing, flows are shown to fall approximately 500 Ml/d over 2 days. Flows crash between 12 and 14 October, with depressions lasting between 19 and 22 days before natural recharge is modelled in early November. Bewdley predicts a daily minimum flow of 336 Ml/d, 182 Ml/d lower than ever recorded, Saxon's Lode predicts a daily minimum 399 Ml/d, 316 Ml/d below existing records and Deerhurst predicts a daily minimum 577 Ml/d, 398 Ml/d below existing records.

The minimum daily flow prediction at U/S Sharpness is 609Ml/d and 382Ml/d at Lower Parting, downstream of the Gloucester and Sharpness canal abstraction. The variability of abstraction quantities and limited data make it difficult to assess whether flows could be reduced significantly further still. This lower section of the River Severn, around Lower Parting, is most at risk to likely significant effects from a severe drought.

In reality, it is unclear what the minimum flows would be if the regulation system did fail. Aquator (version 3) has known problems with the naturalised flows, and discharges are currently built into the background flows so cannot be altered. Therefore exact flow predictions need to be assessed with caution. However, the flow response is the important result for future planning. Should Clywedog fail, the remaining regulation support has a short life and is unlikely to cope. Minimum flows will depend on climatic conditions and abstraction demands at the time of failure, but the River Severn flows can be expected to rapidly decline to baseflow rates until rainfall returns.

The degree of adverse impact resulting from significant flow impacts will depend on the duration of the event and demand management at the time. It is important to note that whilst satisfactory Naturalised flows could not be extracted from Aquator at this time, once the flows crash they are effectively representing the baseflow expected in the absence of regulation support, flows maintained above this level are therefore in the best interest of supporting the environment.

River Severn Drought Order

This model represents the conditions if all routine abstractions and discharges (including licence conditions) were operating, the Environment Agency activated the Severn Drought Order at Clywedog, but no other drought permits or orders were in force. Whilst this may not be entirely realistic for a drought of this magnitude, it is necessary in order to isolate and assess the impacts caused solely by the Environment Agency's Severn drought order, by comparison to the Do Nothing scenario. The aim of the Severn Drought Order is to prolong Clywedog storage and therefore extend the potential regulation period, rather than risk running out of water and subsequently having no/little control over events.

Operating the Severn Drought Order under the Acute scenario does cause the regulation system to begin failing 2-3 days earlier than Do Nothing. The drought order lowers the prescribed flow at Bewdley from 850 Ml/d to 730 Ml/d (over a 5 day mean), which only reduces regulation pressure by 120 Ml/d. Capping the releases at Clywedog at 300 Ml/d is necessary but creates a regulation deficit to achieve 730 Ml/d, which Vyrnwy bank and SGS supplement earlier than under Do Nothing. The available resource remains the same so inevitably the regulation system begins to fail slightly earlier as a result of Clywedog's reduced contribution.

The Severn Drought Order prevents Clywedog from reaching dead water, which has various benefits to the whole Severn catchment. Avoiding dead water enables the 18.2 Ml/d compensation flow to Bryntail to be made throughout, preventing 35 days of little/no flows for this section of watercourse. Due to the 11% storage saving, Clywedog refills faster over the winter (exceeds 90% in April 1977) and therefore flow variation is returned in mid June, 49 days earlier than under Do Nothing.

Downstream, flows are reduced for between 45-48 days before the obvious flow benefits are observed. During this period, flows were reduced from Do Nothing by 139-142 Ml/d, equating to 13-15% flow reductions. Bryntail showed a significant improvement as discussed. Vyrnwy showed no change and Buildwas continued to show no significant flow impacts against the EFI. At Bewdley, no significant deterioration in flows beyond the unavoidable drought impacts were observed. Both Saxon's Lode and Deerhurst showed the initial flow reductions caused a small increase in the duration of Medium Risk EFI failure, related to the 140 Ml/d reduction in flows. At Lower Parting the EFI failure is assessed as High Risk and more prolonged than upstream, however operating the Severn Drought Order only creates a minor increase in duration of this failure. It is difficult to assess whether these lead in flow reductions (prior to any regulation failure) are significant to the environment, and needs to be balanced against the subsequent flow gains it achieves.

Once the regulation system begins to fail, the Severn Drought Order shows clear benefits. Protecting the storage in Clywedog over the previous 45-48 days enables small but continuous releases between 91-63 Ml/d (reduces per day according to remaining storage) to be made throughout the critical flow depression period. Under

Do Nothing only small SGS releases were possible at this point. The regulation support Clywedog continues to provide does have a limited life, but the Acute scenario shows minimum flows are increased by 72-75 Ml, and produce an average flow gain of 89-90 Ml/d.

Modelling supports the aim of the Severn Drought Order. By operating the drought order and regulating to a lower flow target at Bewdley, Clywedog avoids reaching dead water and compensation flows at Bryntail are protected. The drought order does not prevent regulation system failure from occurring if the drought persists, but does enable Clywedog to continue providing regulation support at a reduced rate throughout the Acute scenario, subsequently maintaining higher flows during the worst period. Longer term, the Severn Drought Order enables the reservoir to refill faster, reducing the impacts on flow variation in the upper catchment and preparing the system for a subsequent drought/regulation season.

Full In-combination

This model represents the conditions if the Environment Agency operated the Severn Drought Order at Clywedog (not SGS), and all other significant Drought Permits impacting on the River Severn were in force. All routine abstractions and discharges (including licence conditions) are represented, the Gloucester and Sharpness canal has been modelled with a maximum 300Ml/d abstraction, although assessment will be precautionary worse case and assume higher abstraction is likely during a severe drought.

The River Severn is a very large and complex system of varying geology, topography, regulation, reservoirs, abstractions, transfers and discharges. It is not possible to accurately predict all these interactions in the exact sequence of events and magnitudes with the available tools, but for the purpose of impact assessment the worst case approach has been adopted. Results are very similar to the Severn Drought Order model, with timings and volumes varying slightly. In part this is likely to be due to the interactions between what the Severn Drought Order enforces (e.g. restricting abstractors by 5%) and what the Drought Permits effectively take back/cancel out (e.g. increase abstraction).

Overall, initial flow reductions occur for 1 day longer and reduce flows by 145-147 Ml/d, only 5-7 Ml/d more than the Severn Drought Order model. The flow gains achieved during the flow depression are reduced under the increased abstraction demands, ranging between 76-80 Ml/d, 10-13 Ml/d less than the Severn Drought Order model. Full In-combination still shows a minimum flow improvement of 60-64Ml compared to Do Nothing.

When compared to the Severn Drought Order model, minor additional impacts are observed at Saxon's Lode and Deerhurst, where the duration of Medium Risk EFI failure is slightly increased. However this additional increase, compared to the Severn Drought Order model, equates to 1 day and 7 Ml at both sites.

The most significant observation is the likely significant effects that could be created if abstraction for the Gloucester and Sharpness canal were increased above the 300Ml/d, which is already adding a significant stress to modelled flows at this location. It is difficult to predict what abstraction might be required, but applying the worse case principle, the pumps can physically abstract 691Ml/d from the River Severn. Post drought reports from 1976 and 1989 report high abstractions did occur and that flows were significantly impacted, reducing inflows to the Severn Estuary to nearly zero for short periods.

The Canals and Rivers trust have been working on a Drought Plan for the Gloucester and Sharpness canal, with one action being to consider closing the canal if flows approached 1000Ml/d at Deerhurst, although some abstraction would need to continue to support Bristol Waters abstraction. The Environment Agency would actively encourage this action and close liaison and management would be needed throughout a real drought event.

For the purposes of this assessment, owing to the unknowns and potential capacity for The Canals and Rivers trust to abstract, the full in-combination impact is concluded as having a likely significant effect on the lower River Severn.

Model Data: Chronic Scenario

Severn Regulation impacts

The Acute scenario attempted to model a prolonged one season drought. The question was evident that if significant rainfall arrived earlier than modelled then the flow benefits would never be recognised. This raised the question, “what would be the point, and would it cause more harm than good?” The Chronic scenario was built to investigate this question. By introducing rainfall earlier in the existing Acute scenario the flow benefits were removed, the dry period was then extended over the critical recharge season to produce a more long term drought to test the Severn Drought Order.

Do Nothing Model

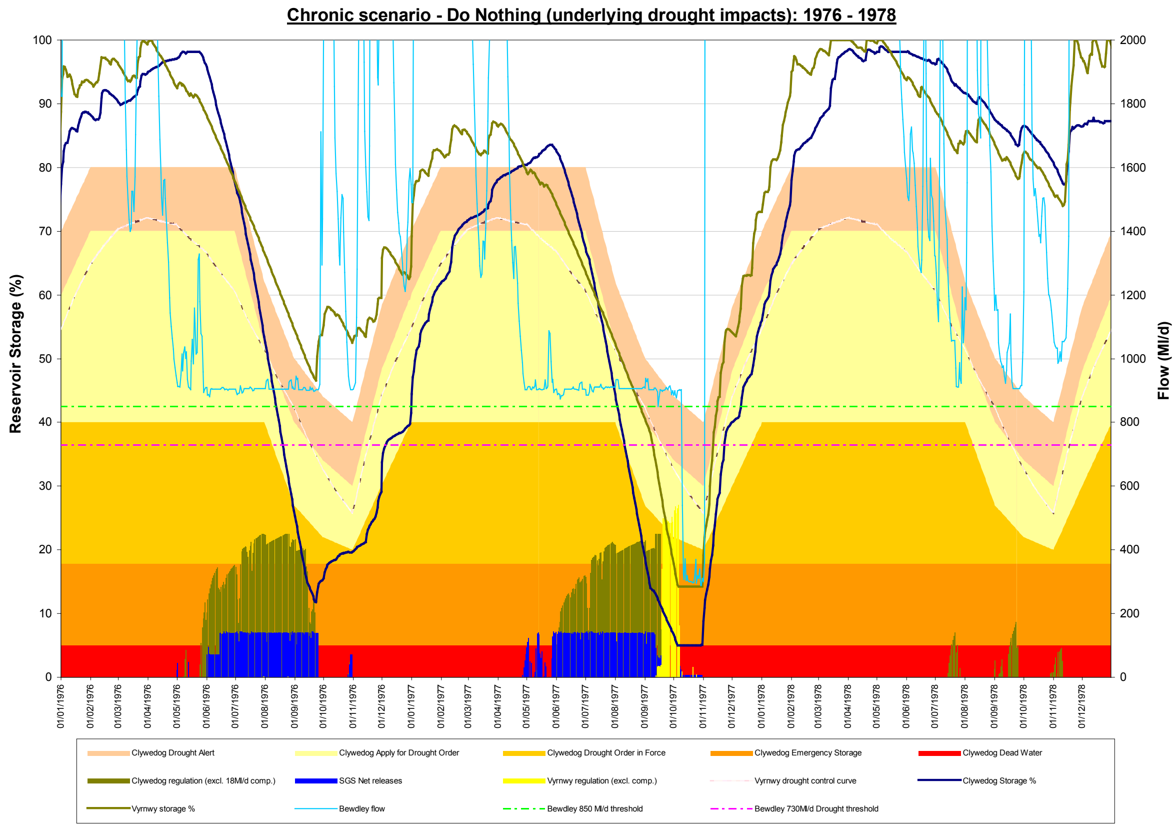


Figure 19 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Do Nothing Chronic model.

Figure 19 presents modelled regulation operation if the Severn Drought Order were not operated, but the Chronic drought scenario were allowed to run it’s course. Appendix K.6 contains a breakdown of key dates and timings for this model run.

The baseline shows how the drought impacts are spread over the two year period. During the first summer (1976), 59030 Ml of regulation is used over 135 days, the majority (74%) sourced from Clywedog. Clywedog storage is drawn down into emergency storage 12%, but rainfall returning in October (Acute delayed until November) prevents dead water from being reached. As dead water is avoided, compensation flows are maintained throughout and no detrimental flow impacts result.

SGS provides a full 135 days of regulation support, with 122 days of continuous releases beginning in June (1976). A total 15595 Ml are provided, 26% of the total resource. No individual annual, or group 5 year licence limits are exceeded, although the heavy usage would be noted by the Environment Agency and the risk to the following year planned for (e.g. familiarise with the option to apply for the SGS drought order).

Throughout the recharge season Clywedog reaches a maximum 84% on 26 May 1977, with continuous regulation releases beginning on 27 May 1977. This helps illustrate the impact of allowing Clywedog to draw down so far in any year, without at least taking preventative measures. Just using Figure 19 it is clear how important obtaining complete recharge is ahead of a full regulation season.

During the critical drought season (1977) Clywedog provides the primary support up until dead water (5%) is reached on 18 September. As with the Acute scenario, Vyrnwy bank can only replace the high releases for a limited time, and SGS cannot provide additional water as maximum rates are already discharging. The regulation system begins to fail (determined as Bewdley prescribed flow failure) 19 days after Clywedog, initially as Vyrnwy bank exhausts, and then further declines as individual SGS Licences are reached.

A total of 187 regulation days and 69,959 Ml combined releases were modelled during the chronic drought year (1977), with Clywedog providing 59% (39620 Ml) of the resource, SGS providing 27% (18085 Ml) and Vyrnwy providing 14% (9254 Ml).

Clywedog provides 114 days regulation support from 27 May 1977 to 18 September, when dead water is reached. Due to the reservoir only being 84% full when continuous regulation begins, it takes only 13 days of <280 Ml/d releases to cross the Drought Alert curve (9 June), 31 days to cross the Drought Order application curve (27 June), 78 days before crossing the Drought Order in force (13 August) curve and 98 days before crossing the emergency storage (2 September) curve. Clywedog storage remains in dead water for 42 days.

Vyrnwy reservoir provided 23 days of regulation support between 13 September and 6 October reaching a minimum storage of 14%, dead water is avoided. SGS activates on 26 April and provides 187 days continuous regulation support until 30 October. Maximum 140 Ml/d net discharges are made continuously from 28 May until individual licence maximums are reached on 12 September, 30 September and 9 October, with net discharges halved on each occasion. The combined licence annual limit is not exceeded, which could suggest with different operation some mitigation options are available.

The SGS individual licences are put under significant pressure during the 1977 drought, regulating for 187 days in total. Although the group and 5 year rolling licence is not exceeded, once again it appears to be the individual licence limits which are reached, causing different phases to shut down as the season progresses. SGS support first steps back from 12 September, reducing from the net 140 Ml/d to 64 Ml/d by the 14 September. Further reductions begin on the 30 September, down to 31 Ml/d by the 2 October, then down to only 7 Ml/d between 9 and 30 October. In reality this could potentially be operated differently to utilise more of the group licence.

Clywedog recovers above dead water on 18 September and above the emergency storage curve on 9 November 1976, but doesn't exceed the Drought Alert curve until 3 February 1978 (239 days below). Vyrnwy recovers above the drought control curve on 9 November 1977 and exceeds 90% storage on 28 January 1978; Clywedog takes until 13 March 1978 to exceed 90% storage.

<u>Environment Agency Drought Order in isolation Model</u>

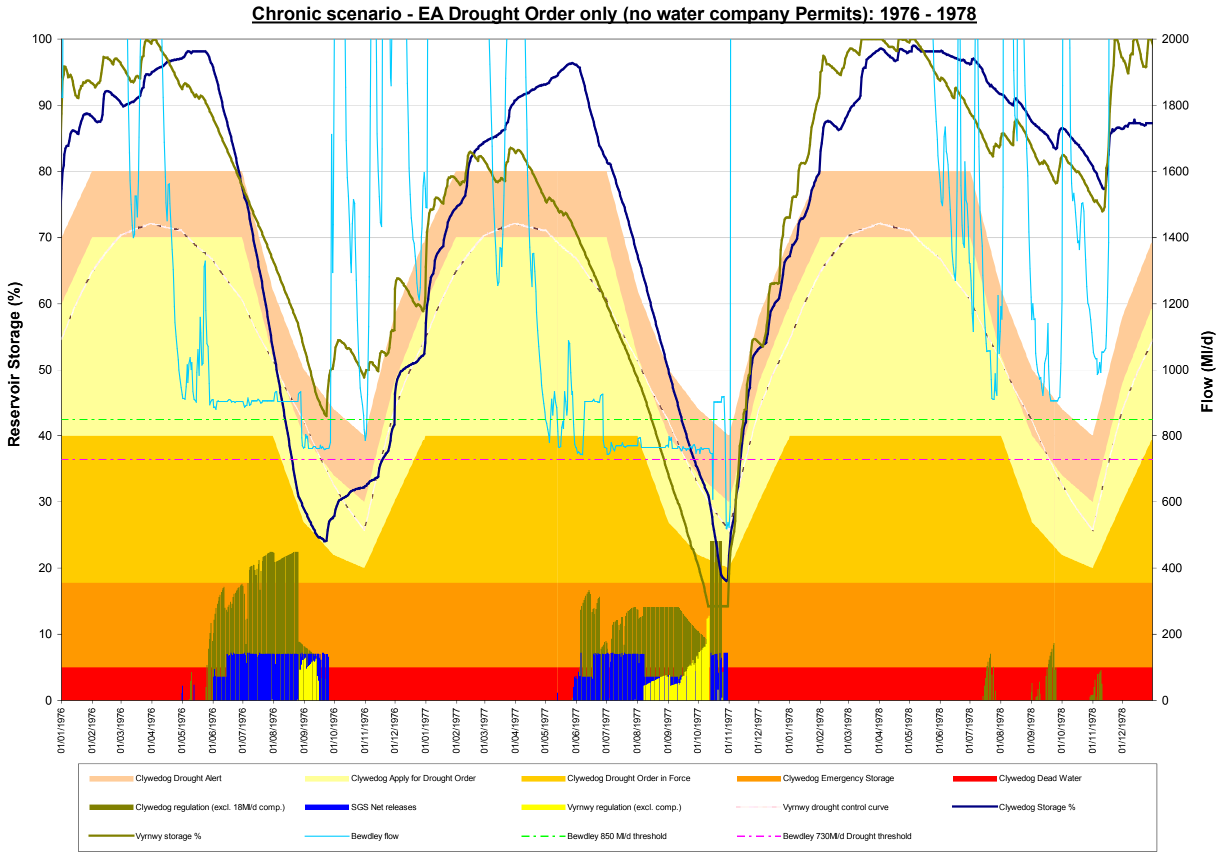


Figure 20 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the Environment Agency Drought Order in isolation model..

Figure 20 presents modelled regulation operation if the Severn Drought Order were operated but no other drought permits or orders were active. Appendix K.6 contains a breakdown of key dates and timings for this scenario.

Drought impacts are spread over the two year period, with the Severn Drought Order being activated separately both years. Figure 20 illustrates how, similarly to the Acute scenario, activating the Severn Drought Order between 25 August 1976 and 14 February 1977 (total 173 days) protects Clywedog storage. In 1976 neither emergency storage or dead water is reached (minimum storage 24%), allowing regulation releases to remain around 150 Ml/d. Rainfall returns in October, before Vyrnwy bank becomes exhausted and therefore no resultant flow crashes are observed downstream.

Using the Severn Drought Order in 1976 saves an additional 15% storage at Clywedog; by May 1977 this has enabled Clywedog to reach 96% before the continuous regulation season begins. During 1977 the Severn Drought Order bounces on and off three times; 24 February (Clywedog 84%) – 4 June, 24 June (Clywedog 84%) - 1 October and 24 October (Clywedog 19%) - 1 February. It is unclear what the model is responding to on the first two occasions as Clywedog storage remains above the trigger curve until 22 October 1977; flow response at Bewdley confirms Aquator is applying the Severn Drought Order conditions, although rainfall flow response masks a large portion of activity.

In reality these early occasions should be discounted as error and only the last activation on 24 October appears linked to Clywedog storage (19% storage; trigger curve 21%). Due to these anomalies timings and volumes will not be analysed in the same detail as the Acute scenario, but used more as an illustration of flow behaviour and trends that could occur in reality. Operation during a real event would be managed differently, preventing unnecessary 'yo yoing' of drought order operations.

The utilisation of the Severn Drought Order in 1976 enables healthy storage to be reached at Clywedog ahead of the 1977 event. The extra 15% storage, and activation of the Severn Drought Order again in 1977, prevents Clywedog reaching emergency storage and dead water. Although the timings and volumes could be inaccurate, the Chronic scenario is demonstrating how the water saved from the previous year can then be released back into the system if a subsequent drought occurs the following year. Under Do nothing, Clywedog storage does not enable these higher releases to be made as the resource is exhausted.

When the Severn Drought Order goes off for the second time on 12 October 1977, Clywedog releases spike back up to 481 Ml/d for 12 days before the drought order reactivates as storage reaches 19%. In reality, such high releases are extremely unlikely when storage is so low, however it demonstrates the spare resource Aquator is then feeding back into the system. In reality, this storage could be released at a lower rate for longer, and prevent the short term flow crashes observed after the 24 October. However if the Severn Drought Order had not been activated on the previous two occasions, there would be less storage in Clywedog and therefore these releases may not be triggered/possible, although more water would still be available than under Do Nothing.

Ignoring the initial two Severn Drought Order activations, Clywedog trigger curves indicate the third activation on 24 October is correct. Clywedog storage has reached 19% (Drought Order in Force curve threshold 21%) and would activate the Drought Order requirement. This could indicate the savings made the previous year delay the requirement in the consecutive year by almost 2 months.

A more conservative interpretation, owing to the additional savings made by the two suspect drought order activations in 1977, would be the Severn Drought Order may not be required until late September/early October, which is still a month later than the previous year. Comparing this to storage in the Do nothing model, Clywedog crosses the Drought Order in Force curve on 13 August 1977, where as the Severn Drought Order crosses on 22 October 1977. This would appear to also support the observation that a drought order application could be delayed by over a month in the consecutive year of drought, in real terms this could also create important stalling time for rainfall to arrive.

SGS operation is significantly different in 1977 compared to Do Nothing as a response to the Severn Drought Order reducing prescribed flows at Bewdley for longer periods and therefore reducing the pressure on the regulation system. SGS operates for 155 days in total (32 days less then Do Nothing); releases are stepped back to 71 Ml/d on 8 August 1977 due to reduced demand. This saves enough licence capacity to increase back to 140 Ml/d between 13 and 30 October, as Clywedog releases are stepped back again as both the Severn Drought Order is activated and emergency storage approaches.

Based on the modelled regulation releases during 1977, a total of 157 regulation days and 60,530 Ml combined releases were modelled during the chronic drought year (1977), with Clywedog providing 65% (39179 Ml) of the resource, SGS providing 25% (15337 Ml) and Vyrnwy providing 10% (6015 Ml).

Full In-combination Model

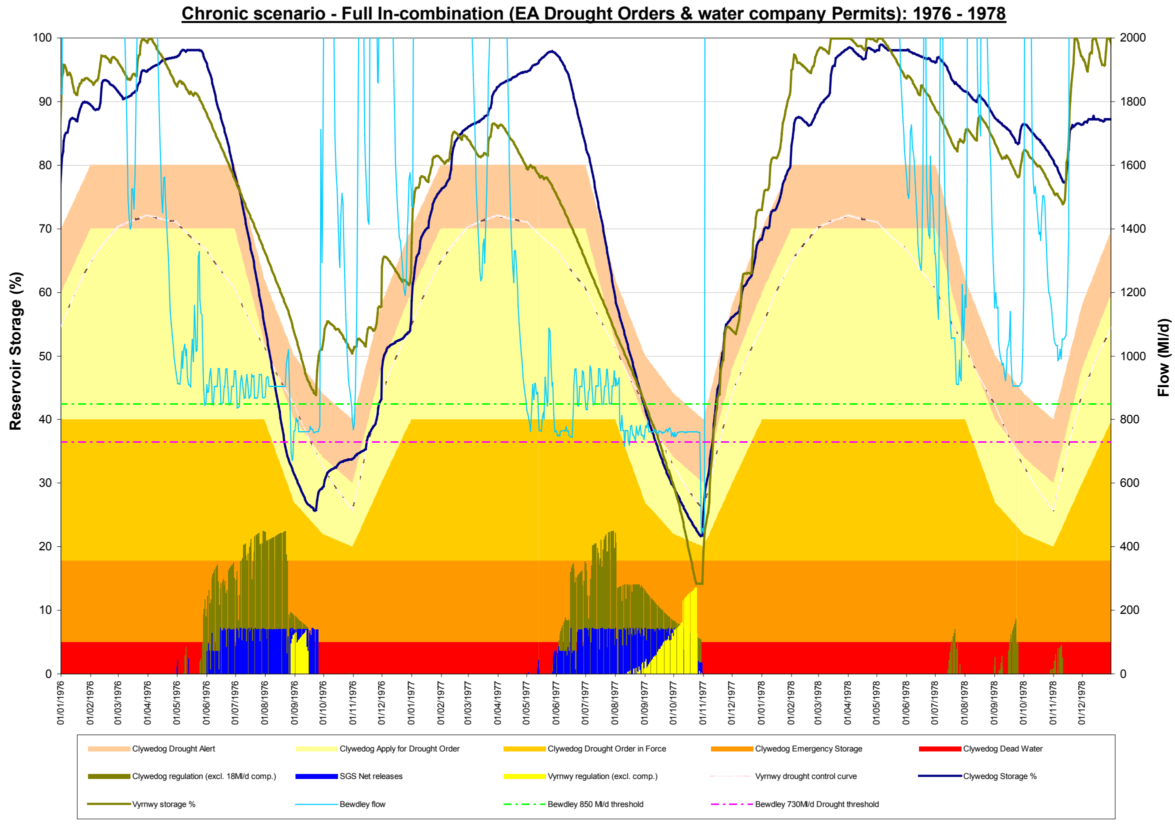


Figure 21 shows the modelled impacts on reservoir storage, alongside the regulation releases made from Clywedog, Vyrnwy and the Shropshire groundwater Scheme under the full in-combination model, which activates all the possible drought Permits as well as the Environment Agency drought order.

Figure 21 presents modelled regulation operation if the Severn Drought Order were operated at the same time as all significant Drought Permits impacting on the River Severn catchment. Appendix K.6 contains a breakdown of key dates and timings for this scenario.

The full in-combination model results are very similar to the Severn Drought Order model for regulation operations during 1976. The Severn Drought Order is activated 1 day earlier in 1976, on 24 August at 34% storage, and remains on for 172 days until 12 February 1977. Once again this prevents emergency storage being reached when compared to Do Nothing, enabling slightly higher releases to be made more for longer.

A 16% saving is made at Clywedog by activating the Severn Drought Order in 1976, enabling 98% to be achieved before continuous regulation begins again in 1977. Full In-combination shows a similar anomalous bounce affect with Severn Drought Order operation during 1977, although the dates are different; 6 March (Clywedog 86%) -13 June and 2 August (Clywedog 58%) - 9 November. Once again, Clywedog storage indicates some time during October would be a more realistic time for the Severn Drought Order to activate, although the Drought Order in Force curve is never crossed the Drought Order Application curve is crossed on 7 September.

The 2 August 1977 activation is the most realistic with Clywedog storage at 56% (Drought Alert zone); the operation again demonstrates how the savings made in 1976 can be used during a subsequent drought to maintain higher regulation for longer compared to Do Nothing.

SGS operation is different again during 1977 compared to Do Nothing and the Severn Drought Order model, although SGS operates for 156 days in total (31 days less then Do Nothing), similar to the Severn Drought Order model. Releases are stepped back to 71 Ml/d on 11 October as individual licence limits are reached, then reduce again from 26 October to 36 Ml/d by the 27 October. Operation in a real event could be managed differently to try and use more of the group licence, or the SGS drought order could be considered.

Based on the modelled regulation releases during 1977, a total of 187 regulation days and 63,969 Ml combined releases were modelled during the chronic drought year (1977), with Clywedog providing 60% (38185 Ml) of the resource, SGS providing 28% (17958 Ml) and Vyrnwy providing 12% (7826 Ml).

Corridor Flow Impacts
The main focus of interpretation and graphing will be the modelled 1977 drought, the impacts and flow behaviour for Chronic 1976 will be very similar to the Acute scenario, just with shorter duration periods and no flow benefits being observed. The main aim of producing a Chronic scenario was to test what could happen if a second drought was to follow in 1977, and assess the more accumulative flow impact where possible.

Due to modelling anomalies relating to when the Severn Drought Order is activated by Aquator, the affected results have to be analysed in terms of general flow behaviour and trends, using judgement to suggest how the results might differ if the drought order were operated more realistically. The Do Nothing baseline is unaffected by this issue, as no drought orders or permits are operated. Therefore the baseline can be used for comparison. EFI testing has been plotted for the assessment points, but not analysed in detail as the duration of low flows under Severn Drought Order operation will be incorrect due to the modelling anomaly.

[Assessment Point 1, Bryntail]

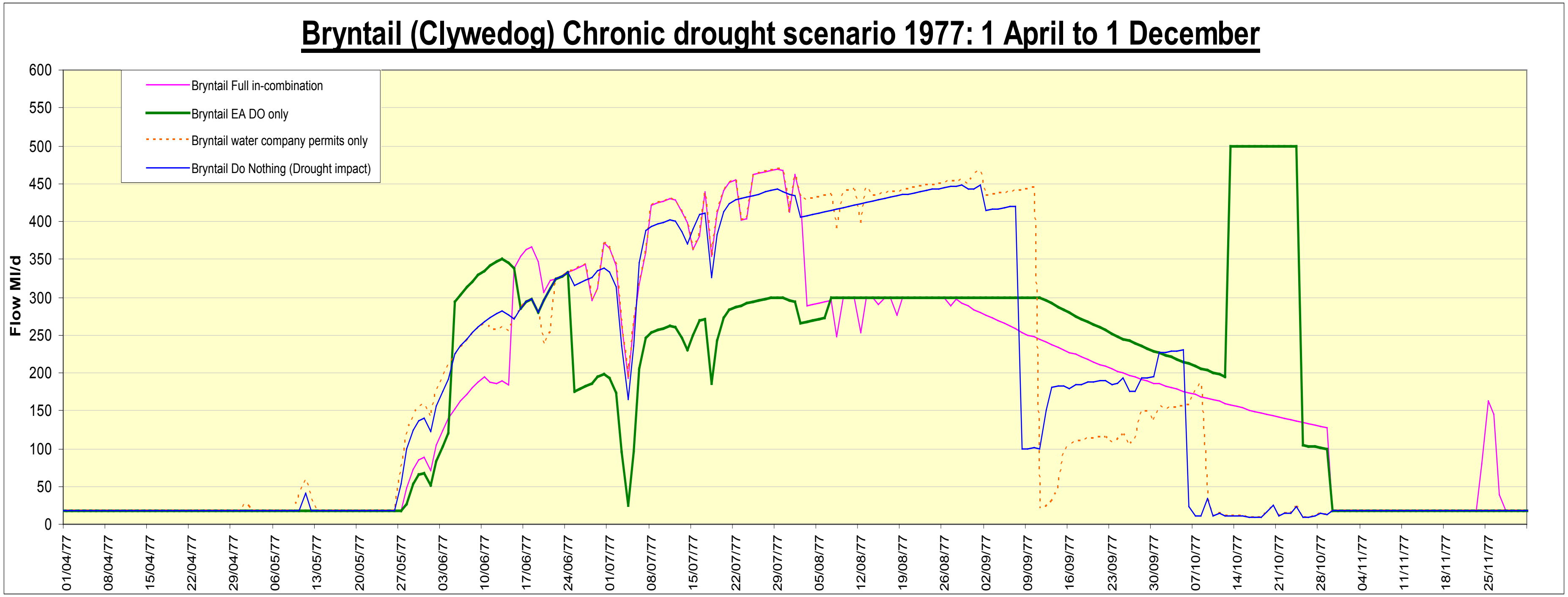


Figure 22 shows the modelled impacts on flows at Bryntail, immediately downstream of Clywedog dam. All models are displayed to illustrate the different impacts on flows caused by varying the regulation operations and drought permits and order. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 22 presents a close up of the hydrographs at Bryntail from 1 April to 1 December 1977, the critical period of low flow interest. Appendix K.2 contains the full period and Appendix K.6 contains a breakdown of key dates and timings for each model.

Table 12

	Chronic Do Nothing Ml/d	Chronic EA DO in isolation Ml/d	Chronic Full In-combination Ml/d	Gauged Ml/d	Naturalised Ml/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	*174*	*175*	*164*	176	216
Q95	18	18	18	18	19
Q99	10	18	18	18	-6
Q99.9	9	18	18	-	-59

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model
No compensation flow failure is observed in 1976. Flow variation is lost for 245 days while Clywedog refills, with similar implications to the Acute scenario, although variation returns when regulation commences in 1977. The change in flow is a sudden increase, but this is common and therefore the environment should have adapted reasonably well. No overall no adverse impacts would be expected.

The 1977 event is more significant to Bryntail; Clywedog reaches dead water on 18 September resulting in compensation flow failure. Do Nothing models 42 days of dead water until 30 October, slightly longer than the Acute scenario, increasing the risk of flows drying up entirely in the upper section although Aquator suggests a minimum flow of 9 Ml/d.

Appendix K.3 shows a mainly High Risk EFI failure between Q60 and Q94, although the lower flows satisfy the EFI. As with Acute we know the flows fall significantly below the 18.2 compensation flow the environment has adapted to, this whole period should therefore be considered as a High Risk failure.

The time period used to calculate the FDC's is significantly shorter than the 18 years of varied flow used to generate the naturalised flow and subsequent EFI, therefore it can only be used as a guide for lower flow failures. The Chronic scenario does span over two significant drought periods, and therefore it is likely to create lower flows for longer than observed in the Acute. The FDC shows the compensation flow of 18.2 Ml/d featuring from Q63, due to the lack of flow variation created by the reservoir refilling and then reaching dead water, it is fair to assume this flow frequency is representative.

Environment Agency Drought Order model
The Environment Agency Drought Order model shows no compensation flow failure, as dead water is avoided in both drought years. No significant change is observed in 1976 flow variation compared to Do nothing, as variation returns as regulation begins in 1977.

Despite the suspect timings of 1977, Clywedog storage is protected by the Severn Drought Order and spare resources are evident in releases made in October 1977, therefore compensation flow is expected to be maintained and higher flows and greater flow variation from Do Nothing would be expected as a result. Although suspect, this is reflected by Appendix K.3 reduced EFI failures between Q62 and Q65, and Q98+.

No significant flow impact beyond the Do Nothing baseline is concluded.

<u>Full In-combination model</u>
The Full in-combination model shows very similar results for 1976, but different releases during the 1977 drought, reflecting how the model simulated the Severn Drought Order activating at different times. Higher flows are shown from mid June to August, when the Severn Drought Order was not active and therefore higher releases would be needed to maintain the 850 Ml/d prescribed flow at Bewdley. Flows are then very similar to the Severn Drought Order, with the absence of the large release pattern in October.

No compensation flow failures occur and the main environmental consideration would be the lack of flow variation, which is reduced in 1977 through the additional releases being made.

Although suspect, Appendix K.3 shows further improvements from Do nothing. Considered with the maintenance of compensation flows throughout and increased flows compared to Do nothing, no significant flow impact is concluded with benefits likely.

Assessment Point 2, Vyrnwy

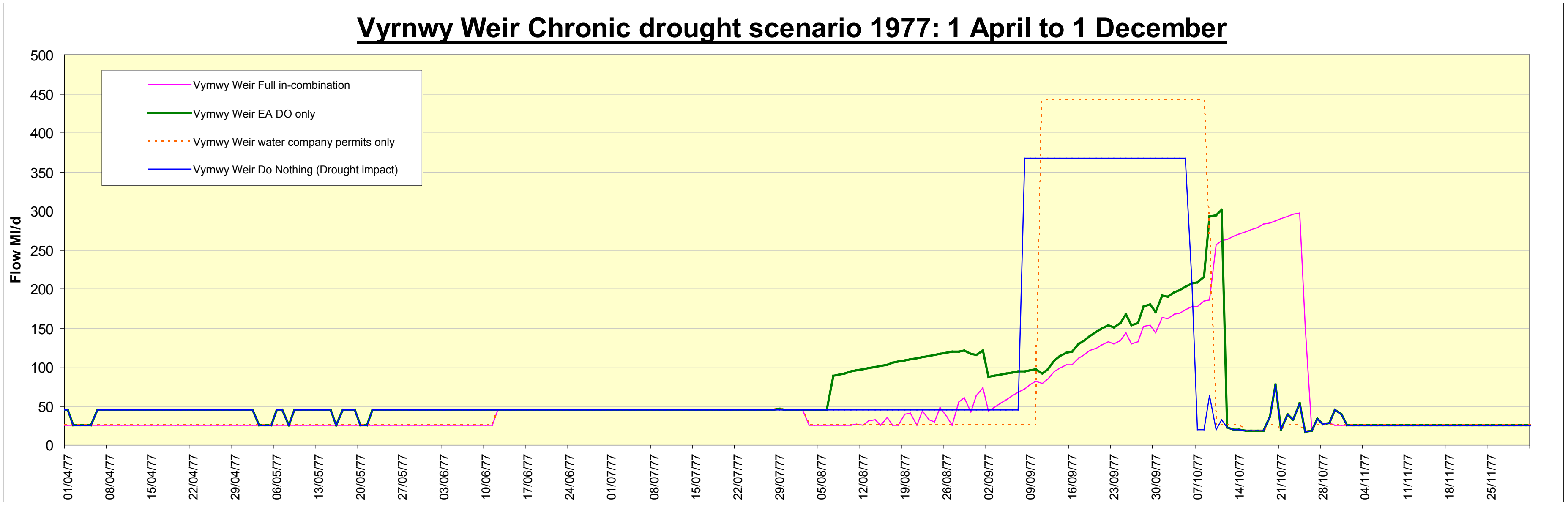


Figure 23 shows the modelled impacts on flows at Vyrnwy, immediately downstream of Reservoir dam. Vyrnwy would not be directly impacted by the operation of an Environment Agency drought order, however changes in the regulation operation would indirectly impact on flows at this AP. All models are displayed to illustrate the different impacts on flows caused by varying the regulation operations and drought permits and order. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 23 presents a close up of the hydrographs at Vyrnwy from 1 April to 1 December 1977, the critical period of low flows. Appendix K.2 contains the full modelled hydrographs from 1975 to 1979 and Appendix K.6 contains a breakdown of key dates and timings for each model.

Table 13

	Chronic Do Nothing Ml/d	Chronic EA DO in isolation Ml/d	Chronic Full In-combination Ml/d	Gauged Ml/d	Naturalised Ml/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	*45*	*45*	*45*	131	426
Q95	25	25	25	25	30
Q99	20	25	25	24	-3
Q99.9	18	18	25	-	-228

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model

The Do Nothing model does not cause compensation flow failure (below 25 Ml/d expected at Vyrnwy Weir) during 1976.

Figure 22 shows during 1977 the higher compensation flow of 45 Ml/d is maintained for the majority of the period between April and September, demonstrating how flows at Cownwy Weir would be low due to the drought conditions, triggering the higher rate at Vyrnwy Weir. Flows peak in 1977 between 8 September and 6 October, as releases of 368 Ml/d are made. There is a period immediately following these high releases, between 7 and 26 October, when Vyrnwy Weir flows appear to intermittently fail the compensation flow. Storage is critically low at 14%, but reaches this on other occasions whilst not failing the compensation flow. Therefore it's unclear whether this is just modelling 'noise' built in to account for human error, or genuine failure as flows bounce between 17.46 Ml/d and 77.57 Ml/d over 20 days.

As with Acute, Appendix K.3 shows nearly the full flow duration curve creating high risk failures of the EFI, until Q95 when flow exceeds, similar to the gauged record. The irregular compensation flow failures occur in the most infrequent percentiles and therefore satisfy the EFI. The environment will have adapted to the residual flow, although it's unclear whether they are genuine failures, occurring irregularly and at most lasting for 7 continuous days. Flow impact will be concluded as a precautionary measure, highlighting the potential issue for mitigation/management in a real event.

Environment Agency Drought Order model

The Severn Drought Order model also shows no compensation flow failure during 1976, but a similar period of intermittent compensation failure in 1977. The period is slightly shorter at 15 days (maximum 7 days continuously), occurring between 12 and 26 October 1977. In reality it is unlikely this would occur, action would be taken to protect the compensation flow during regulation, and United Utilities would operate their own drought management procedures. However, for precaution it will be concluded as having a flow impact.

Full In-combination model

The Full In-combination model incorporates all Drought Permits, technically enabling compensation flows at this site to be lowered to 20 Ml/d. The Model shows no compensation flows below 25 Ml/d during 1976, and only 1 day below (18.09 Ml/d) during 1977. It is unclear what creates the variation between the models and could be modelling noise rather than genuine failures. No significant flow impact is concluded.

Assessment Point 3, Buildwas

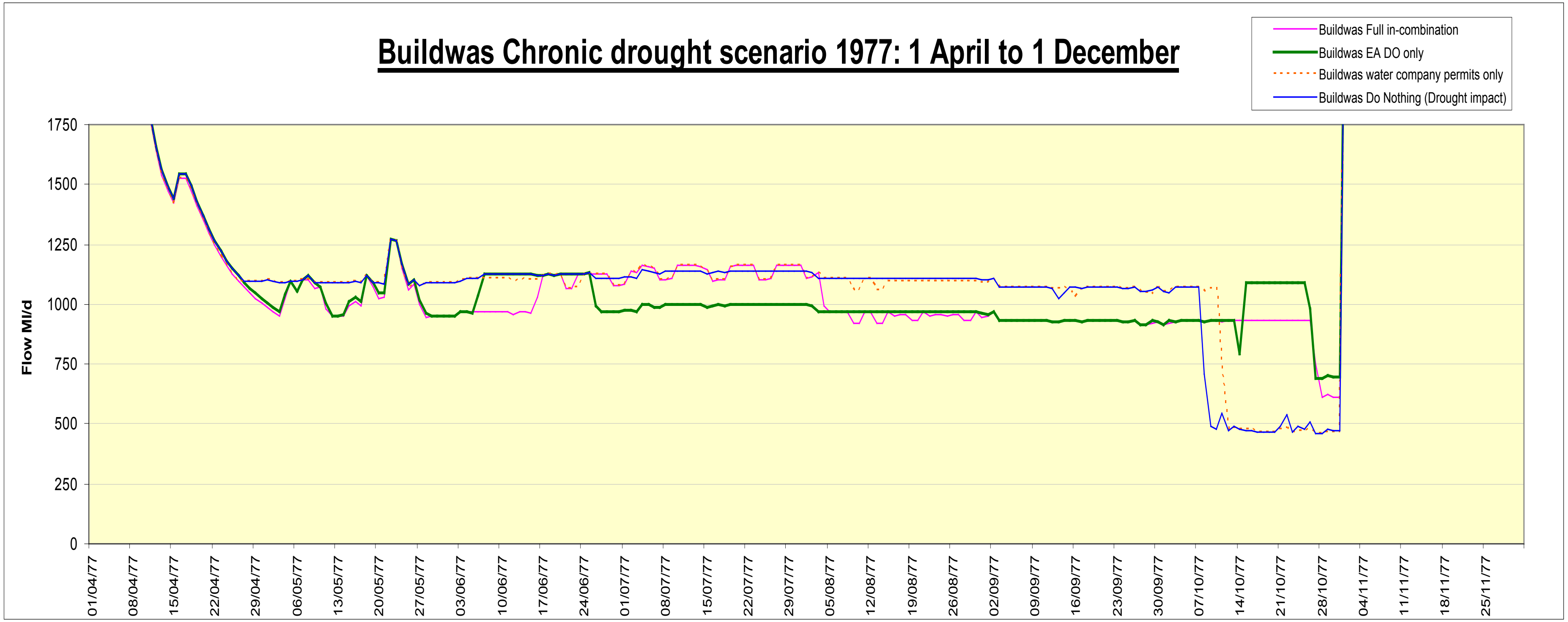


Figure 24 shows all the modelled impacts on flows at Buildwas, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 24 presents a close up of the hydrographs at Buildwas. Appendix K.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix K.6 contains a break down of key dates and timings for each model.

Table 14

	Chronic Do Nothing Ml/d	Chronic EA DO in isolation Ml/d	Chronic Full In-combination Ml/d	Gauged Ml/d	Naturalised Ml/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	*3345*	*3345*	*3345*	5511	5646
Q95	1067	934	931	1030	741
Q99	471	910	904	919	527
Q99.9	459	691	614	-	527

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model
Appendix K.1 shows flow deterioration between June and October 1976, but no flow crashes as the regulation system continues to support until rainfall returns on 29 September. Flows during this period average (mathematical average) at 1070 Ml/d.

The 1977 drought is more significant and illustrates how taking no precautions the previous year, followed by a second drought event, results in a more serious flow crash than the Acute scenario. A minimum flow of 459 Ml/d occurs on 27 October, 53 Ml lower than the Acute Do Nothing minimum. The main difference seems to be the reduced SGS releases (only 7 Ml/d at this point) as individual licence limits have been met, Clywedog and Vyrnwy resources have already been exhausted.

Prior to the regulation system failure in 1977, the Do Nothing model flows at Buildwas average (mathematical average) at 1086 Ml/d. The impacts of regulation failure first impact on Buildwas on 8 October, halving flows to an average of 481 Ml/d (59 Ml/d lower than the Acute scenario). The flow depression lasts 24 days in total before rainfall elevates flows from 1 November.

Appendix K.3 shows more high to mid EFI failures, but due to different time periods being compared it's the low flows that have more relevance. From Q79 onwards the EFI is satisfied, even after flows crash from Q98. Although the minimum flows appear significantly lower than normal conditions, the duration is still relatively short and remains above natural flows. No significant impact on flow is concluded.

Some consideration should be made of the impacts on water levels, especially through Ironbridge Gorge, which forces flow along a narrow section and therefore will be more sensitive to level changes.

Environment Agency Drought Order model
Appendix K.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 27 August. Flows during this period average (mathematical average) at 931 Ml/d, 139 Ml/d lower than Do Nothing. No flow crashes occur as recharge arrives on 26 September, therefore no flow benefits are gained in 1976 by activating the Severn Drought Order. The flow impacts will be the same as assessed for the Acute scenario, minus the benefits.

The flows during 1977 need to be considered with caution as the Severn Drought Order operation dates appear unrealistic. A minimum flow of 689 Ml/d occurs on 28 October, 230 Ml higher than Do Nothing. However, if the Severn Drought Order were not to activate on the first two occasions during 1977, then Clywedog storage would be drawn down faster to support the higher prescribed flow at Bewdley, leaving less spare resource to maintain the flow currently modelled. It is more likely the Do Nothing flows would be matched for longer leading up to the flow crash, at which point the Severn Drought Order should enable the lower prescribed flows to continue as currently modelled, still showing clear benefits from Do Nothing. The high releases made from 12 October would be unlikely, continuing instead at the lower prescribed flow rate until the inevitable flow crash, which is likely to occur sooner than shown and possibly result in lower minimum flows, as a direct consequence of using regulation resources more heavily earlier in the year.

Appendix K.3 is likely to alter, reducing the duration of drift from the Do Nothing leading up to Q98, and probably bringing the flow crash forward to around Q99. Even so, no significant additional EFI failure would be created and flow benefits are likely to be achieved.

No significant adverse impact on flow is concluded.

<u>Full In-combination model</u>
Appendix K1 shows very similar results to the Severn Drought Order model during 1976. The first impacts from the Severn Drought Order occur on 26 August. Flows during this period average (mathematical average) at 924 Ml/d, 146 Ml/d lower than Do Nothing. Recharge arrives on 26 September, again preventing flow benefits from occurring. The flow impacts would be the same as assessed for the Acute scenario, minus the benefits.

The flows during 1977 also need to be considered with caution, although they appear more accountable than the Severn Drought Order model. A minimum flow of 611 Ml/d is currently modelled on 28 October, 152 Ml higher than Do Nothing. If the initial Severn Drought Order activation was removed and the second occurrence delayed to coincide better with Clywedog storage, then the initial flow protection (compared to Do Nothing) is likely to happen. The flow crash would possibly occur sooner and be more severe as the regulation system had been used more extensively earlier in the year.

Appendix K.3 is likely to alter as described for the Severn Drought Order model, with flow benefits still being achieved. No significant impact on flow is concluded.

Assessment Point 4, Bewdley

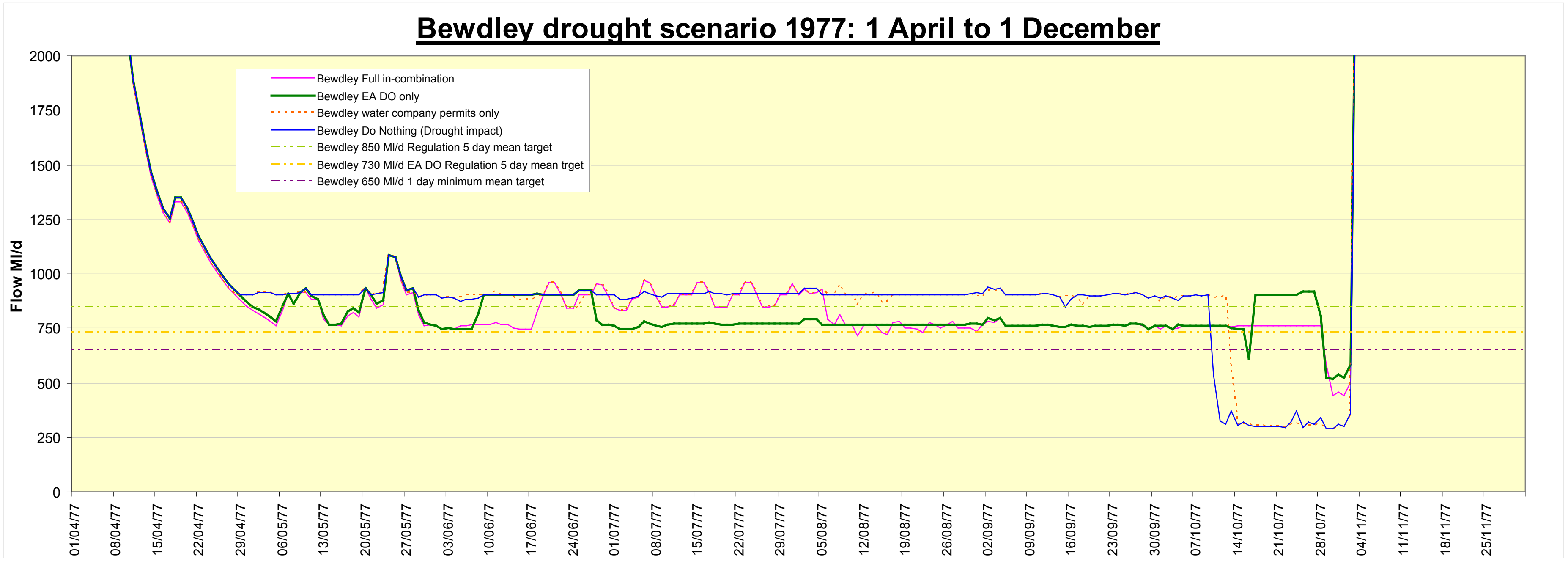


Figure 25 shows all the modelled impacts on flows at Bewdley, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 25 presents a close up of the hydrographs at Bewdley from 1 April and 1 December 1977, the critical period of low flows. Appendix K.1 contains the full modelled hydrographs and Appendix K.6 contains a breakdown of key dates and timings for each model.

Table 15

	Chronic Do Nothing Ml/d	**Chronic EA DO in isolation Ml/d**	**Chronic Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*3250*	*3250*	*3250*	5470	6211
Q95	895	762	761	881	930
Q99	304	745	732	791	715
Q99.9	289	521	444	-	458

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

The same flow loss between Buildwas and Bewdley is shown by the Chronic scenario, demonstrating the high abstraction demand from the Severn and lack of natural runoff during such a severe drought. This does not prevent the normal regulation flow targets from being maintained (when the Severn Drought Order is not active) and no detrimental impacts would be expected.

Do Nothing model
Appendix K.1 shows the reduced flows between June and October 1976, but the 850 Ml/d prescribed flow is maintained throughout. Flows during this period average (mathematical average) at 908 Ml/d, with recharge arriving on 28 September.

During 1977 the drought begins to impact flows from the end of April, steadying out to an average (mathematical average) 903 Ml/d for 163 days. Regulation failure causes flows to crash on 10 October, more than halving flows to an average of 314 Ml/d (54 Ml/d lower than the Acute scenario) with a minimum flow of 289 Ml/d occurring on 29 October. Flow depression lasts 24 days (all below the critical 650 Ml/d 1 day target) before rainfall elevates flows from 3 November.

The increased severity of the flow crash between Acute and Chronic is due to the reduced SGS releases as individual licence limits have been reached earlier, Clywedog and Vyrnwy resources have already been exhausted.

Appendix K.3 shows extensive EFI failure under Do Nothing, for the high to mid flow range this just demonstrates how Chronic has created a scenario with a higher duration of suppressed flows. The loss of flow variation would be a natural consequence of drought, and in reality the 3 year period being considered would still only truly account for a small frequency of low flows when a longer record is analysed. Having shown the prescribed 850 Ml/d flow was maintained up until flows crashed, other than a loss of flow variation no significant impact would be expected up to this point. Therefore only the Q98 onwards should be considered relevant to this assessment. Appendix K.3 shows the Q98 flows fall significantly from satisfying the EFI to the High Risk band. Both the scale of flow change and EFI failure support the conclusion of significant flow impact.

Environment Agency Drought Order model

Appendix K.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 29 August. Flows during this period average (mathematical average) at 769 Ml/d, 139 Ml/d lower than Do Nothing. No flow crashes occur as recharge arrives on 28 September, ending the drought before flow benefits are gained. The flow impacts will be the same as assessed for the Acute scenario, minus the subsequent benefits.

The flows during 1977 need to be considered with caution due to the modelling issues. A minimum flow of 520 Ml/d occurs on 30 October, 231 Ml higher than Do Nothing. If the first two Severn Drought Order activations were discounted as error, the same flow trend discussed at Buildwas would be expected, but with slightly lower flows due to higher abstractions around this area. Overall, flows should still be maintained around the 730 Ml/d prescribed flow mark after the Do Nothing flows crash, utilising the water saved during the 1976 drought order activation. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available. The high releases shown from 17 October would be removed.

The duration of reduced flows prior to the flow crash should be significantly reduced (currently around 105 days) as the Severn Drought Order is operated for a shorter (more accurate) period.

Appendix K.3 would also alter, reducing the duration of drift from the Do Nothing leading up to Q98, as the combined duration of Severn Drought Order operation would be reduced (i.e. less time regulating to lower 730 Ml/d prescribed flows). If the drought continued long enough for a flow crash to occur, the flow drop on the FDC would likely shift closer to Q99 (occurring sooner and so for slightly longer), reducing the benefits slightly.

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, and taking into account the Acute assessment, no further adverse flow impacts would be expected, while more significant flow gains (than Acute) could be achieved if the drought continued for long enough.

No significant adverse impact on flow is concluded.

Full In-combination model

Appendix K.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 28 August, 1 day earlier than the Severn Drought Order model. Flows during this period average (mathematical average) at 759 Ml/d, 149 Ml/d lower than Do Nothing. Recharge on 28 September prevents any flow benefits being achieved. The flow impacts will be the same as assessed for the Acute scenario, minus the subsequent benefits.

The flows during 1977 also need to be considered with caution due to the modelling issues. A minimum flow of 441 Ml/d occurs on 30 October, 152 Ml higher than Do Nothing. If the initial Severn Drought Order activation was discounted as error and the second occurrence delayed to coincide better with Clywedog storage, a similar flow trend as discussed at Buildwas could be expected, also likely to be very similar to the Severn Drought Order.

The duration of reduced flows prior to the flow crash should be reduced (currently modelled at 66 days) as the Severn Drought Order is operated for a shorter (more accurate) period. However the flows preceding the critical period (Do Nothing flow crash) should still be maintained around the 761 Ml/d being modelled (142 Ml/d lower than Do Nothing). A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows. The timing is likely to be very similar to the Severn Drought Order in isolation, however the flows would be lower due to the additional pressures on the system.

Appendix K.3 would alter, reducing the duration of drift from the Do Nothing leading up to Q98, and possibly bringing the flow crash forward to Q99 (occurring sooner and so for slightly longer), subsequently reducing the benefits slightly.

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, and taking into account the Acute assessment, no further adverse flow impacts would be expected. More significant flow gains (than Acute) could be achieved if the drought continued for long enough.

Assessment Point 5, Saxon's Lode

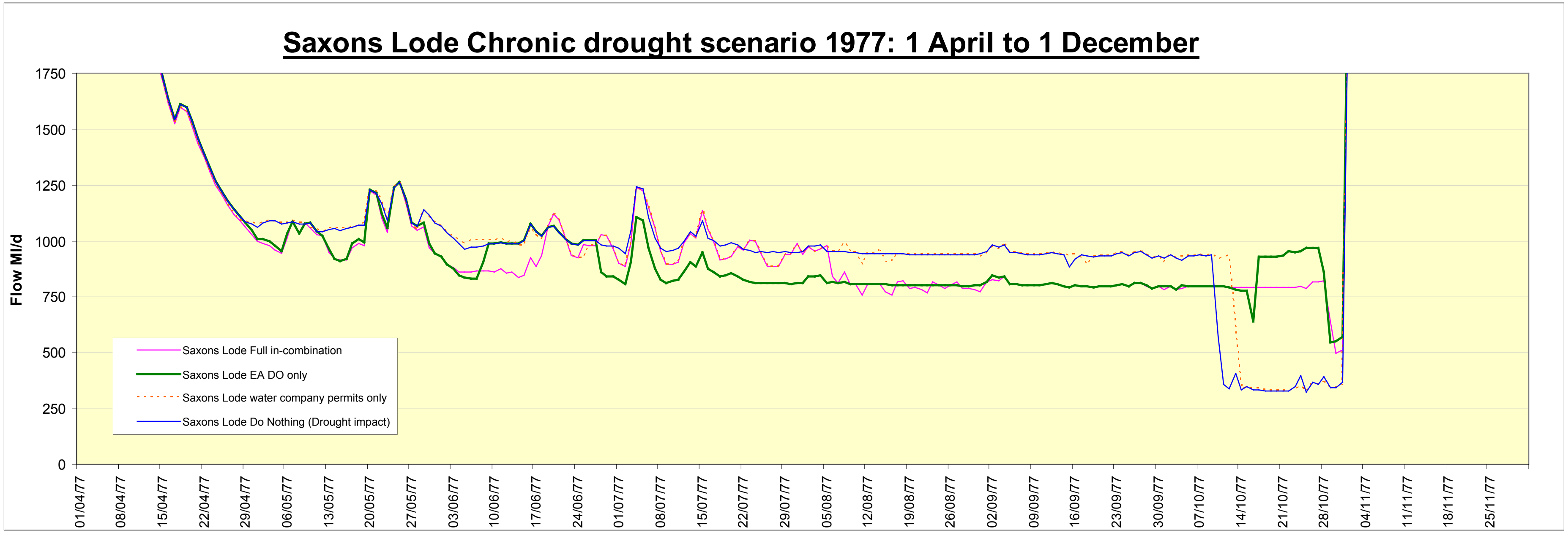


Figure 26 shows all the modelled impacts on flows at Saxon's Lode, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 26 presents a close up of the hydrographs at Saxon's Lode from 1 April to 1 December 1977, the critical period of low flows. Appendix K.1 contains the full modelled hydrographs and Appendix K.6 contains a breakdown of key dates and timings for each model.

Table 16

	Chronic Do Nothing Ml/d	**Chronic EA DO in isolation Ml/d**	**Chronic Full In-combination Ml/d**	**Gauged Ml/d**	**Naturalised Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*3938*	*3938*	*3938*	7991	8523
Q95	939	804	799	1327	1350
Q99	344	791	781	1167	1131
Q99.9	328	551	511	-	536

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model
Appendix K.1 shows reduced flows between June and October 1976, but no flow crash occurs. Flows during this period average (mathematical average) at 961 Ml/d, with recharge arriving on 15 September.

During 1977 the drought begins to impact flows from the end of April, steadying out to an average (mathematical average) 941 Ml/d for approximately 160 days. Regulation failure causes flows to crash on 10 October, more than halving flows to an average of 350 Ml/d (78 Ml/d lower than the Acute scenario) with a minimum flow of 323 Ml/d occurring on 25 October. Flow depression lasts 22 days before rainfall elevates flows from 1 November, 2 days earlier than upstream Bewdley, which is likely due to more localised rainfall feeding down the lower tributaries.

Appendix K.3 shows almost complete EFI failure, as discussed at Bewdley, Q98 onwards should be considered the most relevant to this assessment. Flows up to Q98 already show Low Risk (>10% below EFI) failure, significantly falling to High Risk failure along the FDC. Significant flow impact is concluded.

Environment Agency Drought Order model
Appendix K.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 29 August. Flows during this period average (mathematical average) at 823 Ml/d, 138 Ml/d lower than Do Nothing. No flow benefits are achieved as recharge arrives on 15 September, 13 days earlier (localised rainfall) than Bewdley. Flow impacts from activating the Severn Drought Order would be the same as assessed for the Acute scenario, minus the subsequent benefits.

The flows during 1977 need to be considered with caution due to the modelling issues. A minimum flow of 547 Ml/d occurs on 29 October, 224 Ml higher than Do Nothing. If the first two Severn Drought Order activations were discounted as error, the same flow trend discussed at Buildwas and Bewdley would be expected.

Flows preceding the critical period (Do Nothing flow crash) should still be maintained around the 823 Ml/d being modelled (118 Ml/d lower than Do Nothing), but for a shorter time period as the Severn Drought Order would be activated later. The high releases shown from 17 October would be removed. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available.

Appendix K.3 would alter, again reducing the duration of drift from the Do Nothing leading up to Q98. If the drought continued long enough for a flow crash to occur, the flow drop on the FDC is likely to shift closer to Q99 (occurring sooner and so for slightly longer), marginally reducing the duration of benefit.

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, then the flow impact conclusions from the Acute scenario should be applied. Using the Acute scenario conclusions as a precautionary measure, a minor increase in the duration of Medium Risk EFI failure could be expected, however in the Chronic scenario the flow benefits achieved if the drought continued, would be greater than Acute.

<u>Full In-combination model</u>
The first impacts from activating the Severn Drought Order in 1976 occur on 27 August (Appendix K.1), 1 day earlier than the Severn Drought Order model. Flows during this period average (mathematical average) at 814 Ml/d, 147 Ml/d lower than Do Nothing. Recharge on 15 September prevents any flow benefits being achieved but the flow impacts would be the same as assessed for the Acute scenario.

During 1977 a minimum flow of 673 Ml/d is currently modelled on 30 October, 174 Ml higher than Do Nothing. The flows are suspect due to modelling issues, however the flows preceding the critical period (Do Nothing flow crash) should still be maintained around the 799 Ml/d modelled (142 Ml/d lower than Do Nothing). If the initial Severn Drought Order activation was discounted as error and the second occurrence delayed to coincide better with Clywedog storage, a similar flow trend as discussed at Buildwas and Bewdley could be expected.

Appendix K.3 would alter, reducing the duration of drift from the Do Nothing leading up to Q98, and possibly bringing the flow crash forward to Q99 (reducing the benefits slightly).

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, using the Acute scenario conclusions as a precautionary measure, a minor increase in the duration of Medium Risk EFI failure could be expected (compared to Do nothing), however in the Chronic scenario the flow benefits achieved if the drought continued, would be greater than Acute.

Assessment Point 6, Haw bridge/Deerhurst

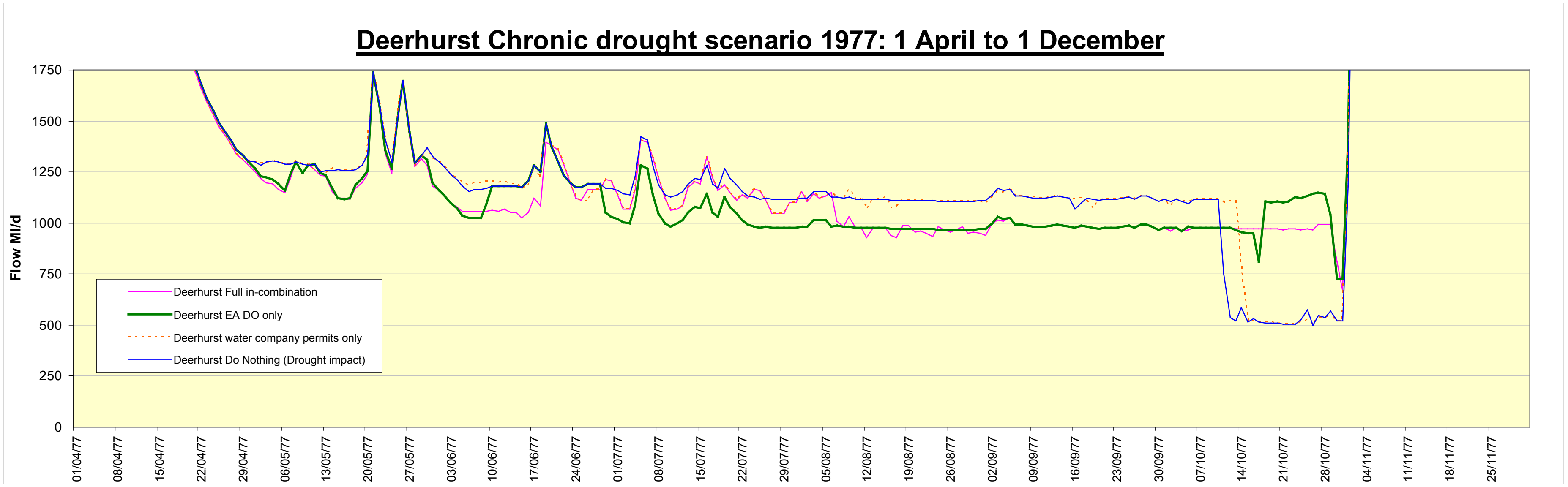


Figure 27 shows all the modelled impacts on flows at Deerhurst, downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS). The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 27 presents a close up of the hydrographs at Deerhurst from 1 April to 1 December 1977. Appendix K.1 contains the full modelled hydrographs and Appendix K.6 contains a breakdown of key dates and timings for each model.

Table 28

	Chronic Do Nothing Ml/d	Chronic EA DO in isolation Ml/d	Chronic Full In-combination Ml/d	Gauged Ml/d	Naturalised Ml/d
	(1975-1977)	(1975-1977)	(1975-1977)	(1990-2007)	(1990-2007)
Q30*	*4418*	*4418*	*4421*	9054	10079
Q95	1108	979	978	1571	1680
Q99	520	966	950	1317	1224
Q99.9	505	727	813	-	730

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

Do Nothing model
Appendix K.1 shows reduced flows between June and October 1976, but no flow crash occurs. Flows during this period average (mathematical average) at 1150 Ml/d, with recharge arriving on 16 September.

The 1977 drought impacts on flows from the end of April, with occasional rainfall spikes until August. The average (mathematical average) flows for this period are 1118 Ml/d (approximately 160 days). Regulation failure causes flows to crash on 11 October, more than halving flows to an average of 537 Ml/d (71 Ml/d lower than the Acute scenario) with a minimum flow of 499 Ml/d occurring on 26 October. Flow depression lasts 21 days before rainfall elevates flows from 1 November, 2 days earlier than upstream Bewdley, which is likely due to more localised rainfall feeding down the lower tributaries.

Appendix K.3 shows almost complete EFI failure, similar to Saxon's Lode, although the lowest flow frequency shows a slightly reduced magnitude of failure. Flows up to Q98 are outside the Low Risk band, but significantly fall into the High Risk failure moving along the FDC. Significant flow impact is concluded.

Environment Agency Drought Order model
Appendix K.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 30 August. Flows during this period average (mathematical average) at 1011 Ml/d, 138 Ml/d lower than Do Nothing. No flow benefits are achieved as recharge arrives on 16 September. Flow impacts from activating the Severn Drought Order would be the same as assessed for the Acute scenario, minus the subsequent benefits.

Flows modelled for 1977 need to be considered with caution due to the modelling issues. A minimum flow of 723 Ml/d occurs on 30 October, 224 Ml higher than Do Nothing. Discounting the first two Severn Drought Order activations as error, the same flow trend discussed at Buildwas, Bewdley and Saxon's Lode would be expected.

Flows preceding the critical period (Do Nothing flow crash) should still be maintained around the 980 Ml/d being modelled (139 Ml/d lower than Do Nothing), but for a shorter time period as the Severn Drought Order would be activated later. The high releases shown from 18 October would be removed. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available.

Appendix K.3 would alter, again reducing the duration of drift from the Do Nothing leading up to Q98. If the drought continued long enough for a flow crash to occur, the flow drop on the FDC is likely to shift closer to Q99. This would marginally reduce the duration of benefit, although flows may remain within the Low Risk band.

Due to modelling issues it is difficult to assess flow impacts with certainty. As with upstream assessment points, if the corrective assumptions being made are reasonable, then the flow impact conclusions from the Acute scenario should be applied.

Using the Acute scenario conclusions as a precautionary measure, a minor increase in the duration of Medium Risk EFI failure could be expected. Importantly, the subsequent flow benefits achieved should be greater than observed in the Acute scenario.

Full In-combination model

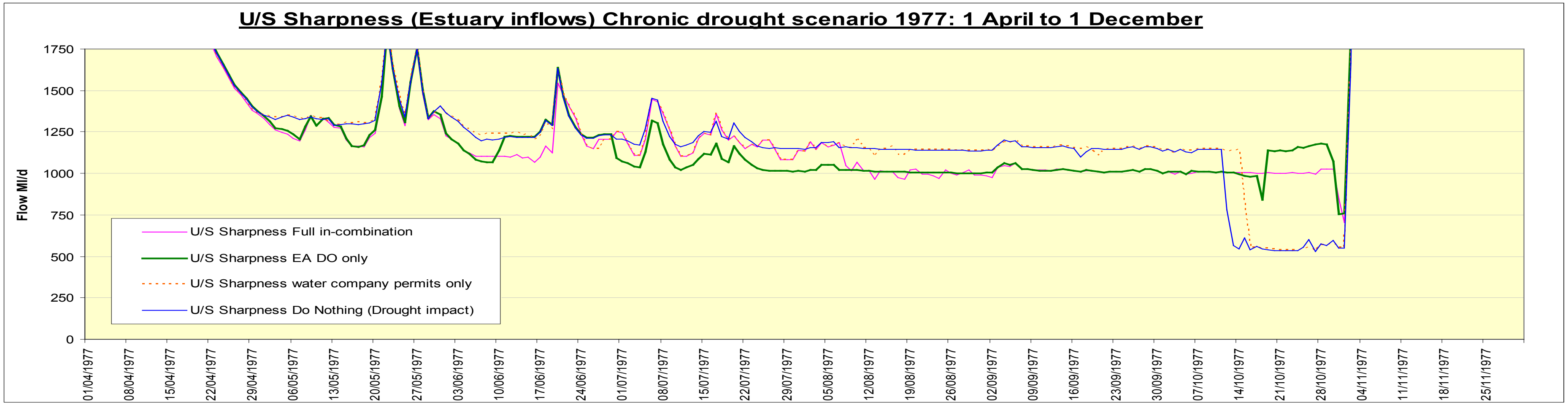
The first impacts from activating the Severn Drought Order in 1976 occur on 30 August (Appendix K.1)). Flows during this period average (mathematical average) at 998 Ml/d, 152 Ml/d lower than Do Nothing. Recharge on 16 September prevents any flow benefits being achieved but the flow impacts would be the same as assessed for the Acute scenario.

During 1977 a minimum flow of 673 Ml/d is currently modelled on 31 October, 174 Ml higher than Do Nothing. The flows are suspect due to modelling issues, however the flows preceding the critical period (Do Nothing flow crash) should still be maintained around the 979 Ml/d modelled (139 Ml/d lower than Do Nothing). As discussed, if the initial Severn Drought Order activation was discounted as error and the second occurrence delayed to coincide better with Clywedog storage, a similar flow trend described for upstream locations could be expected.

Appendix K.3 would alter, reducing the duration of drift from the Do Nothing leading up to Q98, and possibly bringing the flow crash forward to Q99. This would marginally reduce the duration of benefit, although flows may remain within the Low Risk band.

Due to modelling issues it is difficult to assess flow impacts with certainty. However, if the corrective assumptions being made are reasonable, using the Acute scenario conclusions as a precautionary measure, a minor increase in the duration of Medium Risk EFI failure could be expected (compared to Do nothing), however in the Chronic scenario the flow benefits achieved if the drought continued, would be greater than Acute.

Assessment Point 7 U/S Sharpness and assessment point 8 Lower Parting



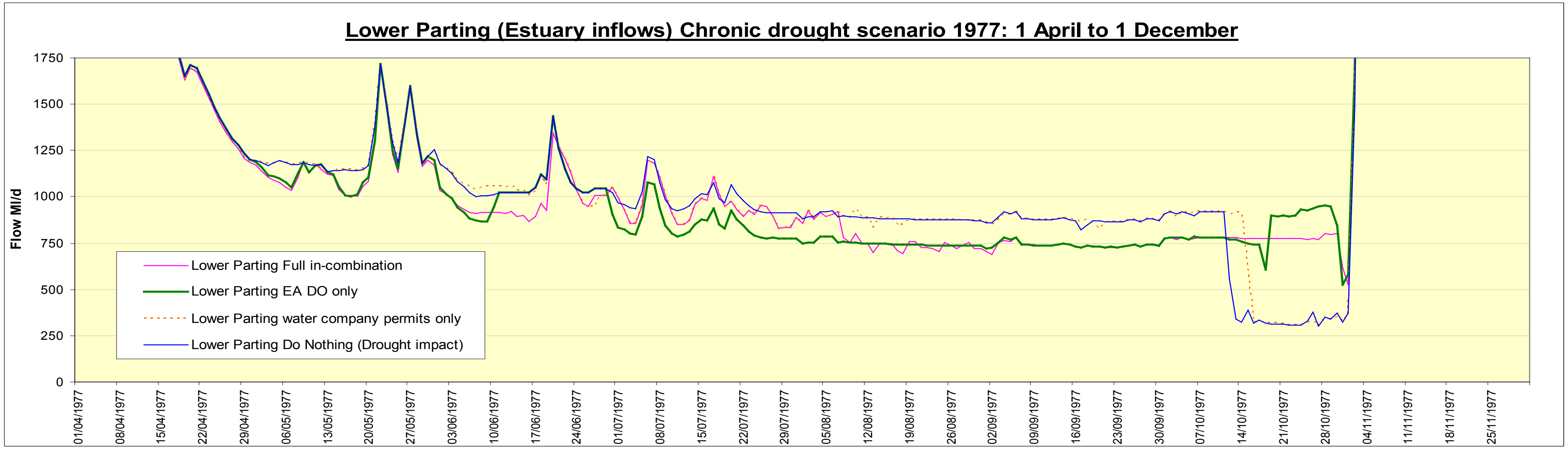


Figure 29 shows all the modelled impacts on flows at U/S Sharpness and Lower parting. Both are downstream of all the regulation inputs (Clywedog, Vyrnwy and SGS) but U/S Sharpness is located upstream of the Gloucester and Sharpness canal abstraction while Lower Parting is downstream. The graph highlights the specific period of interest, when the Environment Agency drought order would be needed/is activated.

Figure 29 presents two close up hydrographs, U/S Sharpness and Lower Parting, from 20 1 April to 1 December 1977. Appendix K.1 contains the full modelled hydrographs from 1975 to 1979 and Appendix K.6 contains a breakdown of key dates and timings for each model.

As discussed for the Acute modelling, Deerhurst is the furthest downstream flow gauge from which to calibrate data. All subsequent downstream flows are estimated from models, previous analysis and observations and need to be considered with greater caution. The greatest caution has been applied to assessing flows downstream of the Gloucester and Sharpness canal abstraction (represented with a maximum 300Ml/d), as variations could be large and alter the results significantly. Worse case assumptions have been applied to ensure a precautionary assessment is under taken.

<u>Table 17</u>

	U/S Sharpness			**Lower Parting**			**Low Flows Enterprise**	
	Chronic Do Nothing Ml/d	**Chronic EA DO in isolation Ml/d**	**Chronic Full In-combination Ml/d**	**Chronic Do Nothing Ml/d**	**Chronic EA DO in isolation Ml/d**	**Chronic Full In-combination Ml/d**	**Modelled Influenced Ml/d**	**Modelled Natural Ml/d**
	(1975-1977)	**(1975-1977)**	**(1975-1977)**	**(1975-1977)**	**(1975-1977)**	**(1975-1977)**	**(1990-2007)**	**(1990-2007)**
Q30*	*1209*	*1117*	*1145*	*983*	*893*	*914*	9772	10213
Q95	578	1005	997	370	735	729	1910	2056
Q99	547	1000	985	319	729	718	1509	1564
Q99.9	532	755	705	304	528	523	1096	1123

**Q30 values for the drought scenarios to be viewed with additional caution due to the short (3 year) record of data used.*

<u>Do Nothing model</u>
Appendix K.1shows reduced flows between June and October 1976, but no flow crash occurs. Flows during this period average (mathematical average) at 1179 Ml/d, with recharge arriving on 16 September.

During the 1977 drought, flows prior to the modelled regulation failure averaged (mathematical average) 1176 Ml/d for U/S Sharpness and 914 Ml/d at Lower Parting. Regulation failure causes flows to crash on 12 October, more than halving flows to an average of 570 Ml/d at U/S Sharpness (70 Ml/d lower than the Acute scenario) and 343 Ml/d at Lower Parting Sharpness (297 Ml/d lower than the Acute scenario). Flow depression lasts 20 days with minimum flows of 532 Ml/d and 304 Ml/d occurring on 27 October, flow recovery begins on 2 November 1977.

Appendix K.6 shows almost complete EFI failure, with flows from Q30 onwards (Acute scenario identified failure from Q50) being mainly within the High Risk (>30% drift from EFI) failure band. EFI's are not definitive and only a short time period was used to generate the modelled FDC's, however these results suggest it is likely the natural drought event would have significant detrimental impacts on the lower River Severn. Further increased when considered against the unknown abstraction maximum's for the Gloucester and Sharpness canal, and the natural channel bifurcation splitting flows through Gloucester.

Likely significant effects concluded for the baseline drought conditions, these would be deemed as unavoidable consequences.

Environment Agency Drought Order model
Appendix K.1 shows the first impacts from activating the Severn Drought Order in 1976 occur on 31 August. Flows during this period average (mathematical average) at 1041 Ml/d for U/S Sharpness and 759 Ml/d for Lower Parting, 138 Ml/d lower than Do Nothing. No flow benefits are achieved by operating the Severn Drought Order as recharge arrives on 16 September. Flow impacts from activating the Severn Drought Order are considered to be the same as assessed for the Acute scenario.

Flows modelled for 1977 need to be considered with caution due to the modelling issues already highlighted (discount first two drought order activations). A minimum flow of 755 Ml/d at U/S Sharpness and 528 Ml/d at Lower Parting is modelled between 31 October and 1 November, 223-224 Ml higher than Do Nothing, demonstrating an obvious flow benefit to the River Severn.

Flows preceding the critical period (Do Nothing flow crash) should still be maintained around the 1037 Ml/d at U/S Sharpness and 1079 Ml/d at Lower Parting being modelled (138-135 Ml/d lower than Do Nothing), but for a shorter time period and the high releases shown from 19 October would be removed. A flow crash would still be inevitable if the drought continued, likely to occur sooner than currently modelled and possibly to lower flows, depending on how much regulation water was still available.

Appendix K.6 would alter, again reducing the duration of drift from the Do Nothing leading up to Q98. The EFI would still not be satisfied but the magnitude of failure would remain similar, managing to stay within the Low Risk band compared to the Do Nothing which is clearly into the High Risk failure band. If the drought continued long enough for a flow crash to occur, the flow drop on the FDC is likely to shift closer to Q99, marginally reducing the duration of benefit. However, the flow benefits are clearly beneficial for this section of the River Severn and the conclusions for Acute scenario lead in time can be applied.

Full In-combination model
The first impacts from activating the Severn Drought Order in 1976 occur on 30 August (Appendix K.1). Flows during this period average (mathematical average) at 1026 Ml/d for U/S Sharpness and 745 Ml/d for Lower Parting, 153 Ml/d lower than Do Nothing. Recharge on 16 September prevents any flow benefits being achieved but the flow impacts would be the same as assessed for the Acute scenario.

Results need to be considered with caution due to modelling errors; During 1977 a minimum flow of 705 Ml/d at U/S Sharpness and 524Ml/d at Lower Parting is modelled on 1 November, 173-220 Ml higher than Do Nothing. The flows are suspect due to modelling issues, however the flows preceding the critical period (Do Nothing flow crash) should still be maintained around 1079 Ml/d and 818 Ml/d as modelled (130-96 Ml/d lower than Do Nothing).

Appendix K.6 would alter as discussed for the Severn Drought Order assessment, with slight changes in magnitude to account for greater abstraction under full in-combination. The biggest unknown in context of the full in-combination assessment, as with the Acute scenario, is the abstraction activities of The Canals and Rivers trust for the Gloucester and Sharpness canal. Modelling currently assumes a maximum 300Ml/d abstraction, however larger abstractions may be required to support the canal and Bristol Waters public water supply needs, significantly reducing flows in the lower River Severn further. Taking the precautionary worse case approach, likely significant effects are concluded.

CONCLUSIONS: CHRONIC SCENARIO

The Chronic drought scenario represents a dry summer and winter (1975) preceding a drought summer (1976), which triggers the need for a Severn Drought Order but significant rainfall returns before true flow benefits are achieved, a second drought summer follows (1977). The main focus of the Chronic scenario is the second drought year (1977), and what impact applying a Severn Drought Order one year without achieving flow benefits could have on a consecutive drought year.

As highlighted in the Acute scenario conclusions, the greatest uncertainty remains around the Gloucester and Sharpness canal abstractions and it's impact on the lower River Severn during a severe drought. The River Severn splits between U/S Sharpness and Lower parting, with monitoring (between 1977-2007) indicating approximately 40% of flow goes down the East channel and 60% down the West channel. Low flows occurring due to the drought would become further divided and flow velocity decreased encouraging siltation and saline intrusion. The degree of flow loss and subsequent impacts is unclear without more data/monitoring, however this stretch of the river Severn could potentially be at high risk during a severe drought and likely significant effects have been concluded as a precautionary measure.

Baseline, Do Nothing

The Do Nothing model predicts the drought conditions and unavoidable impacts on the current environment, if the Severn Drought Order was not operated. The model presents the best available flow predictions for a worse case theoretical drought of long term duration.

The Chronic scenario once again proved the importance of Clywedog as the primary source of Severn regulation water. Modelling highlighted that if Clywedog becomes exhausted, Vyrnwy bank can only offer a short term replacement for the large volumes of regulation required, and SGS does not have enough capacity to replace the reservoir volumes. It also appears likely during such a drought, that Vyrnwy storage would also become critically low and could pose another resource issue that would need careful management with the appropriate water company. The key message appears to again be, once Clywedog becomes exhausted the whole regulation system is likely to fail. Forward planning is needed during any event, considering the impact on the subsequent year if resources are drawn down too low.

The 1976 drought event does not appear to have any significant flow impacts under Do Nothing, owing to the continued high releases being made as part of normal Severn regulation. To some degree this is a game of chance, if rainfall had not arrived, events would have followed the Acute scenario, however on this occasion recharge was received and so no adverse flow impacts were observed along the Severn corridor. Significant flow impacts were observed during the 1977 drought (Do Nothing) at Bryntail, Bewdley, Saxon's Lode and Deerhurst, the same locations identified in the Acute scenario.

Bryntail is potentially at high risk of significant flow impact, as the 18.2 Ml/d compensation flow is failed for 42 days between 18 September and 10 October. Modelling indicates a minimum flow of 9 Ml/d, however with no releases being made from the reservoir, the area immediately downstream of the dam is likely to become dry, extending downstream until significant natural baseflow returns.

As a precautionary measure, Vyrnwy Weir was concluded as having a significant flow impact. Over 20 days (7 to 26 October) during 1977, irregular compensation flow failures were recorded, all below the minimum 25 Ml/d compensation flow. A minimum 17.46 Ml/d occurred on 25 October. It's unclear whether this is modelling error, although storage was at 14% and 7 continuous days recorded compensation flow failure.

From Bewdley, it can be expected the whole River Severn downstream would be affected to varying degree's by the naturally developing drought. If the regulation system failed, flows are shown to fall up to 600 Ml over 2 days. Flows crash between 8 and 11 October 1977, with depressions lasting between 21 and 24 days before natural recharge occurs in early November. Bewdley predicts a minimum flow of 289 Ml/d, 229 Ml/d lower than ever recorded, Saxon's Lode predicts a minimum 323 Ml/d, 392 Ml/d below existing records and Deerhurst predicts a minimum 499 Ml/d, 476 Ml/d below existing records. Greater uncertainty surrounds the lower River Severn as discussed, assuming a maximum 300 Ml/d abstraction to the Gloucester and Sharpness canal, a minimum daily flow of 532Ml/d at U/S Sharpness and 304Ml/d at Lower Parting was modelled. The magnitude of predicted flow impact is certainly significant, the degree of adverse impact would depend on the duration of the event and sensitivity of the environment.

In reality, it is not possible to exactly predict what the minimum flows would be if the regulation system did fail and they should be viewed as advisory only. All drought events are unique with varying prevailing conditions and abstraction demands creating different responses to the same rainfall patterns. However, the flow behaviour is the important result for drought planning. Should Clywedog fail, the remaining regulation support has a short life and is unlikely to cope. Once the regulation system goes into failure, minimum flows can be expected to rapidly decline to baseflow rates until rainfall returns, highlighting the need to operate the River Severn Drought Order.

Severn Drought Order

This model represents the conditions if the Environment Agency operated the Severn Drought Order at Clywedog, all routine abstractions and discharges were active, but no other drought permits or orders were in force.

The modelled 1976 drought event and Severn Drought Order operation appear reliable and results could be used with reasonable confidence. Flow impacts for the 1976 portion of the event were concluded to be the same as the Acute scenario, but without the immediate flow gain being achieved.

During 1977 the Severn Drought Order is modelled to bounce on and off on 3 occasions, 24 February – 4 June, 24 June to 12 October and 24 October – 1 February, all which reduce the prescribed flow at Bewdley to the 730 Ml/d. The first two activations appear false, as Clywedog storage was at 84% on both occasions, whilst the Drought Order in force curve would be crossed at 40%. The third activation on 24 October, although slightly late, is an accurate response to Clywedog storage.

It is unclear what the Aquator model is responding to on these occasions. The system is complex and Aquator was not designed to isolate the Environment Agency's Severn Drought Order for testing. A number of other triggers and linkages to system failures elsewhere could have caused these false activations.

As a result the 1977 flow results had to be assessed subjectively, making informed assumptions about how differently the flows would have responded if the Severn Drought Order had only been activated on one occasion, likely during October. It is more likely the Do Nothing flows would be matched for longer leading into the critical flow period, drawing Clywedog storage down further earlier in the regulation season as a result. Flows would then be lowered to maintain the Bewdley drought flow target (730 Ml/d 5 day mean) as modelled, continuing at this flow beyond the Do Nothing flow crash (as modelled). The high flows in mid October would be removed, instead maintaining the drought order prescribed flow. If the drought continued the regulation system would still inevitably fail, potentially sooner and to lower flows than currently modelled as less regulation water would be available due to higher flow maintenance earlier in the season (removing the false drought order activations).

Although the results could not be analysed in great detail owing to the modelling anomaly, the flow behaviour and trends were still valuable. By activating the Severn Drought Order in 1976, although no flow benefits were immediately achieved 16% storage was saved at Clywedog. This enabled the reservoir to reach 96% before regulation began in 1977, translating to longer regulation at 730Ml/d (5 day mean) after the Do Nothing model showed system failure and flow crashes. Modelling also suggests a greater protection of the minimum flows during any subsequent regulation failure, as Clywedog and SGS continue to have more resources to give than under Do Nothing.

With the exception of Bryntail, where compensation flows are protected with obvious benefits, significant flow impacts were difficult to conclude with certainty for 1977, due to the modelling issues. A precautionary approach was adopted, assuming a very similar impact as assessed under the Acute scenario due to the reduced flows leading into the critical drought period (which are likely to be of similar duration), but with a greater flow benefit being achieved as the drought developed. Significant flow impacts were concluded at Saxon’s Lode, Deerhurst the lower River Severn (U/S Sharpness and Lower Parting).

As a precautionary measure, Vyrnwy Weir was also concluded as having a significant flow impact, similar to the Do Nothing model. The number of days was reduced, but over 15 days (12 to 26 October), irregular compensation flow failures were recorded, all below the normal compensation (and Drought Permit) flow target of 25 Ml/d. A minimum 17.46 Ml/d occurred on 25 October. Storage again reached 14% and flows failed on 7 consecutive days.

Modelling supports the aim of the Severn Drought Order, and demonstrated the long term benefits it’s operation can create in a subsequent drought year. By operating the drought order in 1976, no flow benefits are immediately observed, but the storage saved is carried over into the subsequent regulation season (1977). This more long term saving is translated into preventing regulation system failure for longer than under Do nothing (opposite to Acute scenario), and potentially maintaining higher minimum flows during any subsequent regulation system failure, if the drought were to continue.

Interestingly, although the Severn Drought Order operation appears wrong (premature activations), it does demonstrate what could be expected if the control curves were altered and the Severn Drought Order were considered at an earlier point in a developing drought. The duration of reduced prescribed flow would be significantly increased, however the flow benefits during critical periods could be more substantial as larger quantities of water were available. Would need to be considered in balance with other catchment interests, as this would impact on water company abstractions and depends on whether the reduced prescribed flow is considered to have an adverse impact on the environment.

Full In-combination

This model represents the conditions if the Environment Agency operated the Severn Drought Order at Clywedog, and all other significant Drought Permits impacting on the River Severn were in force. The model already accounts for all the normal abstraction and discharge activity permitted within the Severn regulation catchment.

The modelled 1976 drought and Severn Drought Order operation appear reliable and results could be used with reasonable confidence. Flow impacts for the 1976 portion of the event were concluded to be the same as the Acute scenario, but without the immediate flow gain being achieved.

Modelling the Severn Drought Order operation in 1977 highlighted the same anomaly, although the drought order only activated twice; 6 March – 13 June and 2 August – 9 November. On the March occasion Clywedog storage was at 86%, and in August 58%, Bewdley flows illustrate the drought conditions were being operated, although high rainfall masks some operation. The August activation is still slightly premature, but appears more accurate.

Due to the similarities between the Severn Drought Order model results and the Full In-combination shown with the Acute scenario, and the suspect Chronic results, it was assumed a very similar flow response to the Severn Drought Order model. By delaying the Severn Drought Order activation to correspond with Clywedog storage more, a very similar flow response to that produced by the Acute scenario is expected. The duration of reduced flows leading into the critical period would be shortened, with the consequence of causing regulation failure slightly earlier than modelled, but still later than Do Nothing.

The main area of uncertainty was again around the Lower Parting assessment and abstraction for the Gloucester and Sharpness canal. Owing to the variability of abstraction quantity and splitting of the channel, there is the potential for significant detrimental impacts as modelled flows have already reached a critical minimum by this location. The Canals and Rivers trust have identified options to close the canal at critical flows, and would be encouraged to do so, however the Environment Agency has no legal powers to enforce such action. Therefore the precautionary worst case principle was applied and likely significant effects concluded for the lower River Severn (mainly from the channel bifurcation to Lower Parting).

Due to the modelling issues significant flow impacts were difficult to conclude with certainty at other locations for 1977. No flow impact was concluded at Vyrnwy, as the compensation flow failure only occurred on 1 day. A precautionary approach was adopted to conclude a significant flow impact at Saxon’s Lode and Deerhurst, where the duration of Medium Risk EFI failure could be slightly increased by operating the Severn Drought Order, but the resulting flow benefits would be significant and clear.

ESTUARY INFLOW ASSESSMENT

Background and methodology

Deerhurst and Haw bridge represent the last downstream flow gauges on the River Severn. The sites (Haw Bridge and Deerhurst) represent the furthest downstream location from which flow data can be accurately measured and Severn regulation operation can be assessed with confidence. All downstream flow and Severn Estuary inflows are assessed using computer models, which provide the best available information based on known abstractions and discharges.

Haw Bridge records go back to 1971 and record the impacts of historic droughts summarised in Appendix B, however the site is impacted by tidal back water. Deerhurst was operational from 1995, constructed to cope with the tidal influences experienced in this section. Flow data from the gauging stations is plotted and assessed for upstream comparison, however the downstream modelled location 'Lower Parting' represents the Estuary inflows used to assess the overall impact on the Severn Estuary.

In order to assess the impact of the drought order on the Severn Estuary, flow targets were used to provide a guide on how significant the flow decreases could be to the environment. This only provides a guide on flow quantity, what this 'looks like' on the ground and how it impacts the ecology remains very difficult to assess and historic drought events need to be used to inform final conclusions.

Stage 3 RoC used the WFD transitional waterbody flow targets (2008 report by SNIFFER) as an aid to assess the current flow regime, assessing gauged and modelled (Low Flows 2000) natural flows to conclude no likely significant effect. The WFD Sensitivity Ranking (sensitivity to abstraction) for the Severn Estuary came out as low, reflecting the large tidal range and area involved.

WFD and CAMS both calculate recommended 'Environmental Flow Indicator' (EFI) targets based on the expected natural flow (removal of abstractions and discharges) and how sensitive a watercourse ecosystem is perceived to be to abstraction (based on ecological and biological evidence). The sensitivity of the ecosystem determines how far below the natural flow duration curve (FDC) the EFI will be set, providing an indication of a minimum flow requirement before environmental damage 'could' start to occur.

Using the same methodology as the Review of Consents (RoC), both the Good and Moderate ecological status EFI's were updated with current natural data (naturalised via decomposition at Deerhurst and modelled Low Flows Enterprise data at Lower Parting/Elmore) and plotted against the modelled drought scenario's. It is important to note that as with all the flow assessment work, the drought scenario FDC's are based on short time periods which skew the whole FDC towards lower flows, realistically only the values from the 90th percentile will be useful to this investigation.

In an attempt to provide more context around the modelled drought impacts, additional FDC's were plotted at Deerhurst to show what the WFD flow targets 'would be,' using the Do Nothing scenario's as the alternative natural/baseline flow (Aquator design makes it difficult to separate a truly naturalised flow sequence). However these were not included as the flow reductions permitted were unrealistic and potentially damaging to the environment.

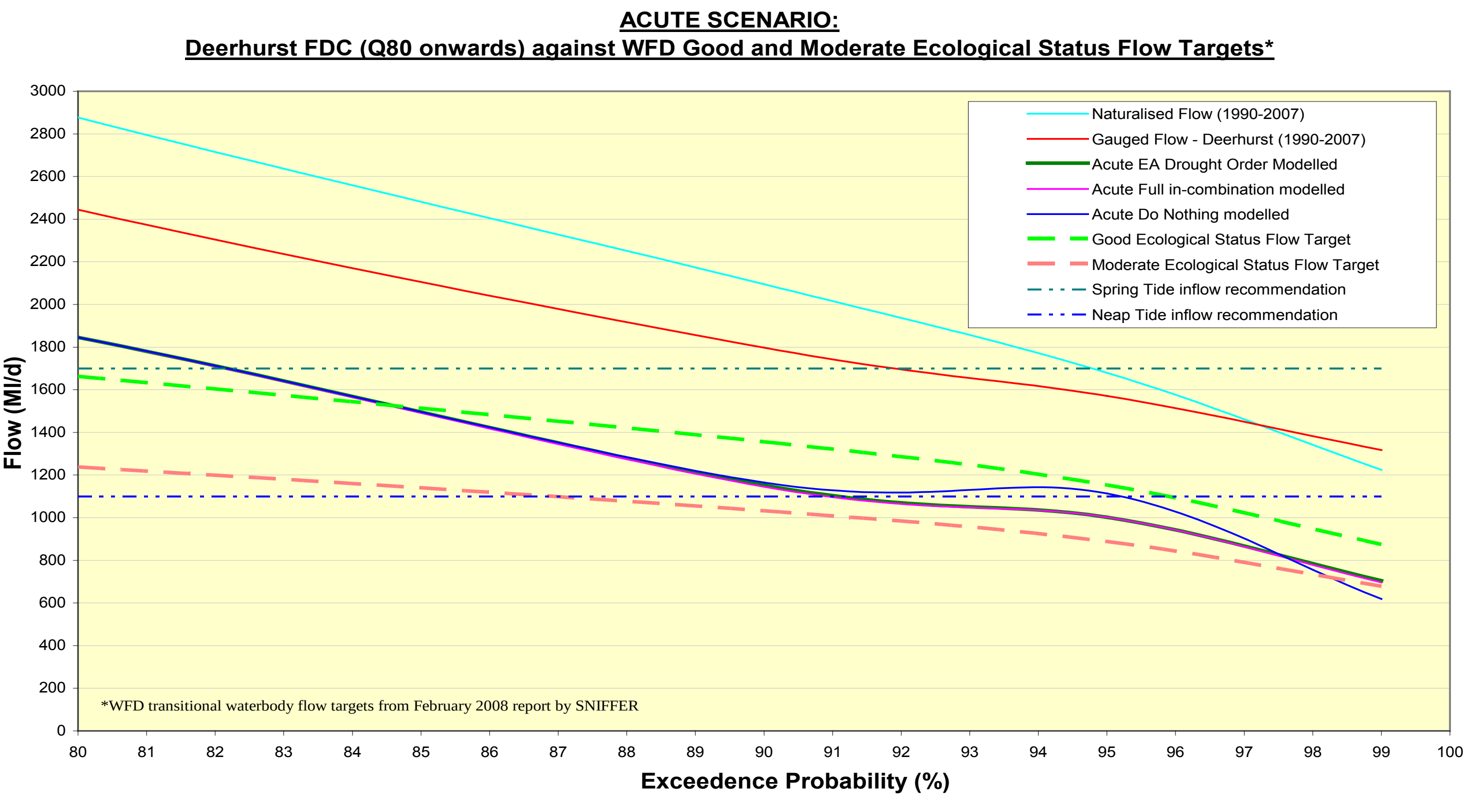
WFD flow targets provide a general guide to Estuary sensitivity to abstraction and freshwater inflows, however site specific targets should be utilised where available.

An investigation was undertaken (Hutcherson and Wade) into the residual flow requirements to the Upper Severn Estuary in 1992, concluding the tide height to be highly influential (due to saline water movement) on how much freshwater inflow would be required to restrict the amount of saline intrusion up the River Severn. A Neap tide flow target of 1200Ml/d and Spring tide flow target of 1800Ml/d were recommended to help support the Severn Estuary environment, and protect freshwater abstractions. These flow targets have also been included in the assessment for completeness.

Acute Scenario: Deerhurst

Figure 30 show how under the current flow regime (abstractions and discharges as they exist today), Severn Regulation operation supports flows above the Severn Estuary's Good Ecological Status (GES) FDC at all times/flows, and above what would naturally occur from the 97th percentile. This supports the RoC findings and confirms that Severn Regulation is supporting WFD achievement and raising the lowest and most drought related flows above what would naturally occur at the Deerhurst location.

Figure 30: Assessment Point 6 Deerhurst



Testing against the residual flow targets, the graphs demonstrate that even under natural conditions the Spring Tide inflow target would be failed by up to 576 Ml for 5% (Q95) of the time (approximately 37 days over the 2 year period). The current flow regime slightly increases this period to 8% (Q92) of the time (average 58 days), but reduces the magnitude of failure to 483 Ml, an improvement of 93 Ml. Both natural and current flows consistently support the Neap Tide inflow target at Deerhurst.

Acute Scenario: Haw Bridge/Deerhurst

Do Nothing

This investigation is primarily concerned with flows during the severe drought scenario's modelled. The 1990-2007 flow records from Haw Bridge and Deerhurst gauging station were used for comparison, in line with CAMS and RoC, but its important to note the most significant drought represented was 1995/96 (owing to the time period used), when the Severn drought order was not used. This will make the modelled drought scenario's appear disproportionately more severe than ever recorded before, however the Deerhurst gauge represents the best available data for this investigation.

At Deerhurst, using the gauged record (1990-2007) for comparison, a drought of acute magnitude could be reducing the expected Q95 low flows by up to 670Ml, a 43% reduction. The minimum flows modelled following regulation failure suggest flows could drop as much as 980Ml lower, a 74% reduction. These flow reductions should only be used as a worse case indication of the magnitude of flow reduction possible during a severe drought.

Using the existing WFD EFI's as a guide, the Acute scenario drought event could cause deterioration from GES for approximately 15% of the 3 year period being considered, equating to about 164 days in total. There is some marginal deterioration below MES for approximately 2% of the period, approximately 22 days over 3 years.

The range of flow deterioration varies, taking account of only the 90th percentile and higher; deterioration from GES is between 155-200Ml. In context of the sensitivity of the Severn Estuary, the magnitude of deterioration and the length of time it occurs for should not be significant. Short term impacts will vary according to the time of year deterioration occurs, which cannot be accurately predicted although is more likely between September and November.

WFD allows for movement within a band, and the 2% (22 days) change into MES would be very short term and in context of modelling errors, would not be considered conclusive. WFD directive article 4.6 also allows for temporary deterioration caused by exceptional natural events, such as prolonged droughts. The Do Nothing scenario represents the closest to baseline and unavoidable drought events as we can currently model, and therefore results are considered to fall under article 4.6.

Assessing flows against the Spring and Neap Tide targets shows some failures, as expected during a natural drought event. The Spring Tide inflow target could be at risk of failure for an additional 10% or 110 days over the 3 year period (from Q82), a total 168 days. Risk of failing the Neap Tide inflow target, possibly more significant, could occur for 5% (Q95) of the time, approximately 55 days. It is important to note the risk is increased, but would only impact the environment if the low flows occurred in conjunction with the relevant tidal conditions. These failure risks would mainly translate into allowing further upstream movement of saline water during natural tidal fluctuations, and alter the amount of inundation along the River Severn channel.

Impacts are likely to vary according to channel variations and be short term in nature. The main impacts (saline intrusion and reduced wetted perimeter) are likely to be experienced along the Lower Tidal Severn channel, outside of the Natura 2000 designated site. The impacts under the Do Nothing scenario demonstrate the majority of these impacts would be of natural cause.

River Severn Drought Order

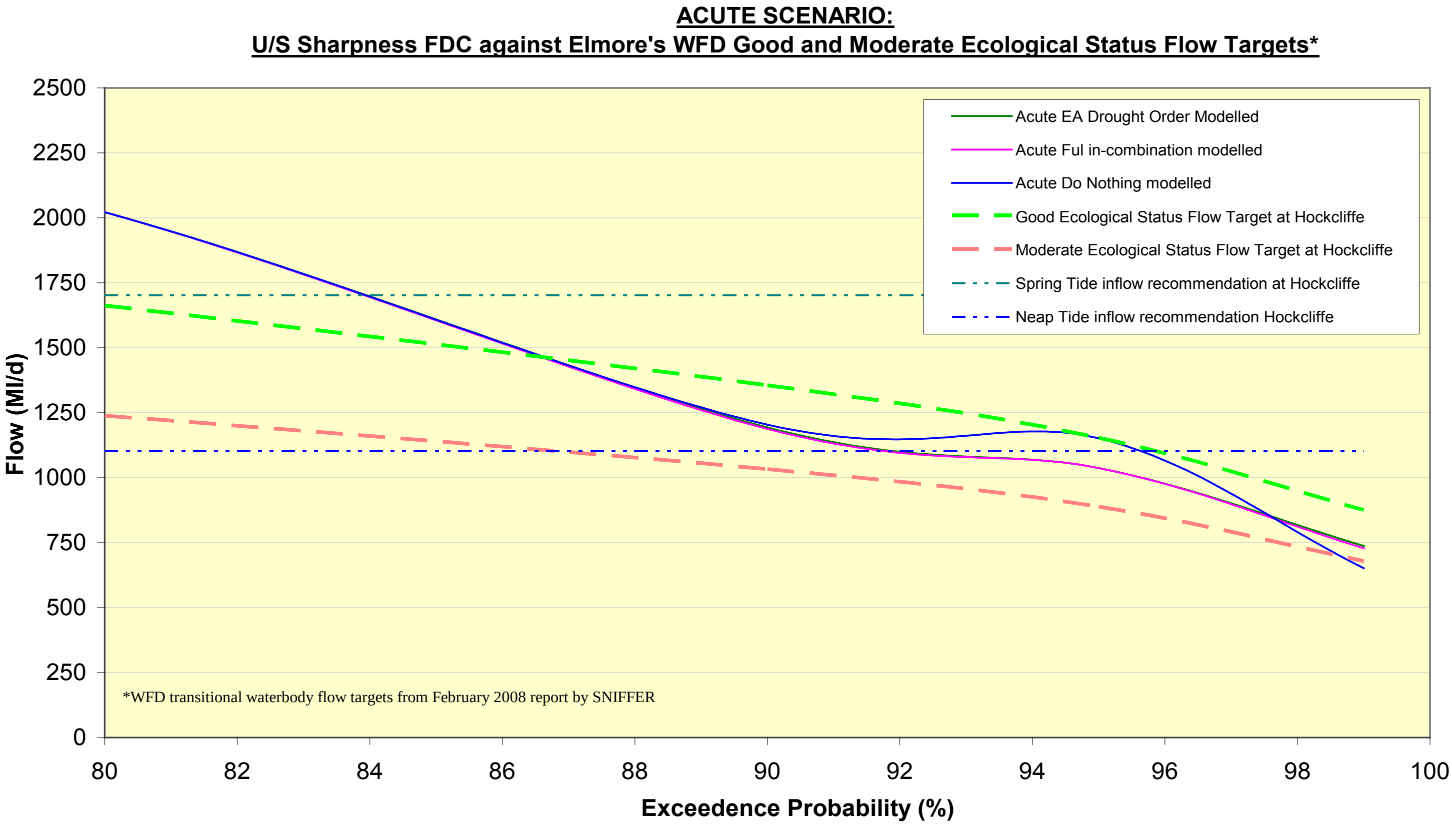
The Severn Drought Order causes no additional GES deterioration or failures of the Spring Tide inflow target. The overall magnitude of deterioration does alter slightly, reflecting the lowered prescribed flow at Bewdley for a greater length of time whilst protecting a higher minimum flow. Operating the Severn Drought Order prevents any potential deterioration below MES, an improvement on the Do Nothing scenario.

Operating the Severn drought order and lowering the prescribed flows does increase the risk of failing the Neap Tide inflow target by an additional 4% (Q91) compared to the Do Nothing scenario. This could increase risk up to 9% over the 3 year period, a total 99 days (a 44 day increase), actual impacts would vary according to when Neap tides occurred in relation to the low flows.

Full In-combination

The full in-combination FDC is very similar to the Severn drought order, reflecting how the majority of ‘other’ influences have already been incorporated. No additional WFD deterioration is caused, only a slight increase in magnitude, and no additional Neap Tide inflow target failure is created.

Figure 31: Assessment Point 7 U/S Sharpness and Assessment Point 8 Lower Parting



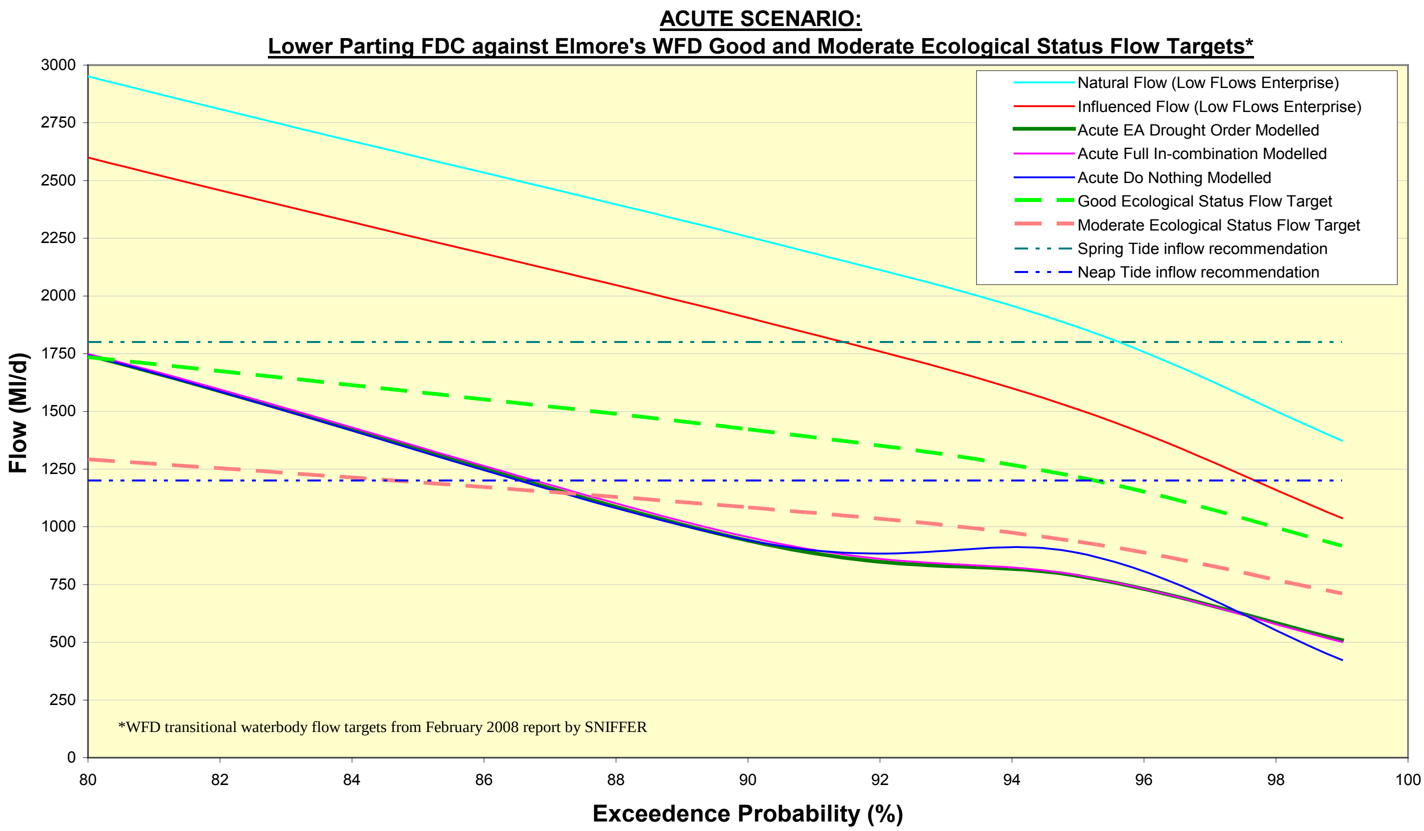


Figure 31 provides close ups from the 80th percentile

U/S Sharpness is located upstream of the Gloucester and Sharpness canal and therefore reflects the more natural flow accretion as the catchment area increases. Lower Parting is located downstream of the large abstraction for the Gloucester and Sharpness canal, the large decrease in flows demonstrates the magnitude of impact this abstraction has. It is important to note a maximum 300 Ml/d abstraction has been modelled based on recent actual information, however the Canals and Rivers Trust (was British Waterways) have confirmed a maximum 691 Ml/d could be abstracted if needed. This higher figure will be considered under the in-combination scenario's assessment.

Low Flows Enterprise has been used to model a natural and influenced (with abstractions and discharges) FDC at Lower Parting (no gauging stations present) for comparison, the error margin will be higher than at Deerhurst due to the lack of real data for calibration, but does represent the best available data at this time.

Lower Parting (Figure 31) flows suggest under current conditions, Severn Regulation operation still supports flows above the Severn Estuary's Good Ecological Status (GES) FDC at all times/flows. Unlike Deerhurst, low flows are not restored to being higher than would naturally occur. This represents the influence of large abstractions for the Gloucester and Sharpness canal, and subsequently to Bristol Water (from the canal) at Purton.

As with Deerhurst, the graphs suggest that even under natural conditions the Spring Tide inflow target would be failed at certain times of the year. Lower Parting flows, and therefore freshwater inflows to the Estuary, fall below the Spring Tide inflow target by up to 427 Ml for 4% (Q96) of the time (approximately 15 days a year). As shown at Deerhurst, the modelled influenced flow regime increases this period to 8% (Q92) of the time (approximately 29 days a year), however, unlike Deerhurst the magnitude of failure is increased to 762 Ml. Modelled natural flows appear to support the Neap Tide inflow target at all times, however the modelled influenced data suggests a risk of 2% (average 7 days per year) failure by up to 162 Ml, which is a deterioration from flow conditions at Deerhurst.

Acute Scenario: Estuary inflows

Do Nothing

Comparing the U/S Sharpness FDC against the Lower Parting highlights the impact the Gloucester and Sharpness canal abstraction can have during low flows, and the risk it could pose during a severe drought. As this assessment is focusing on the Severn Estuary impacts, the Lower Parting FDC will be used to represent the potential worse case.

Using the WFD EFI's as a guide, the Acute 'do nothing' scenario drought event could cause deterioration from GES for approximately 20% of the 3 year period being considered, equating to about 219 days in total. Deterioration below MES could also occur for approximately 13% of the period, approximately 142 days over 3 years. It is difficult to conclude how much of the failure is genuinely additional to Deerhurst, and how much the short time period used skews the results, however it is evident that flows would be significantly lower at this location as a result of the additional large abstraction to the Gloucester and Sharpness canal.

The range of flow deterioration varies, taking account of only the 90th percentile and higher; deterioration from GES is between 480-621Ml and deterioration from MES is between 142-387Ml. Assessing flows against the Spring and Neap Tide targets shows additional failures expected during a natural drought event. The Spring Tide inflow target could be at risk of failure for an additional (compared to normal flow regime) 13% or 142 days over the 3 year period (from Q79), a total 200 days. Risk of failing the Neap Tide inflow target could occur for an additional 11% (Q87) or 120 days over the 3 year period (from Q87), a total 135 days.

Severn Drought Order
The Severn Drought Order causes no additional GES or MES deteriorations, or additional Spring or Neap Tide inflow target failures. Results indicate the Severn Drought Order would not create a significant extra burden on the Severn Estuary environment, beyond the stress already resulting from the natural drought event. Should regulation failure occur, benefits would be achieved for the Severn Estuary by increasing the minimum flows experienced.

Full In-combination
The full in-combination FDC is very similar to the Severn drought order, no additional WFD deterioration is caused, or additional Tidal inflow targets failed. However the graphs only represent the recent actual abstractions from the Gloucester and Sharpness canal as a maximum 300 Ml/d. The Canals and Rivers Trust have confirmed the pumps could take a maximum 691 Ml/d, and reports from the 1976 and 1989 drought events highlight large canal abstractions over brief periods reducing the Estuary inflows to almost zero. If this situation were repeated for a longer period, then likely significant effects cannot be ruled out.

SEVERN ESTUARY CONCLUSIONS: ACUTE SCENARIO

The Severn Estuary, being the furthest downstream section of the River Severn, will be impacted by the greatest number of accumulated abstractions and discharges of all the assessment points considered. The River Severn has flowed 345km in length to reach the Estuary. The size of the catchment, significance in terms of water resource supply, and variation of habitat environment make it difficult to assess with great accuracy.

The droughts of 1976 and 1989 have shown that inflows to the Severn Estuary can be seriously depleted for short periods, as a result of reduced rainfall and a combination of abstractions from the River Severn. The worst impacts were observed from the natural channel split in Gloucester down to the Severn Estuary. The channel split divides flows, with the Canal and Rivers Trust abstracting from the East channel at varying quantities. Significant flow reductions at this location have depleted water levels to the extent where little to no flows were passing over the downstream weirs.

Slower flows during low flow periods increase the amount of sediment deposition and evidence shows the lower section of the River Severn is the most vulnerable to short term siltation problems.

Previous drought reports found evidence to indicate the Severn Estuary Natura 2000 site is not highly sensitive to changes in the freshwater inflows, with impacts being largely restricted to the lower tidal River Severn, outside the designated site.

To assess the Severn Estuary freshwater inflows Haw Bridge/Deerhurst flows were considered initially, then modelled data from U/S Sharpness and Lower Parting. Haw bridge and Deerhurst are the furthest downstream flow gauges with continuous flow records, enabling calibration of models and accurate assessment of the regulation system. Deerhurst was constructed to cope with the tidal influences of the Severn Estuary, and currently provides the best available flow data. However it is over 45 km (in channel) upstream of the Severn Estuary Natura 2000 site and excludes the significant abstraction for the Gloucester and Sharpness canal (and subsequent Bristol Water abstraction from the canal at Purton). U/S Sharpness was modelled to provide an indication of possible flows just upstream of the abstraction point and channel split, while Lower Parting was modelled as the main assessment point for the impacts on the Severn Estuary, incorporating the canal abstraction and representing the most likely inflows to the Natura 2000 site.

Comparing the U/S Sharpness flow duration curve (FDC) against the Lower Parting FDC clearly demonstrates the impact the Gloucester and Sharpness canal abstraction can have as part of the accumulative in-combination effects. As highlighted in the main River Severn conclusions, the greatest modelling uncertainty remains around the Gloucester and Sharpness canals varying abstraction and it's in-combination impacts on the lower River Severn during a severe drought.

An average monthly abstraction profile was calculated from recent actual data provided by the Canal and Rivers Trust, however there is the potential for greater or lesser abstraction than was modelled. While the abstraction remains exempt from licensing regulation, a pragmatic approach has been adopted. The recent actual data has been used to represent the abstraction within modelling, however for the in-combination assessment the 691 Ml/d worse case figure (provided by the Canals and Rivers Trust) has been considered. This approach is a balance between what is likely to occur under current legislation (e.g. Habitat's Directive), and what is theoretically possible (e.g. 1976 and 1989 drought reports highlight large canal abstractions being taken for brief periods, reducing flows into the Severn Estuary to nearly zero).

Do Nothing

The Do Nothing scenario represents the possible flows if no drought orders or permits were applied to help manage the developing drought, but all normal abstractions and discharges continue (includes Gloucester and Sharpness canal 300 Ml/d abstraction), as would be expected in reality. Modelling has shown that initial flow conditions would be better under the 'do nothing' scenario, however if the drought continued and resources ran out, flow crashes and subsequent minimum flows would be severe and resilience for the following year greatly reduced by not operating the River Severn Drought Order.

Comparing the modelled drought flows at Deerhurst to the gauged record (1990-2007) illustrates some of the potential flow reductions that could be considered unavoidable during a severe drought event. Deerhurst Q95 flows could fall by up to 670Ml, a 43% reduction. If a drought were to continue long enough for regulation resources to be exhausted, then comparisons indicate minimum flows could drop as much as 980Ml, a 74% reduction. The potential magnitude of flow reduction in the lower reaches of the River Severn is significant, through the natural lack of baseflow and runoff, and exasperated by the in-combination impacts of upstream abstractions.

Do Nothing Results indicate the natural drought event could cause temporary failure of the WFD Good Ecological Status (GES) and Moderate Ecological Status (MES) flow targets. Inflows to the Severn Estuary (as modelled at Lower Parting) could experience short term (20% of 3 year period, equating to 219 days) deterioration from GES, ranging from 480-621Ml from the 90th percentile. Of this period, 142 days (13% over 3 year period) of 142-387Ml MES deterioration could also be experienced. The magnitude of the failures is significant, but the WFD flow deterioration would be temporary and as a direct result of an exceptional natural drought event (covered by WFD Directive article 4.6), as proven by the consistent GES maintained during normal flows and the same abstractions.

Do Nothing Results indicate the natural drought event could increase the number of days Estuary inflows failed to meet the recommended Spring and Neap tide flow targets. At Deerhurst, the Spring Tide inflow target could be at risk of failure for an additional 10% or 110 days over the 3 year period (from Q82), and 5% (Q95) or 55 days for the Neap Tide inflow target, when compared to the normal flow regime. Once the Gloucester and Sharpness canal abstraction is accounted for at lower Parting, the risk of failures increases. The Spring Tide inflow target could be at risk of failure for an additional (compared to normal flow regime) 13% or 142 days over the 3 year period (from Q79), a total 200 days. Risk of failing the Neap Tide inflow target could occur for an additional 11% (Q87) or 121 days over the 3 year period (from Q87), a total 136 days.

It is important to note the 'risk' from tidal inflow target failures is increased, but potential impacts would only result if the low flows arrived in conjunction with the relevant tidal conditions. These failure risks would mainly translate into allowing further upstream movement of saline water during natural tidal fluctuations, and alter the amount of inundation along the River Severn channel. Evidence from previous droughts and the sensitivity of the Severn Estuary would indicate that lower freshwater inflows would not have a significant effect on the Natura 2000 site itself, especially considering the short term and temporary nature of the lowest flows.

In terms of river levels, although it is not possible to accurately predict the decrease in levels at this time, using the 1976 drought event as a benchmark, it is likely that flows around the natural channel split could be particularly low and hardly passing over the weirs. Low and slow flows would also increase silt deposition and cause the channel to become clogged until high rainfall and flows returned. This would mainly impact the lower Tidal River Severn and have obvious impacts to fish migration and navigation in the short term.

The ‘do nothing’ scenario provides the benchmark comparison for assessing whether the River Severn Drought Order would have any additional positive or negative impacts on the Severn Estuary Natura site. Modelling shows some temporary deterioration below the transitional waterbody WFD flow targets, and some increased Spring and Neap tide flow targets are to be expected.

<u>Severn Drought Order</u>
The Severn Drought Order causes no additional GES or MES deteriorations compared to the ‘do nothing’ scenario. The overall magnitude of deterioration does alter slightly, reflecting the lowered prescribed flow at Bewdley for a greater length of time whilst protecting higher minimum flows.

Operating the Severn drought order creates no additional Spring Tide inflow target failures compared to the ‘do nothing’ scenario. At Deerhurst, the risk of failing the Neap Tide inflow target is increased by 4% (Q91) compared to the Do Nothing scenario, however no additional increase is observed at Lower Parting due to the lower flows already being experienced under the ‘do nothing’ scenario.

If regulation failure were to occur (sources became too low to support any prescribed flow at Bewdley), the results show the River Severn Drought Order would maintain higher minimum flows during the critical drought period than possible under the ‘do nothing’ scenario. This benefit supports the drought orders design purpose, and would support both abstractors and the environment.

The Severn Estuary has a low sensitivity to freshwater inflows, and results show no additional harm (based on existing flow targets) would be caused beyond the naturally occurring drought effects. Benefits could also be achieved by operating the drought order, if the event out lasted the remaining water resources. **No likely significant effect is concluded.**

<u>Full In-combination</u>
The full in-combination FDC is very similar to the Severn drought order, based on the Gloucester and Sharpness canal still abstracting a maximum of 300 Ml/d. Compared to the ‘do nothing’ scenario, these results show no additional WFD deterioration, or additional Tidal inflow target failures. The magnitude of flow reductions does increase compared to the River Severn Drought Order in isolation, so the magnitude of short term impact would be greater although the length of time this might be experienced for remains the same.

As discussed, the difference in flows between the U/S Sharpness and Lower Parting locations, as well as Deerhurst, clearly indicate the biggest impact at these locations is the Gloucester and Sharpness canal abstraction. The in-combination affects from this abstraction (at a maximum 300 Ml/d) pushes the FDC into MES WFD deterioration under all scenario’s.

The canals and Rivers Trust are currently exempt from licensing and have the capacity to abstract up to 691 Ml/d (a maximum of 300 Ml/d was modelled). The

1976 and 1989 drought reports identified large abstractions for short periods, which had significant impacts (e.g. water levels and siltation) along the lower Tidal River Severn, leaving almost zero freshwater inflow to the Severn Estuary. Fish kills within the Severn Estuary did not correlate with the abstractions, and the impacts were short term and temporary.

Under current legislation the canal abstraction remains exempt from licensing, although the Bristol Water abstraction at Purton, which relies on the canal, is licensed. The operating agreement for the canal abstraction contains flow controls that protect the river environment during normal conditions, but does contain a disclaimer for extreme droughts. The Canals and Rivers Trust identify a trigger flow at Deerhurst for closing the canal to navigation, which the Environment Agency would strongly encourage, but at present this remains a voluntary act. In the absence of any regulatory powers, the maximum abstraction remains a potential risk and could reduce the modelled Estuary inflows to almost zero. **For this reason, the in-combination investigation cannot confidently conclude no likely significant effect on the Natura 2000 site and designated species.**

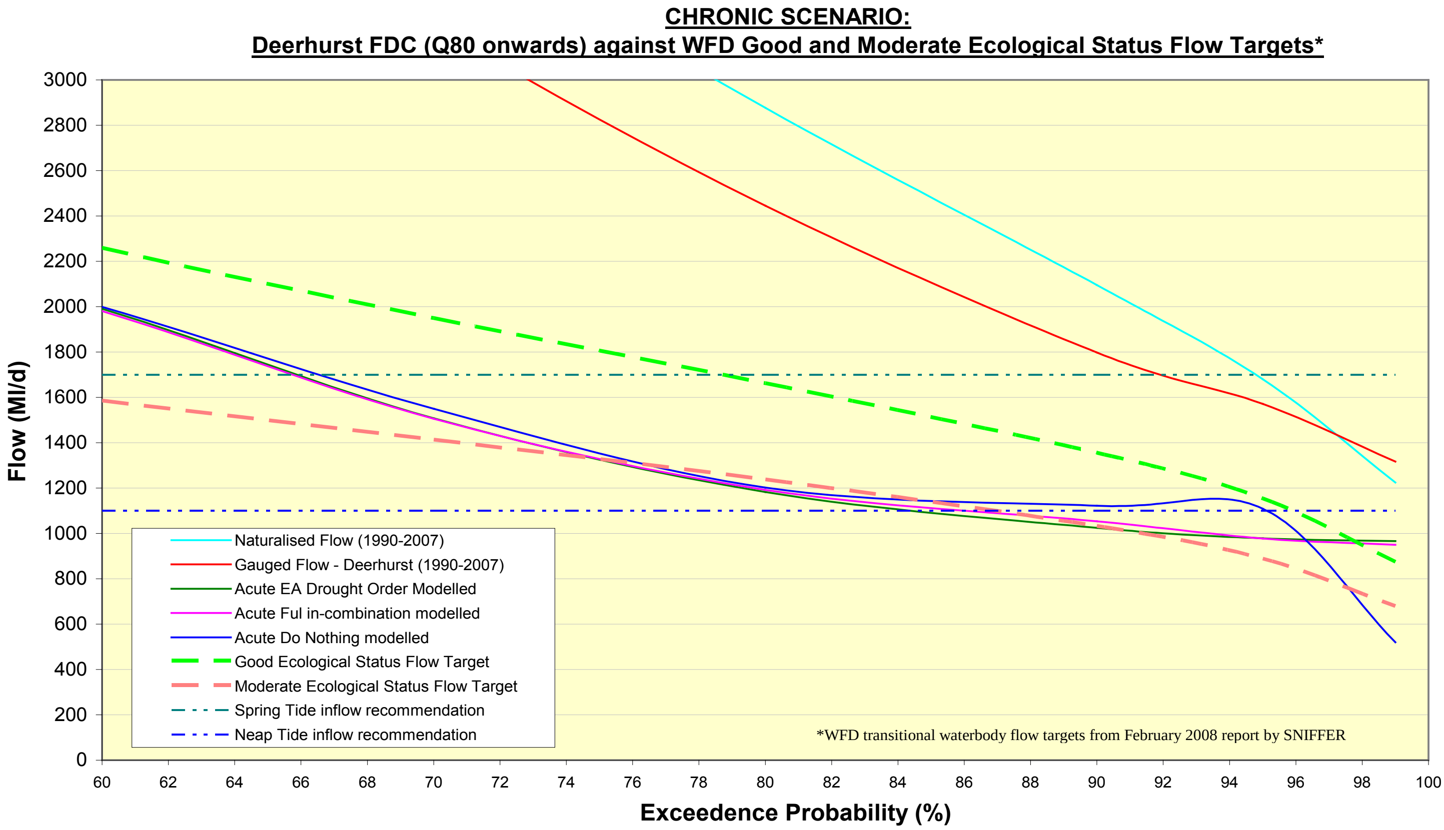
Chronic Scenario

The modelled Chronic drought scenario's represent what could happen if an acute drought year were followed by a further dry winter and second severe drought summer. Where appropriate (e.g. excluding the 'do nothing' scenario's) the River Severn Drought Order is operated during both summers. The duration of the initial acute drought summer has been reduced to exclude obvious flow benefits from the first year to test the long term value and regulation implications of the River Severn Drought Order.

Assessment Point 6 Deerhurst

Modelling errors were identified with the Chronic scenario, differing between the Severn Drought order and Full In-combination modelling, where the drought order activates on and off falsely before the operation curves indicate a need. Due to this greater uncertainty the Chronic results will be assessed more generally for guidance and flow behaviour trends, rather than specific details and duration of impact, as the uncertainty is too high to use with confidence.

Figure 32: Assessment Point 6 Deerhurst



Do Nothing

At Deerhurst a drought of this magnitude, compared with the gauged record (Haw Bridge/Deerhurst1990-2007), could be reducing the expected Q95 low flows by up to 463 Ml (30% reduction) and the minimum flows by 797 Ml (61% reduction). The greater magnitude compared to the Acute modelling reflects the greater length of time for which the Chronic drought (scenario) is predicted to last.

As with the Acute scenario, it's important to note the gauged record used for comparison only includes the 1995/96 drought event, and all modelled flow reductions should only be used as a guide.

The existing WFD EFI's suggest the Chronic 'do nothing' scenario drought event could cause deterioration from GES for approximately 60% of the 3 year period being considered, reflecting the long term lack of runoff being simulated and two consecutive drought events exasperating the natural underlying event. There is some marginal deterioration below MES between Q76-84, but the more reliable deterioration would be for a minimal 3% (Q97) of the 3 year period, when flows crash as the regulation sources are exhausted.

Assessing flows against the Spring and Neap Tide target shows more potential failures than under the Acute scenario, representative of a more prolonged/reoccurring drought. Comparing the flows against the gauged (Haw bridge/Deerhurst1990-2007) record suggests the Spring Tide inflow target could be at risk of failure for an additional 25% over the 3 year period (33% in total, from Q67). Risk of failing the Neap Tide inflow target could increase to 5% (Q95) of the 3 year period. It is important to note the risk is increased, but would only impact the environment if the low flows occurred in conjunction with the relevant tidal conditions. The impacts on the ground would be very similar to those discussed for the Acute scenario, largely impacting the lower tidal River Severn.

Severn Drought Order

Due to the false activations of the Severn Drought Order during modelling the slight drift away from Do Nothing prior to around Q80 should be discounted. The FDC general trend after Q80 is likely to be similar to what could be expected, reflecting the lead in time when the Severn drought order is lowering prescribed flows by approximately 140 Ml/d. This is followed by clear flow benefits when the water saved from the previous years Severn Drought Order usage can be returned to the system to prevent/greatly reduce the flow crash observed if the drought order were not activated in the first year.

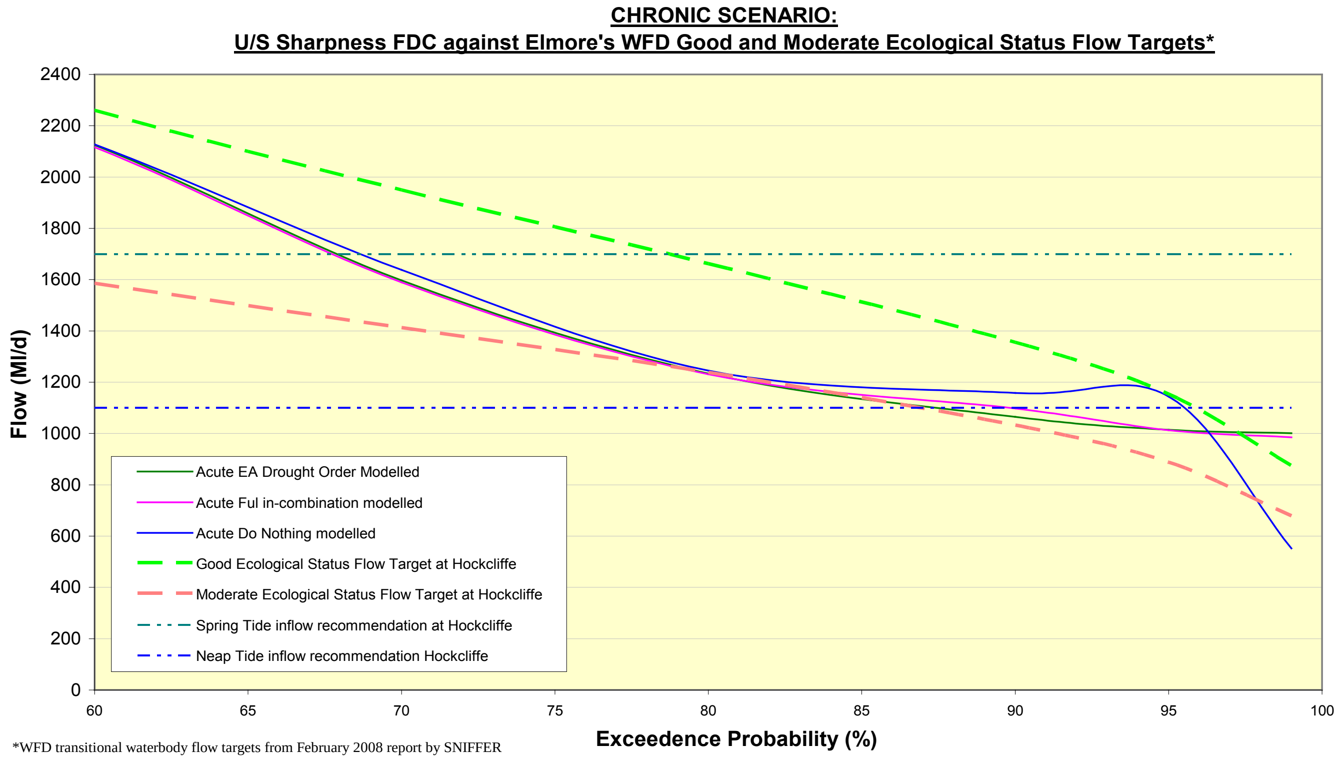
No additional WFD deterioration is caused, some minor increases in duration are evident but not significant in context of modelling uncertainty. Most significantly, the FDC suggests that during the most critical low flow periods (second summer) of the Chronic scenario, the Severn Drought Order would be protecting and returning flows above GES, and therefore complying with WFD at the height of drought. This cannot be concluded with great confidence, but the flow trend suggests the benefits to downstream flow and the Estuary, measured at Deerhurst, could be very beneficial to the Severn Estuary as apposed to taking no action and allowing the drought to run its course.

Operating the Severn drought order and lowering the prescribed flows does increase the risk of failing the Neap Tide inflow target by an additional 10% (Q85) compared to the Do Nothing scenario. This could increase risk up to 15% over the 3 year period, but again the actual impacts would vary according to whether the Neap tides occurred at the same time as the low flow events.

Full In-combination

The full in-combination FDC is very similar to the Severn drought order. No additional WFD deterioration is caused (slight alterations in magnitude) while very similar benefits are observed. Risk of Neap Tide inflow failure is increased by a further 1%.

Figure 33: Assessment Point 7 U/S Sharpness and Assessment Point 8 Lower Parting



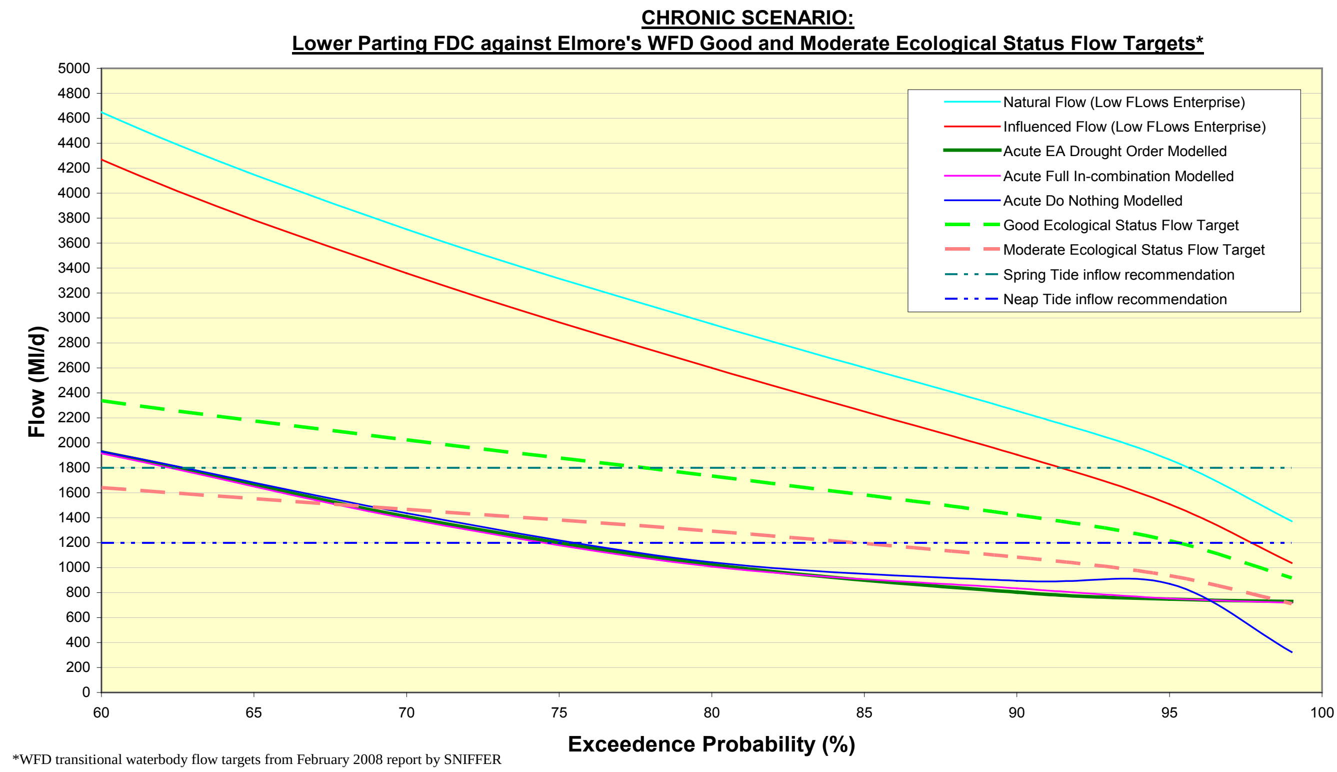


Figure 33 provide close ups from the 80th percentile.

As previously discussed (current environment section and Acute Scenario), U/S Sharpness is located upstream of the Gloucester and Sharpness canal abstraction and Lower Parting is located downstream, therefore representing more realistic Severn Estuary inflows. Natural and influenced data plotted is modelled from Low Flows Enterprise, as no continuous flow gauges exist this far into the tidal influences of the Severn Estuary.

Do Nothing

Once again, comparing the U/S Sharpness FDC against the Lower Parting clearly demonstrates the impact the Gloucester and Sharpness canal abstraction can have during low flows/drought conditions.

The WFD EFI's suggest the Chronic scenario drought event could cause deterioration from GES for approximately 62% of the 3 year period being considered, with 31% accounting for deterioration below MES. Compared to Deerhurst, the MES deterioration at Lower Parting is more conclusive, although due to modelling errors the duration is likely to be an over estimate.

Using the Low Flows Enterprise influenced data as a comparison, the Spring Tide inflow target could be at risk of failure for an additional 29% over the 3 year period (37% in total, from Q67). Risk of failing the Neap Tide inflow target could increase to 25% (Q95) over the 3 year period.

Severn Drought Order

Due to the modelling errors the slight drift away from Do Nothing prior to around Q80 should be discounted.

Compared to the benchmark 'do nothing' scenario, no additional WFD deterioration is caused but some minor increases in duration are evident, but not significant in context of modelling uncertainty. Flows at Deerhurst suggested the lowest flows could achieve GES for the Severn Estuary by operating the Severn Drought Order. However Lower Parting illustrates how the large abstraction for the Gloucester and Sharpness canal could significantly reduce the benefit of operating the Severn Drought Order to the Severn Estuary, as flows hardly achieve MES at this location.

Operating the Severn drought order creates no additional risk of Spring or Neap tide inflow targets.

Compared to the 'do nothing' scenario, there are still obvious flow benefits experienced during the most critical periods of the drought. The regulation failure identified in the 'do nothing' scenario is almost avoided, and without modelling errors is likely to have been prevented by operating the River Severn Drought Order.

Full In-combination

Assuming a maximum canal abstraction of 300 Ml/d, the full in-combination FDC is very similar to the Severn drought order. No additional WFD deterioration, Spring or Neap tidal inflow target failure is caused (slight alterations in magnitude). The flow benefits show the same trend as the Severn Drought Order scenario, with a slightly lower magnitude of benefit owing to the higher water company abstractions.

As discussed under the acute scenario, the potential for the Canals and Rivers Trust to abstract a maximum of 691 Ml/d needs to be taken into account under the in-combination assessment. If this quantity were to be abstracted during a severe drought, then inflows to the Severn Estuary would be reduced significantly more.

SEVERN ESTUARY CONCLUSIONS: CHRONIC SCENARIO

The Chronic scenario represents a theoretical dry winter (1975) followed by a drought summer (1976) where the Severn Drought Order triggers are crossed. In scenarios where the drought order is operated, no flow benefit is gained in the first year due to the arrival of autumn recharge. Winter rainfall remains below average, resulting in a subsequent severe drought summer (1977) where the River Severn Drought Order is triggered again.

Modelling errors were identified with the Chronic scenario, differing between the Severn Drought Order and Full In-combination modelling, where the drought order activates falsely, well before the operation curves indicate a need. Due to this greater uncertainty the Chronic results were assessed more generally for guidance and flow behaviour trends, rather than specific details and duration of impact as the uncertainty is too high to use results with confidence.

The specific impacts likely on the ground for the Severn Estuary Natura 2000 site, and lower tidal Severn if a Chronic drought occurred, are likely to be very similar to those discussed for the Acute scenario. The same areas would be at high risk from the same issue's, such as saline intrusion, sediment deposition, lowered water levels reducing passage over weirs and reduced habitat at watercourse margins. However the environment would have been stressed to differing degree's over two subsequent summer drought events, and several dry winters. The accumulated stress on the environment and limited water resources is therefore likely to be greater, although the activation of the Severn Drought Order in the first year has been shown to safe guard water for a subsequent drought year sufficiently enough to make significant flow benefits compared to the 'Do Nothing' option.

As previously highlighted, the greatest modelling uncertainty remains around the Gloucester and Sharpness canal abstraction and it's in-combination impacts on the lower tidal River Severn during a severe drought. There is the potential for greater or lesser abstraction than modelled, and close liaison would be required during a real event to manage all the conflicting interests to balance the water user and environment needs appropriately.

Do Nothing

The Do Nothing scenario represents the possible flows if no River Severn Drought Order or water company drought permits were operated to manage the developing drought. All normal abstractions and discharges continue (Gloucester and Sharpness canal 300 Ml/d abstraction included), and the Severn Regulation system is operated to continue maintaining 850 Ml/d at Bewdley. As with the Acute scenario, initial flow conditions appear better under the 'do nothing' scenario, however if the drought continued and resources ran out, flow crashes and subsequent minimum flows would be severe.

The main difference with the Chronic two summer drought scenario, is the resilience for the second/following years drought is greatly reduced by not operating the River Severn Drought Order. Resources are allowed to expire during the first drought, significantly reducing the refill capacity of Clywedog and therefore entering the subsequent drought with insufficient resources to cope.

Comparing the modelled drought flows at Deerhurst to the gauged record (1990-2007) suggests Q95 flows could fall by up to 463Ml, a 30% reduction. If the drought continued long enough to exhaust regulation resources, comparisons indicate minimum flows could fall by up to 797Ml, a 61% reduction. When compared against the Acute scenario, the reductions are smaller, which reflects the longer term nature of the Chronic scenario and how the duration spreads the impacts over the FDC. Even so, the potential magnitude of flow reduction in the lower reaches of the River Severn is significant and likely to have temporary adverse impacts.

Do Nothing Results indicate the natural drought event could cause temporary failure of Good Ecological Status (GES) and Moderate Ecological Status (MES) flow (WFD transitional waterbody) targets. Deerhurst could experience deterioration from good ecological status (GES) for up to 60% (Q40) of the 3 year period, some marginal deterioration below MES between Q76-84 but the more reliable deterioration would be for a minimal 3% (Q97) of the 3 year period. However in terms of inflows to the Estuary, Lower Parting needs to be used, reflecting the Gloucester Sharpness canal abstraction. Inflows to the Severn Estuary could deteriorate below GES for 62% of the 3 year period being considered, with 31% of time accounting for deterioration below MES. It is important to note that higher or lower abstraction is possible for the canal.

Assessing flows against the recommended Spring and Neap Tide flow target shows more potential failures than modelled under the Acute scenario, to be expected over the more prolonged period of a chronic drought. Comparing Deerhurst flows against the gauged (1990-2007) record suggests the Spring Tide inflow target could be at risk of failure for an additional 25% over the 3 year period (33% in total, from Q67). Using Low Flows Enterprise influenced data as a comparison for Lower Parting and the Estuary inflows, the Spring Tide inflow target could be at risk of failure for an additional 29% over the 3 year period (37% in total, from Q67). At Deerhurst, risk of failing the Neap Tide inflow target could increase to 5% (Q95) over the 3 year period, and 25% (Q95) at Lower Parting and into the Severn Estuary.

It is important to note the ‘risk’ of failure is increased, but would only translate into impacts to the environment if the low flows occurred in conjunction with the relevant tidal conditions. The impacts on the ground would be very similar to those discussed for the Acute scenario, largely impacting the lower tidal River Severn. Evidence from previous droughts and the sensitivity of the Severn Estuary would indicate that lower freshwater inflows would not have a significant effect on the Natura 2000 site itself.

Severn Drought Order

Due to the false activations of the Severn Drought Order during modelling the slight drift away from Do Nothing prior to around Q80 should be discounted. The FDC general trend after Q80 is likely to be similar to what could be expected, reflecting the lead in time when the Severn drought order is lowering prescribed flows by approximately 140 Ml/d, followed by clear flow benefit when the water saved from the previous years Severn Drought Order usage can be returned to the system to prevent/greatly reduce the flow crash observed if the drought order is not activated.

No additional WFD deterioration is caused, some minor increases in duration are evident but not significant in context of modelling uncertainty. Flows at Deerhurst suggested the lowest flows could achieve GES for the Severn Estuary by operating the Severn Drought Order, however due to the large abstraction for the Gloucester and Sharpness canal, Lower Parting shows the scale of this benefit to the Severn Estuary has reduced to only just achieving MES. When compared to the option to Do Nothing, the benefit is still clear and with mitigation work with the canals and Rivers Trust this benefit could be increased to the Severn Estuary if abstraction could be significantly reduced at critical periods.

Operating the Severn drought order and lowering the prescribed flows does increase the risk of failing the recommended Neap Tide target at Deerhurst by an additional 10% (Q85) compared to the Do Nothing scenario. However by Lower Parting there is no additional failure compared to the Do Nothing scenario, suggesting the underlying drought and the in-combination abstractions have already caused the failures that would directly impact on the Severn Estuary.

Results show no additional harm (based on existing flow targets) beyond the naturally occurring drought effects would be caused by operating the River Severn Drought Order. Significant flow benefits would be achieved during the second years summer drought, when water saved during the initial years drought order operation could be used for regulation, delaying the need for a second drought order operation and potentially preventing regulation failure from occurring. **No likely significant effect is concluded.**

Full In-combination
The full in-combination FDC is very similar to the Severn drought order, based on the Gloucester and Sharpness canal still abstracting a maximum of 300 Ml/d. No additional WFD deterioration is caused (slight alterations in magnitude) while very similar benefits are observed. Risk of Neap Tide inflow failure at Deerhurst is increased by a minor 1%, however no change is observed at Lower Parting, which represents the Estuary inflows.

As previously discussed, the Canals and Rivers Trust are currently exempt from licensing and have the capacity to abstract up to 691 Ml/d (a maximum of 300 Ml/d was modelled). The operating agreement for the canal abstraction contains flow controls that protect the river environment during normal conditions, but does contain a disclaimer for extreme droughts. In the absence of any regulatory powers, the maximum abstraction remains a potential risk and could reduce the modelled Estuary inflows to almost zero (based on 1976 and 1989 drought reports). **The in-combination investigation cannot confidently conclude no likely significant effect on the Natura 2000 site and designated species.**

OVERALL SEVERN ESTUARY CONCLUSIONS

Flow modelling incorporates all normal abstractions and discharges, what could happen if no drought orders or permits were operated, if the River Severn Drought Order but no water company drought permits were operated, and what could happen if the River Severn Drought Order and all known Drought Permits were operated in-combination. The results cannot account for temperature variations or sudden storm events, likely during a real event, but not predictable or quantifiable at this stage. It is understood that prolonged high temperatures and sudden high rainfall events would further exasperate the stresses already being encountered.

To assess the Severn Estuary inflows, Deerhurst was considered but modelled data for Lower Parting was used for the final conclusions, due to its location and consideration of the Gloucester and Sharpness canal abstraction. Water framework Directive (WFD) 'transitional waterbody' flow targets (in line with RoC) and the 1992 Spring and Neap tide flow recommendations were used to assess the likely flow impacts on the Severn Estuary, from the River Severn Drought Order.

Acute and Chronic 'do nothing' results indicate the natural drought event could cause temporary failure of the WFD Good Ecological Status (GES) and Moderate Ecological Status (MES) flow targets. The magnitude of the flow failures is significant, but the deterioration would be short term. The 'do nothing' results also indicate the natural drought event could increase the number of days Estuary inflows failed to meet the recommended Spring and Neap tide flow targets. However, the actual number of days affected would depend on whether the low flows occurred on the same days as the Spring and Neap tides.

The River Severn channel splits between U/S Sharpness and Lower Parting, monitoring data (spot gaugings between 1977-2007) indicates approximately 40% of flow goes down the East channel and 60% down the West channel, where the Canal and Rivers Trust abstract. Low flows occurring during the drought would become divided and flow velocity would decrease further, encouraging siltation and saline intrusion around this location. The magnitude of flow reductions is likely to be significant to the lower tidal Severn in the short term, however once recharge returns the flows would be expected to recover and WFD targets would be restored and maintained. The lower tidal River Severn has been identified as potentially being at high risk during a severe drought, however this reach is outside the Natura 2000 designation area.

The impact on the Severn Estuary Natura 2000 site will be limited to localised dependence on freshwater inflows and impacts on Hydromorphology, as the freshwater channel wetted perimeters and general flow velocity would be reduced. Only features and species intolerant to salinity or dependant on freshwater inundation are likely to be impacted. In context of the sensitivity of the Severn Estuary, the high magnitude deteriorations would be short term and therefore unlikely to have a significant impact. The degree of impact to migratory species will vary according to the time of year the deterioration occurs (more likely between September and November) and what other weather conditions occur (e.g. high temperatures).

The risks and failures modelled under the 'do nothing' scenario's (acute and chronic droughts) represent the natural drought effects, which are considered a direct result of an exceptional natural drought event and come under article 4.6 of the WFD. These results have therefore been used as the benchmark for what impacts could occur during acute or chronic droughts, and used to assess what additional impacts the River Severn Drought Order and in-combination water company drought permits could have.

The Severn Drought Order caused no additional GES or MES deteriorations compared to the 'do nothing' scenario for either acute or chronic modelling. The overall magnitude and duration of deterioration altered slightly, reflecting the lowered prescribed flow at Bewdley for a greater length of time whilst protecting higher minimum flows under both Acute and Chronic droughts. The results also showed operating the Severn drought order creates no additional Spring or Neap tide inflow target failures at Lower Parting, compared to the 'do nothing' scenario.

If regulation failure were to occur (sources became too low to support any prescribed flow at Bewdley), the results show the River Severn Drought Order would maintain higher minimum flows during the critical drought period than possible under the 'do nothing' scenario. This illustrates how lowering the prescribed flow can prolong the remaining storage in Clywedog, leaving some water for regulation during the most critical period of the drought event. This would benefit both abstractors and the environment.

Modelling the Chronic scenario showed if two consecutive drought order years occur, utilising the Severn Drought Order in the first year would significantly improve the ability to protect the River Severn flow and Severn Estuary inflows in the subsequent year. The water saved by operating the drought order during the first drought summer, would be available for regulation in the second year. This would delay the need for a drought order in the second year as Clywedog storage would be higher, and greatly reduce the risk of regulation failure compared to the 'do nothing' option. These results support the need for operating the River Severn Drought Order, and allay modelling concerns that no flow benefits would be gained unless Regulation failure was reached.

It is also important to highlight the potential risk of not operating the River Severn Drought Order during severe events when water company drought permits are active. If this were to occur, and the drought extended into regulation failure, then flows would crash to minimums lower than the 'do nothing' scenario. This would potentially cancel out benefits of not operating the drought order, by increasing the magnitude of flow reductions and threatening supplies and flows for the following year/s.

Modelling in-combination with the water company drought permits identified no additional WFD deterioration, or additional tidal inflow target failures, assuming a maximum 300 Ml/d abstraction for the Gloucester and Sharpness canal. The magnitude of flow reductions does increase compared to the River Severn Drought Order in isolation, so the magnitude of short term impact would be greater, although the length of time this might be experienced for remains the same.

The difficulty with in-combination assessment, is under current legislation the Canals and Rivers Trust are exempt from licensing, but have the capacity to abstract up to 691 Ml/d (a maximum of 300 Ml/d was modelled). The operating agreement for the canal abstraction contains flow controls that protect the river environment during normal conditions, but does contain a disclaimer for extreme droughts. The Canals and Rivers Trust identify a trigger flow at Deerhurst for closing the canal to navigation, which the Environment Agency would strongly encourage, but at present this remains a voluntary act. In the absence of any regulatory powers, the maximum abstraction remains a potential risk. If the full quantity were abstracted, the modelled (Aquator) Estuary inflows could be reduced significantly more.

Historic drought flows and naturalised flow sequences down to Deerhurst gauging station indicate the Severn Drought Order has not created a significant extra burden on the main River Severn, compared to what would have naturally occurred in the past. During the worst periods of drought the Regulation system was maintaining higher flows than could naturally have occurred, even with the drought order operational. However flow data is not available further downstream of Deerhurst, so the true impacts of the Gloucester and Sharpness canal cannot be quantified from flow data. Several drought reports state flows around the channel split and inflows to the Estuary were reduced to almost zero by the canal abstraction for short periods in 1976 and 1989.

Modelled acute and chronic scenario's have concluded no additional WFD or tidal flow target failures are caused by activating the River Severn Drought Order, when compared to the 'do nothing' scenario. All flow and level reductions would be temporary and short term, with flow benefits to the environment by operating the Severn Drought Order. **Therefore, no likely significant effect is concluded for the River Severn Drought Order in isolation.**

Initial in-combination modelling for both acute and chronic scenario's concluded no additional WFD or tidal inflow target failures occurred, although the amount of flow reduction (i.e. greater short term impact) was increased. Modelling originally assumed a maximum Gloucester and Sharpness canal abstraction of 300 Ml/d, however the Canals and Rivers Trust confirmed 691 Ml/d could be taken. **Due to evidence in previous drought reports, and the Environment Agency having no legal powers to control the abstraction, the report must conclude that likely significant effects could be caused to the Severn Estuary from in-combination activities**. Large abstractions from the channel split during such critical drought flows could have locally significant impacts on the lower tidal Severn, which could subsequently impact downstream on inflows and navigation pathways for migratory species of the Natura 2000 site.

FLOW CONCLUSIONS

It is important to acknowledge the River Severn is a large and highly complicated system. Models are very important, but can never truly represent the real situation and results need to be considered with this in mind. The Aquator model is the best available tool we have at this time, but was not specifically designed to predict drought flows and demands. Deliberate error was built into the model to account for weather forecast and lag time difficulties encountered in real life, but how the Environment Agency operates the different regulation sources is likely to differ during a real event. The results are an indication of the potential worse case scenario's and help us identify important trends and problems to inform better drought management, they cannot provide the exact flows or timings that will be encountered.

It also needs to be understood the drought scenario's created have never occurred in recorded history, so all results and impacts are theoretical. Every drought event will be unique and produce different challenges. In particular, the exact timing and severity of a drought can not be guaranteed.

In the attempt to model what the Severn Drought Order impacts were in isolation to in-combination impacts, other drought permits and orders were removed from the in isolation modelling. However, all other routine abstractions and discharges, including the high demand expected and higher than normal abstraction by the Gloucester and Sharpness canal were incorporated into the Severn Drought order modelling. This may have created an unfair test/representation of the singular impacts from the Severn drought Order, as 'other' water users and high demands were already being incorporated. This could also explain why the full in-combination modelling identified little change when compared to the Severn Drought Order flows, as the majority of 'in-combination' impacts were already being modelled. The result is a bias towards modelling in-combination impacts, which may do the Severn Drought Order a slight injustice, but does reflect a more realistic conceptualisation and supports the precautionary approach of assessing the worse case scenario.

The Do nothing models represent what could occur during droughts of these magnitudes, and all impacts have been assessed against improvements or deteriorations from this baseline. It needs to be remembered that droughts are natural events, and cannot be prevented only managed. Do Nothing is considered to represent what would occur if no drought management action was taken to protect water supplies or the environment.

Modelling has helped illustrate how robust the Severn regulation system is today, modelling pushed the system into very rare drought magnitudes in order to trigger the need for the Severn Drought Order. In reality, having three separate sources allows Clywedog to be rested early in the season if there is deemed to be a high regulation risk and the catchment is more likely to experience dry/drought conditions. All the actions available to the Environment Agency allow time to be 'brought' to prolong the resource available from Clywedog whilst recharge is awaited, lowering the probability of needing to utilise the drought order at present.

Real drought events have shown how the antecedent conditions at the commence of the regulation season are the critical facture in whether a Drought Order will be required if dry weather persists. For the Midlands region, historic droughts have shown that two subsequent dry years are critical in reducing groundwater levels and therefore baseflows to rivers in the second year. Natural baseflow in the catchment is the primary driver for how much regulation support will be required in the absence of rainfall, low/below average baseflow will result in high regulation releases being required to supplement the deficit. Consistent releases of over 400 Ml/d can cause Clywedog to cross the SDO in a single season if dry weather persists, as shown by modelling and the 1976 drought event. In order for baseflow to have naturally receded to significantly low levels, a long term shortage of rainfall (i.e. drought event) needs to have occurred, likely to be of magnitude greater than a 1 in 20 year over more than 6 months for the whole River Severn catchment scale.

Once Clywedog is releasing large volumes in the absence of recharge, it is clear from real events (e.g. 1976) and modelling, that storage depletes quickly. Approximately 1% is lost per day when 500 Ml/d is released, which supports the original design and 100 day rule applied to Clywedog operation. With appropriate management, which could include a drought order under rare circumstances, Clywedog is likely to avoid dead water during a one season drought and maintain some level of regulation support. The recharge season immediately following a drought/high regulation season will be critical in determining how it performs if a second drought year follows. If the drought order was operated during the first drought year and sufficient recharge is received, the water saved in Llyn Clywedog could be critical in providing significant flow improvements above the drought baseline in the subsequent drought event, demonstrated by the Chronic scenario modelling.

Modelling has shown that with prolonged droughts and insufficient recharge, the regulation system could fail (i.e. individual licences/sources begin to run out of water) even with the Severn Drought Order in operation. Depending on remaining storage in Vyrnwy bank and SGS, modelling suggests activating the Severn Drought Order could cause regulation system failure at the same time/earlier than if no action were taken (shown by Acute scenario), as pressure is diverted to the alternative sources earlier. However, even when this occurs and the Bewdley prescribed flow of 730 Ml/d (5 day mean) is failed, the water saved in Clywedog storage then enables a higher residual flow to be maintained than if the Severn Drought Order had not been activated.

Modelling has also identified the Severn Drought Order could be operated during a drought, without flow benefits being immediately achieved (refer to the Chronic scenario). The environmental cost would be to have created additional flow stress during an already stressed period. The Environment Agency acknowledges this is a risk that would always need to be assessed against long term weather forecasts, carefully balanced against the potential flow damage not operating the Severn Drought Order could allow to happen.

Modelling the Chronic scenario has helped to demonstrate that if the Severn Drought Order is operated during an event when recharge occurred before flow benefits were achieved, the resources saved one year could be critical in safeguarding against a consecutive drought or high regulation season the following year. Therefore, even though short term savings may not be translated into immediate flow benefits, the Severn Drought Order could have an important long term role and potentially be more beneficial in long term droughts than shorter acute events. Modelling suggested the storage savings made during the first Severn Drought Order year, could prevent or significantly delay regulation failure in the following drought.

Both the Acute and Chronic modelling identified a lack of conceptualisation and data around the Gloucester and Sharpness canal abstraction and the relationship with Bristol Water abstraction from the canal. A maximum abstraction of 300Ml/d based on recent actual data was manually applied to the Aquator model, although post drought reports for 1976 and 1989 suggest abstraction to the canal increased to

680Ml/d for short periods, subsequently drying up inflows to the Estuary. The situation is further complicated by the channel bifurcation through Gloucester dividing flows approximately 60:40, with the canal abstraction taking from the smaller East channel. This poses a significant risk to the lower River Severn under the full in-combination scenario and needs further investigation and close liaison during a real event.

Real drought events (e.g. 1976) identify regulation beginning from April to early June, but reservoir storage and/or flows are not considered at significant risk until mid July onwards, when formal drought order applications were made. Variations of the Severn Drought Order typically came into force in early August through into September. Modelling identified that with the additional regulation resources now available, this risk is likely to be delayed towards the end of August/early September, although abstraction demand is an important factor.

The Severn Drought Order will reduce Severn corridor flows for a given period, but even under the rare drought magnitudes modelled, it prevents complete regulation failure at Clywedog. Ultimately the water saved early on enables the minimum flows to be increased along the whole Severn catchment when the regulation system goes into unavoidable failure as the drought continues. This reduces the severity of drought stress on flows during the most critical period. Importantly, the reduction in flow caused by the drought order prior to the obvious benefits, does not lower flows below the modelled baseflow (baseflows shown after regulation failure in Do Nothing scenario), and is therefore still maintaining an artificially elevated flow (above natural) benefit along the River Severn.

Forward planning is needed during any event, considering the impact on the subsequent year if resources are drawn down too low.

Limitations/Assumptions

The River Severn is the longest river in Great Britain, has the second largest tidal range in the world, and involves numerous complex abstractions and discharges as well as artificial flow regulation. Modelling the flow response of such a complex catchment made up of so many variables is very difficult with high confidence. This investigation can only provide a snapshot of potential impacts at a limited number of locations due to the scale of catchment being considered, it is acknowledged that local variation could be significant.

Modelling can only provide a somewhat black and white interpretation of a set of events. The reality is all drought events are unique and how we respond operationally will be different to a model, according to what information and confidence we have in forecasts at the time. The flow modelling should only be used as a guide for some possible worse case drought events to highlight the risks and help the Environment Agency better plan for drought and water resource management.

Droughts of these magnitudes have never occurred within our records of flows and rainfall, therefore cannot be calibrated with accuracy. Historic droughts and previous operation of the River Severn Drought Order does provide an initial baseline, but it must be acknowledged that water resource management and demand has changed since these events and the severity and length of these actual events has been increased. The results should be used as a guide to identify potential trends and highlight monitoring needs and potential remediation, however they cannot be used as a definitive prediction of how flows will behave.

Historic data is varied and flow records in particular rarely go back as far as the 1975-1976 event, particularly in the lower River Severn. Monitoring and methodologies have also changed since records began, making it very difficult to accurately compare datasets without accumulating further errors and uncertainty.

Aquator can model Severn Regulation rigidly to meet the basic prescribed flow criteria at Bewdley, but in reality forecasts and travel times do not allow for such high accuracy. Parameters within Aquator were adjusted to build in some natural error, but sudden changes in releases from all regulation sources are still evident, but unlikely to occur in reality. SGS in particular, is modelled to on off operate, where as in reality the resource requires preparation and then would be utilised as continuously as possible, stepping other resources back where needed, in order to increase operational efficiency and staff resources. These variations need to be acknowledged and understood when using the modelling results.

Flows from effluent returns is significantly different between Aquator and SIMCAT and needs to be investigated further to determine which model/method should be utilised for drought management and prediction in the future. Modelling identified that Aquators minimum flows were significantly lower (approximately half) in the lower River Severn/Severn Estuary inflows than SIMCAT could replicate. Further investigation identified that even if all natural runoff were switched off within SIMCAT, effluent alone would maintain flows significantly higher than Aquator was predicting. The greatest uncertainty was around the Severn Estuary inflows, and the worse case flows from Aquator were adopted in accordance with Habitats Regulations.

Modelling and interpretation clearly identified gaps in baseline drought data and a true understanding between how changes in flows would impact ecology on the ground. Best available methods were adopted, but expert opinion had to be adopted regularly in the absence of clear flow targets and models to predict ecological impacts based on flow reductions for a regulated river.

In an attempt to provide an indication of possible impacts Environmental Flow Indicators were used to provide a rough indication of significance. Risk bands were calculated by subtracting 10% per band from the original EFI. Although the EFI methodology is widely used, the modelled drought scenario's only included 3 years worth of flow data to calculate flow duration curves from. This produces a low flow biased FDC, skewing flows lower where as a longer period would have incorporated more higher range flows, likely reducing EFI failures. This limitation was taken into account when assessing the results where possible, but will have added to the uncertainty around concluding significant flow impacts on ecology.

Overall the highest uncertainty in flow data surrounds the Lower River Severn and Severn Estuary inflows, also the highest environmental risk area. A lack of continuous monitoring and the tidal influences makes it very difficult to determine what the full impacts could be.

Monitoring Recommendations

Baseline monitoring

1. Maintain existing River Severn continuous flow gauges and ensure they are well calibrated to low flows
    - Bryntail - critical
    - Dolwen – critical
    - Abermule
    - Vyrnwy Weir – critical

- Llanymynech
- Buildwas – critical
- Bewdley – critical
- Saxon's Lode – critical
- Haw Bridge
- Deerhurst - critical

2. Need cross sectional and inundation monitoring along the River Severn, frequency once every 5 years – investigate whether this could be combined with flood teams existing monitoring programme with additional drought monitoring for events only.
3. Spot flow gaugings around the channel split in Gloucester, to gain confidence around the percentage of flow split and improve conceptual understanding inside the appropriate models. Select a location up and downstream of the Gloucester and Sharpness canal abstraction for the West channel to help quantify its impact.

<u>Event Monitoring - additional</u>

1. Spot Flow gaugings of tributaries in the Upper reaches of the River Severn, around Llyn Clywedog.
2. Level monitoring over weirs within the River Severn channel split (unclear who owns/maintains them).
3. Spot Flow gaugings of inflows to the Severn Estuary, as far downstream as possible and accounting for tide activity.

<u>Mitigation options (only relevant where significant impact determined)</u>

The River Severn Drought Order would be a last resort option for the Environment Agency in an attempt to sustain the remaining water resources of the River Severn. All other appropriate action should have been taken, the Environment Agency Midlands region would have declared 'Drought status' and communicated the implications publicly through the media, wide spread flow restrictions (HoF's) and irrigation bans (S57) would be in force, the Montgomery canal abstractions reduced (as part of the Regulation agreement) and where water companies were applying for Drought Permits hose pipe bans would be in force.

Additional options could be considered, although they may not prevent the need for the River Severn Drought Order, they may delay its need and/or provide greater flexibility within the regulation system. Some options to consider are;

1. Consider approaching United Utilities for an 'overdraft' on the Vyrnwy Bank. This would only be beneficial if there were sufficient excess storage in Lake Vyrnwy, and if UU were willing and able to loan the water to the River Severn catchment, at low risk to the water supply need.
2. If appropriate/necessary, consider activating the Shropshire Groundwater Scheme drought order to provide additional support to Llyn Clywedog. This would only be beneficial if the individual annual licences, or rolling 5 year licence were being approached. During the Aquator modelling for this report, the Shropshire Groundwater Scheme annual licence quantities were found to be a limiting factor. In a real event, rather than cutting back this regulatory support an application could be made for the SGS Drought Order. If granted this drought order could free up some further support to the River Severn and ensure higher minimum flows can be maintained and some strain can be taken off Llyn Clywedog and Vyrnwy Bank storage. However, it is important to note the quantities would not be significant if Llyn Clywedog failed, but would help reduce the overall consequences on the River Severn if regulation were to fail (Bewdley prescribed flow no longer achievable).

3. Hold regular meetings with The Canals and Rivers trust, particularly regarding the Gloucester and Sharpness canal abstraction and encourage closing the canal to navigation to preserve water resources (water supply to Bristol would need to be maintained). The abstraction currently requires no licence and therefore carries no abstraction restrictions, being limited only by inflows to the Estuary and corresponding tides (saline intrusion implications), large abstractions could pose a significant risk to the downstream flows during extreme drought flows.
4. Explore the option for emergency augmentation to the lower River Severn and Estuary of Severn Trent utilising Chelmarsh bankside storage for abstraction, reducing abstraction pressure in the short term and using Vyrnwy bank to refill Chelmarsh. This would only be beneficial in emergency situations, when sufficient storage is available in Vyrnwy bank to repay Chelmarsh, and there was not sufficient travel time to simply rely on releases from Lake Vyrnwy. This emergency option would be short term (days to a week) and incur additional costs to the Environment Agency, who would need to pay Severn Trent water for using the water.
5. Seek additional reductions from abstractors up to 20%. Some water companies maybe able to rely on supplies other than the River Severn (i.e. rest their Severn abstraction through transfers). Each drought is different and conditions elsewhere could be worse than on the Severn. However, scope for reducing demand on the Severn may be restricted by priorities elsewhere and this option is unlikely to be achievable in a large scale drought event.

Future work recommendations

1. Develop a flow ‘prediction’ model or improve existing models capability, to cater for the needs of Drought Order and Permit investigations.
2. Integrate water quality and water resource flow models to ensure continuity.
3. Develop hydro-ecological ‘prediction’ tools capable of assessing the regulation experienced along the River Severn.
4. Investigate whether an inundation model, similar to flood risk mapping but for low flows, can be developed (particularly in the high risk area’s such as the Lower Tidal River Severn) to help visualise and quantify the environmental impacts.
5. Need to more realistically separate the Severn Drought Order in isolation and full in-combination impacts, or abandon Severn Drought Order in isolation as not feasible. Inside the full in-combination, need to explore whether abstraction is/needs to be increased to fully licensed quantities to better reflect worse case impacts.
6. Explore how well non-water company abstraction is represented and how easily it can be manipulated inside Aquator.
7. Incorporate the Shropshire Groundwater Scheme Drought Order operation in modelling work.
8. Need to improve the Gloucester and Sharpness canal abstraction and conceptualisation inside the Severn Drought Order modelling.
    a. Enter a specific drought related abstraction profile for the canal, replacing the current monthly average used.
    b. Check how the tributaries CAM and Frome are represented in Aquator – if directly to the River Severn then it might be more appropriate to represent ‘Total abstraction’ for the canal (i.e. including Cam and Frome) to remove from the River Severn. However, both tributaries maybe further downstream than flow models can work therefore not necessary.

9. Investigate how the Gloucester and Sharpness canal abstraction is represented inside Severn Corridor CAMS and the WRGIS tool to ensure the maximum worse case abstraction volume is included.
10. Investigate how the Gloucester and Sharpness canal abstraction is represented inside Low Flows Enterprise, and whether the channel split can be built into the model.
11. Get reservoir storage levels prior to 1990 onto WISKI to capture important historic droughts. It's unclear who would have these potentially hard copy records, Environment Agency only appear to have occasional graphs as part of post drought reports.
12. The Canals and Rivers trust do not currently measure all of their abstraction (losses mainly) and submit returns data annually – investigate whether abstraction returns could be requested more frequently during Severn Regulation operation, in line with other Act of Parliament partners. Or as a minimum through potential/drought critical periods. The aim would be to better conceptualise flows into the Severn Estuary and aid efficient operation of Severn Regulation.
13. Investigate whether The Canals and Rivers trust could bring the Gloucester and Sharpness canal operations in line with the Montgomery canal. This would involve setting out agreed abstraction reductions and operations to cater specifically for high regulation demand and drought conditions.

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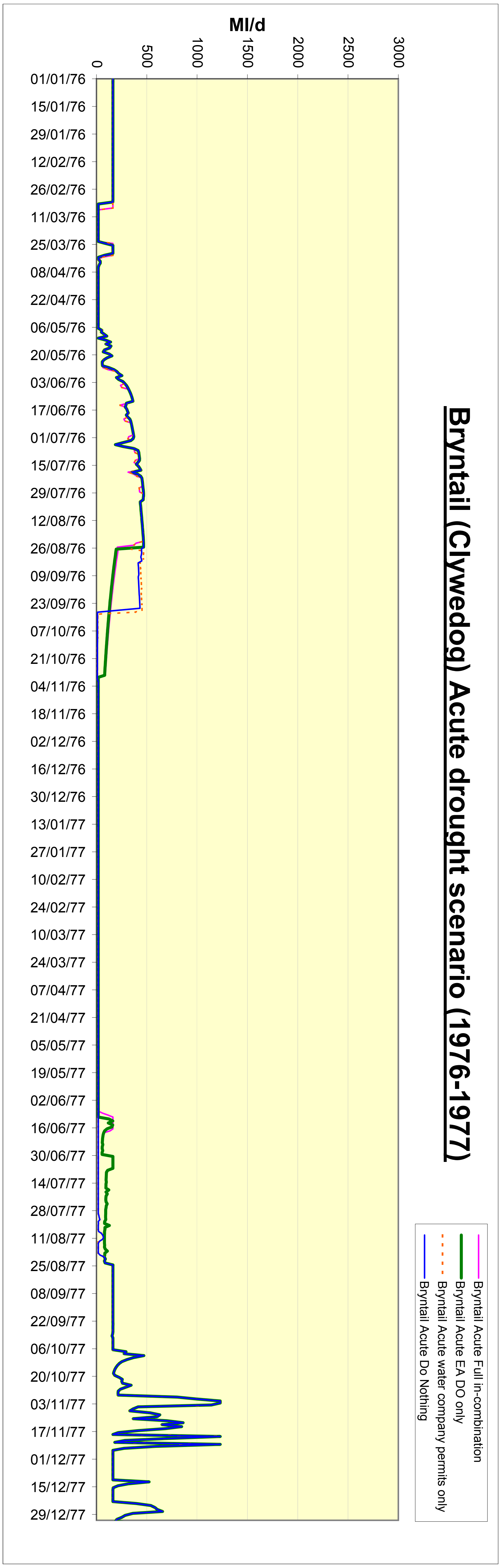
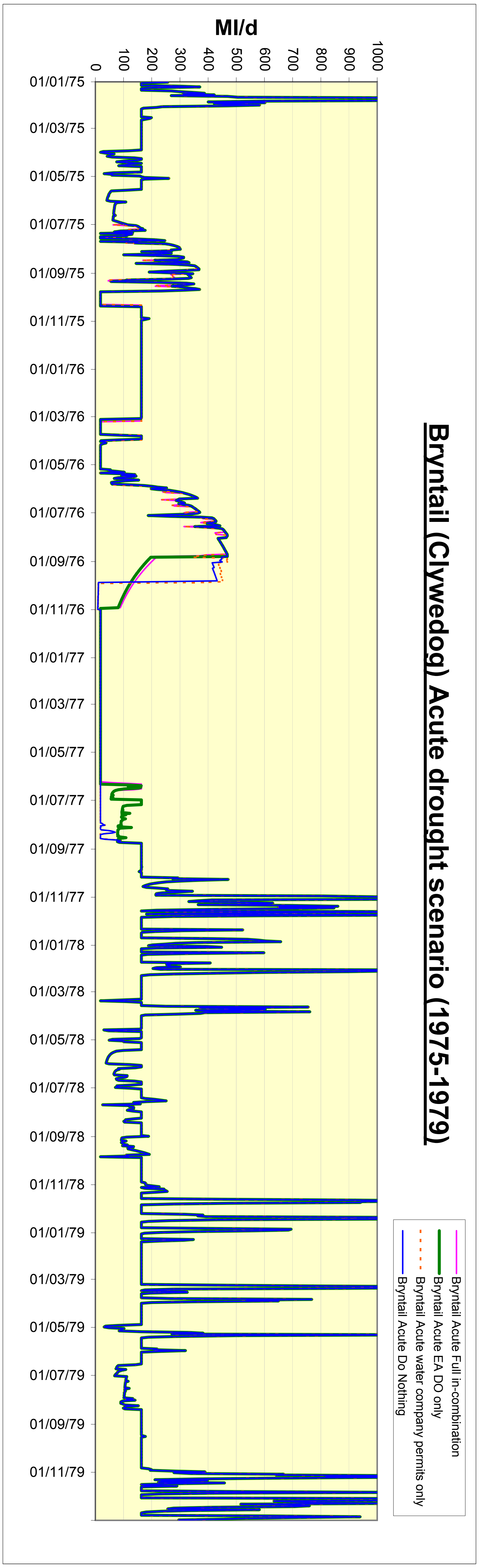
Appendix J.1

Acute scenario: Hydrographs


Bryntail (Clywedog) Acute drought scenario (1976-1977)
Ml/d
Bryntail Acute Full in-combination
Bryntail Acute EA DO only
Bryntail Acute water company permits only
Bryntail Acute Do Nothing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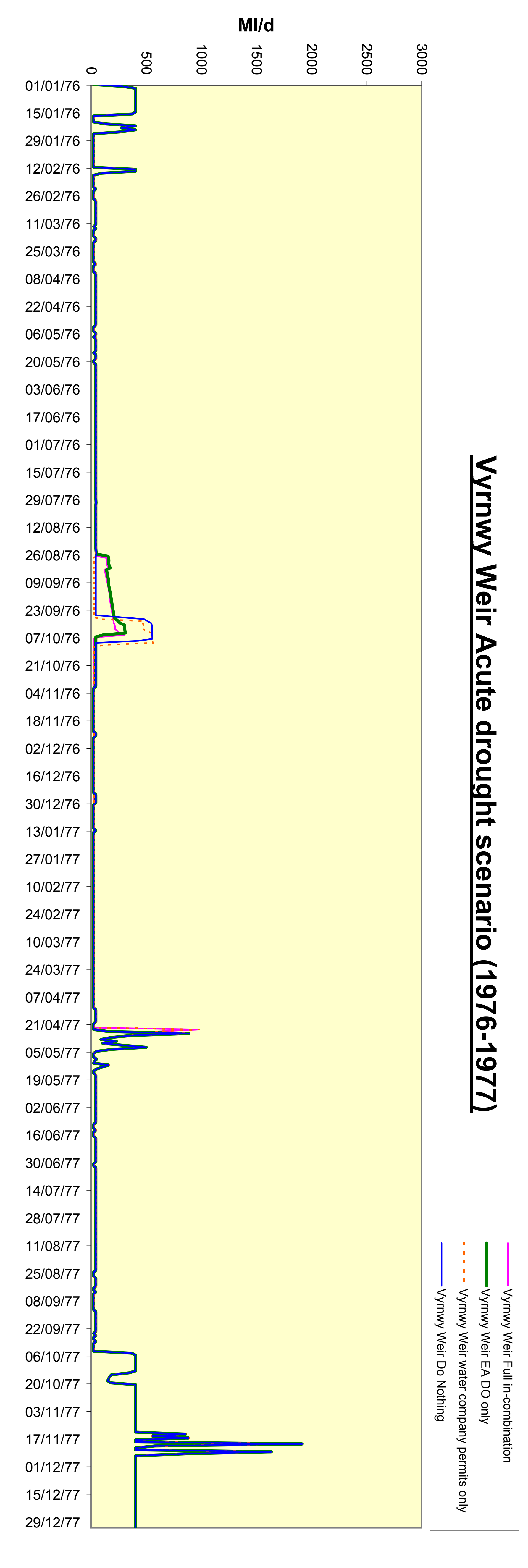
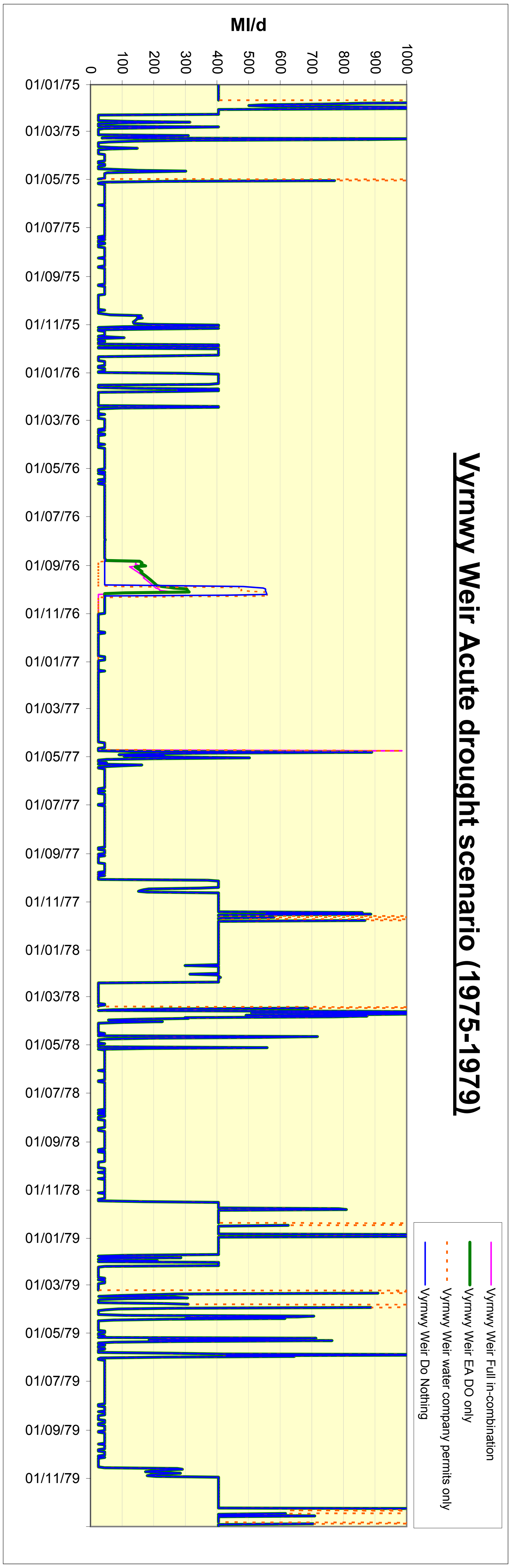
Ml/d
Bryntail Acute Full in-combination
Bryntail Acute EA DO only
Bryntail Acute water company permits only
Bryntail Acute Do Nothing


Vyrnwy Weir Acute drought scenario (1976-1977)
Ml/d
Vyrnwy Weir Full in-combination
Vyrnwy Weir EA DO only
Vyrnwy Weir water company permits only
Vyrnwy Weir Do Nothing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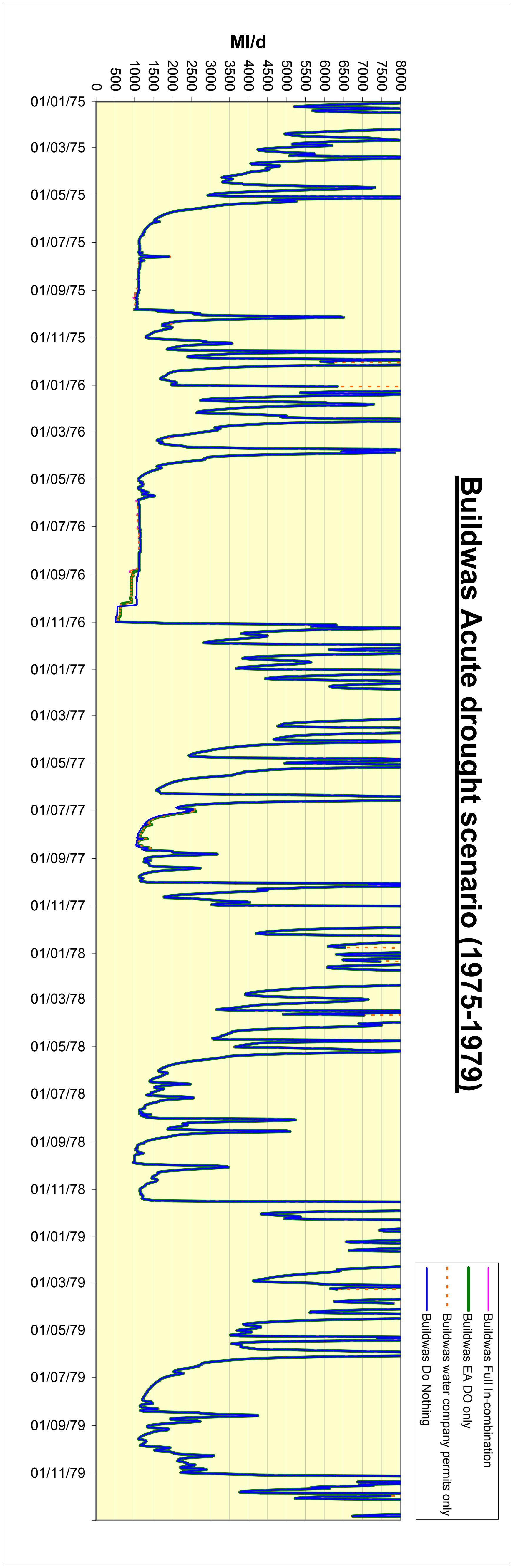
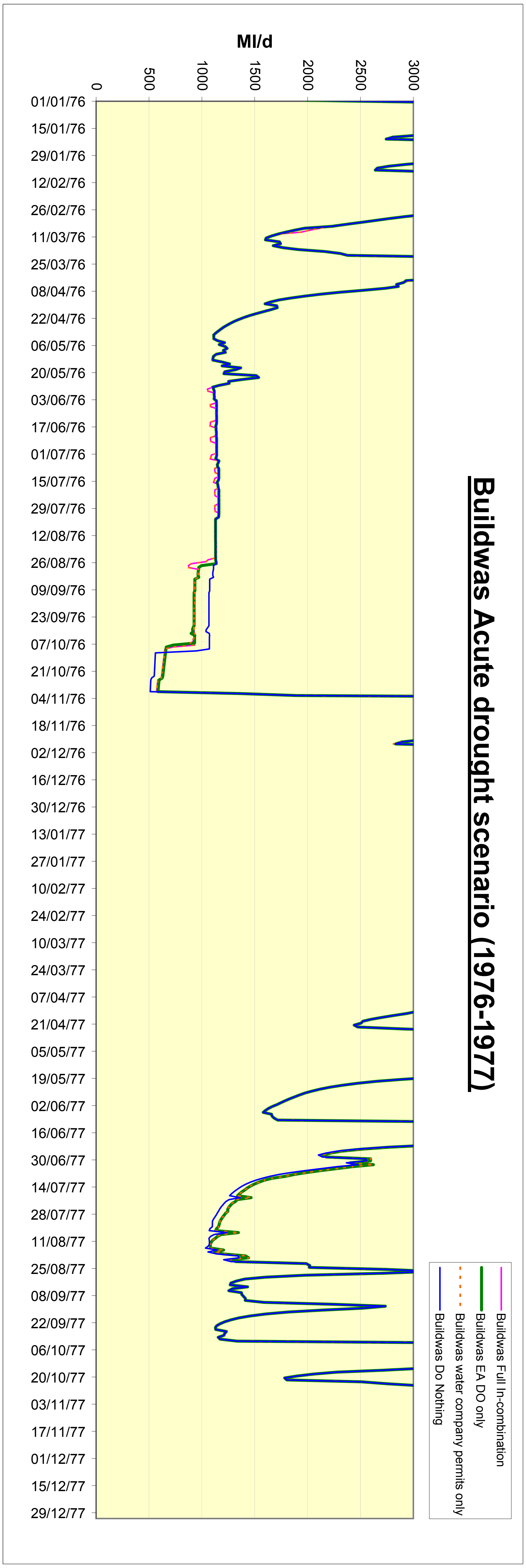
Ml/d
Vyrnwy Weir Full in-combination
Vyrnwy Weir EA DO only
Vyrnwy Weir water company permits only
Vyrnwy Weir Do Nothing


Buildwas Acute drought scenario (1975-1979)
Ml/d
Buildwas Full In-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing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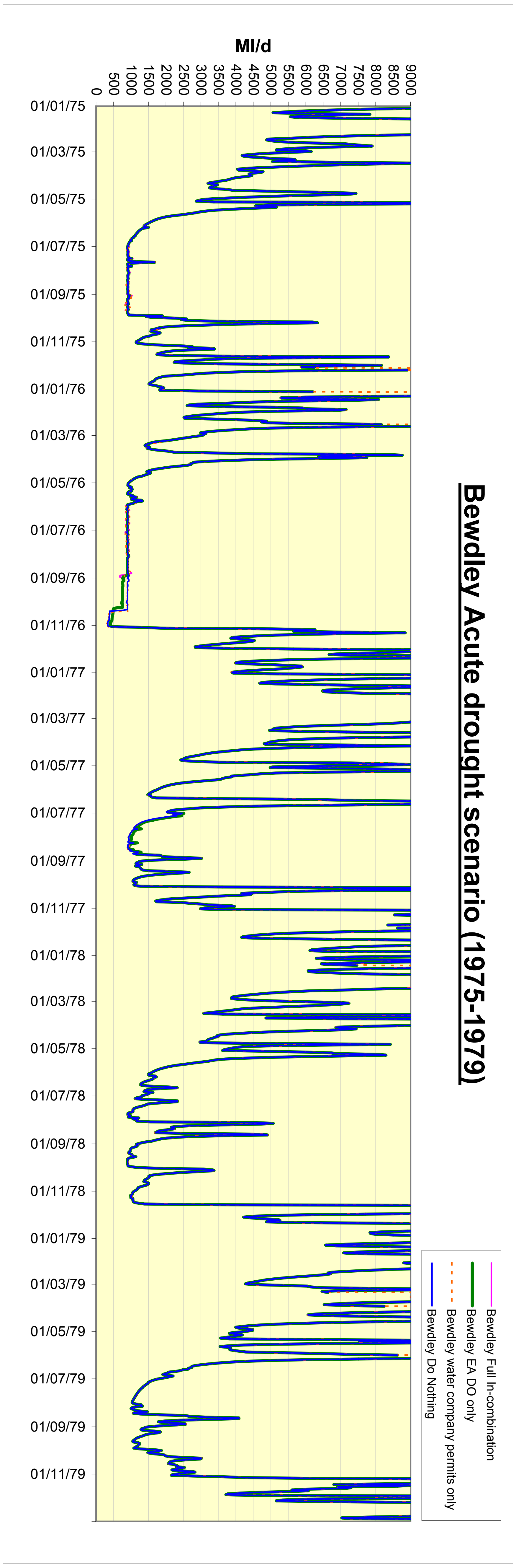
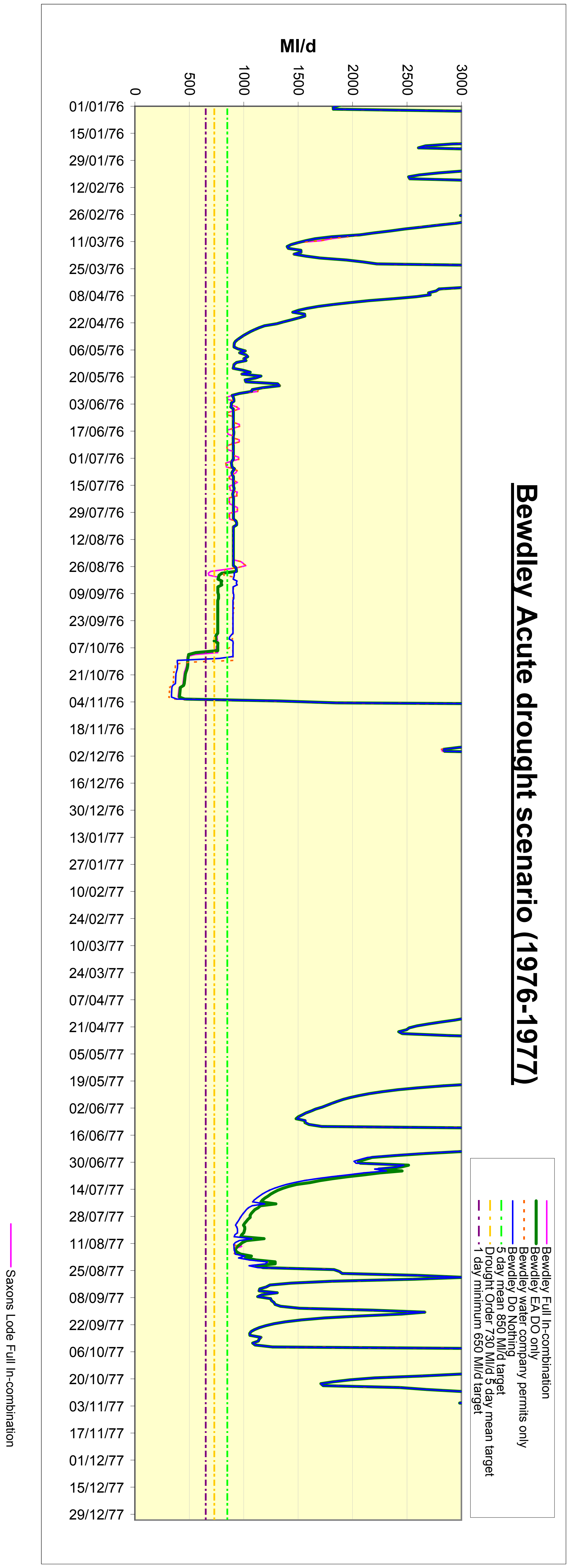
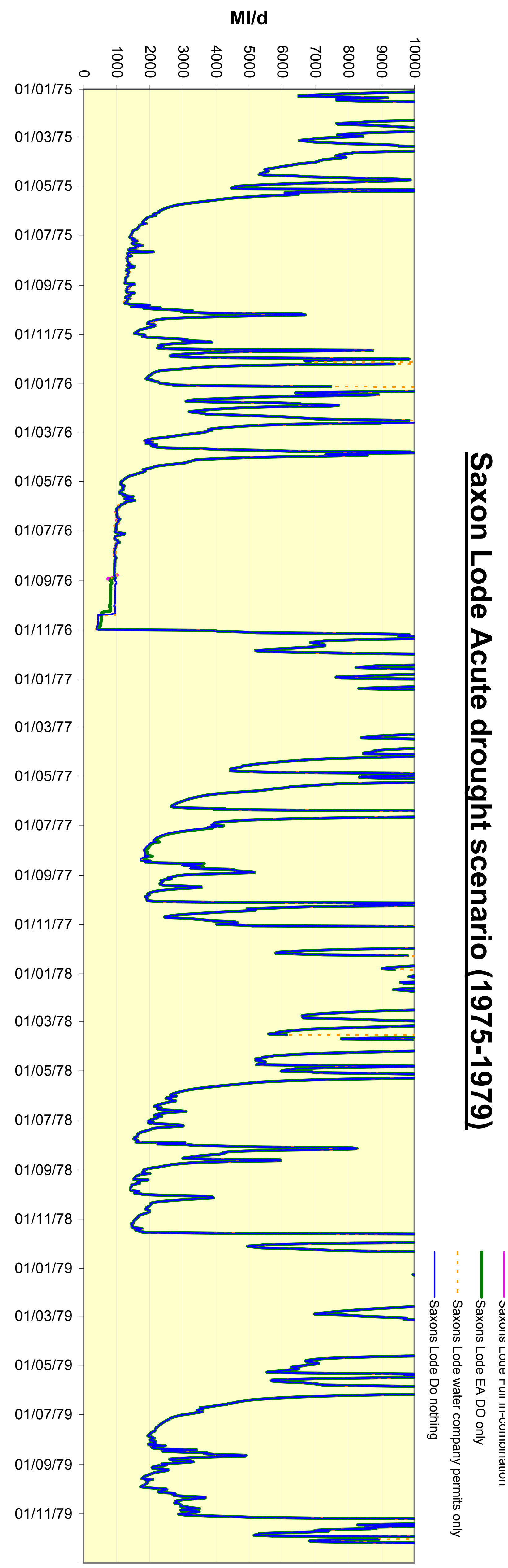
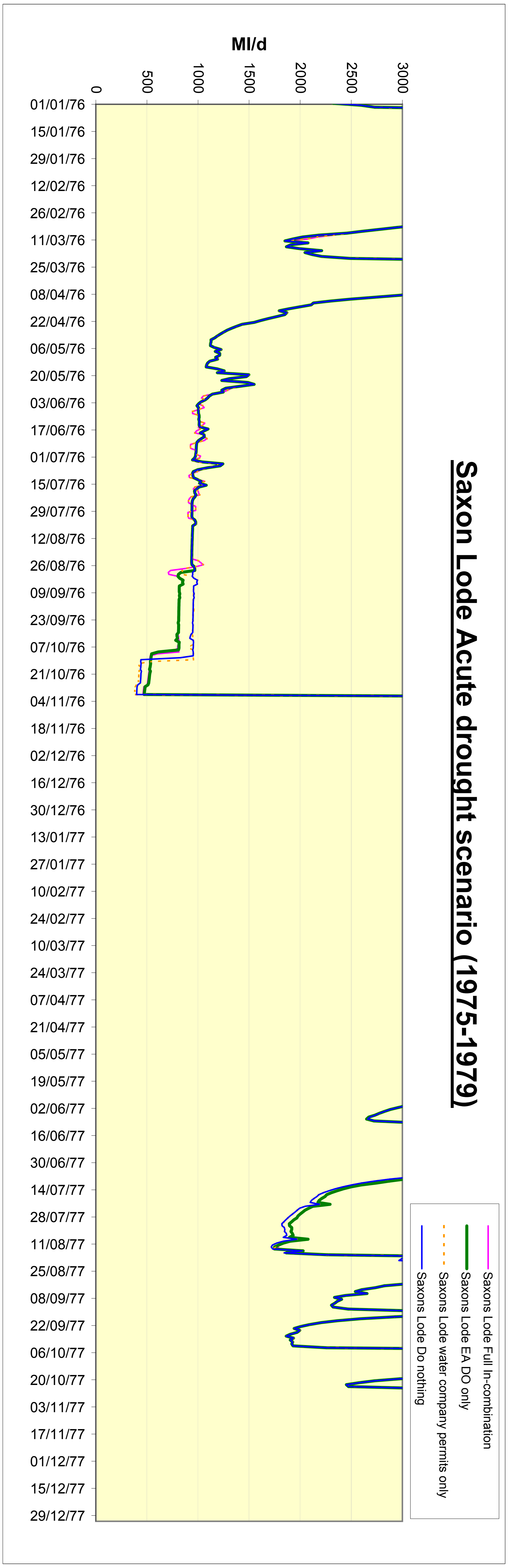
Ml/d
Buildwas Full In-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing


Bewdley Acute drought scenario (1975-1979)
Ml/d
Bewdley Full In-combination
Bewdley EA DO only
Bewdley water company permits only
Bewdley Do Nothing


Bewdley Acute drought scenario (1976-1977)
Ml/d
Bewdley Full In-combination
Bewdley EA DO only
Bewdley water company permits only
Bewdley Do Nothing
5 day mean 850 Ml/d target
Drought Order 730 Ml/d 5 day mean target
1 day minimum 650 Ml/d target
Saxons Lode Full In-combination


Saxon Lode Acute drought scenario (1975-1979)
Ml/d
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do nothing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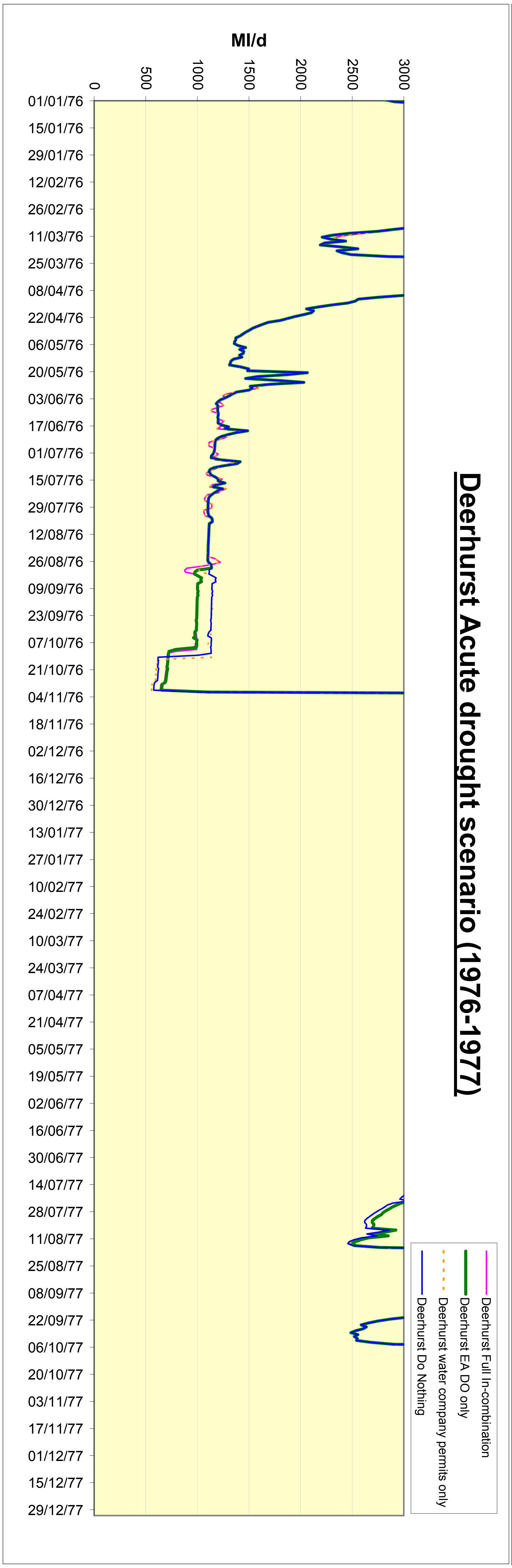
Ml/d
Saxons Lode Full In-combination
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do nothing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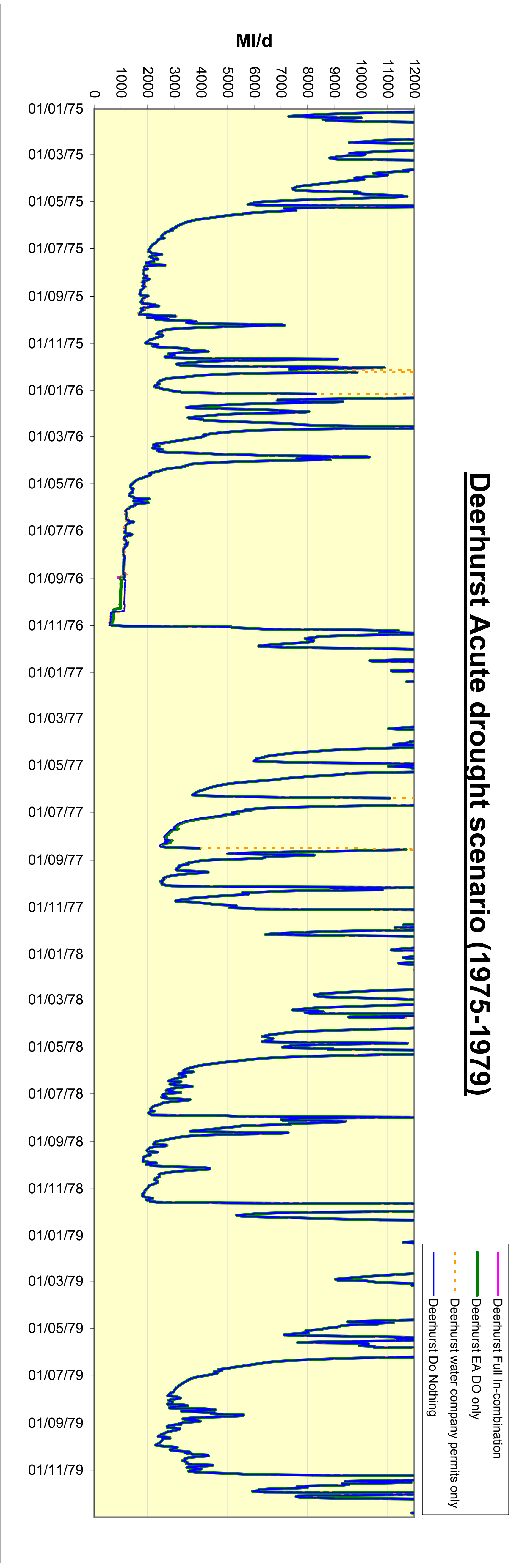
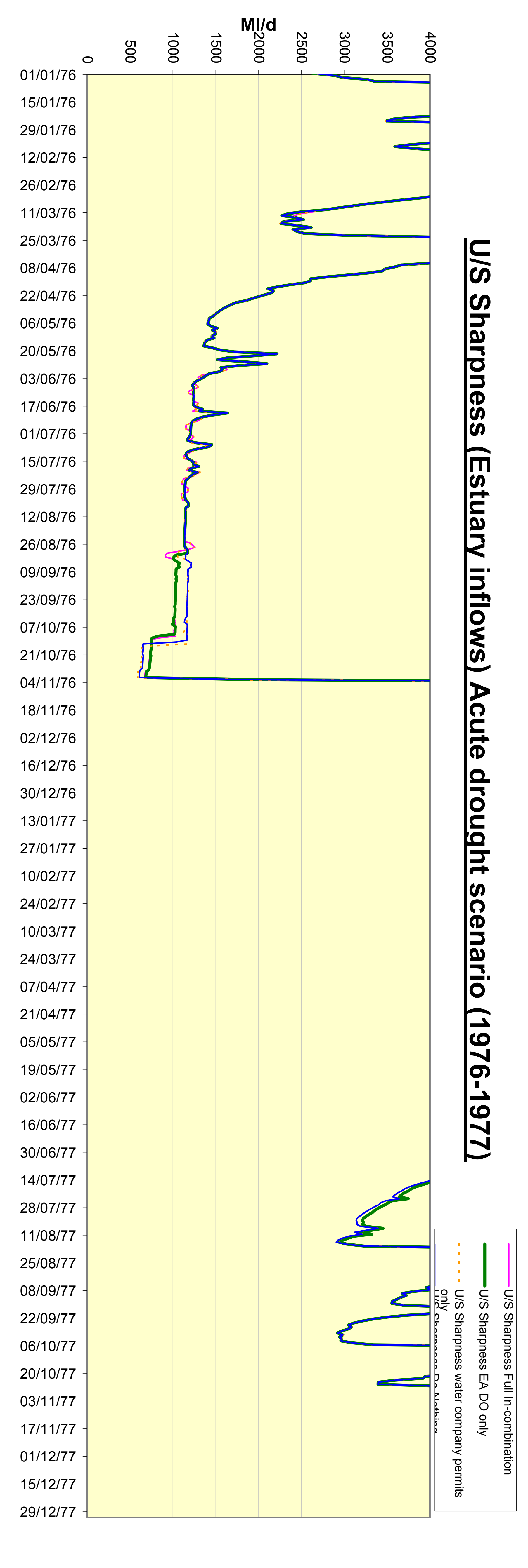
Ml/d
Deerhurst Full In-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing


Deerhurst Acute drought scenario (1975-1979)
Ml/d
Deerhurst Full In-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing


U/S Sharpness (Estuary inflows) Acute drought scenario (1976-1977)
Ml/d
0
500
1000
1500
2000
2500
3000
3500
4000
01/01/76
15/01/76
29/01/76
12/02/76
26/02/76
11/03/76
25/03/76
08/04/76
22/04/76
06/05/76
20/05/76
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17/06/76
01/07/76
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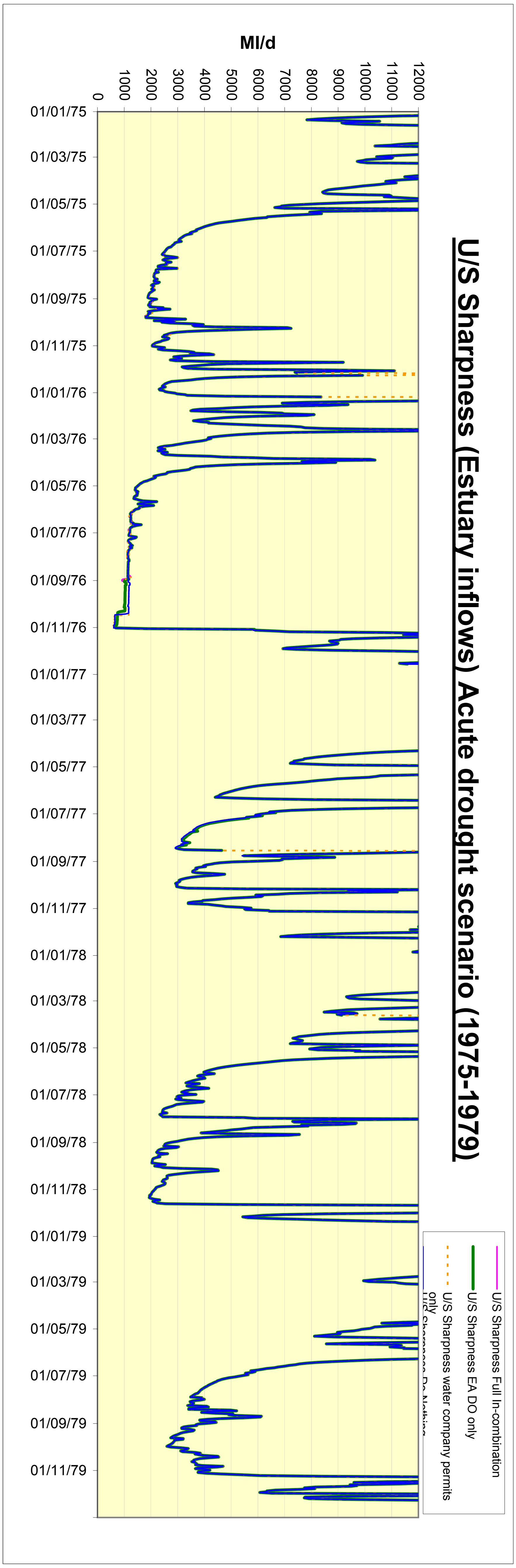
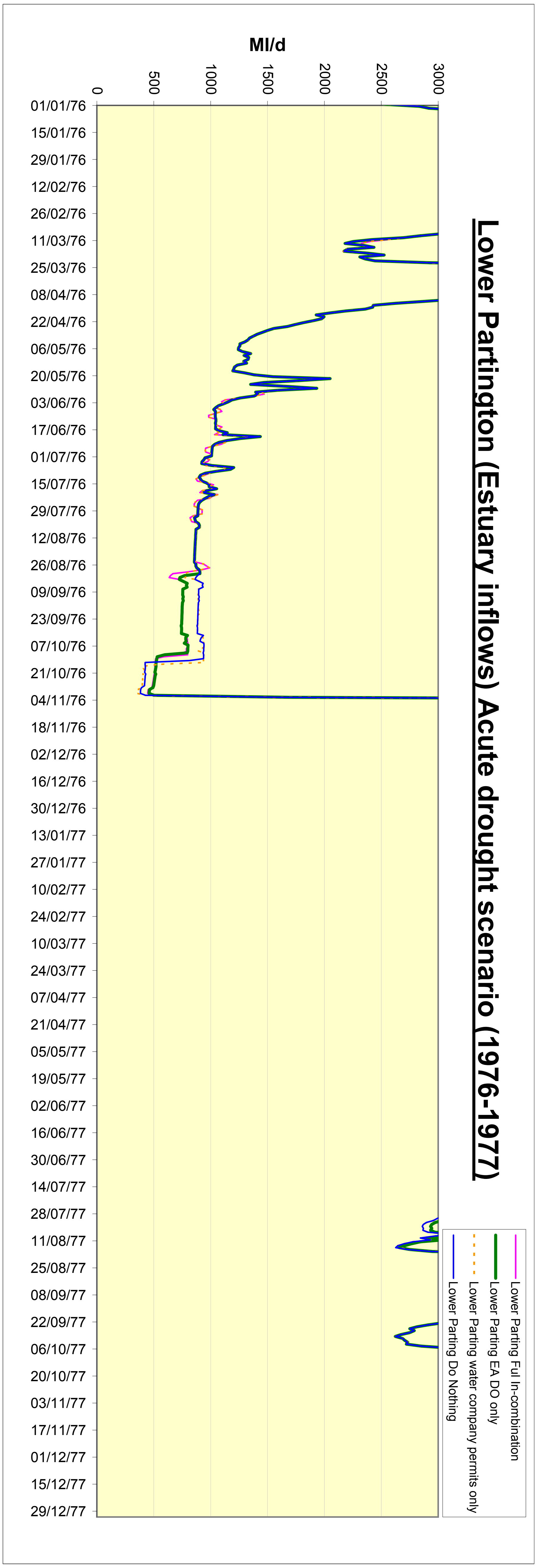
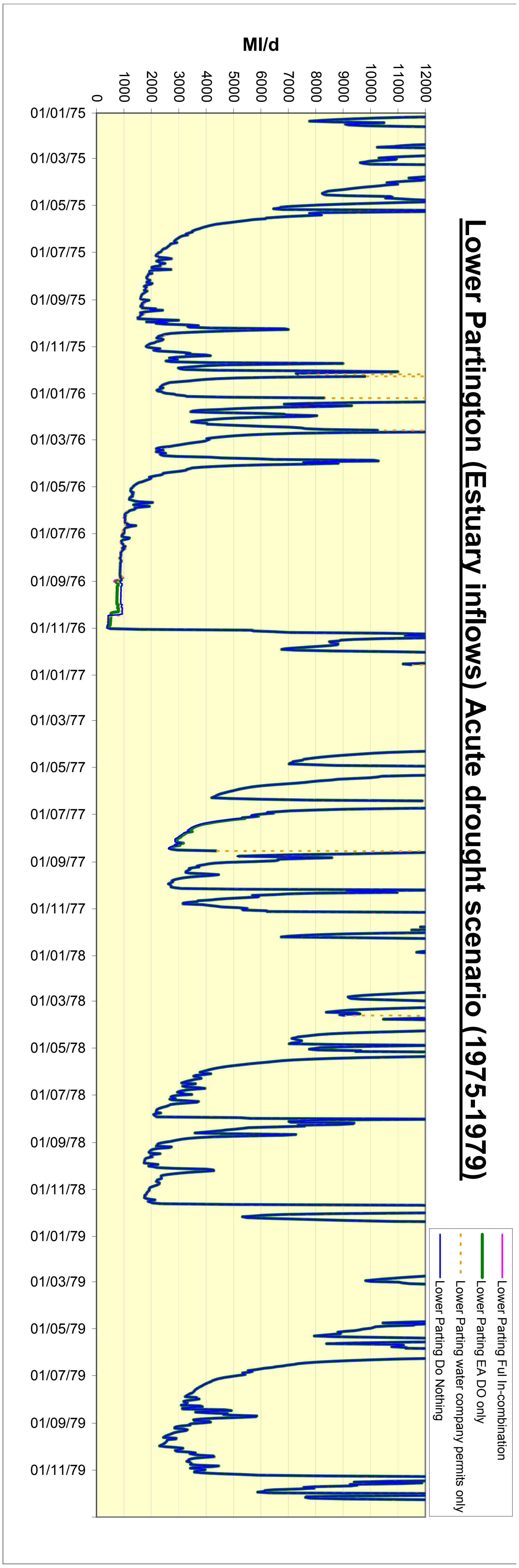
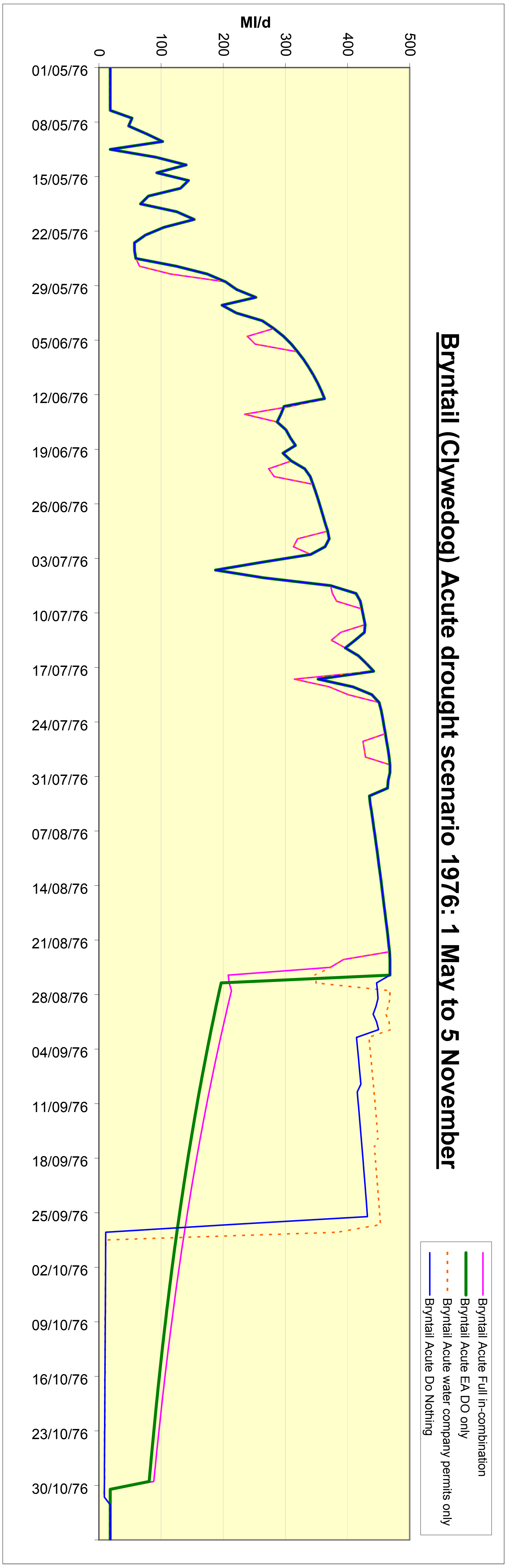
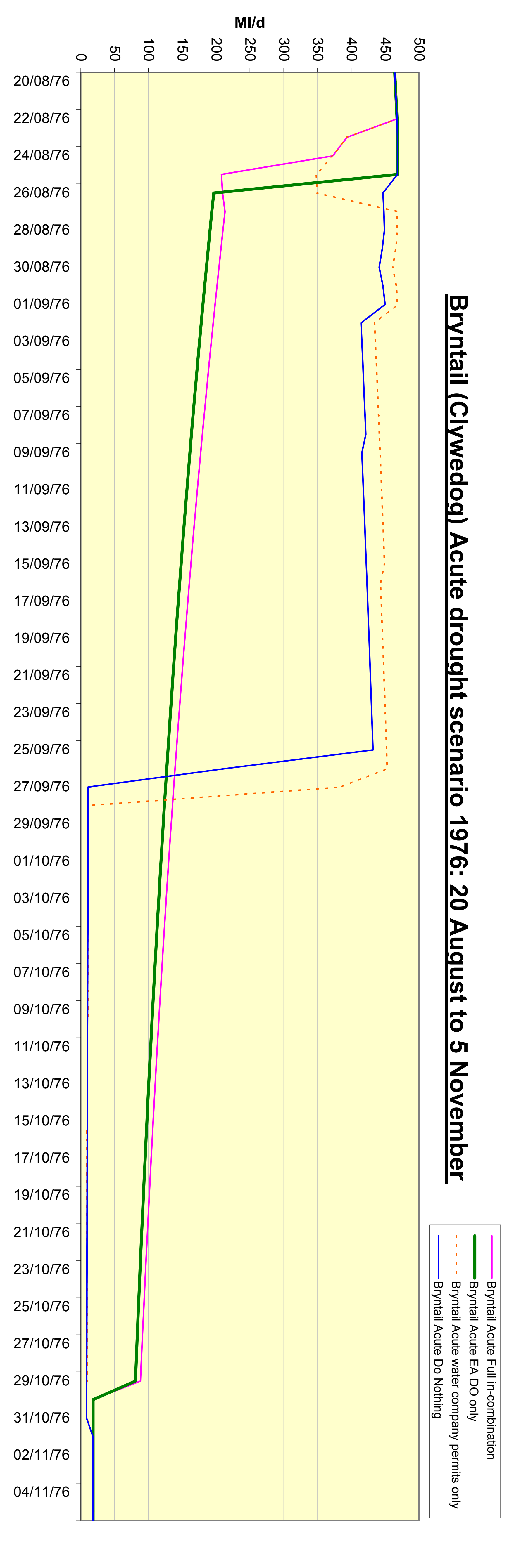
15/12/77
29/12/77
U/S Sharpness Full In-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only

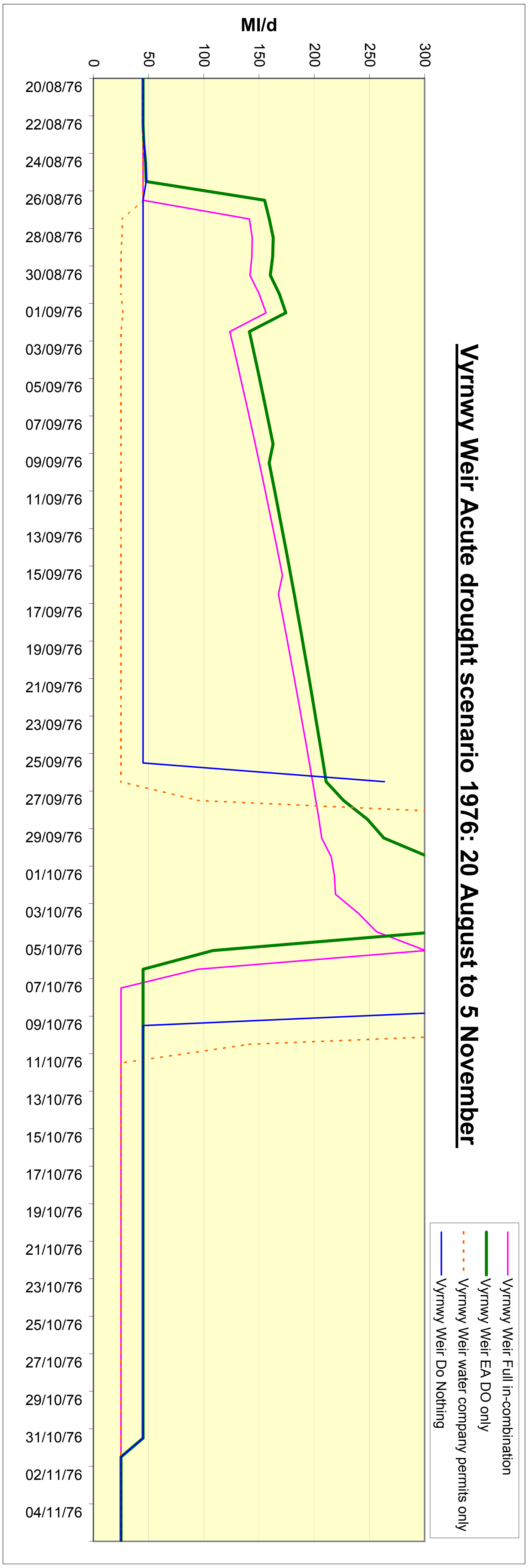

U/S Sharpness (Estuary inflows) Acute drought scenario (1975-1979)
Ml/d
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
11000
12000
01/01/75
01/03/75
01/05/75
01/07/75
01/09/75
01/11/75
01/01/76
01/03/76
01/05/76
01/07/76
01/09/76
01/11/76
01/01/77
01/03/77
01/05/77
01/07/77
01/09/77
01/11/77
01/01/78
01/03/78
01/05/78
01/07/78
01/09/78
01/11/78
01/01/79
01/03/79
01/05/79
01/07/79
01/09/79
01/11/79
U/S Sharpness Full In-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only

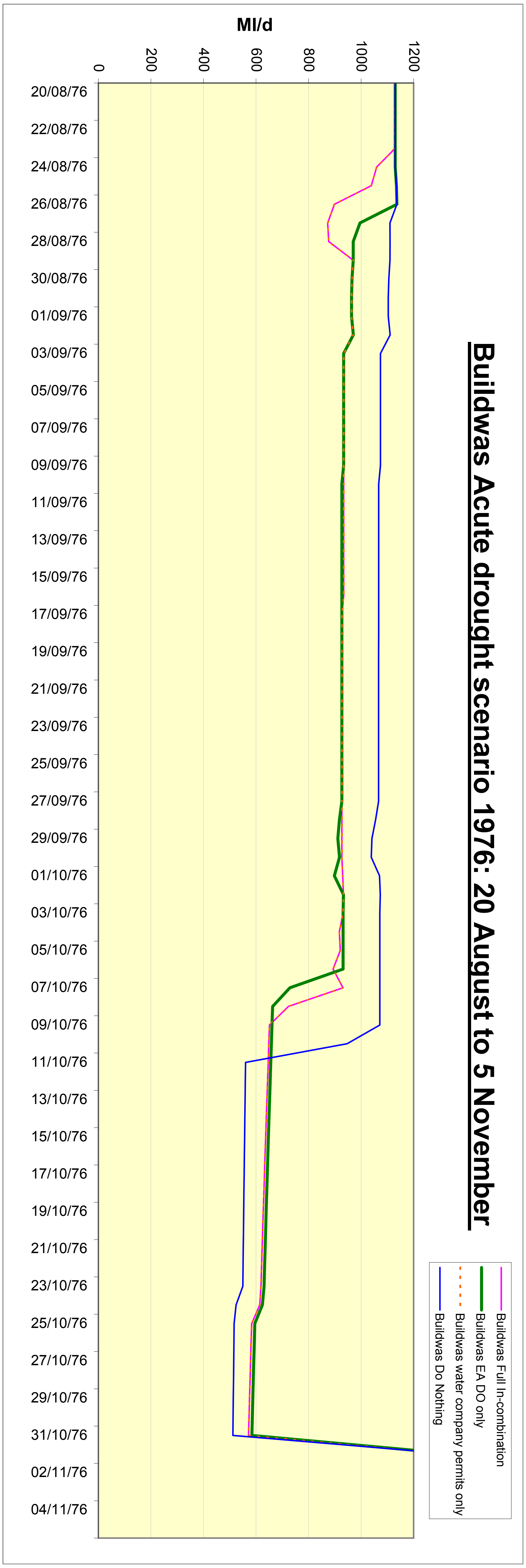

Lower Partington (Estuary inflows) Acute drought scenario (1976-1977)
Ml/d
Lower Parting Ful In-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing

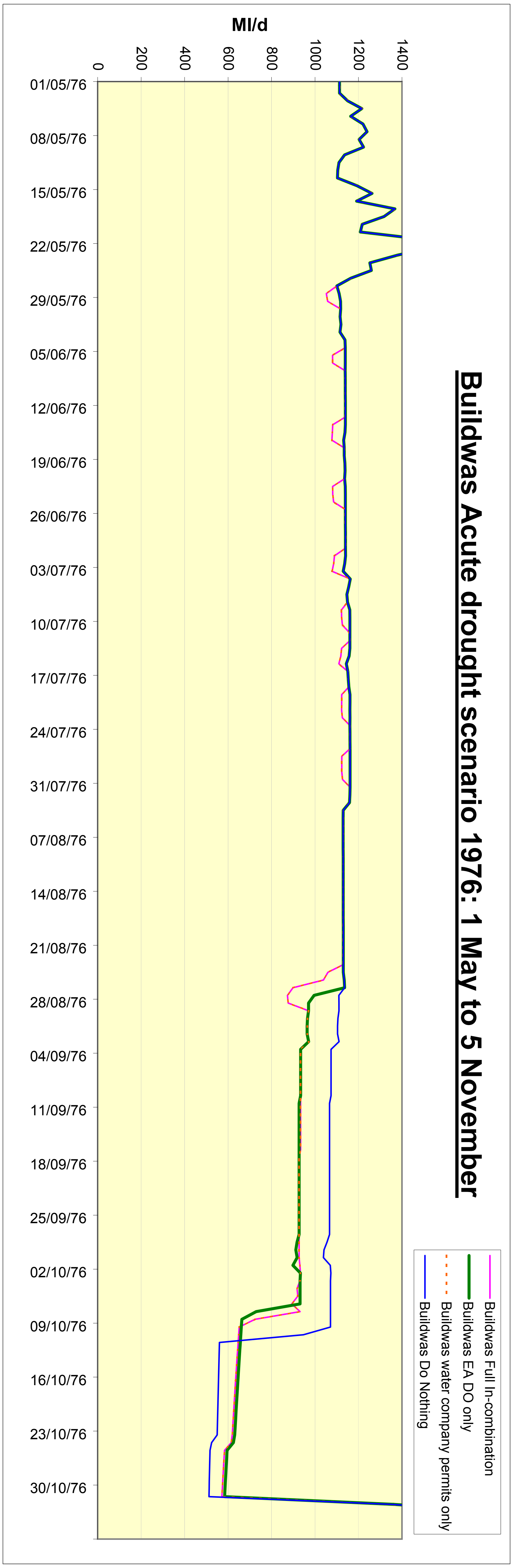

Lower Partington (Estuary inflows) Acute drought scenario (1975-1979)
Ml/d
Lower Parting Ful In-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing

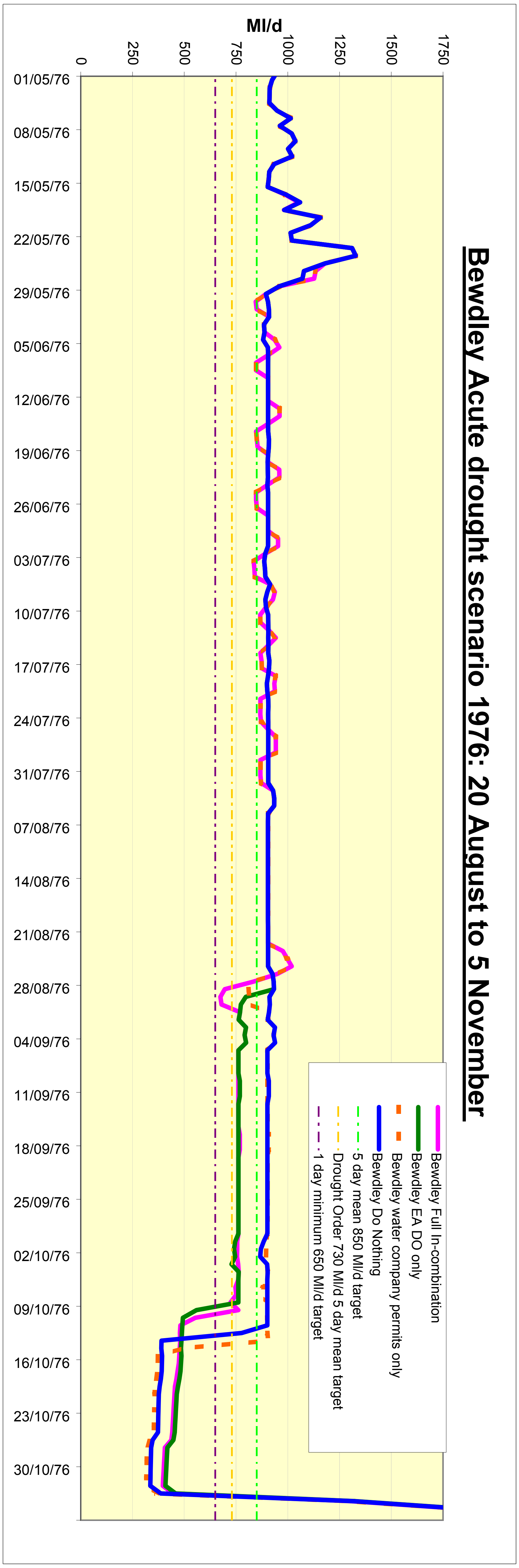

Bryntail (Clywedog) Acute drought scenario 1976: 1 May to 5 November
Ml/d
Bryntail Acute Full in-combination
Bryntail Acute EA DO only
Bryntail Acute water company permits only
Bryntail Acute Do Nothing

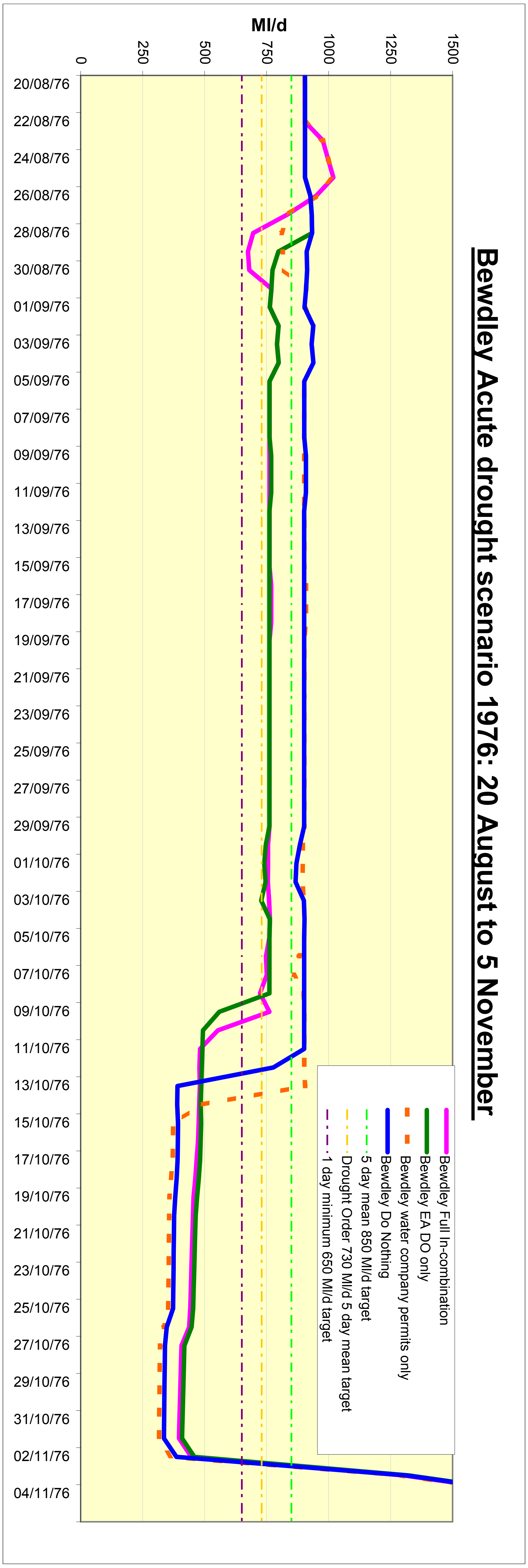

Bryntail (Clywedog) Acute drought scenario 1976: 20 August to 5 November
Ml/d
Bryntail Acute Full in-combination
Bryntail Acute EA DO only
Bryntail Acute water company permits only
Bryntail Acute Do Nothing


Vyrnwy Weir Acute drought scenario 1976: 20 August to 5 November
Ml/d
0
50
100
150
200
250
300
20/08/76
22/08/76
24/08/76
26/08/76
28/08/76
30/08/76
01/09/76
03/09/76
05/09/76
07/09/76
09/09/76
11/09/76
13/09/76
15/09/76
17/09/76
19/09/76
21/09/76
23/09/76
25/09/76
27/09/76
29/09/76
01/10/76
03/10/76
05/10/76
07/10/76
09/10/76
11/10/76
13/10/76
15/10/76
17/10/76
19/10/76
21/10/76
23/10/76
25/10/76
27/10/76
29/10/76
31/10/76
02/11/76
04/11/76
Vyrnwy Weir Full in-combination
Vyrnwy Weir EA DO only
Vyrnwy Weir water company permits only
Vyrnwy Weir Do Nothing

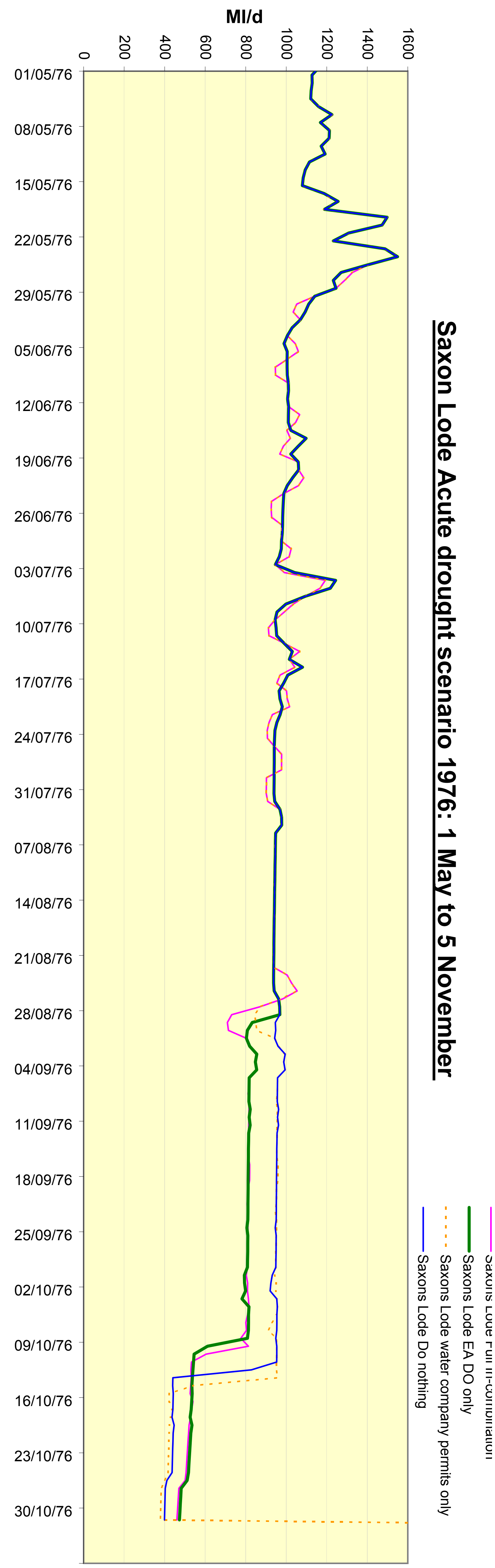

Buildwas Acute drought scenario 1976: 20 August to 5 November
Ml/d
0
200
400
600
800
1000
1200
20/08/76
22/08/76
24/08/76
26/08/76
28/08/76
30/08/76
01/09/76
03/09/76
05/09/76
07/09/76
09/09/76
11/09/76
13/09/76
15/09/76
17/09/76
19/09/76
21/09/76
23/09/76
25/09/76
27/09/76
29/09/76
01/10/76
03/10/76
05/10/76
07/10/76
09/10/76
11/10/76
13/10/76
15/10/76
17/10/76
19/10/76
21/10/76
23/10/76
25/10/76
27/10/76
29/10/76
31/10/76
02/11/76
04/11/76
Buildwas Full In-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing

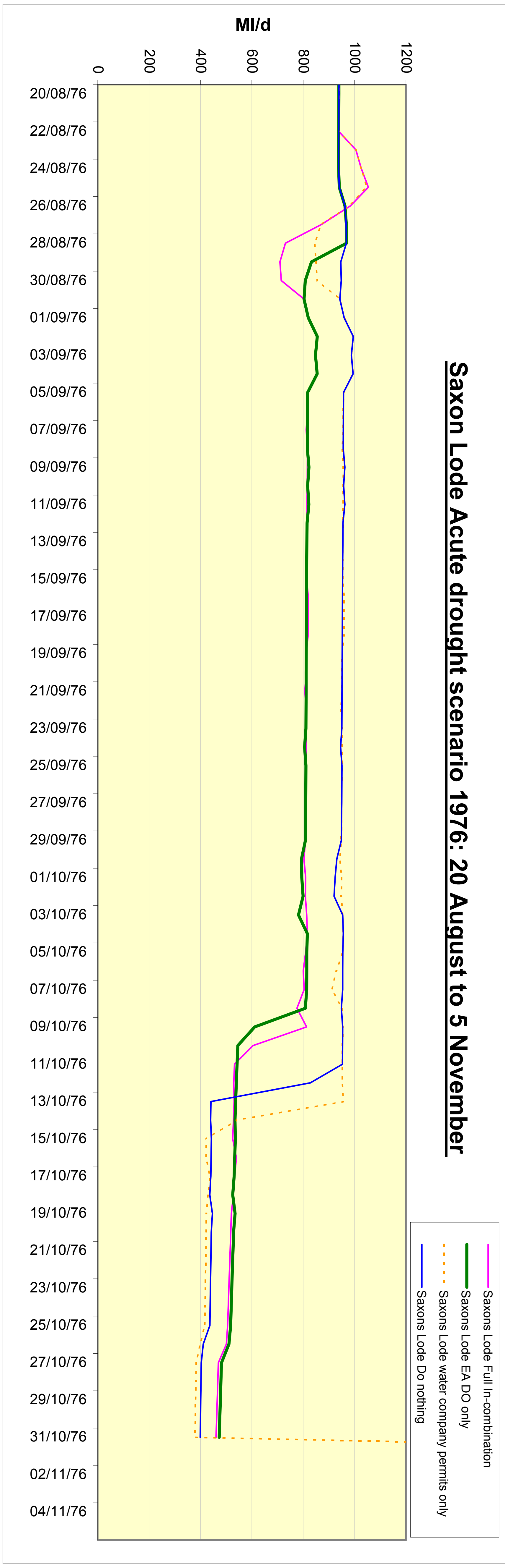

Buildwas Acute drought scenario 1976: 1 May to 5 November
Ml/d
0
200
400
600
800
1000
1200
1400
01/05/76
08/05/76
15/05/76
22/05/76
29/05/76
05/06/76
12/06/76
19/06/76
26/06/76
03/07/76
10/07/76
17/07/76
24/07/76
31/07/76
07/08/76
14/08/76
21/08/76
28/08/76
04/09/76
11/09/76
18/09/76
25/09/76
02/10/76
09/10/76
16/10/76
23/10/76
30/10/76
Buildwas Full In-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing

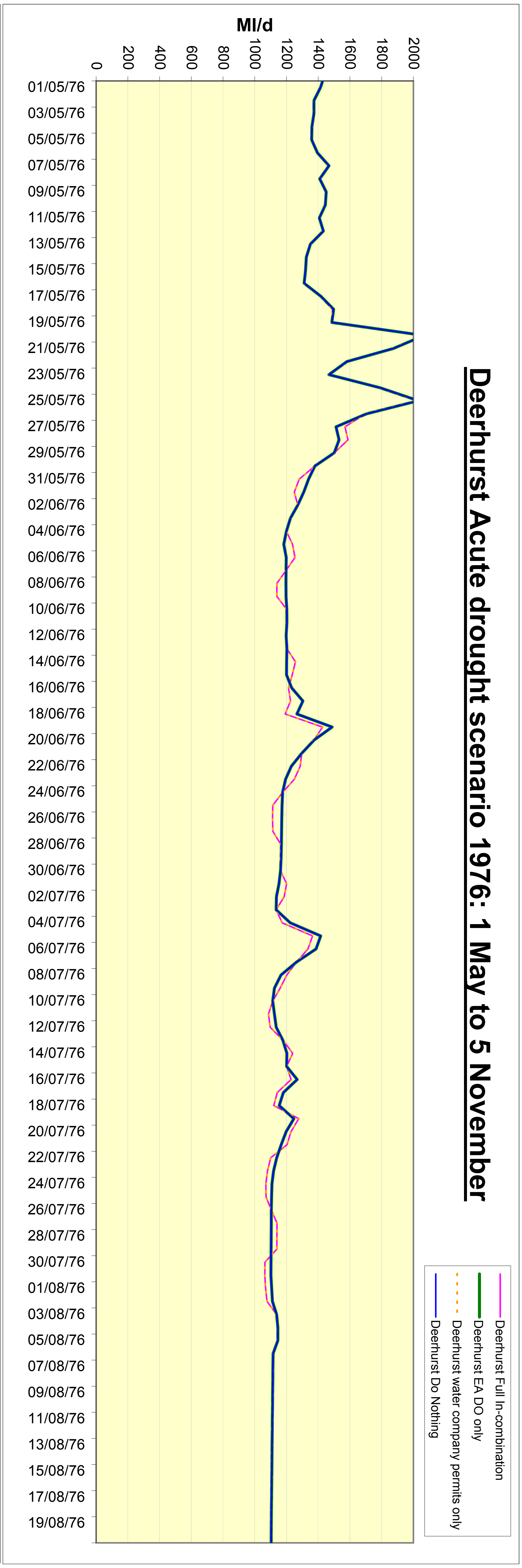


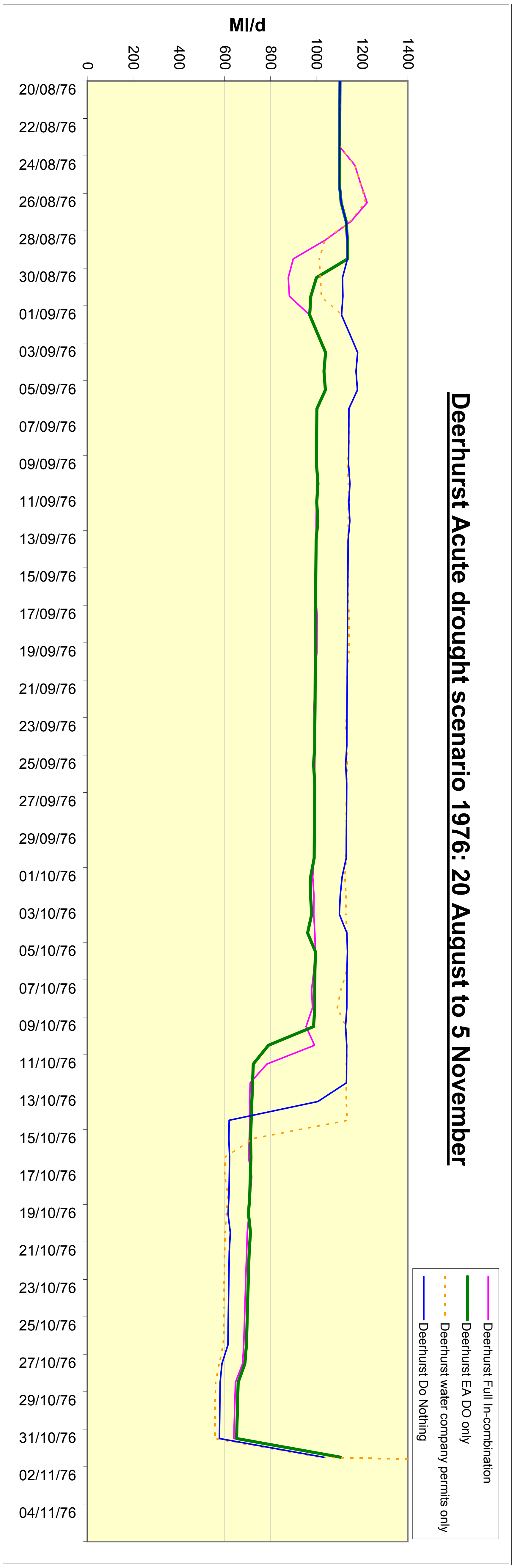


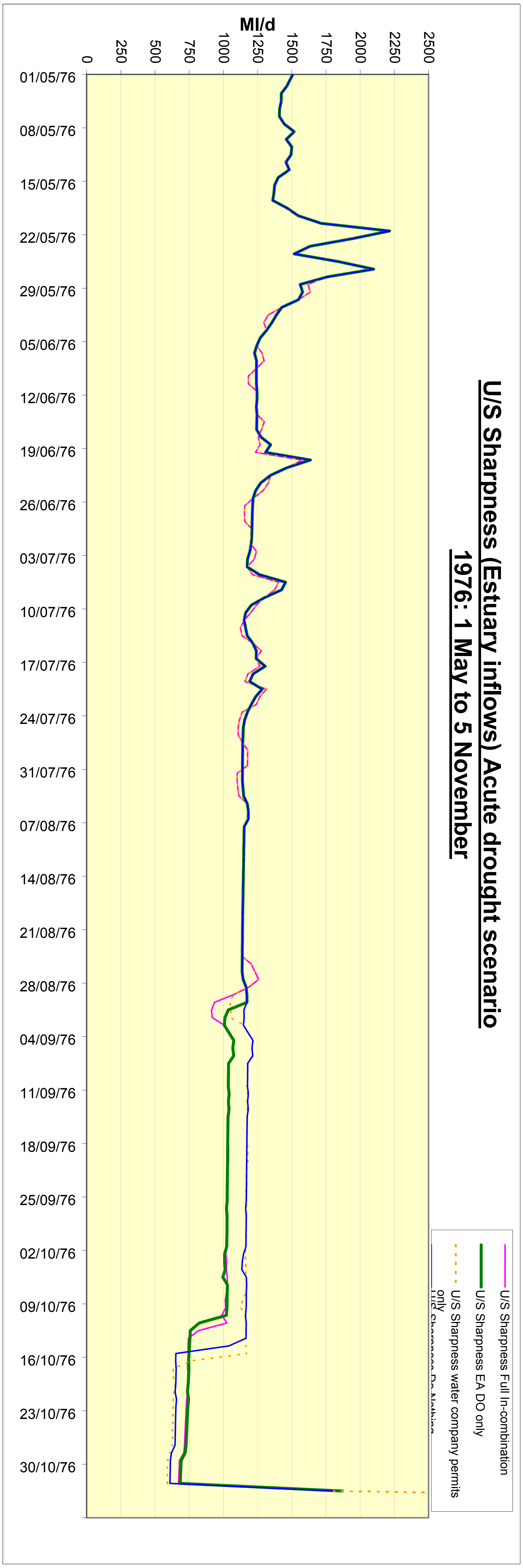
Saxons Lode Full In-combination

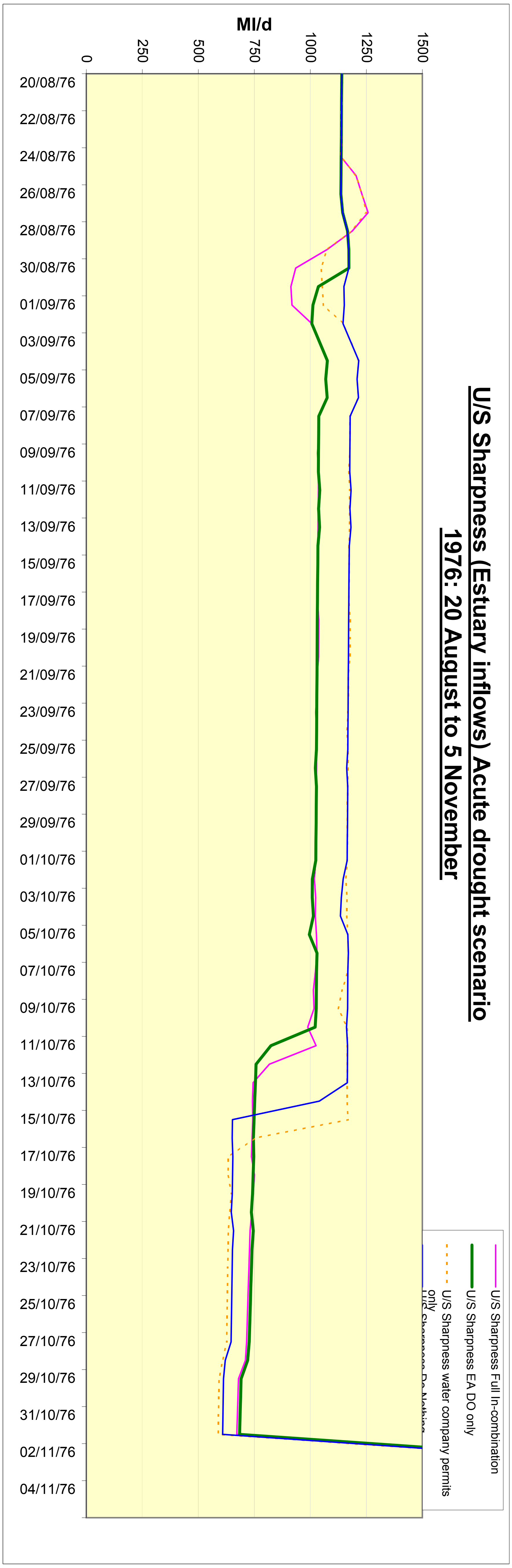

Saxon Lode Acute drought scenario 1976: 1 May to 5 November
Ml/d
0
200
400
600
800
1000
1200
1400
1600
01/05/76
08/05/76
15/05/76
22/05/76
29/05/76
05/06/76
12/06/76
19/06/76
26/06/76
03/07/76
10/07/76
17/07/76
24/07/76
31/07/76
07/08/76
14/08/76
21/08/76
28/08/76
04/09/76
11/09/76
18/09/76
25/09/76
02/10/76
09/10/76
16/10/76
23/10/76
30/10/76
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do nothing

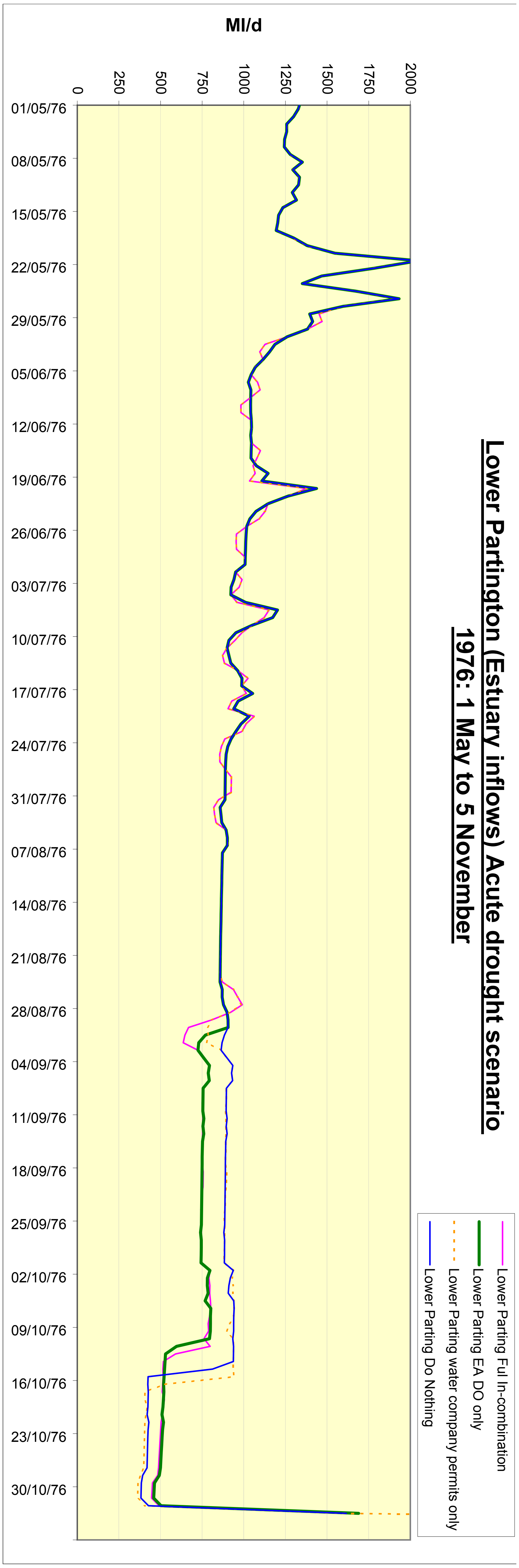

Saxon Lode Acute drought scenario 1976: 20 August to 5 November
Ml/d
0
200
400
600
800
1000
1200
20/08/76
22/08/76
24/08/76
26/08/76
28/08/76
30/08/76
01/09/76
03/09/76
05/09/76
07/09/76
09/09/76
11/09/76
13/09/76
15/09/76
17/09/76
19/09/76
21/09/76
23/09/76
25/09/76
27/09/76
29/09/76
01/10/76
03/10/76
05/10/76
07/10/76
09/10/76
11/10/76
13/10/76
15/10/76
17/10/76
19/10/76
21/10/76
23/10/76
25/10/76
27/10/76
29/10/76
31/10/76
02/11/76
04/11/76
Saxons Lode Full In-combination
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do nothing

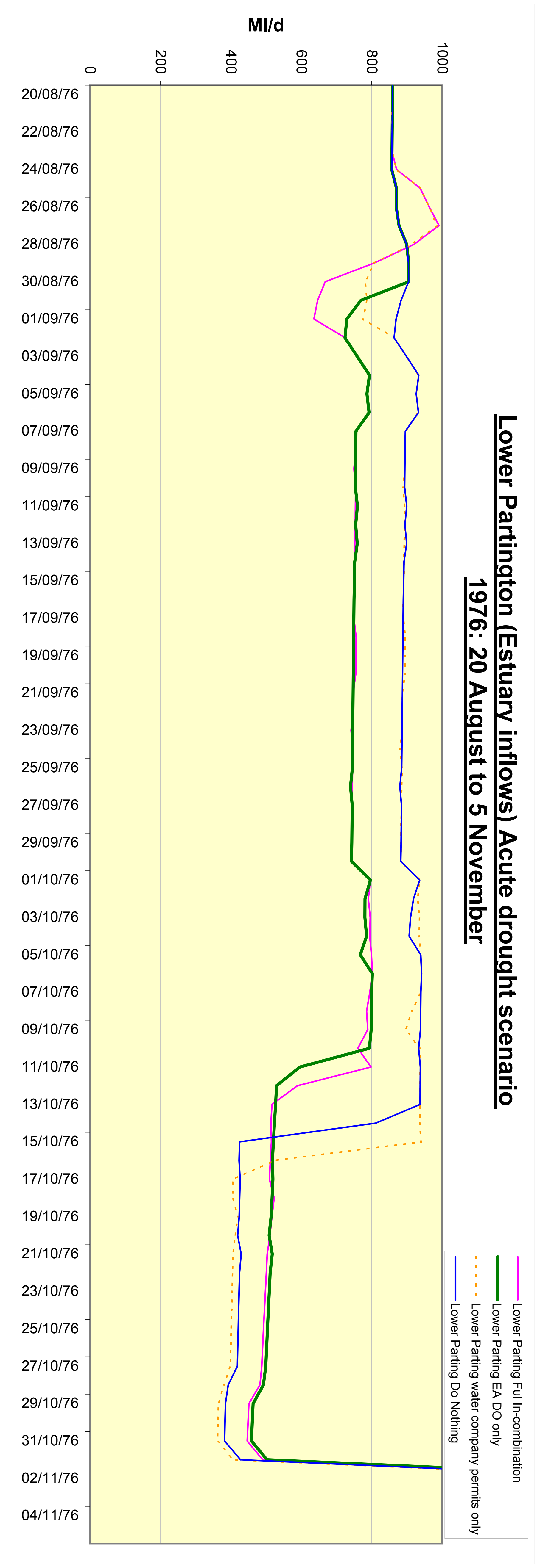

Deerhurst Acute drought scenario 1976: 1 May to 5 November
Ml/d
0
200
400
600
800
1000
1200
1400
1600
1800
2000
01/05/76
03/05/76
05/05/76
07/05/76
09/05/76
11/05/76
13/05/76
15/05/76
17/05/76
19/05/76
21/05/76
23/05/76
25/05/76
27/05/76
29/05/76
31/05/76
02/06/76
04/06/76
06/06/76
08/06/76
10/06/76
12/06/76
14/06/76
16/06/76
18/06/76
20/06/76
22/06/76
24/06/76
26/06/76
28/06/76
30/06/76
02/07/76
04/07/76
06/07/76
08/07/76
10/07/76
12/07/76
14/07/76
16/07/76
18/07/76
20/07/76
22/07/76
24/07/76
26/07/76
28/07/76
30/07/76
01/08/76
03/08/76
05/08/76
07/08/76
09/08/76
11/08/76
13/08/76
15/08/76
17/08/76
19/08/76
Deerhurst Full In-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing


Deerhurst Acute drought scenario 1976: 20 August to 5 November
Ml/d
0
200
400
600
800
1000
1200
1400
20/08/76
22/08/76
24/08/76
26/08/76
28/08/76
30/08/76
01/09/76
03/09/76
05/09/76
07/09/76
09/09/76
11/09/76
13/09/76
15/09/76
17/09/76
19/09/76
21/09/76
23/09/76
25/09/76
27/09/76
29/09/76
01/10/76
03/10/76
05/10/76
07/10/76
09/10/76
11/10/76
13/10/76
15/10/76
17/10/76
19/10/76
21/10/76
23/10/76
25/10/76
27/10/76
29/10/76
31/10/76
02/11/76
04/11/76
Deerhurst Full In-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing


U/S Sharpness (Estuary inflows) Acute drought scenario
1976: 1 May to 5 November
Ml/d
0
250
500
750
1000
1250
1500
1750
2000
2250
2500
01/05/76
08/05/76
15/05/76
22/05/76
29/05/76
05/06/76
12/06/76
19/06/76
26/06/76
03/07/76
10/07/76
17/07/76
24/07/76
31/07/76
07/08/76
14/08/76
21/08/76
28/08/76
04/09/76
11/09/76
18/09/76
25/09/76
02/10/76
09/10/76
16/10/76
23/10/76
30/10/76
U/S Sharpness Full In-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only

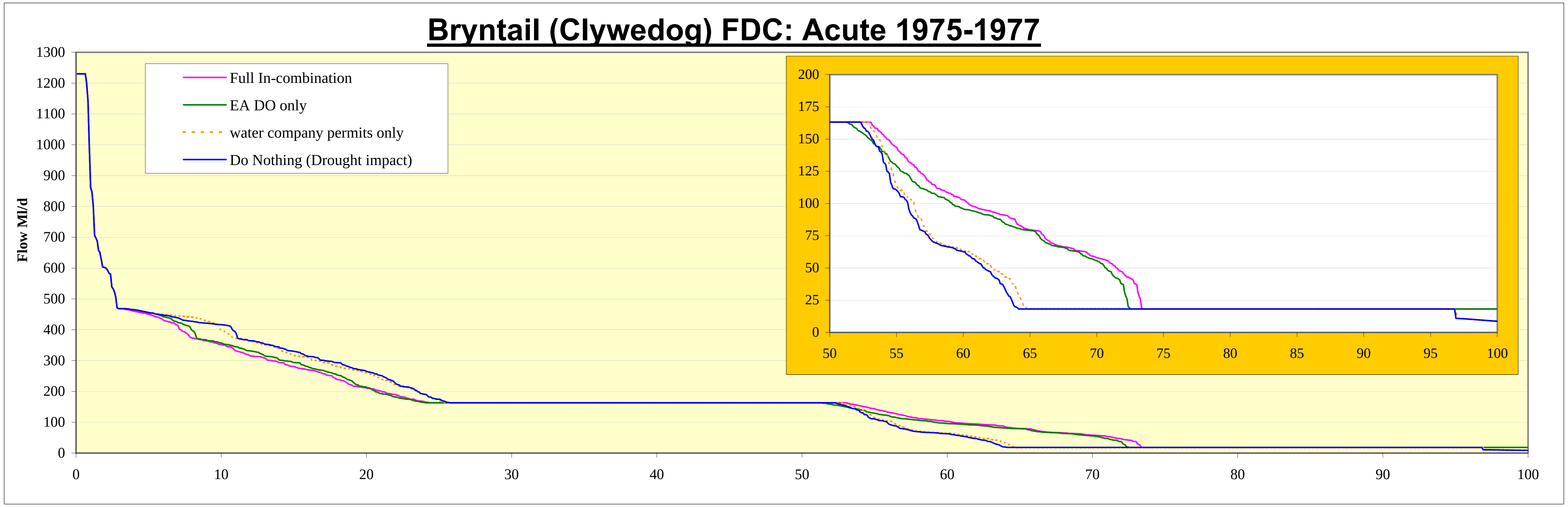

U/S Sharpness (Estuary inflows) Acute drought scenario
1976: 20 August to 5 November
Ml/d
0
250
500
750
1000
1250
1500
20/08/76
22/08/76
24/08/76
26/08/76
28/08/76
30/08/76
01/09/76
03/09/76
05/09/76
07/09/76
09/09/76
11/09/76
13/09/76
15/09/76
17/09/76
19/09/76
21/09/76
23/09/76
25/09/76
27/09/76
29/09/76
01/10/76
03/10/76
05/10/76
07/10/76
09/10/76
11/10/76
13/10/76
15/10/76
17/10/76
19/10/76
21/10/76
23/10/76
25/10/76
27/10/76
29/10/76
31/10/76
02/11/76
04/11/76
U/S Sharpness Full In-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only

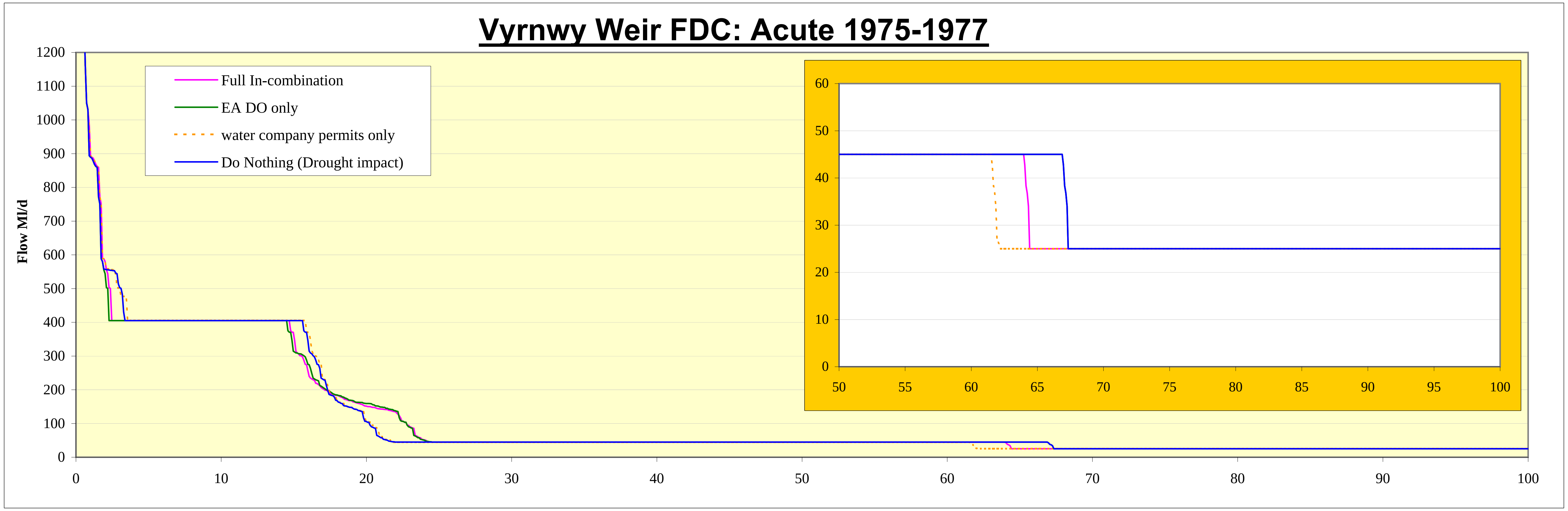

Lower Partington (Estuary inflows) Acute drought scenario
1976: 1 May to 5 November
Ml/d
Lower Parting Ful In-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing

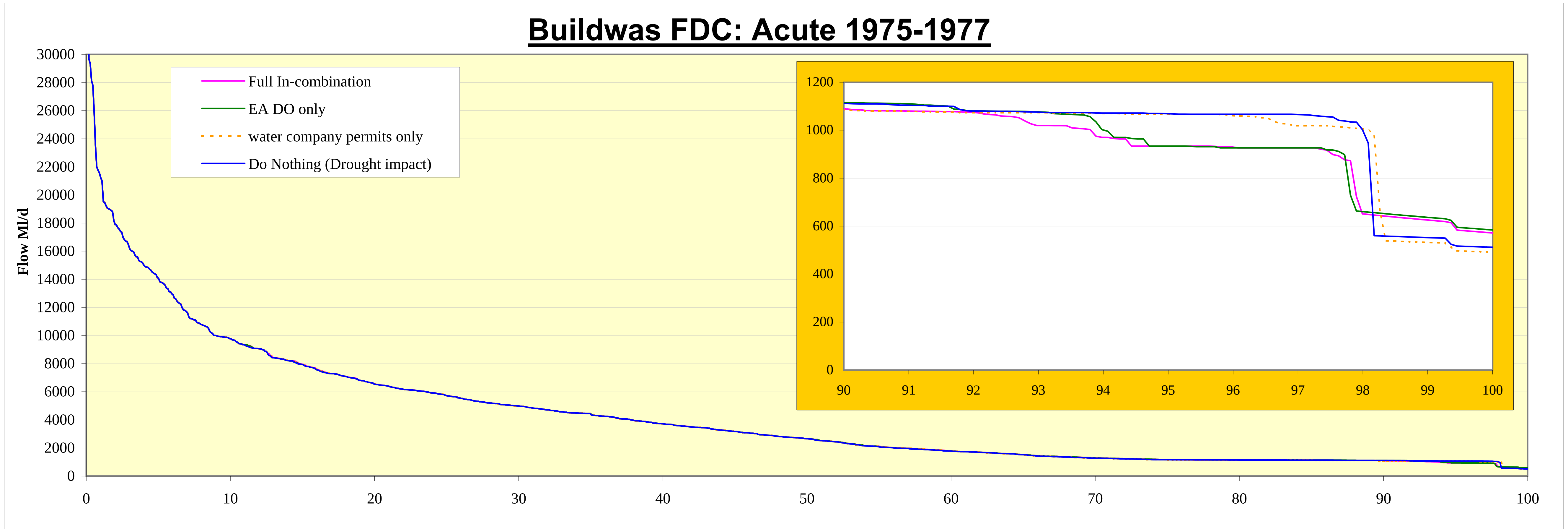

Lower Partington (Estuary inflows) Acute drought scenario
1976: 20 August to 5 November
Ml/d
Lower Parting Ful In-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing

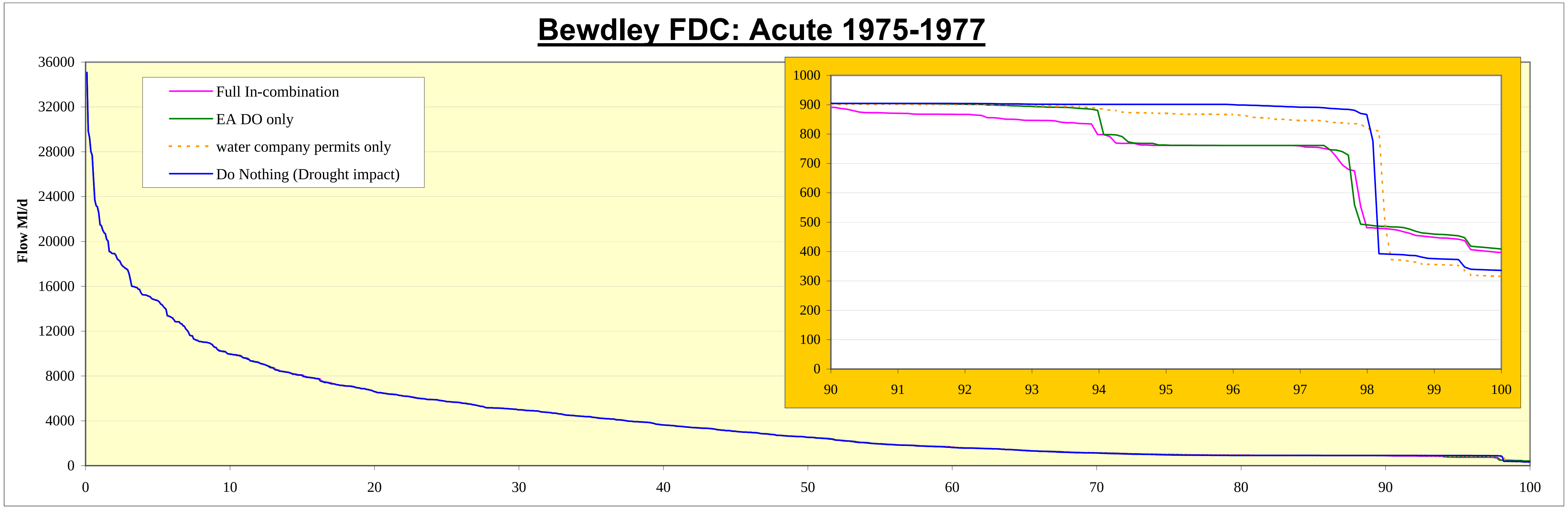
Appendix J.2

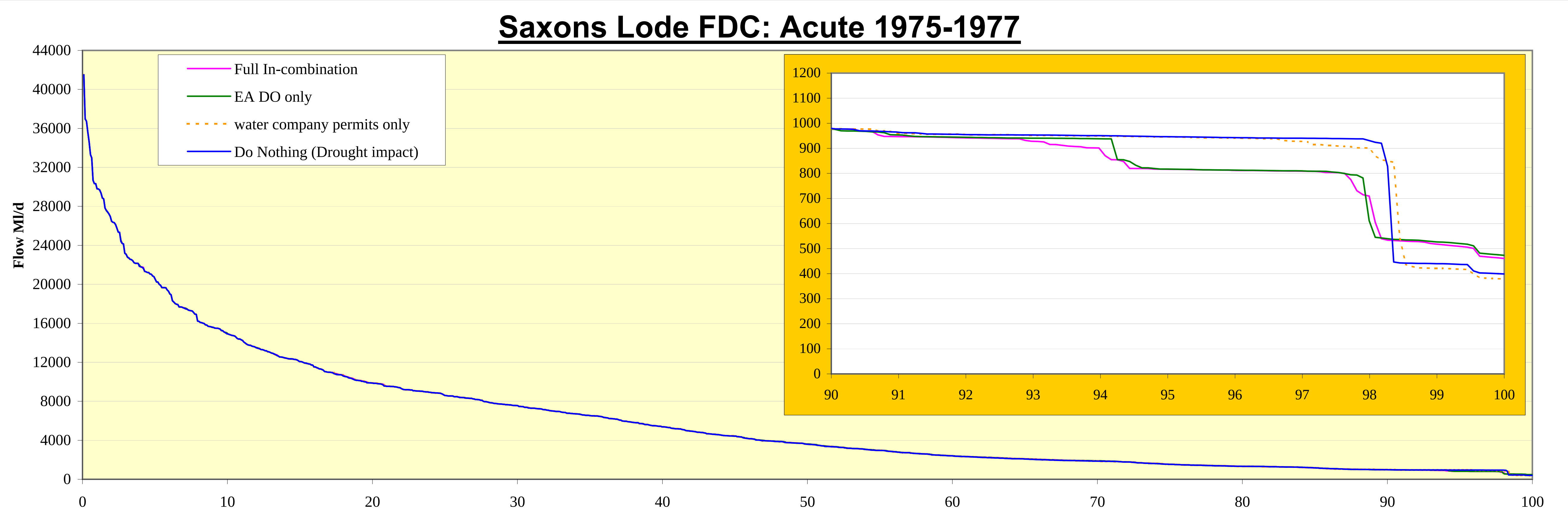
Acute scenario: Flow Duration Curves

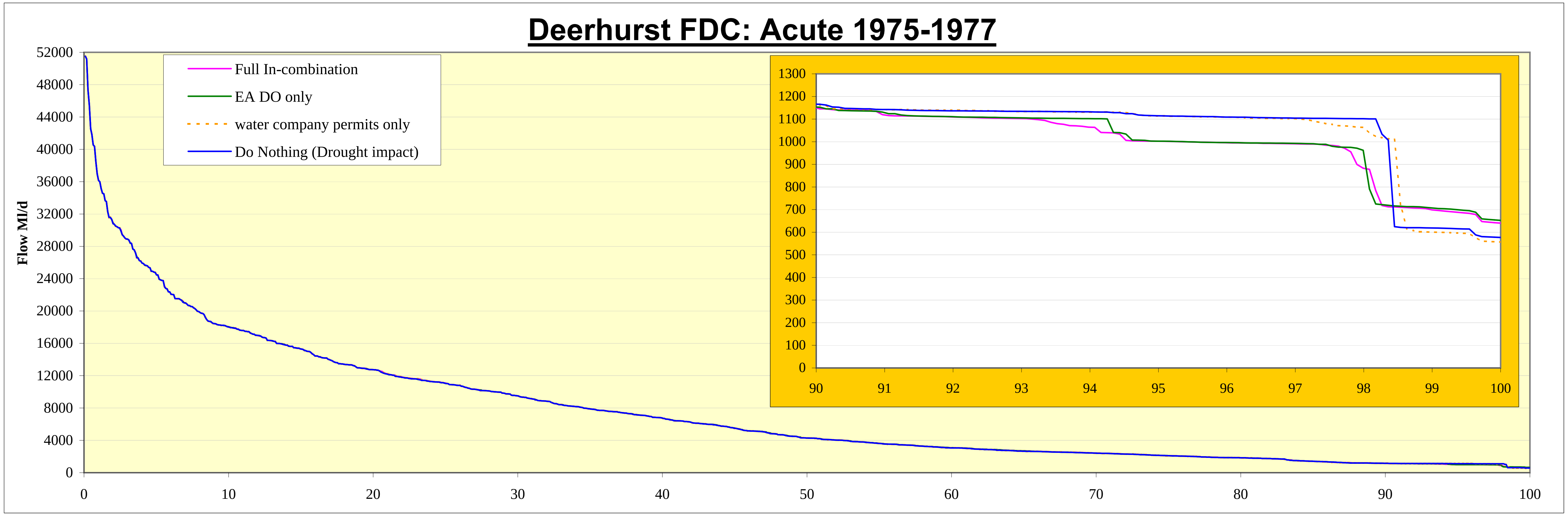

Bryntail (Clywedog) FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
1300
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
200
175
150
125
100
75
50
25
0
50
55
60
65
70
75
80
85
90
95
100

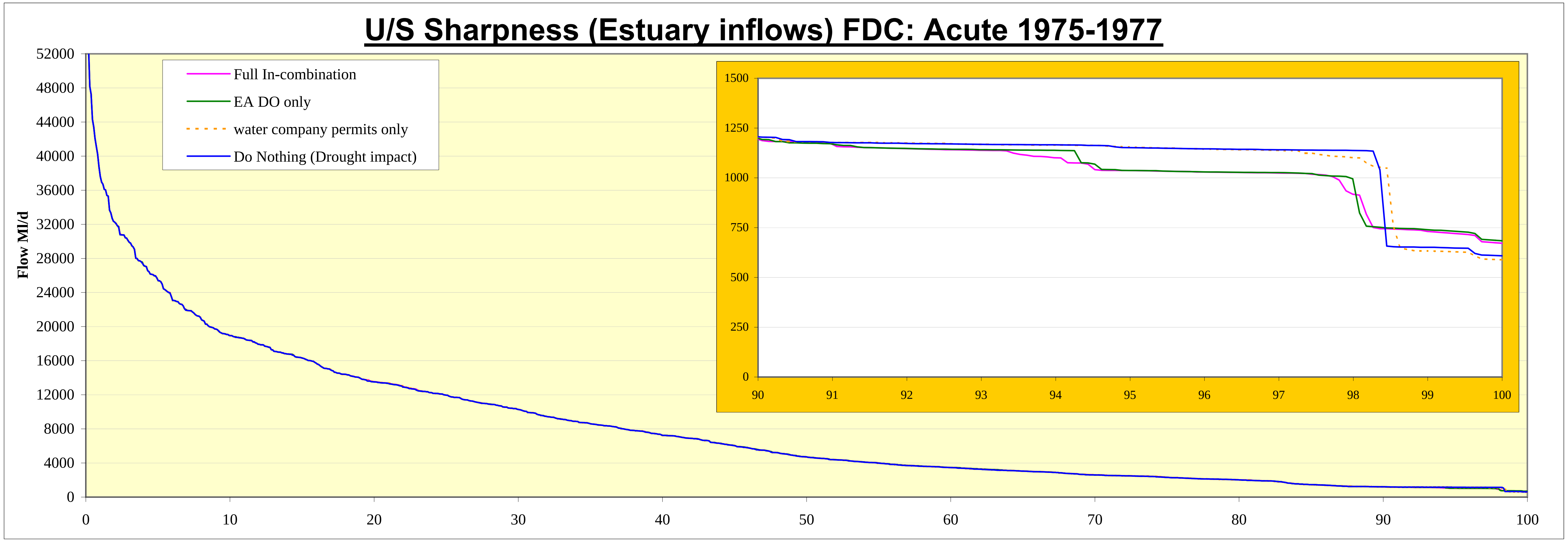

Vyrnwy Weir FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
60
50
40
30
20
10
0
50
55
60
65
70
75
80
85
90
95
100

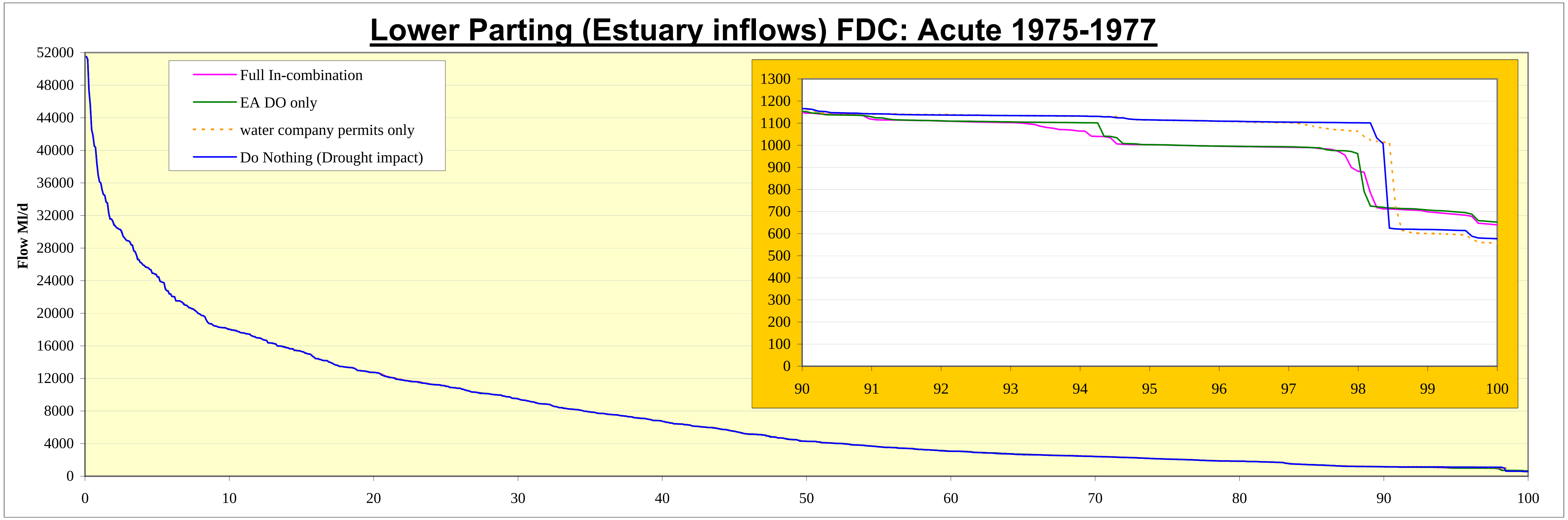

Buildwas FDC: Acute 1975-1977
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Flow Ml/d


Bewdley FDC: Acute 1975-1977
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Flow Ml/d


Saxons Lode FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)

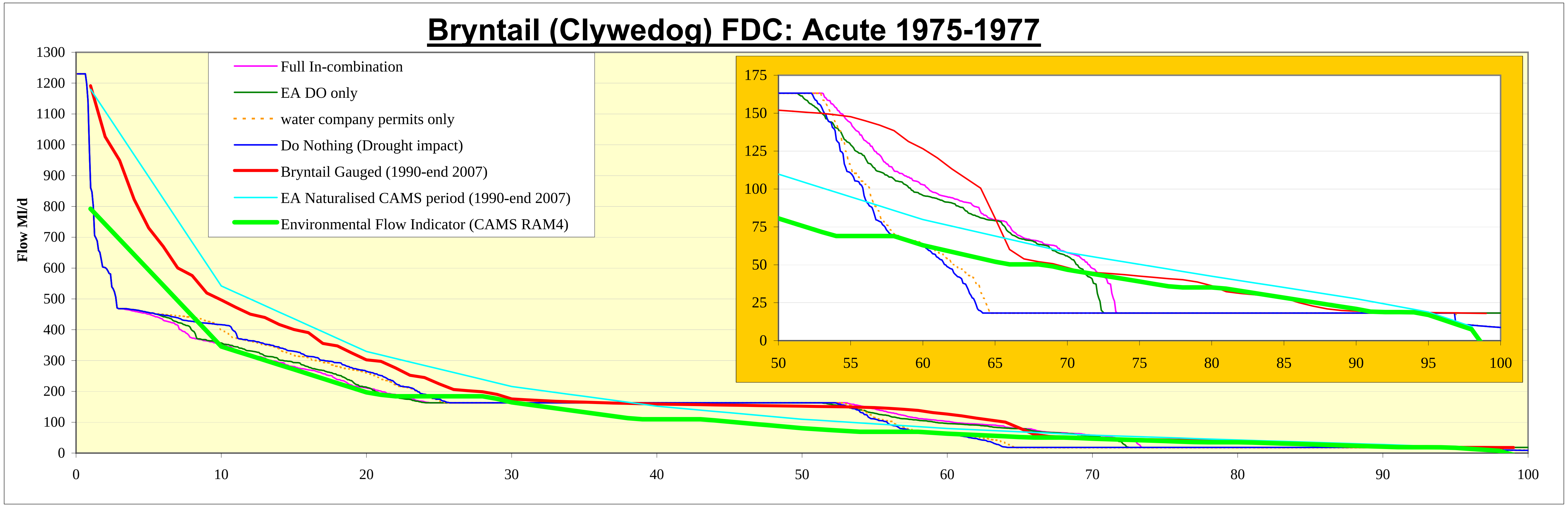

Deerhurst FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)

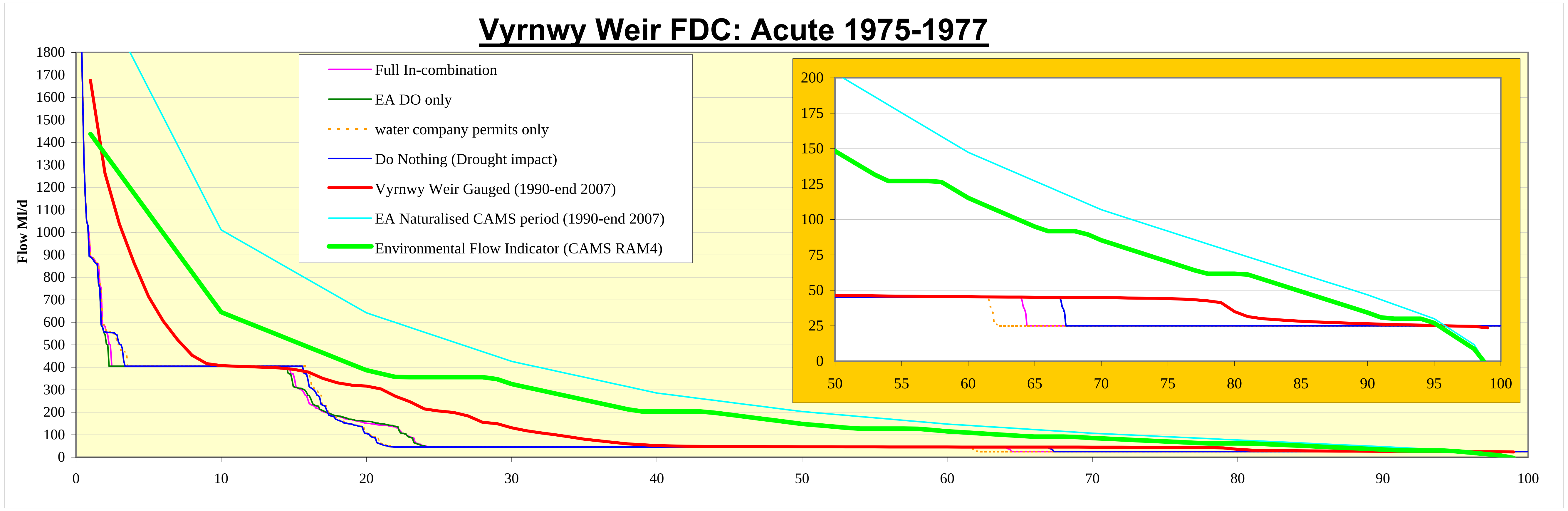

U/S Sharpness (Estuary inflows) FDC: Acute 1975-1977
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Flow Ml/d

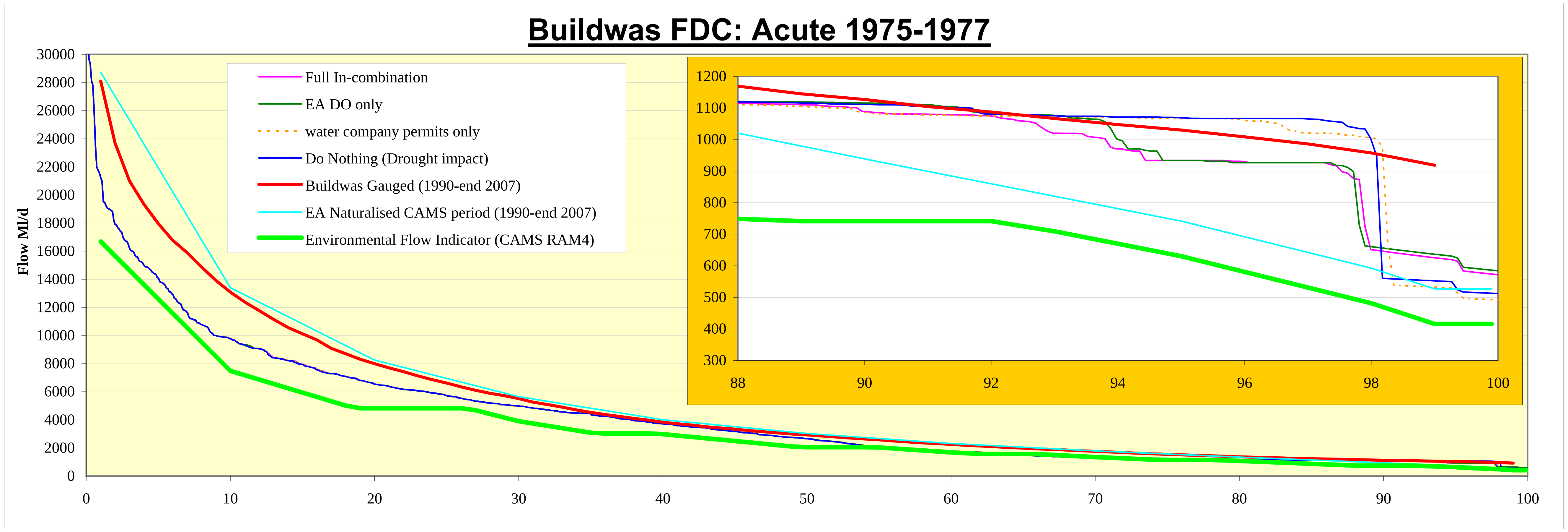

Lower Parting (Estuary inflows) FDC: Acute 1975-1977
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Flow Ml/d

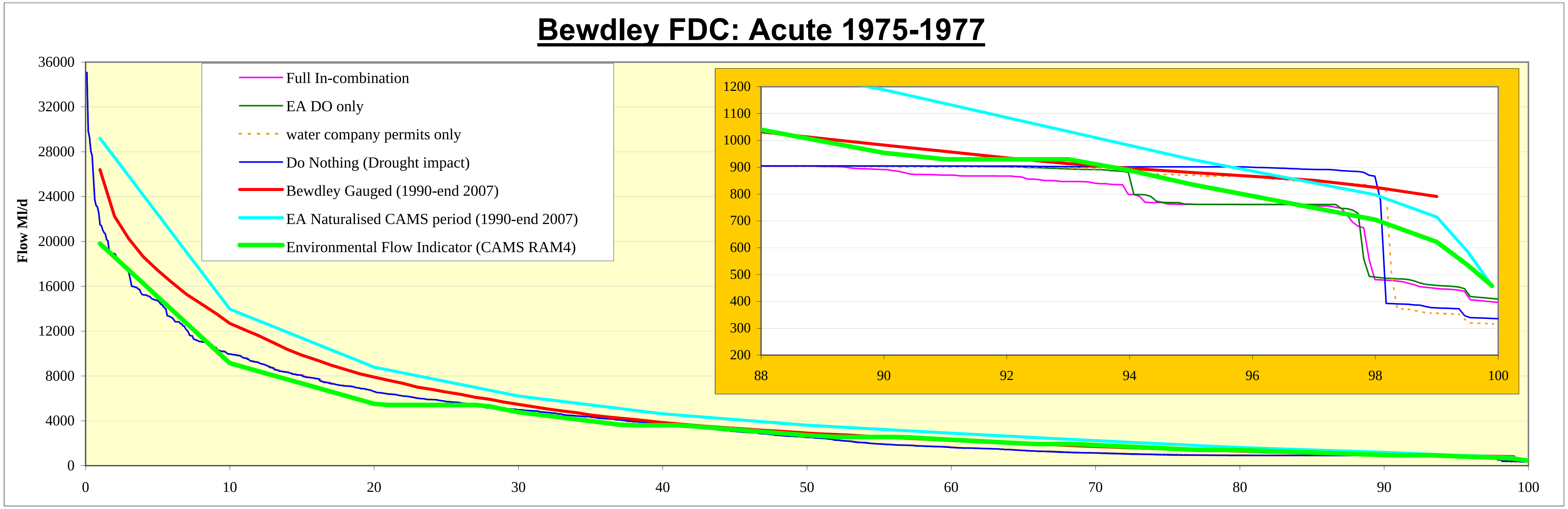
Appendix J.3

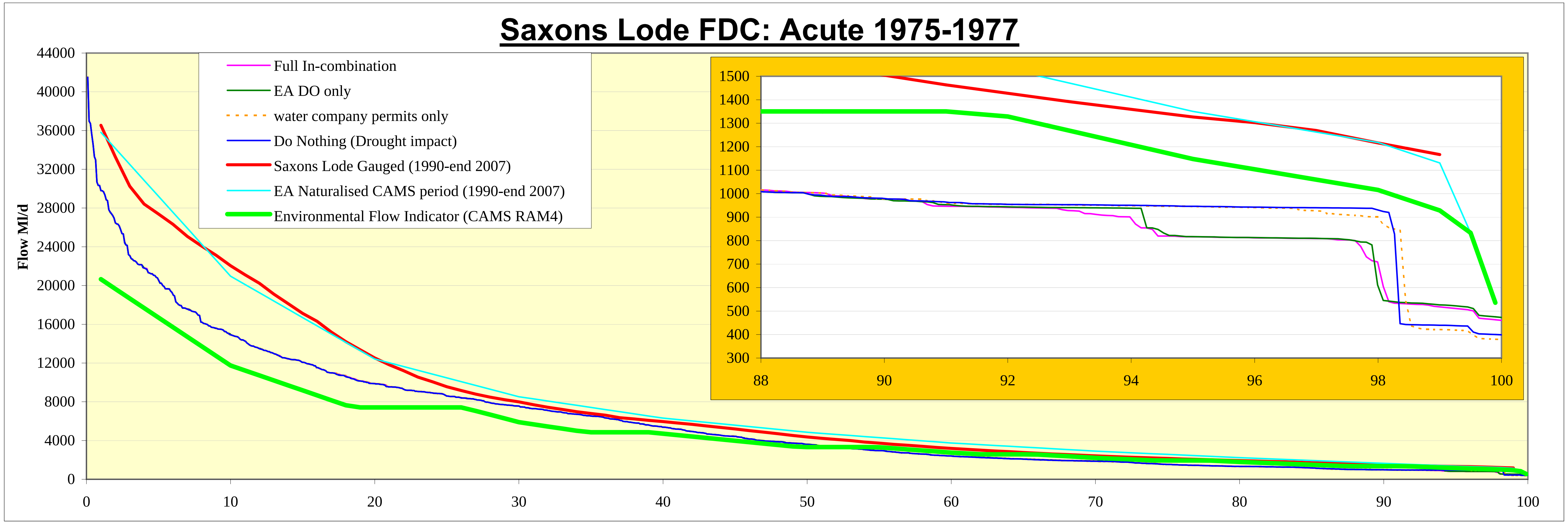
Acute scenario: Environmental Flow Indicator Flow Duration Curves

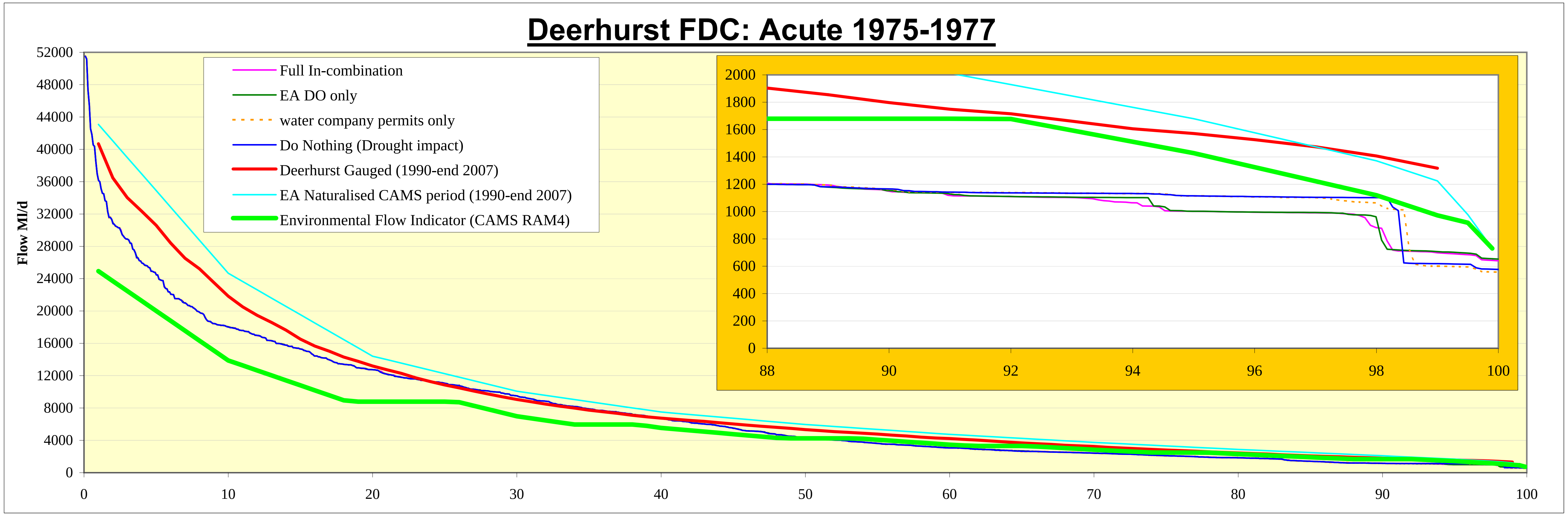

Bryntail (Clywedog) FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Bryntail Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

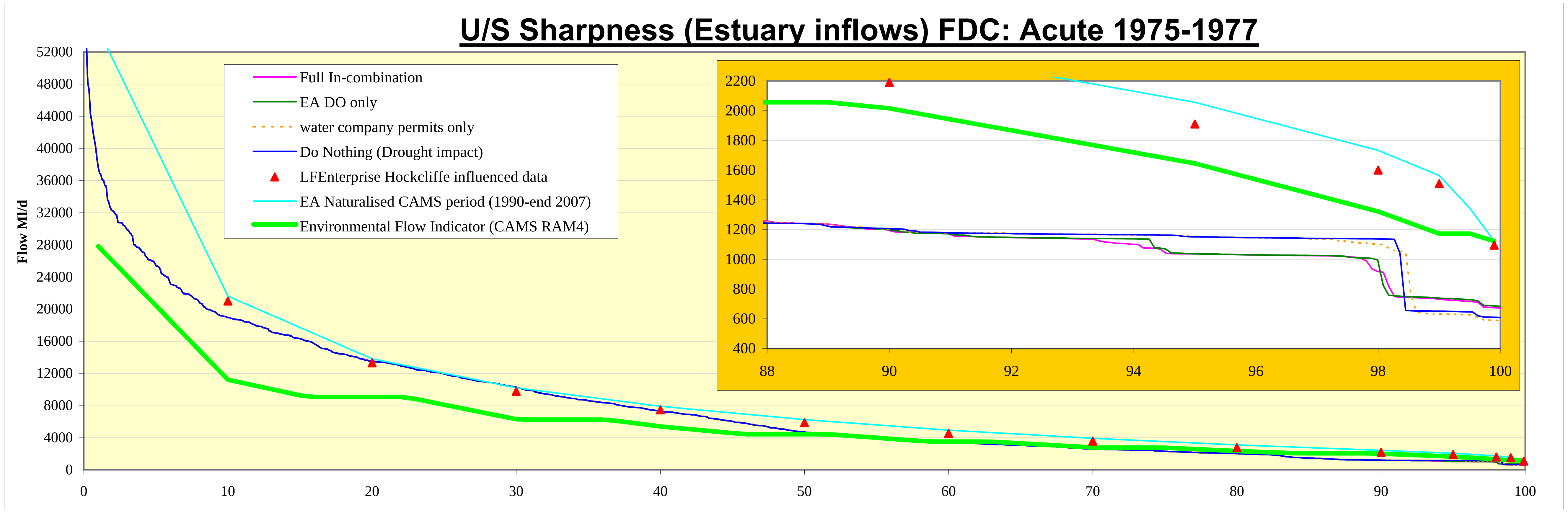

Vyrnwy Weir FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Vyrnwy Weir Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

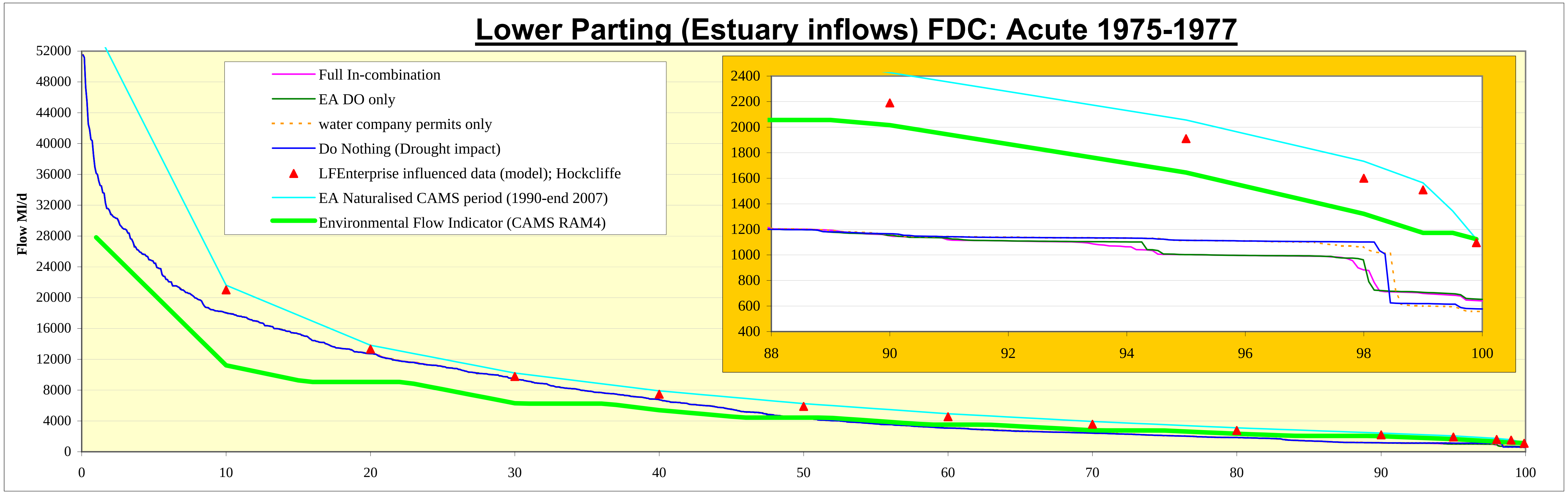

Buildwas FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Buildwas Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

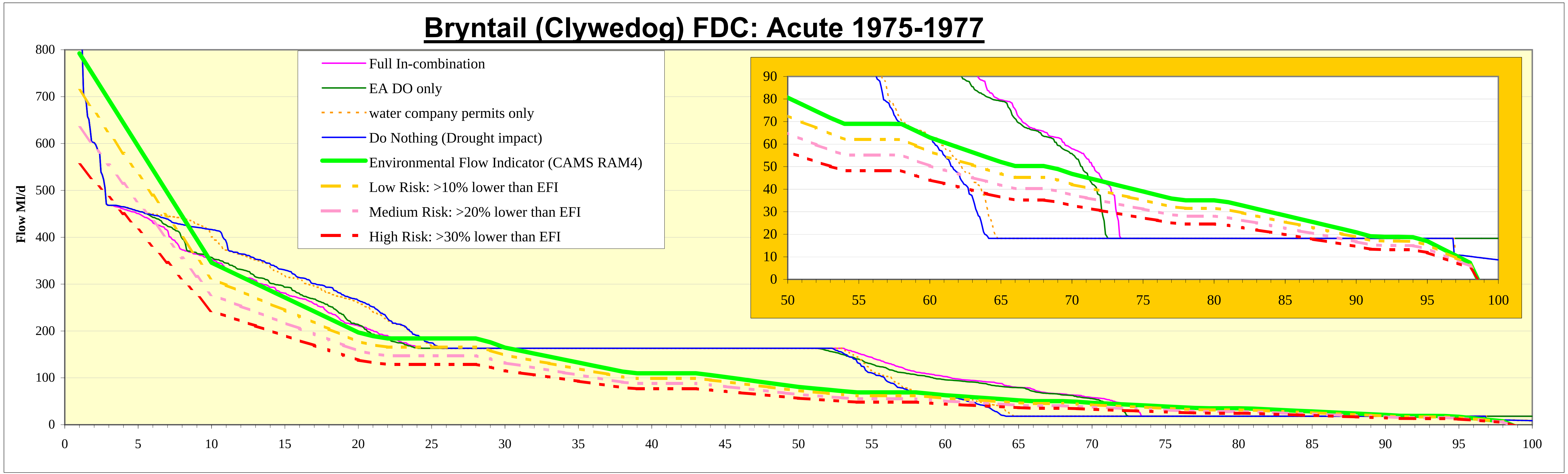

Bewdley FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Bewdley Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

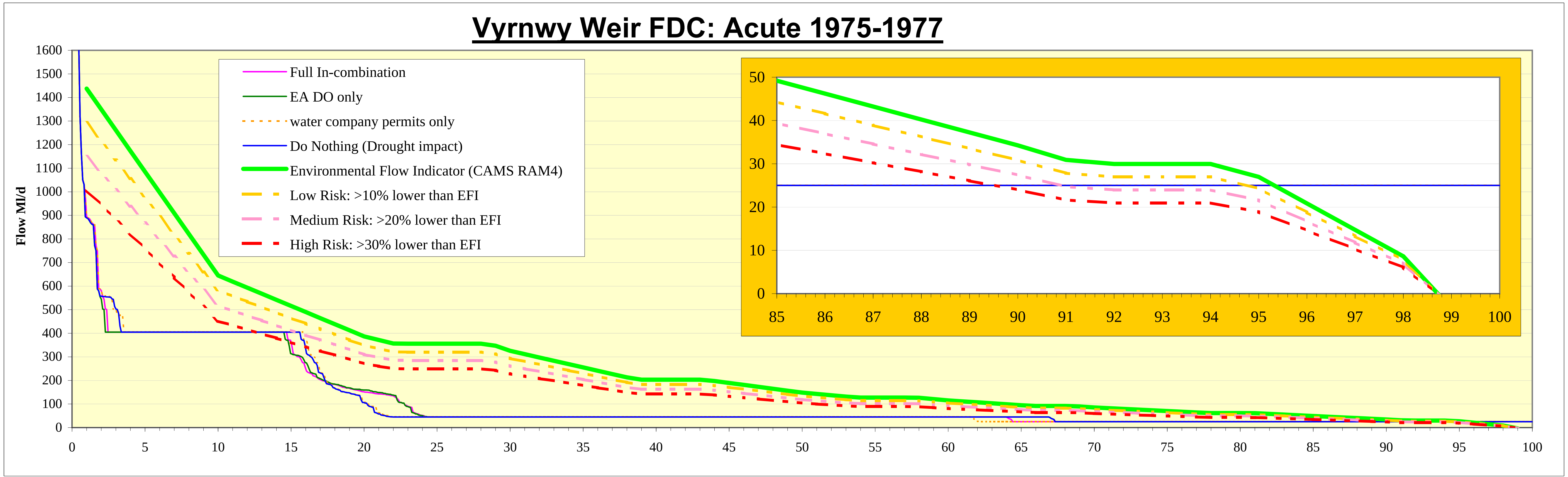

Saxons Lode FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Saxons Lode Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

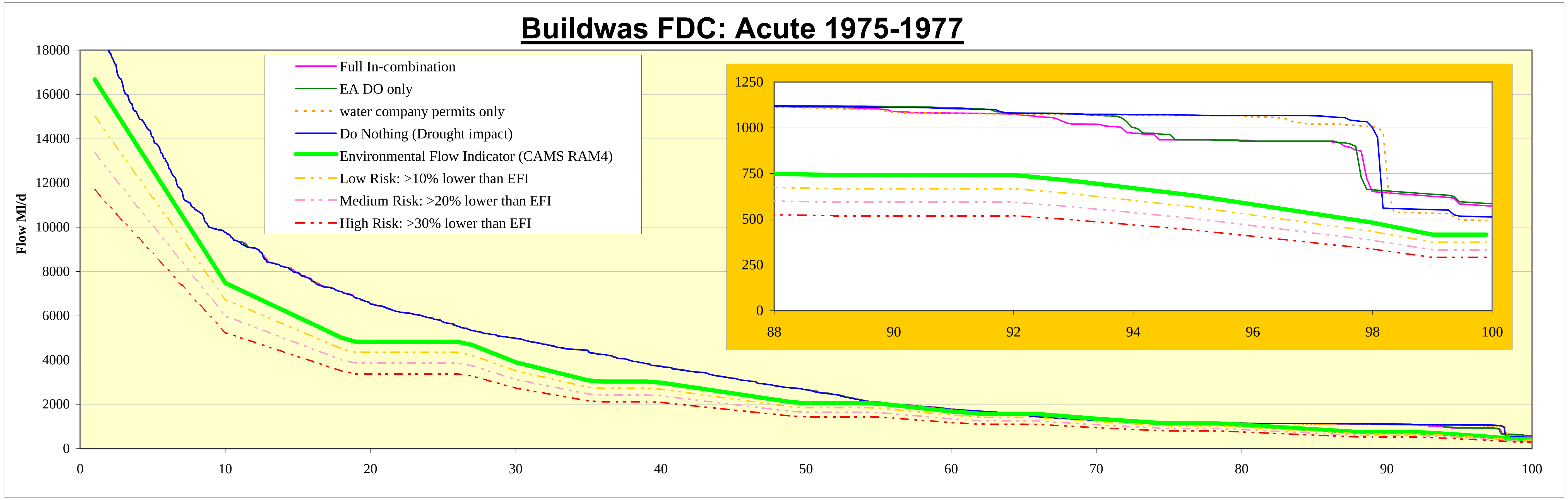

Deerhurst FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Deerhurst Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

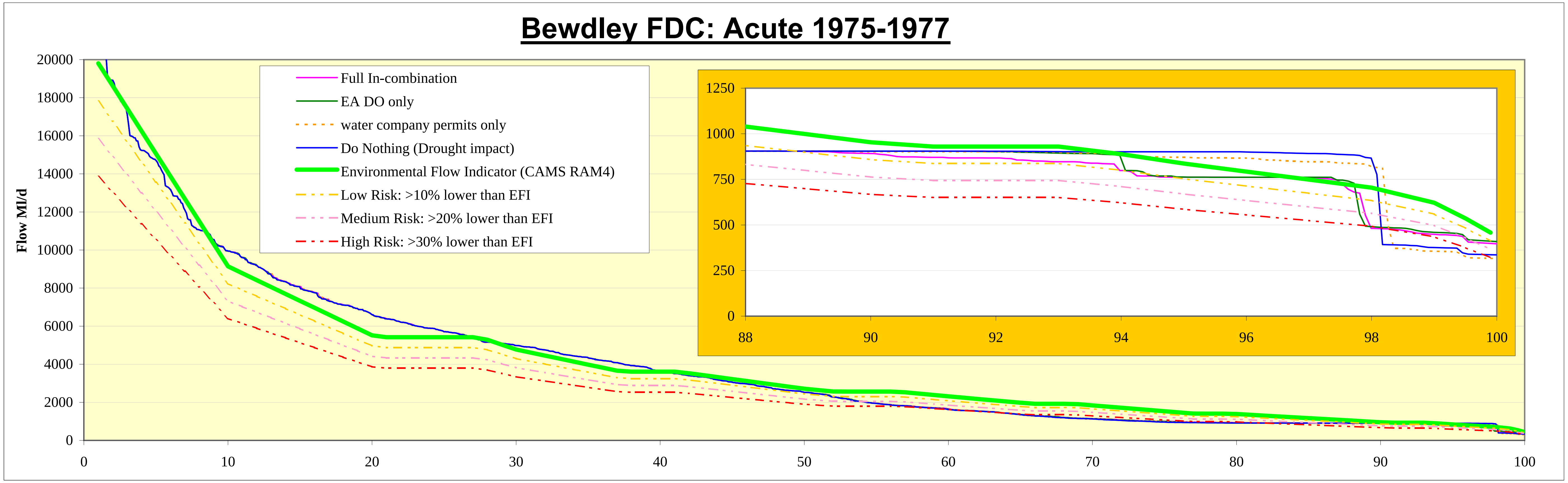

U/S Sharpness (Estuary inflows) FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
LFEnterprise Hockcliffe influenced data
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

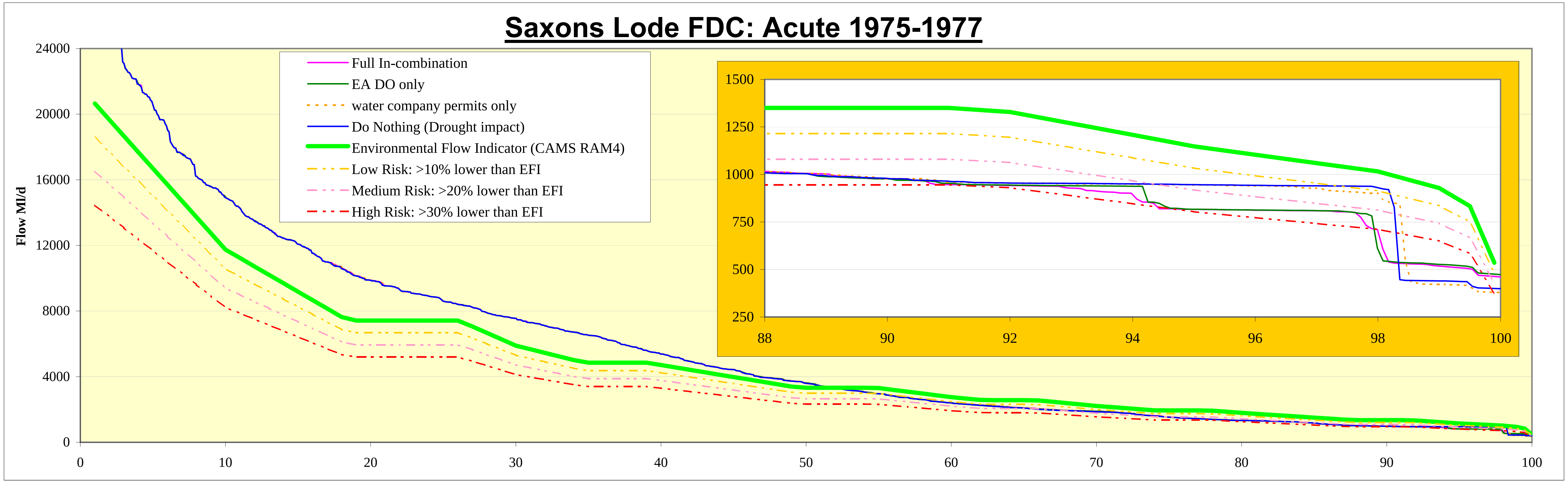

Lower Parting (Estuary inflows) FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
LFEnterprise influenced data (model); Hockcliffe
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

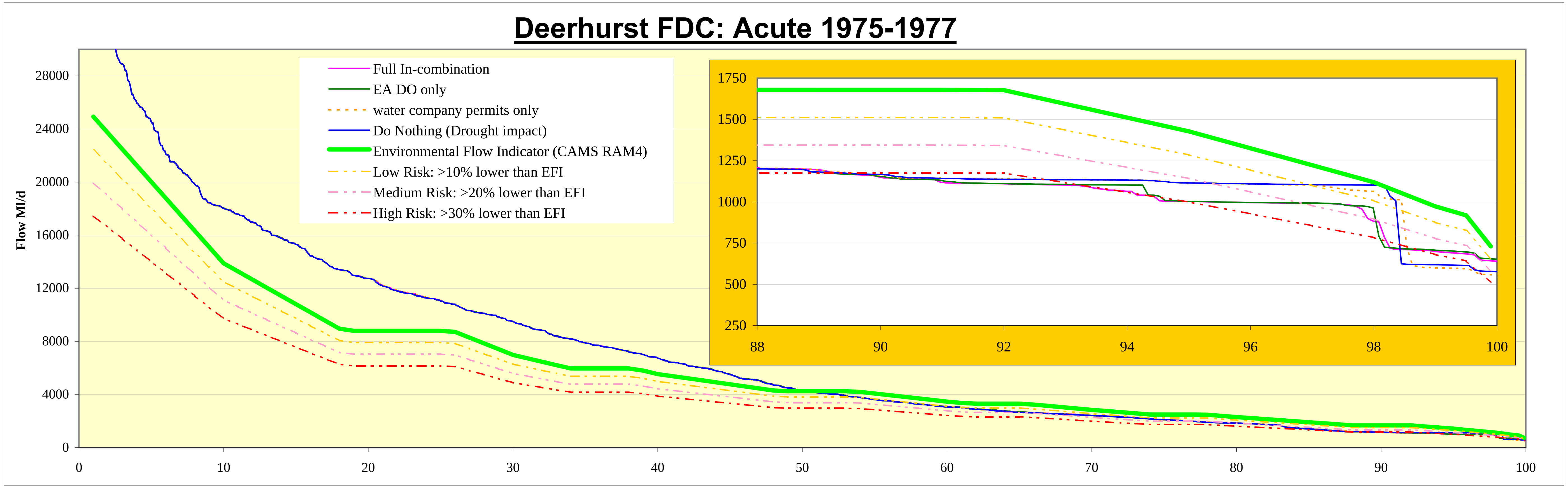

Bryntail (Clywedog) FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI

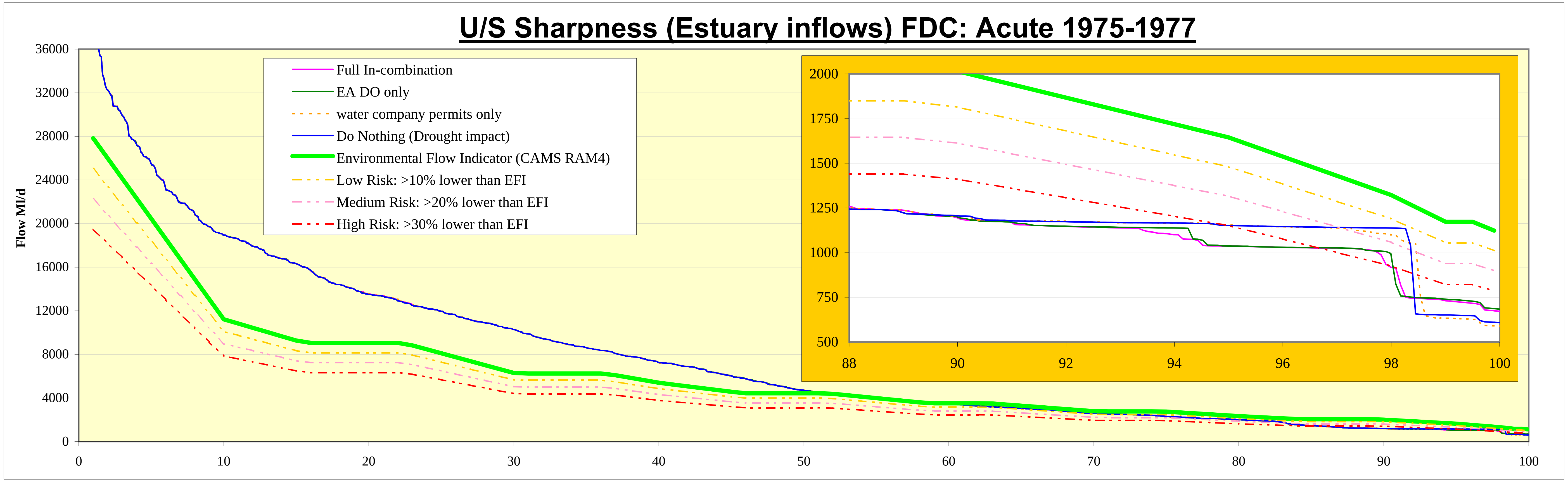

Vyrnwy Weir FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI

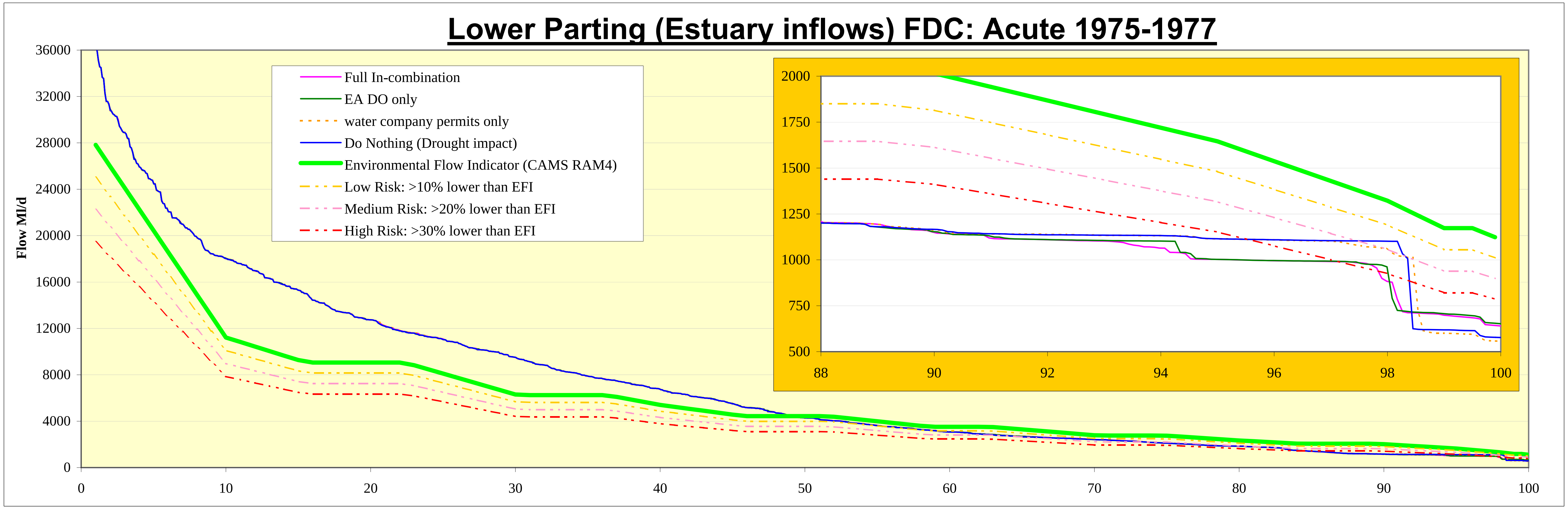

Buildwas FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Bewdley FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Saxons Lode FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Deerhurst FDC: Acute 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


U/S Sharpness (Estuary inflows) FDC: Acute 1975-1977
Flow Ml/d
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
0
10
20
30
40
50
60
70
80
90
100
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI
2000
1750
1500
1250
1000
750
500
88
90
92
94
96
98
100


Lower Parting (Estuary inflows) FDC: Acute 1975-1977
Flow Ml/d
36000
32000
28000
24000
20000
16000
12000
8000
4000
0
0
10
20
30
40
50
60
70
80
90
100
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI
2000
1750
1500
1250
1000
750
500
88
90
92
94
96
98
100

Appendix J.4

Acute scenario: Comparison Summary Statistics

Acute scenario

Severn Regulation system

1975

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Diff. (Ml)	% Diff.	Clywedog releases Ml	Diff. (Ml)	% Diff.	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %
Do Nothing	19004.99			15.69			18989.29			0.00	63.02		100.00		71.42		100.00
EA DO in isolation	19004.99	0.00	0	15.69	0.00	0	18989.29	0.00	0	0.00	63.02	0	100.00	0	71.42	0	100.00
Wc Permits only	18052.19	-952.80	-5	96.59	80.90	515	17955.59	-1033.70	-5	0.00	64.82	2	100.00	0	71.42	0	100.00
Full In-combination	18052.19	-952.80	-5	96.59	80.90	515	17955.59	-1033.70	-5	0.00	64.82	2	100.00	0	71.42	0	100.00

1976

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Diff. (Ml)	% Diff.	Clywedog releases Ml	Diff. (Ml)	% Diff.	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %
Do Nothing	70219.46			17743.50			46374.36			6101.60	5.00		98.10		21.54		99.91
EA DO in isolation	64556.77	#######	-8	17707.60	-35.90	0	40747.57	-5626.79	-12	6101.60	15.61	11	98.10	0	21.55	0	99.91
Wc Permits only	70166.40	-53.06	0	17707.60	-35.90	0	46357.21	-17.15	0	6101.60	5.00	0	98.10	0	23.66	2	99.91
Full In-combination	64021.73	#######	-9	17671.70	-71.80	0	40248.44	-6125.92	-13	6101.60	16.59	12	98.10	0	23.67	2	99.91

1977

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Diff. (Ml)	% Diff.	Clywedog releases Ml	Diff. (Ml)	% Diff.	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %
Do Nothing	217.25			0.00			217.25			0.00	26.04		89.58		37.09		100.00
EA DO in isolation	217.25	0.00	0	0.00	0.00	0	217.25	0.00	0	0.00	36.71	11	97.47	8	37.10	0	100.00
Wc Permits only	205.51	-11.74	-5	0.00	0.00	0	205.51	-11.74	-5	0.00	26.04	0	89.58	0	39.45	2	100.00
Full In-combination	205.51	-11.74	-5	0.00	0.00	0	205.51	-11.74	-5	0.00	37.70	12	97.81	8	39.46	2	100.00

1978

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml			Clywedog releases Ml			Vyrnwy releases Ml	Min. Clywedog Storage %		Max. Clywedog Storage %		Min. Vyrnwy Storage %		Max. Vyrnwy Storage %
Do Nothing	3064.46			0.00			3064.46			0.00	77.37		99.02		73.94		100.00
EA DO in isolation	3064.46	0.00	0	0.00			3064.46			0.00	77.37		99.02		73.94		100.00
Wc Permits only	3064.46	0.00	0	0.00			3064.46			0.00	77.37		99.02		73.94		100.00
Full In-combination	3064.46	0.00	0	0.00			3064.46			0.00	77.37		99.02		73.94		100.00

1979

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml			Clywedog releases Ml			Vyrnwy releases Ml	Min. Clywedog Storage %		Max. Clywedog Storage %		Min. Vyrnwy Storage %		Max. Vyrnwy Storage %
Do Nothing	16.85			0.00			16.85			0.00	83.30		100.00		79.03		100.00
EA DO in isolation	16.85	0.00	0	0.00			16.85			0.00	83.30		100.00		79.03		100.00
Wc Permits only	16.85	0.00	0	0.00			16.85			0.00	83.30		100.00		79.03		100.00
Full In-combination	16.85	0.00	0	0.00			16.85			0.00	83.30		100.00		79.03		100.00

Acute scenario

Minimum Flows

1975

	Bryntail (Clywedog) min. flow Ml/d	Ml/d Diff.	Vyrnwy min. flow Ml/d	Ml/d Diff.	Buildwas min. flow Ml/d	Ml/d Diff.	Bewdley min. flow Ml/d	Ml/d Diff.	Saxons Lode min. flow Ml/d	Ml/d Diff.	Deerhurst min. flow Ml/d	Ml/d Diff.	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Ml/d Diff.	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures	% Diff.
Do Nothing	18.20		25.00		1002.62		891.14		1250.07		1685.23		1808.54		1511.64		0	0	0	
EA DO in isolation	18.20	0	25.00	0	1002.62	0	891.14	0	1250.07	0	1685.23	0	1808.54	0	1511.64	0.00	0	0	0	0
Wc Permits only	18.20	0	25.00	0	975.11	-27.51	836.16	-54.99	1208.44	-41.63	1646.56	-38.67	1773.26	-35.28	1476.36	-35.28	2	0	0	0
Full In-combination	18.20	0	25.00	0	975.11	-27.51	836.16	-54.99	1208.44	-41.63	1646.56	-38.67	1773.26	-35.28	1476.36	-35.28	2	0	0	0

1976

	Bryntail (Clywedog) min. flow Ml/d	Ml/d Diff.	Vyrnwy min. flow Ml/d	Ml/d Diff.	Buildwas min. flow Ml/d	Ml/d Diff.	Bewdley min. flow Ml/d	Ml/d Diff.	Saxons Lode min. flow Ml/d	Ml/d Diff.	Deerhurst min. flow Ml/d	Ml/d Diff.	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Ml/d Diff.	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures	% Diff.
Do Nothing	8.67		25.00		512.05		335.89		398.89		576.92		608.86		382.44		22	21	21	
EA DO in isolation	18.20	9.53	25.00	0	584.12	72.08	409.00	73.11	473.06	74.17	652.15	75.24	684.09	75.24	458.76	76.32	66	26	25	4
Wc Permits only	8.67	0	25.00	0	492.05	-20.00	315.77	-20.13	378.89	-20.00	556.92	-20.00	588.86	-20.00	362.44	-20.00	34	20	20	-1
Full In-combination	18.20	9.53	25.00	0	571.57	59.52	396.58	60.69	460.61	61.72	639.95	63.03	671.89	63.03	446.67	64.23	78	28	24	3

1977

	Bryntail (Clywedog) min. flow Ml/d	Ml/d Diff.	Vyrnwy min. flow Ml/d	Ml/d Diff.	Buildwas min. flow Ml/d	Ml/d Diff.	Bewdley min. flow Ml/d	Ml/d Diff.	Saxons Lode min. flow Ml/d	Ml/d Diff.	Deerhurst min. flow Ml/d	Ml/d Diff.	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Ml/d Diff.	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures
Do Nothing	18.20		25.00		1033.77		907.95		1716.80		2457.90		2906.90		2623.15		0	0	0
EA DO in isolation	18.20	0	25.00	0	1079.41	46	922.15	14	1747.29	30	2487.35	29	2920.05	13	2623.15	0	0	0	0
Wc Permits only	18.20	0	25.00	0	1022.03	-12	907.95	0	1727.89	11	2470.69	13	2920.05	13	2623.15	0	0	0	0
Full In-combination	18.20	0	25.00	0	1079.41	46	922.15	14	1747.29	30	2487.35	29	2920.05	13	2623.15	0	0	0	0

1978

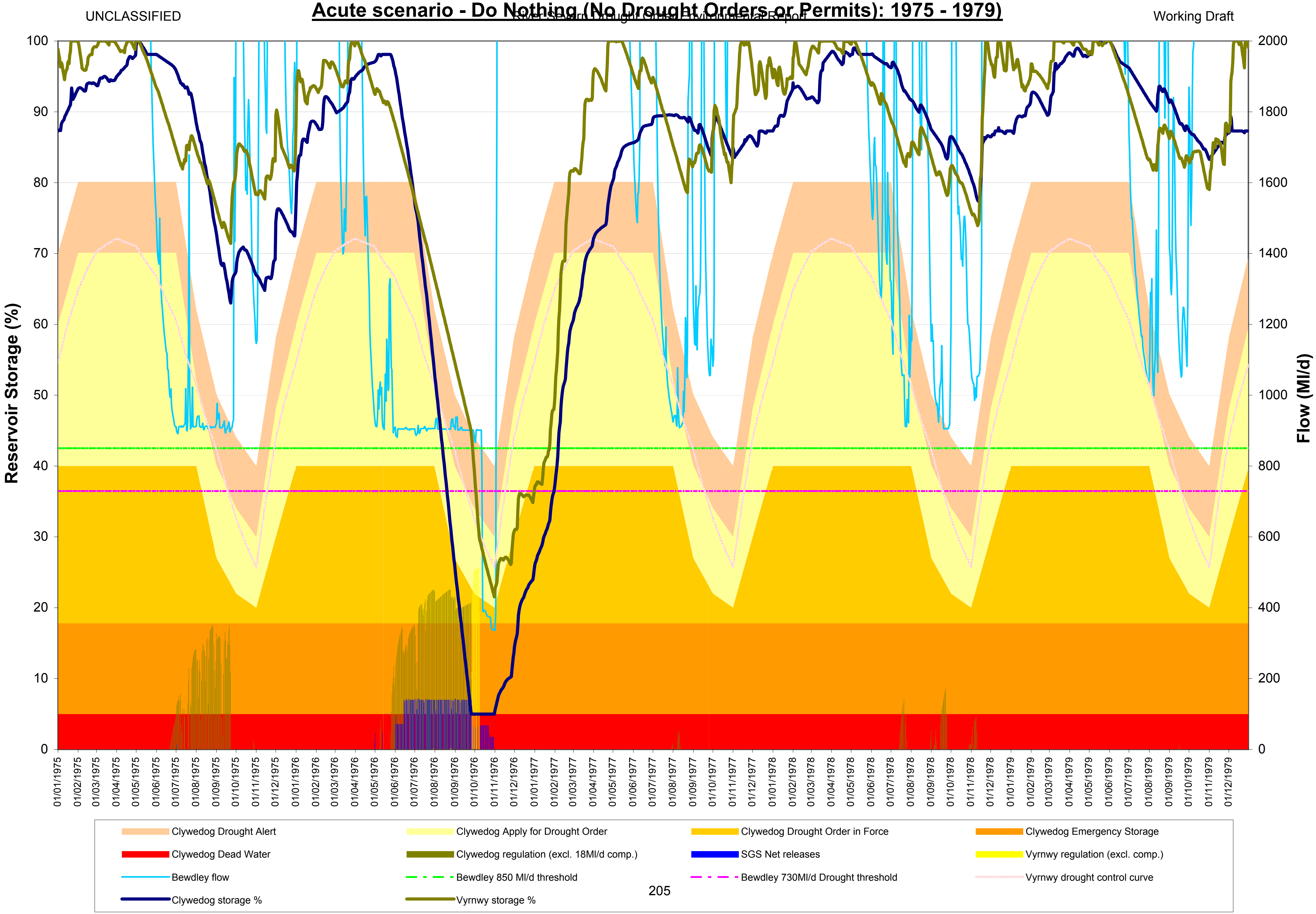
	Bryntail (Clywedog) min. flow Ml/d	Vyrnwy min. flow Ml/d	Buildwas min. flow Ml/d	Bewdley min. flow Ml/d	Saxons Lode min. flow Ml/d	Deerhurst min. flow Ml/d	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures
Do Nothing	18.20	25.00	969.18	905.04	1423.58	1807.88	1934.38		1735.80	0	0	0
EA DO in isolation	18.20	25.00	969.18	905.04	1423.58	1807.88	1934.38		1735.80	0	0	0
Wc Permits only	18.20	25.00	969.18	905.04	1423.58	1807.88	1934.38		1735.80	0	0	0
Full In-combination	18.20	25.00	969.18	905.04	1423.58	1807.88	1934.38		1735.80	0	0	0

1979

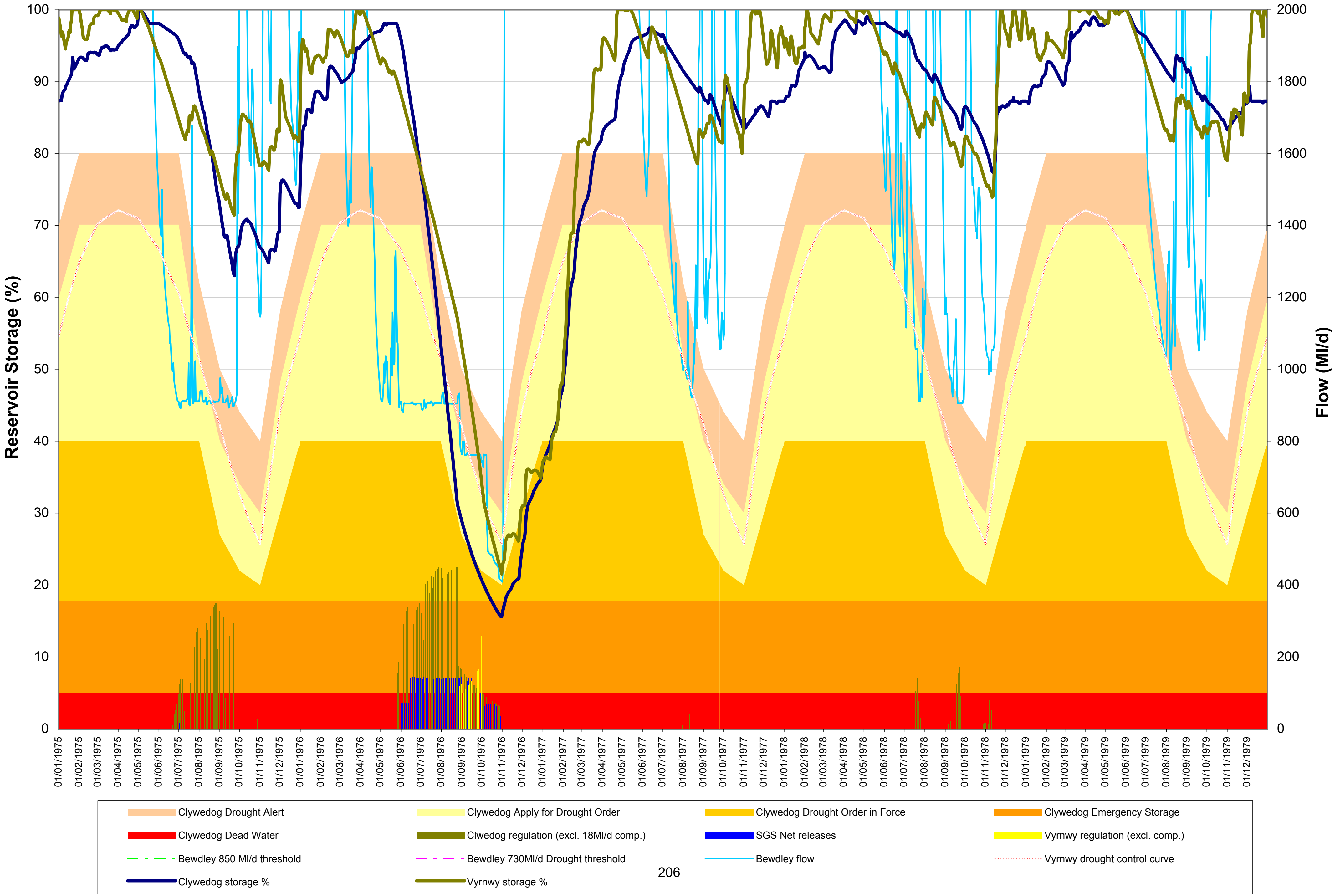
	Bryntail (Clywedog) min. flow Ml/d	Vyrnwy min. flow Ml/d	Buildwas min. flow Ml/d	Bewdley min. flow Ml/d	Saxons Lode min. flow Ml/d	Deerhurst min. flow Ml/d	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures
Do Nothing	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0
EA DO in isolation	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0
Wc Permits only	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0
Full In-combination	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0

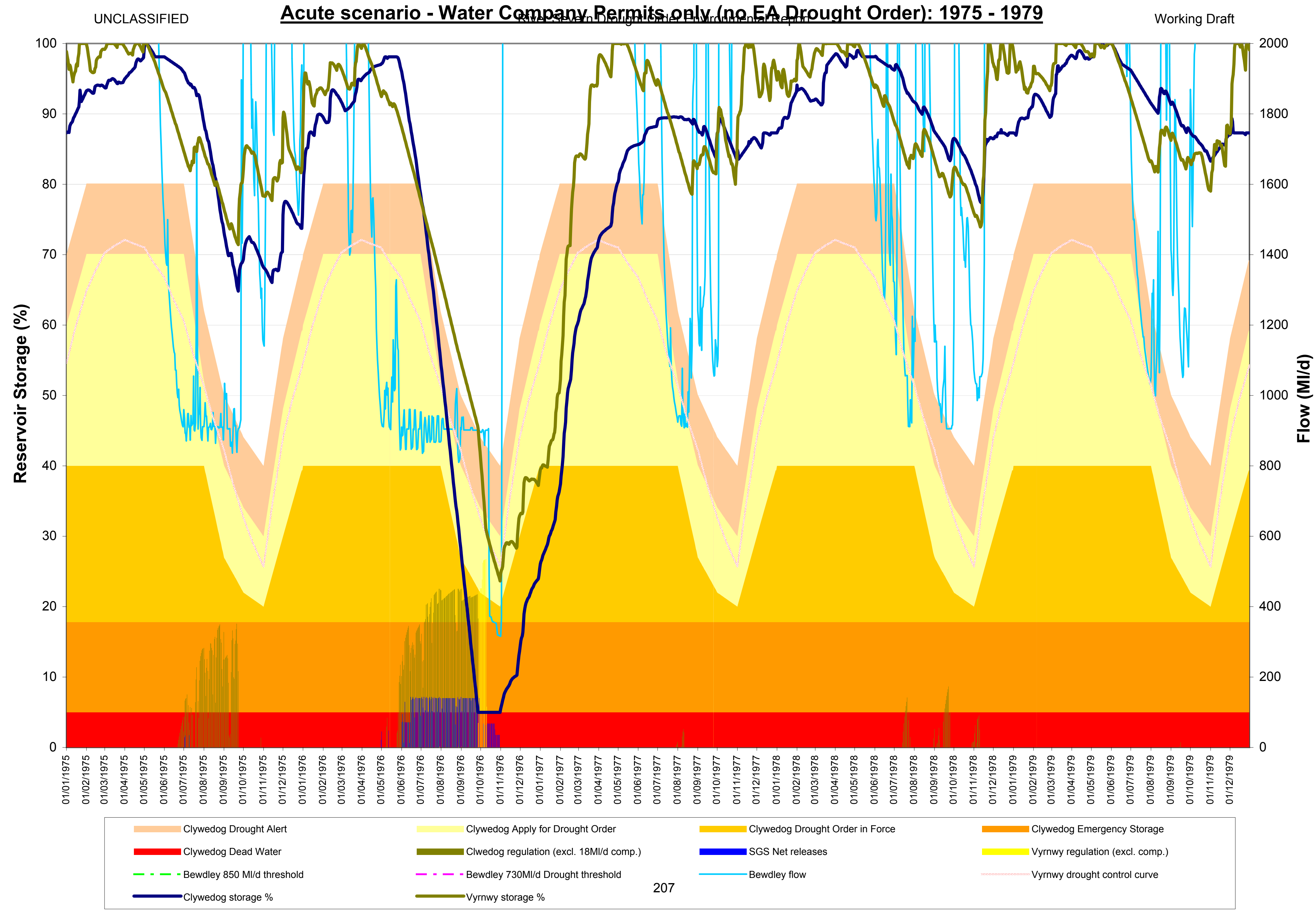
Appendix J.5

Acute scenario: Reservoir Operations


Acute scenario - Do Nothing (No Drought Orders or Permits): 1975 - 1979
Reservoir Storage (%)
Flow (Ml/d)
Clywedog Drought Alert
Clywedog Apply for Drought Order
Clywedog Drought Order in Force
Clywedog Emergency Storage
Clywedog Dead Water
Clywedog regulation (excl. 18Ml/d comp.)
SGS Net releases
Vyrnwy regulation (excl. comp.)
Bewdley flow
Bewdley 850 Ml/d threshold
Bewdley 730Ml/d Drought threshold
Vyrnwy drought control curve
Clywedog storage %
Vyrnwy storage %

Acute scenario - EA Drought Order only (no water company Permits): 1975 - 1979




Acute scenario - Water Company Permits only (no EA Drought Order): 1975 - 1979
Reservoir Storage (%)
Flow (Ml/d)
0
10
20
30
40
50
60
70
80
90
100
0
200
400
600
800
1000
1200
1400
1600
1800
2000
01/01/1975
01/02/1975
01/03/1975
01/04/1975
01/05/1975
01/06/1975
01/07/1975
01/08/1975
01/09/1975
01/10/1975
01/11/1975
01/12/1975
01/01/1976
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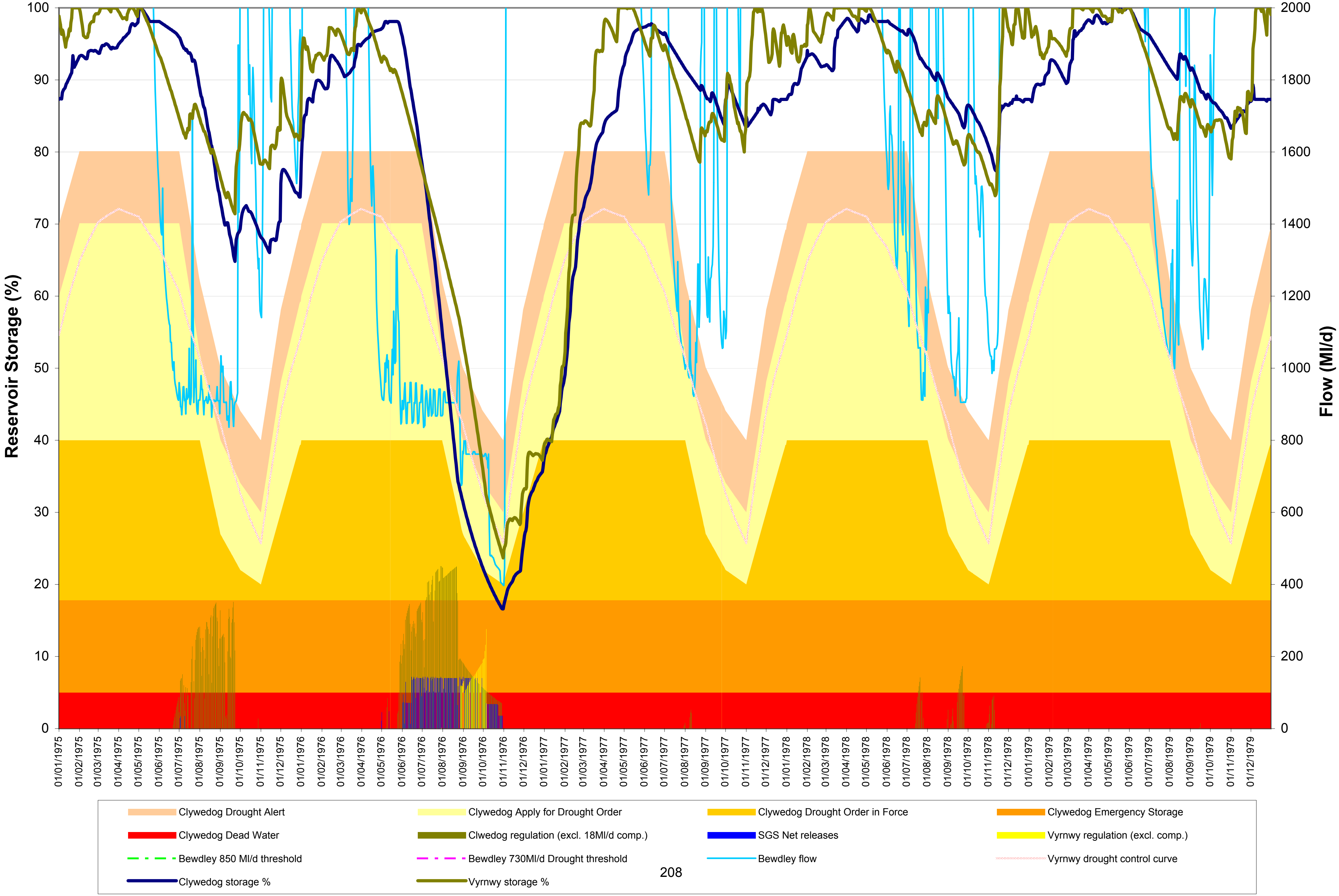
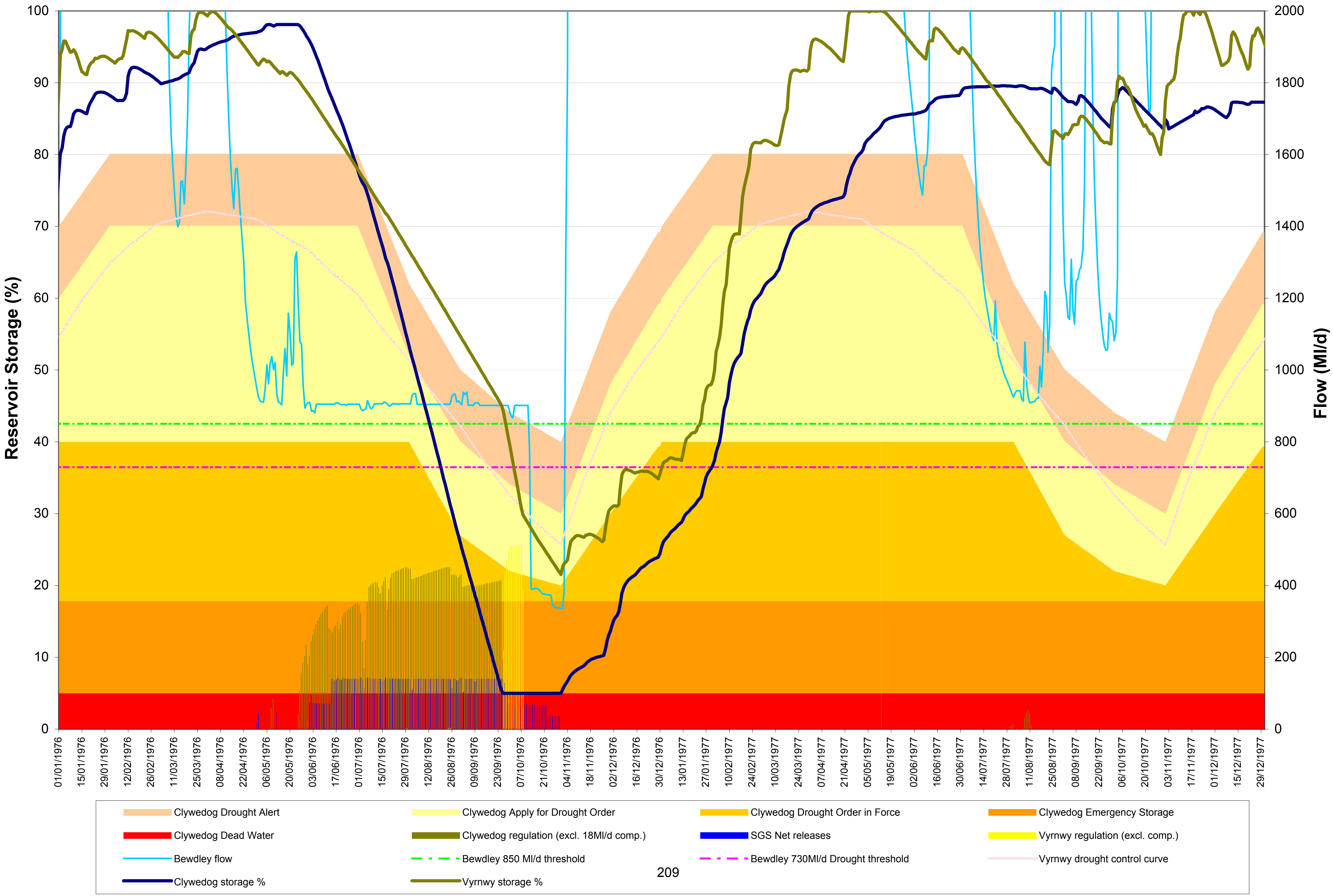
01/04/1979
01/05/1979
01/06/1979
01/07/1979
01/08/1979
01/09/1979
01/10/1979
01/11/1979
01/12/1979
Clywedog Drought Alert
Clywedog Apply for Drought Order
Clywedog Drought Order in Force
Clywedog Emergency Storage
Clywedog Dead Water
Clwedog regulation (excl. 18Ml/d comp.)
SGS Net releases
Vyrnwy regulation (excl. comp.)
Bewdley 850 Ml/d threshold
Bewdley 730Ml/d Drought threshold
Bewdley flow
Vyrnwy drought control curve
Clywedog storage %
Vyrnwy storage %

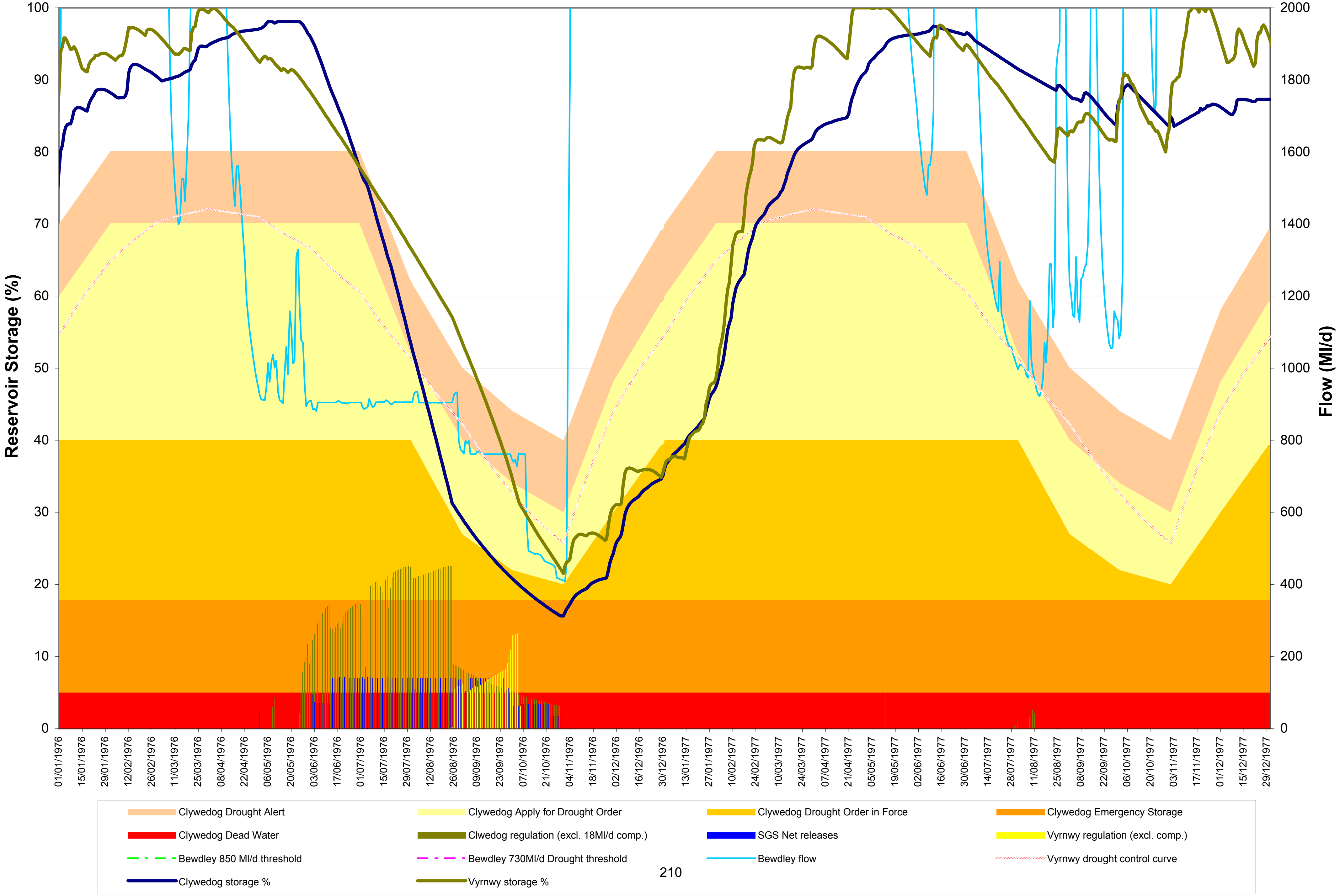
Acute scenario - Full In-combination (EA Drought Orders & water company Permits): 1975 - 1979



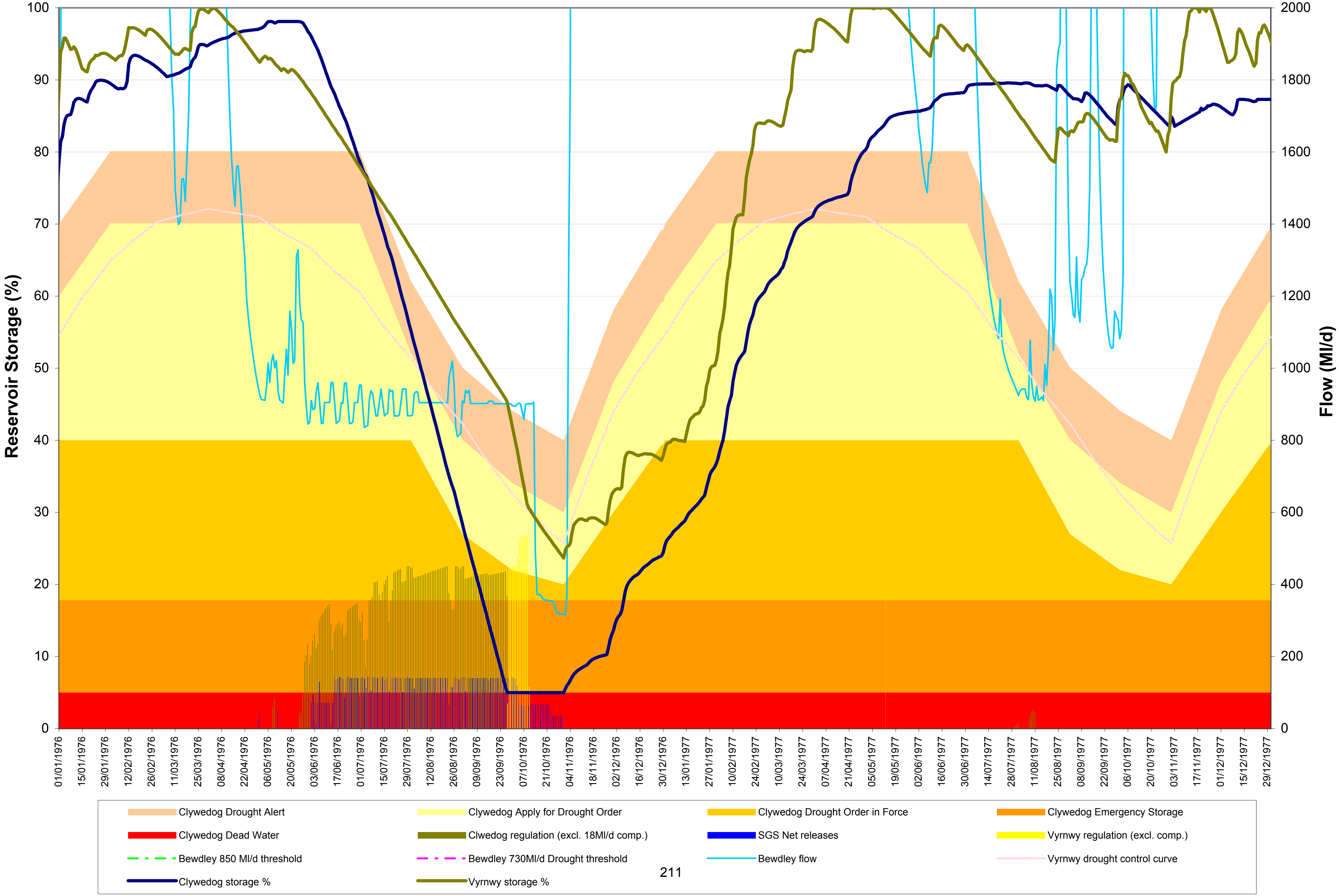
Acute scenario - Do Nothing (No Drought Orders or Permits): 1976 - 1977



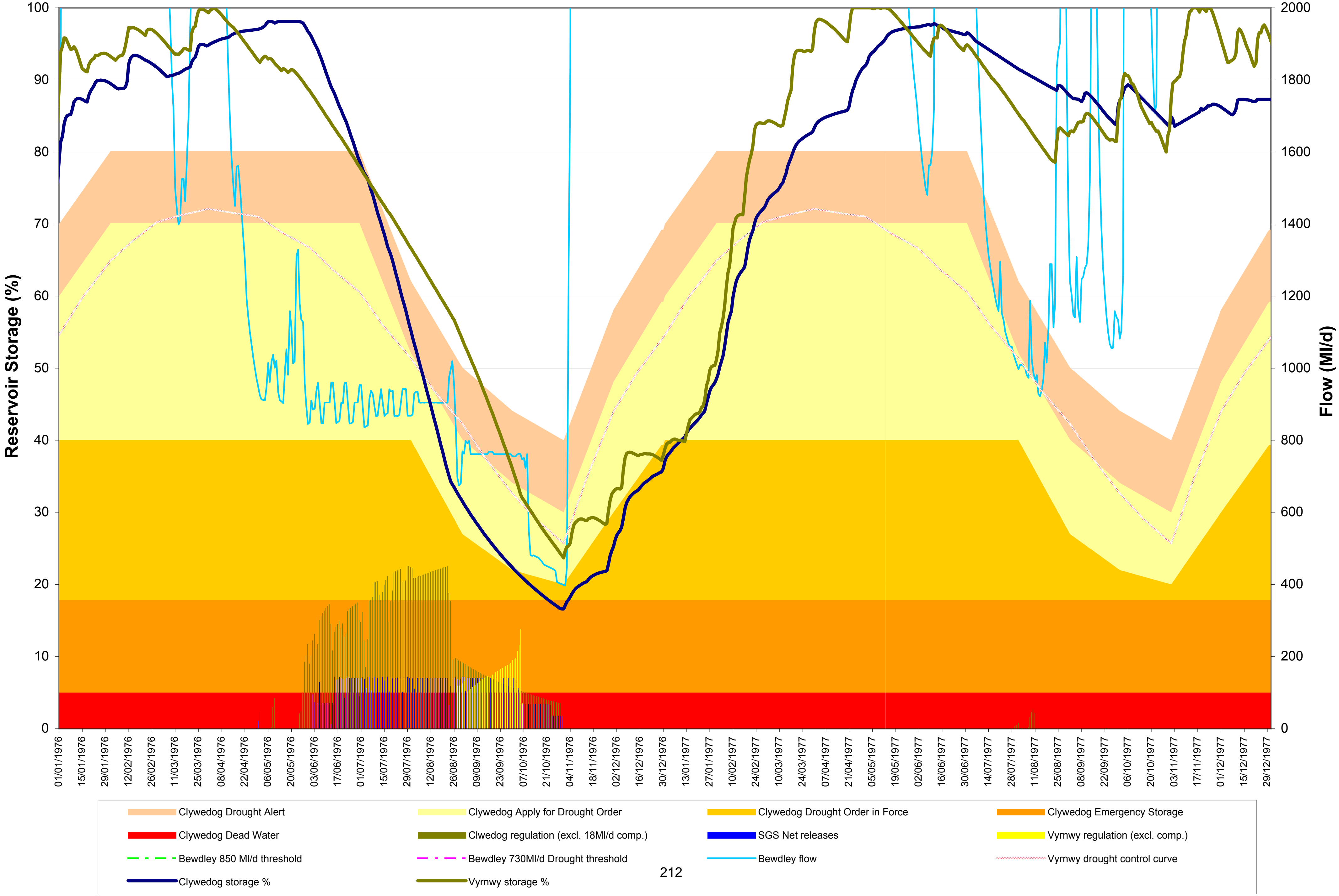
Acute scenario - EA Drought Order only (no water company Permits): 1976 - 1977

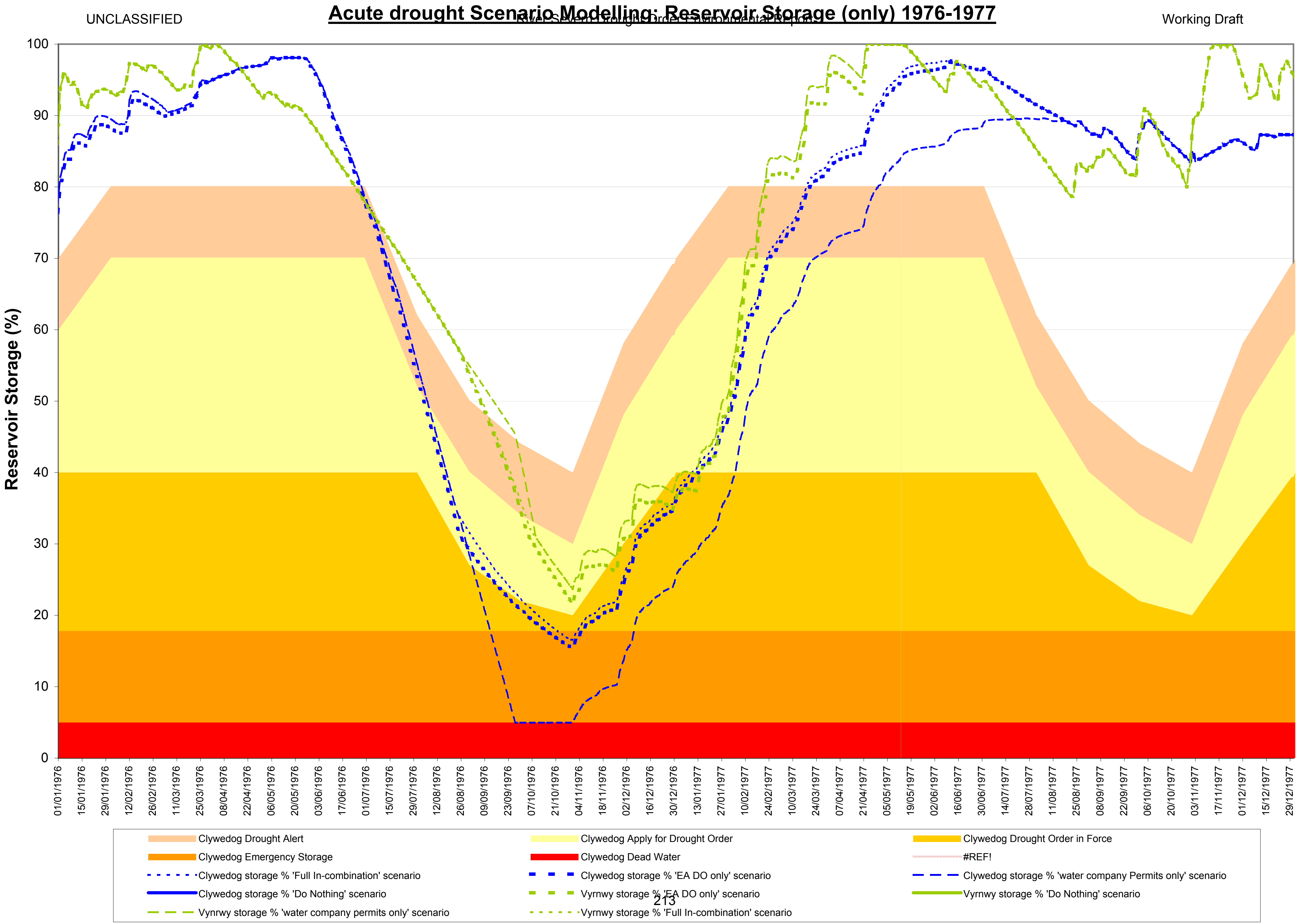


Acute scenario - Water Company Permits only (no EA Drought Order): 1976 - 1977



Acute scenario - Full In-combination (EA Drought Orders & water company Permits): 1976 - 1977




Acute drought Scenario Modelling: Reservoir Storage (only) 1976-1977
Reservoir Storage (%)
Clywedog Drought Alert
Clywedog Apply for Drought Order
Clywedog Drought Order in Force
Clywedog Emergency Storage
Clywedog Dead Water
#REF!
Clywedog storage % 'Full In-combination' scenario
Clywedog storage % 'EA DO only' scenario
Clywedog storage % 'water company Permits only' scenario
Clywedog storage % 'Do Nothing' scenario
Vyrnwy storage % 'EA DO only' scenario
Vyrnwy storage % 'Do Nothing' scenario
Vynrwy storage % 'water company permits only' scenario
Vyrnwy storage % 'Full In-combination' scenario

Appendix J.6

Acute scenario: Critical regulation dates

1976 Critical regulation stats: Acute

	Do Nothing	EA DO in isolation	Full In-combination	Wc Permits only
Start of continuous regulation	25/05/1976	25/05/1976	25/05/1976	25/05/1976
Clywedog D. Alert	27/06/1976	27/06/1976	29/06/1976	29/06/1976
DO app. Crossed	03/08/1976	03/08/1976	08/08/1976	08/08/1976
DO in force crossed	29/08/1976	18/09/1976	02/10/1976	02/09/1976
DO activated	-	**25/08/1976**	**24/08/1976**	-
Emergency storage	10/09/1976	15/10/1976	21/10/1976	13/09/1976
min storage	26/09/1976	31/10/1976	31/10/2011	26/09/1976
Dead water	26/09/1976	-	-	26/09/1976
Days in dead water	36	0	0	36
recovery above dead water	01/11/1976	-	-	01/11/1976
recovery above emergency storage	07/12/1976	06/11/1976	04/11/1976	07/12/1976
DO turned off	-	15/01/1977	10/01/1977	-
No. Days DO active	-	144	140	-
recovery above D. alert	30/04/1977	21/03/1977	19/03/1977	30/04/1977
Source exhausted	**Yes (dead water)**	**No - emergency storage**	**No - emergency storage**	**Yes (dead water)**
Regulation stops	26/09/1976	29/10/1976	29/10/1976	27/09/1976
No. Continuous Regulation days	125	158	158	126
Vyrnwy activated continuously	26/09/1976	23/08/1976	27/08/1976	27/09/1976
Vyrnwy drought control curve	08/10/1976	04/10/1976	11/10/1976	15/10/1976
min storage	31/10/1976	31/10/1976	31/10/2011	31/10/1976
recovery above D.c.curve	10/02/1977	10/02/1977	10/02/1977	10/02/1977
Source exhausted	**No - severe shortage (curve)**	**No - severe shortage (curve)**	**No - severe shortage (curve)**	**No - severe shortage (curve)**
Regulation stops	08/10/1976	05/10/1976	06/10/1976	10/10/1976
No. Continuous Regulation days	13	44	41	14
SGS activated continuously	01/06/1976	01/06/1976	01/06/1976	01/06/1976

1st halves	28/09/1976	29/09/1976	05/10/1976	04/10/1976
halves again	22/10/1976	24/10/1976	24/10/1976	24/10/1976
Source exhausted	**No - licence limit**	**No - licence limit**	**No - licence limit**	**No - licence limit**
Regulation stops	30/10/1976	31/10/1976	30/10/1976	31/10/1976
No. Continuous Regulation days	152	153	152	153
No. Days regulation in total	166	166	166	166
7 Regulation continuous period	152	153	152	153

Aquator Demand Saving level dates (water company restrictions)

Level 1	18/8/76 - 24/3/77	18/8/76 - 14/1/77	22/8/76 - 10/1/77	22/8/76 - 5/2/77
Level 2 (hosepipe ban &/or 5% SDO restriction)	25/8/76 - 5/2/77	25/8/76 - 25/2/77	24/8/76 - 24/2/77	24/8/76 - 24/3/77

1976 Critical flow periods: Acute

Bryntail	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
Bryntail comp flow becomes continuous	01/11/1976	30/10/1976	30/10/1976	01/11/1976
Bryntail comp flow failure (<18.2 Ml/d)	27/09/1976	-	-	28/09/1976
No. days failure	**35**	-	-	**34**
Bryntail comp flow recovery (>18.2 Ml/d)	01/11/1976	-	-	01/11/1976
Flow variation returns	30/07/1977	11/06/1977	08/06/1977	30/07/1977
No. days without flow variation (excl. comp flow failures)	*271*	224	221	*271*
No. days without flow variation (including comp flow failures)	*306*	-	-	*305*

FDC impacts noticed (Do Nothing baseline)	Q5-Q25 higher flows than other scenario's - Q52-Q73 lower flows - Q97 lower flows	Q6-Q25 lower flows than other scenario's - Q52-Q73 higher flows - Q97 higher flows (critical period)	About the same as EA DO	About the same as Do Nothing
Q95	18.20	18.20	18.20	18.20
Q99	9.34	18.20	9.34	18.20
Q99.9	8.73	18.20	8.73	18.20
FDC impacts against natural and LT record (CAMS data)	Generally lower throughout, period Q40-Q55 where higher then slumps to compensation flow for longer, reflecting drought. Extreme low flows lower, comp failed.	see above & Do Nothing	see above & Do Nothing	see above & Do Nothing
EFI failure?	<Q8 flows fail. Q60-Q94 (flows 62.93-18.81 Ml/d) - crosses into high risk. Main issue is mid range flows, created by lack of flow variation as reservoir refills/runs	No - Not beyond Do Nothing baseline	No - Not beyond Do Nothing baseline	No - Not beyond Do Nothing baseline
Vyrnwy Weir	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
Vyrnwy comp flow failure (<25 Ml/d)	-	-	-	-
Flow variation returns	24/04/1977	24/04/1977	23/04/1977	23/04/1977
FDC impacts noticed (Do Nothing baseline)	Reaportions some of the higher flows. Not a large difference between scenario's.	Small differences in flow regime. Some higher flows (Q15 ish) utilised slightly later (Q18-Q22 ish).	Small differences in flow regime. Some higher flows (Q15 ish) utilised slightly later (Q18-Q22 ish).	Mainly Do Nothing scenario.
Q95	25.00	25.00	25.00	25.00
Q99	25.00	25.00	25.00	25.00
Q99.9	25.00	25.00	25.00	25.00
FDC impacts against natural and LT record (CAMS data)	Mainly removed higher flow variation and scale, compensation flow time period extended in frequency as reservoir refills.			
EFI failure?	Yes, but normal conditions fail. Heavily modified waterbody, ecology happy? Flows meet EFI after Q95.	Same situation as DO Nothing	Same situation as DO Nothing	Same situation as DO Nothing
Buildwas	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**

SDO impacts 1st noticed	-	27/08/1976	26/08/1976	-
Average flow maintained during SDO activation period	1075	935	930	1069
Average Diff from Do Nothing (Ml/d)	-	*minus 140*	*minus 145*	*minus 6*
Flow crash	10/10/1976	07/10/1976	08/10/1976	12/10/1976
Cross over point	-	11/10/1976	11/10/1976	*same*
Average SDO flow maintained after crash (Ml/d)	540	629	616	518
Average Diff from Do Nothing (Ml/d)	-	*plus 89*	*plus 76*	*minus 22*
No. days crashed prior to Do Nothing	-	3	2	same
Min flow date	31/10/1976	31/10/1976	31/10/1976	31/10/1976
flow recovery	01/11/1976	01/11/1976	01/11/1976	01/11/1976
No. days flows crashed	22	25	24	20
No. days of impact before benefit realised (lower than Do Nothing)	-	45	48	-
No. days flows maintained above Do Nothing	-	21	21	3
FDC impacts noticed	Below nat & gauged up until Q85 (Nat) and Q89 (G), where high regulation kicks in. Flow never actually drops below the naturalised (18 yr).	SDO impacts from Q93. Benefits realised Q98+	SDO impacts from Q91 mainly. Benefits realised Q98+	Impacts from Q96. Flow crash Q98, worse than DN.
Q95	1068	934	934	1067
Q99	551	635	623	531
Q99.9	513	586	573	493
EFI failure?	No significant failures - Minor (<10%) between Q65 & Q72	No additional failure beyond DO Nothing baseline	No additional failure beyond DO Nothing baseline	No additional failure beyond DO Nothing baseline
Bewdley	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
SDO impacts 1st noticed	-	29/08/1976	28/08/1976	-

Average flow maintained during SDO activation period	903	764	757	897
Average Diff from Do Nothing (Ml/d)	-	*minus 139*	*minus 146*	*minus 6*
Flow crash	12/10/1976	09/10/1976	10/10/1976	14/10/1976
Cross over point	-	13/10/1976	13/10/1976	*same*
Average SDO flow maintained after crash (Ml/d)	368	458	445	346
Average Diff from Do Nothing (Ml/d)	-	*plus 90*	*plus 77*	*minus 22*
No. days crashed prior to Do Nothing	-	3	2	0 (2 days later!)
Min flow date	01/11/1976	01/11/1976	01/11/1976	01/11/1976
flow recovery	03/11/1976	03/11/1976	03/11/1976	03/11/1976
No. days flows crashed	22	25	24	20
No. days of impact before benefit realised (lower than Do Nothing)	-	45	46	-
No. days flows maintained above Do Nothing	-	21	21	
FDC impacts noticed	Clearly below normal and natural conditions - reflects drought with reduction in higher flows, closer at lower flows when regulation impacts. Flow crash Q98.	SDO impacts from Q94. Benefits realised Q98+	SDO impacts from Q90. Benefits realised Q98+	Impacts from Q90. Flow crash Q98, worse than DN.
Q95	901	762	870	762
Q99	375	458	355	446
Q99.9	337	411	317	398

EFI failure?	Yes - largely due to overall loss of mid flow variation, unavoidable drought conditions. Critical low flows - Q98+ crashes beyond 30% lower than EFI.	Slight increase in length (time) of failures but overall improvement on DN magnitude of critical low flow failure - stays within 30% of EFI at Q98 and comes within 20% at Q99	similar to EA DO, slight increase in period again.	V similar to DN, but greater failure at critical low flow.
Saxon's Lode	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
SDO impacts 1st noticed	-	29/08/1976	28/08/1976	-
Average flow maintained during SDO activation period	954	814	807	947
Average Diff from Do Nothing (Ml/d)	-	*minus 140*	*minus 147*	*plus 7*
Flow crash	12/10/1976	09/10/1976	14/10/1976	10/10/1976
Cross over point	-	13/10/1976	13/10/1976	*same*
Average SDO flow maintained after crash (Ml/d)	428	518	508	409
Average Diff from Do Nothing (Ml/d)	-	*plus 90*	*plus 80*	*minus 19*
No. days crashed prior to Do Nothing	-	3	2	0 (2 days later)
Min flow date	31/10/1976	31/10/1976	31/10/1976	31/10/1976
flow recovery	01/11/1976	01/11/1976	01/11/1976	01/11/1976
No. days flows crashed	20	23	22	18
No. days of impact before benefit realised (lower than Do Nothing)	-	46	47	-
No. days flows maintained above Do Nothing	-	19	19	-
FDC impacts noticed	Below naturalised and gauged from normal period throughout - reflects drought event.	SDO impacts from Q94. Benefits realised Q98+	SDO impacts from Q92. Benefits realised Q98+	Impacts from Q96. Flow crash Q98, worse than DN.
Q95	946	817	945	816
Q99	440	526	421	515

Q99.9	400	475	380	463
EFI failure?	Yes, from Q52, due to drought. Critical low flow period see's improvement from regulation up to flow crash Q98, then greater than 30% below EFI.	SDO activating from Q94, creates increased time of failure but reduces magnitude after flow crash to within 30% of EFI.	Same as EA DO, slight increase in time of failure.	V similar to DN, but greater failure at critical low flow.
Deerhurst	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
SDO impacts 1st noticed	-	31/08/1976	29/08/1976	-
Average flow maintained during SDO activation period	1136	996	989	1129
Average Diff from Do Nothing (Ml/d)	-	*minus 140*	*minus 147*	*minus 7*
Flow crash	13/10/1976	10/10/1976	15/10/1976	11/10/1976
Cross over point	14/10/1976	14/10/1976	14/10/1976	14/10/1976
Average SDO flow maintained after crash (Ml/d)	608	698	688	589
Average Diff from Do Nothing (Ml/d)	-	*plus 90*	*plus 80*	*minus 19*
No. days crashed prior to Do Nothing	-	3	2	0 (2 days later)
Min flow date	31/10/1976	31/10/1976	31/10/1976	31/10/1976
flow recovery	01/11/1976	01/11/1976	01/11/1976	01/11/1976
No. days flows crashed	19	22	21	17
No. days of impact before benefit realised (lower than Do Nothing)	-	45	47	-
No. days flows maintained above Do Nothing	-	18	18	-
FDC impacts noticed	Below naturalised and largely below gauged throughout - reflects drought event.	SDO impacts from Q94. Benefits realised Q98+	SDO impacts from Q94. Benefits realised Q98+	Impacts from Q97. Flow crash Q98, worse than DN.
Q95	1114	1002	1114	1002
Q99	619	705	600	696

Q99.9	578	654	558	642
EFI failure?	Yes, from Q52, due to drought. Critical low flow period see's improvement from regulation up to flow crash Q98, then greater than 30% below EFI.	SDO activating from Q94, creates increased time of failure but reduces magnitude after flow crash to within 30% of EFI.	Same as EA DO, slight increase in time of failure.	V similar to DN, but greater failure at critical low flow.
U/S Sharpness	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
SDO impacts 1st noticed	-	31/08/1976	30/08/1976	-
Average flow maintained during SDO activation period	1170	1031	1023	1166
Average Diff from Do Nothing (Ml/d)	-	*minus 139*	*minus 147*	*minus 4*
Flow crash	14/10/1976	11/10/1976	12/10/1976	16/10/1976
Cross over point	15/10/1976	15/10/1976	15/10/1976	15/10/1976
Average SDO flow maintained after crash (Ml/d)	640	731	721	621
Average Diff from Do Nothing (Ml/d)	-	*plus 91*	*plus 81*	*minus 19*
No. days crashed prior to Do Nothing	-	3	2	0 (2 days later)
Min flow date	01/11/1976	01/11/1976	01/11/1976	01/11/1976
flow recovery	02/11/1976	02/11/1976	02/11/1976	02/11/1976
No. days flows crashed	19	22	21	17
No. days of impact before benefit realised (lower than Do Nothing)	-	46	48	-
No. days flows maintained above Do Nothing	-	18	18	-
FDC impacts noticed	naturalised and influenced data throughout - reflects drought event.	SDO impacts from Q91. Benefits realised Q98+	SDO impacts from Q91. Benefits realised Q98+	Impacts from Q97. Flow crash Q98, worse than DN.
Q95	1152	1037	1154	1037

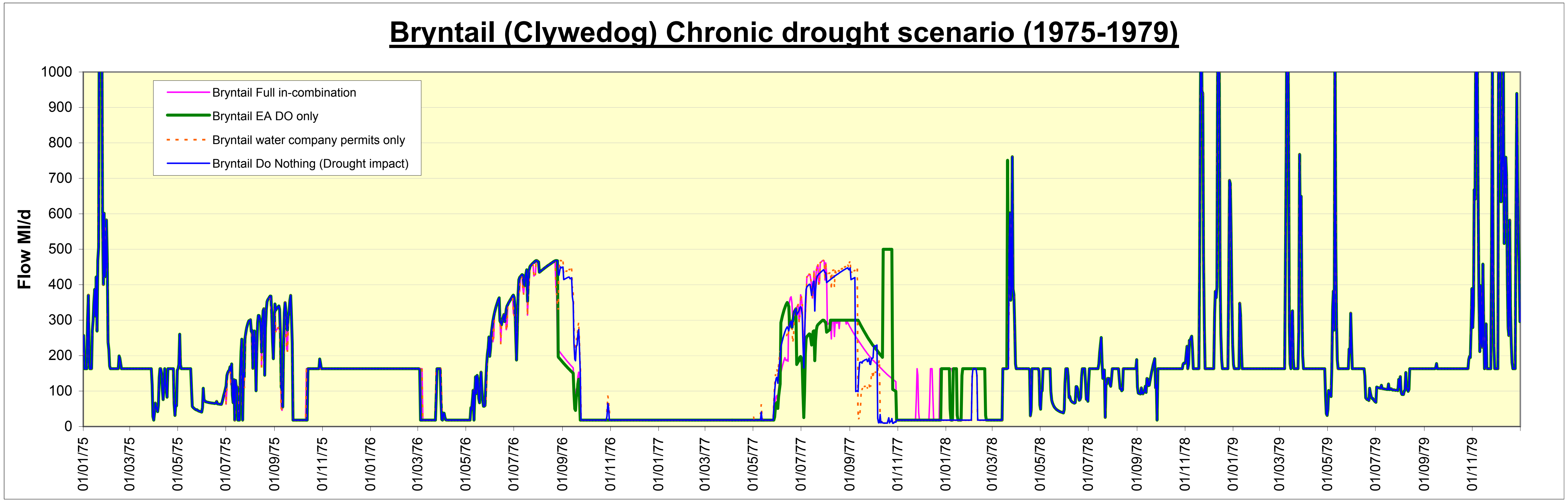
Q99	651	737	633	729
Q99.9	610	686	590	674
EFI failure?	Yes, from Q52, due to drought. Critical low flow period see's improvement from regulation up to flow crash Q98, then greater than 30% below EFI.	SDO activating from Q94, creates increased time of failure but reduces magnitude after flow crash, most SDO period over 30% from EFI.	Same as EA DO.	V similar to DN, but greater failure at critical low flow.
Lower Parting	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
SDO impacts 1st noticed	-	31/08/1976	30/08/1976	-
Average flow maintained during SDO activation period	904	762	757	902
Average Diff from Do Nothing (Ml/d)	-	*minus 142*	*minus 147*	*minus 2*
Flow crash	14/10/1976	11/10/1976	12/10/1976	16/10/1976
Cross over point	15/10/1976	15/10/1976	15/10/1976	15/10/1976
Average SDO flow maintained after crash (Ml/d)	415	505	496	396
Average Diff from Do Nothing (Ml/d)	-	*plus 90*	*plus 81*	*minus 19*
No. days crashed prior to Do Nothing	-	3	2	0 (2 days later)
Min flow date	01/11/1976	31/10/1976	31/10/1976	31/10/1976
flow recovery	02/11/1976	02/11/1976	02/11/1976	02/11/1976
No. days flows crashed	19	22	21	17
No. days of impact before benefit realised (lower than Do Nothing)	-	46	48	-
No. days flows maintained above Do Nothing	-	18	18	-
FDC impacts noticed	Below LFE modelled naturalised and influenced data throughout - reflects drought event.	SDO impacts from Q91. Benefits realised Q98+	SDO impacts from Q91. Benefits realised Q98+	Impacts from Q97. Flow crash Q98, worse than DN.

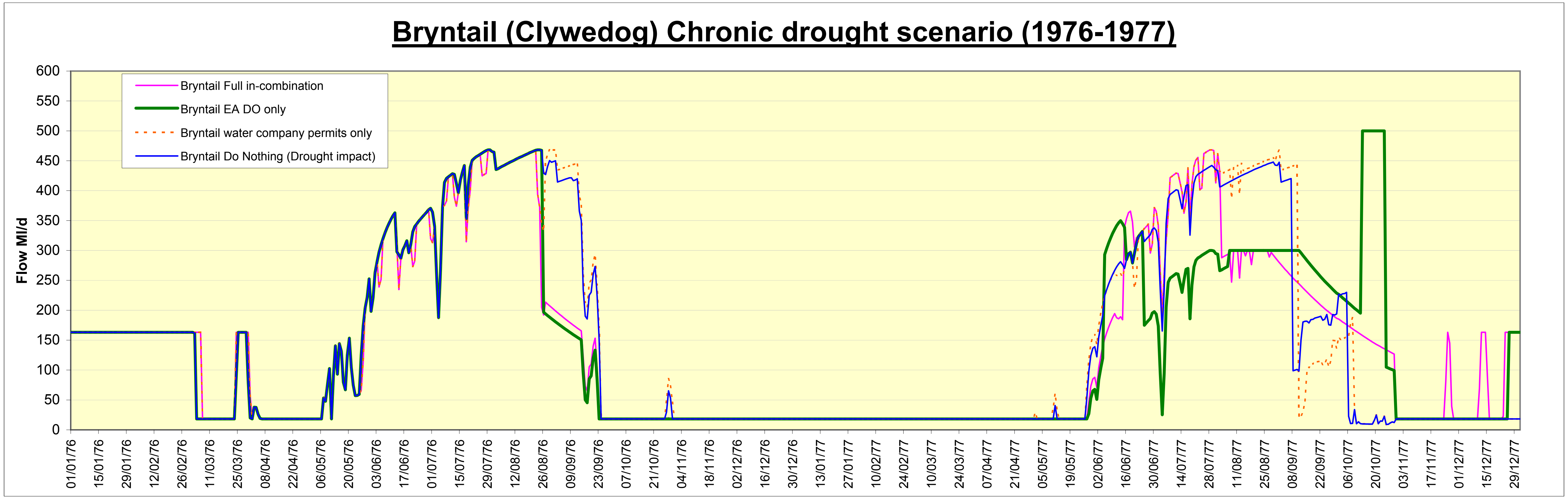
Q95	887	787	886	791
Q99	424	509	405	501
Q99.9	384	461	364	449
EFI failure?	Yes, from Q52, due to drought. Critical low flow period see's improvement from regulation up to flow crash Q98, then greater than 30% below EFI.	SDO activating from Q94, creates increased time of failure but reduces magnitude after flow crash, most SDO period over 30% from EFI.	Same as EA DO.	V similar to DN, but greater failure at critical low flow.

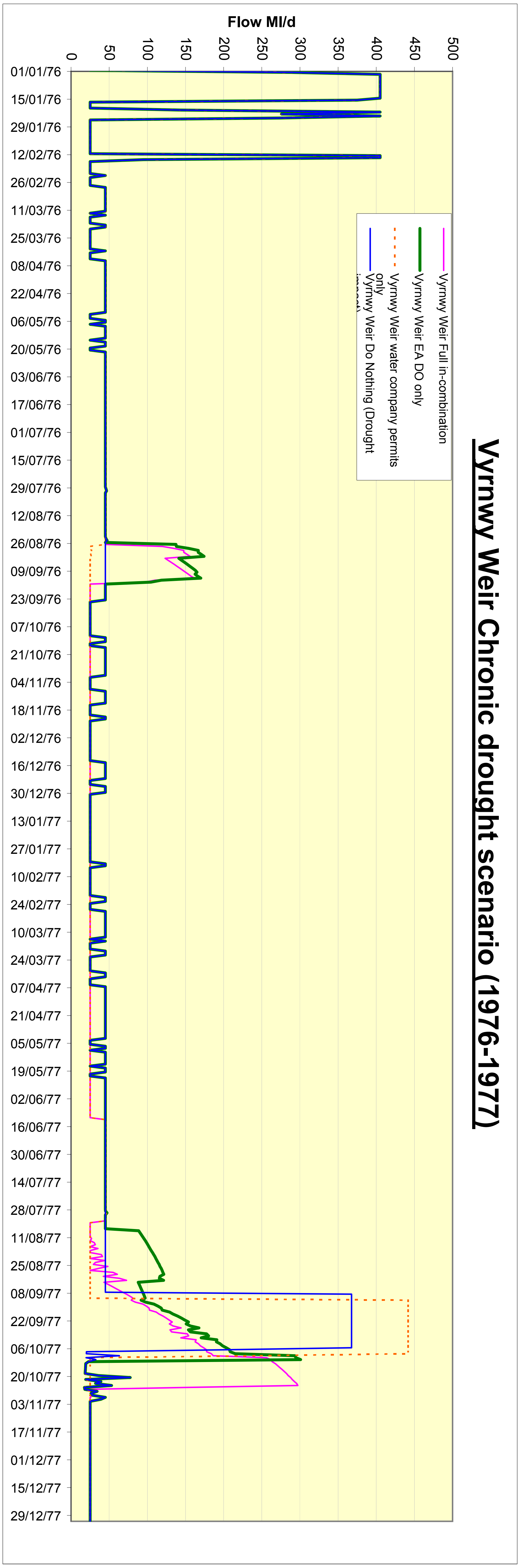
Appendix K.1

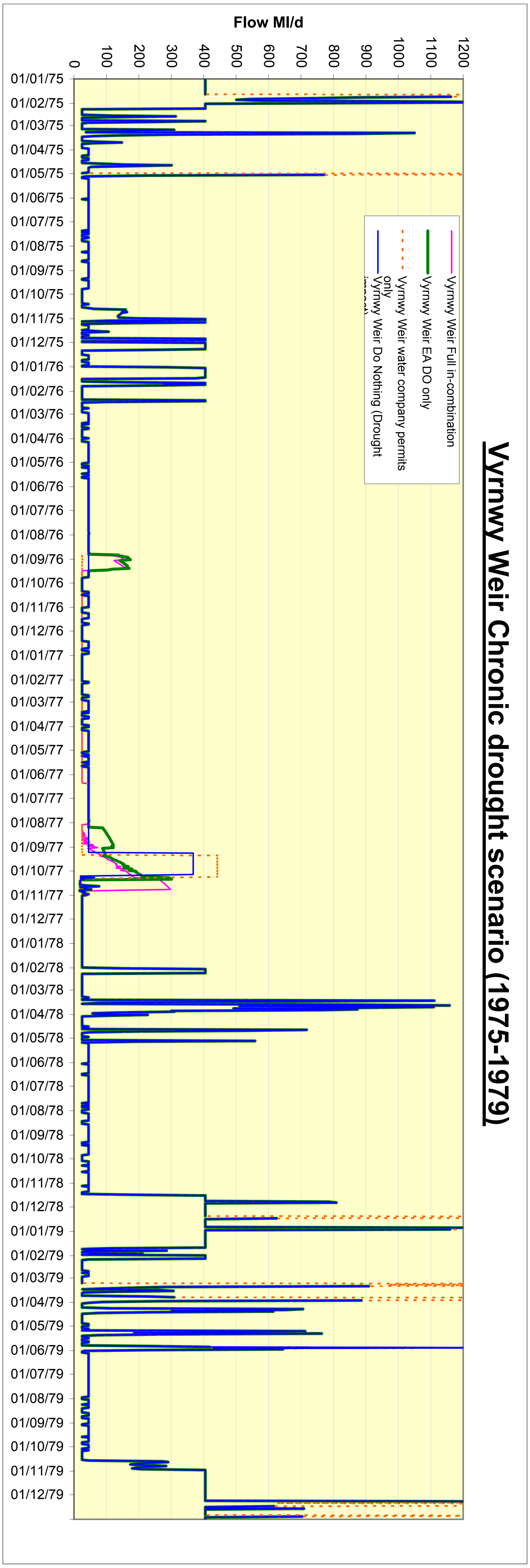
A Chronic scenario: Hydrographs

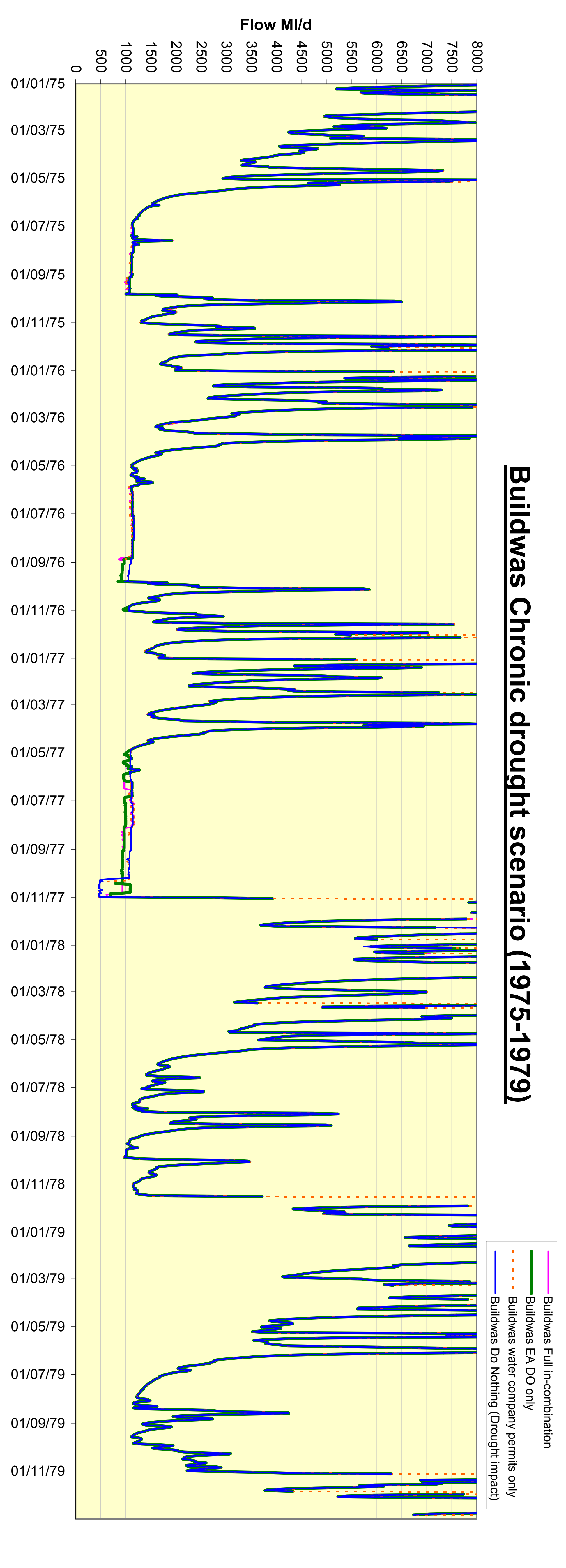
Chronic Scenario

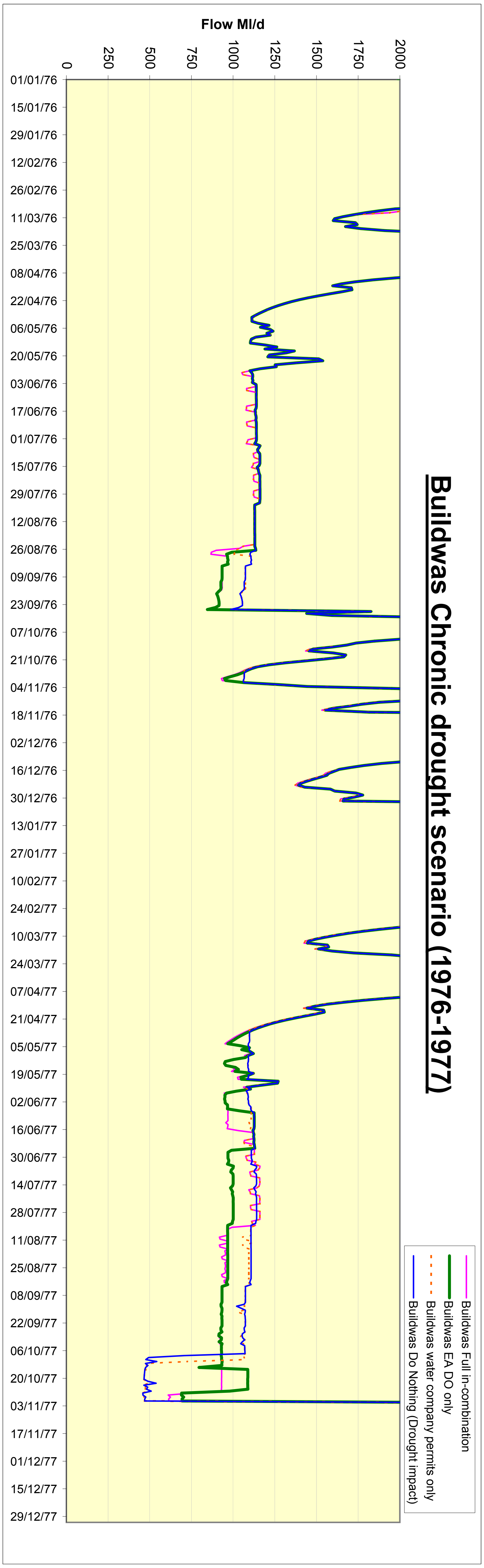


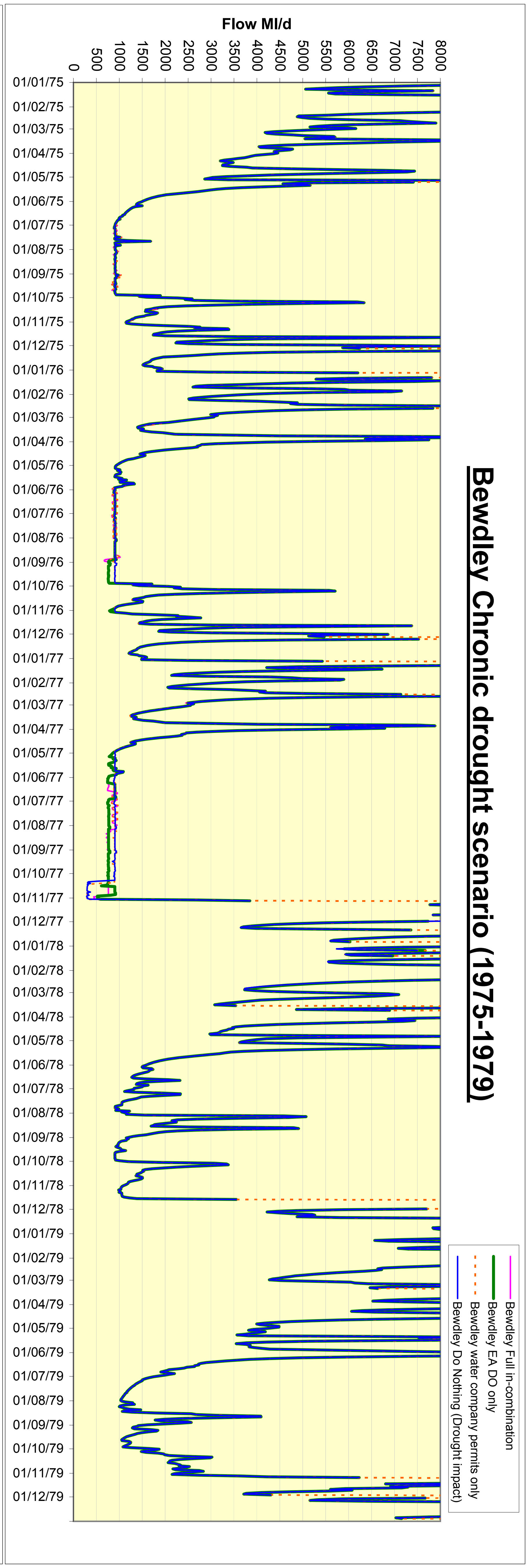


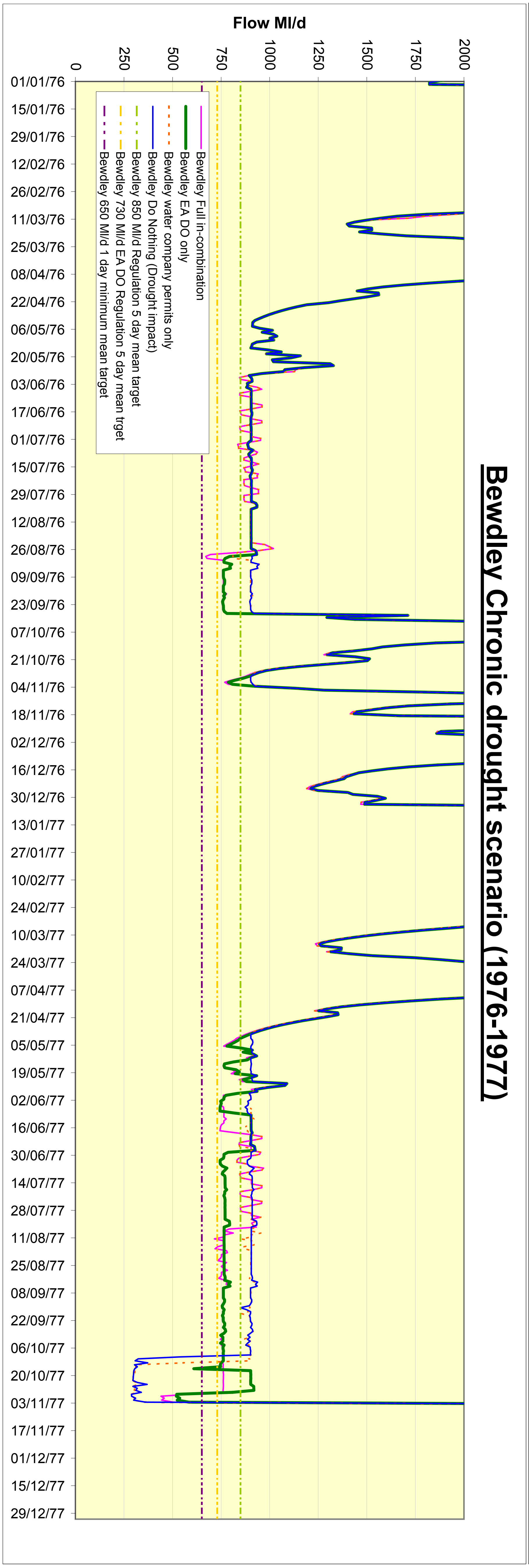

Vyrnwy Weir Chronic drought scenario (1976-1977)
Flow Ml/d
Vyrnwy Weir Full in-combination
Vyrnwy Weir EA DO only
Vyrnwy Weir water company permits only
Vyrnwy Weir Do Nothing (Drought


Vyrnwy Weir Chronic drought scenario (1975-1979)
Flow Ml/d
Vyrnwy Weir Full in-combination
Vyrnwy Weir EA DO only
Vyrnwy Weir water company permits only
Vyrnwy Weir Do Nothing (Drought

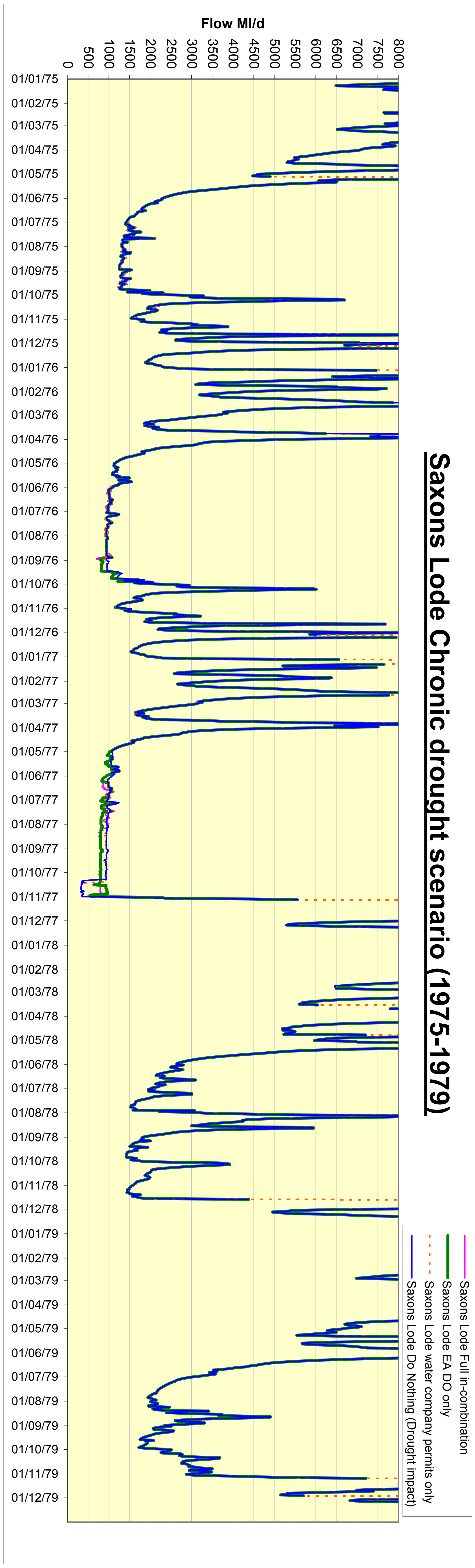

Buildwas Chronic drought scenario (1975-1979)
Flow Ml/d
Buildwas Full in-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing (Drought impact)

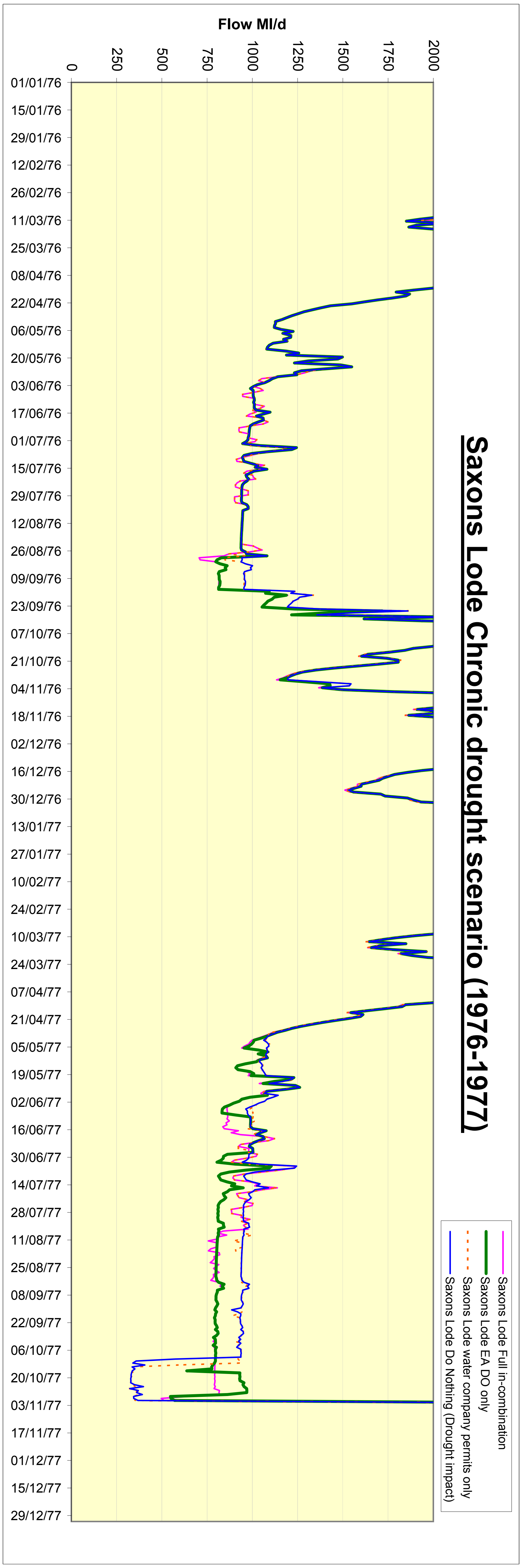

Buildwas Chronic drought scenario (1976-1977)
Flow Ml/d
Buildwas Full in-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing (Drought impact)

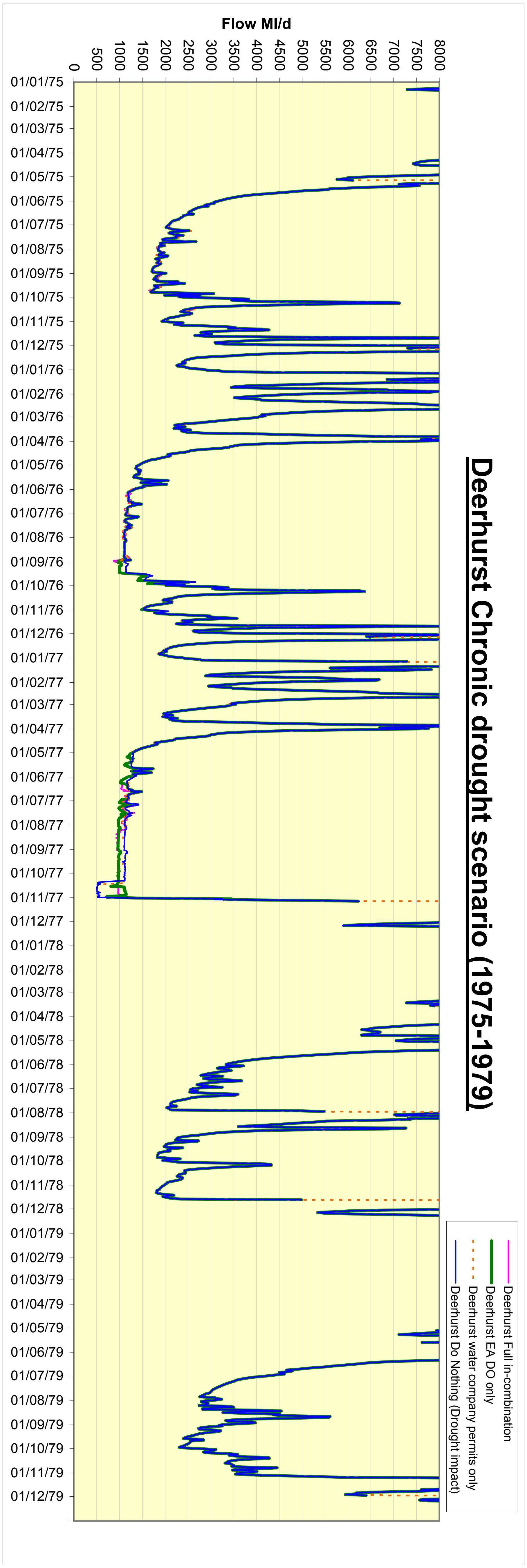




Saxons Lode Full in-combination


Saxons Lode Chronic drought scenario (1975-1979)
Flow Ml/d
Saxons Lode Full in-combination
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do Nothing (Drought impact)


Saxons Lode Chronic drought scenario (1976-1977)
Flow Ml/d
Saxons Lode Full in-combination
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do Nothing (Drought impact)


Deerhurst Chronic drought scenario (1975-1979)
Flow Ml/d
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500
8000
01/01/75
01/02/75
01/03/75
01/04/75
01/05/75
01/06/75
01/07/75
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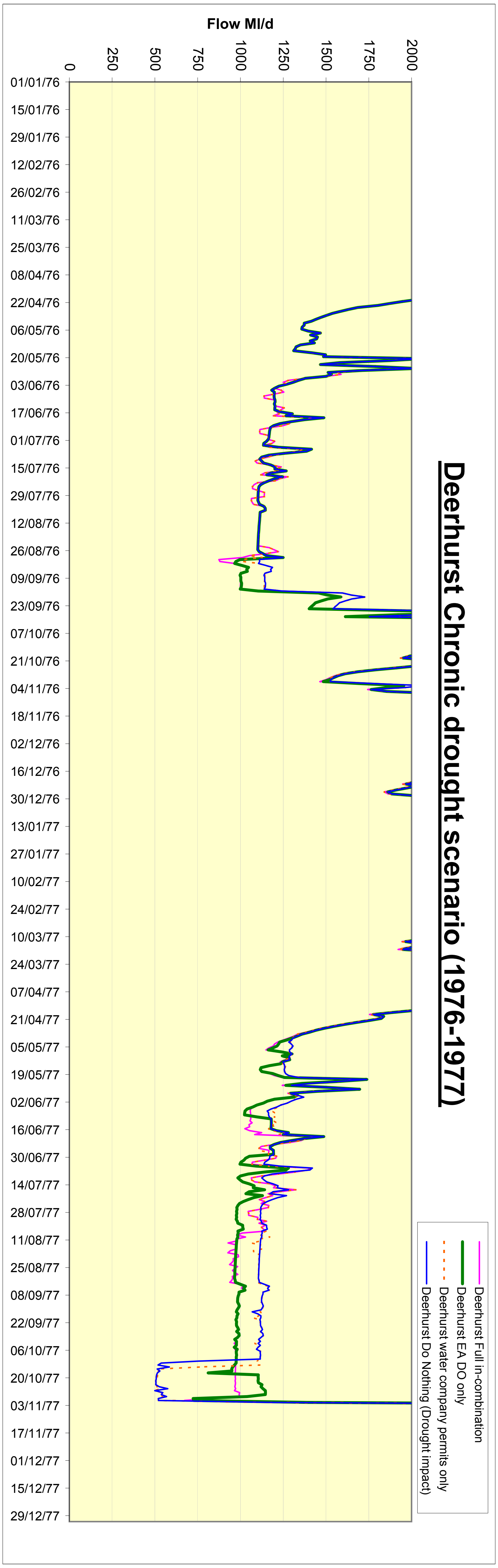
01/01/79
01/02/79
01/03/79
01/04/79
01/05/79
01/06/79
01/07/79
01/08/79
01/09/79
01/10/79
01/11/79
01/12/79
Deerhurst Full in-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing (Drought impact)


Deerhurst Chronic drought scenario (1976-1977)
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
2000
01/01/76
15/01/76
29/01/76
12/02/76
26/02/76
11/03/76
25/03/76
08/04/76
22/04/76
06/05/76
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25/08/77
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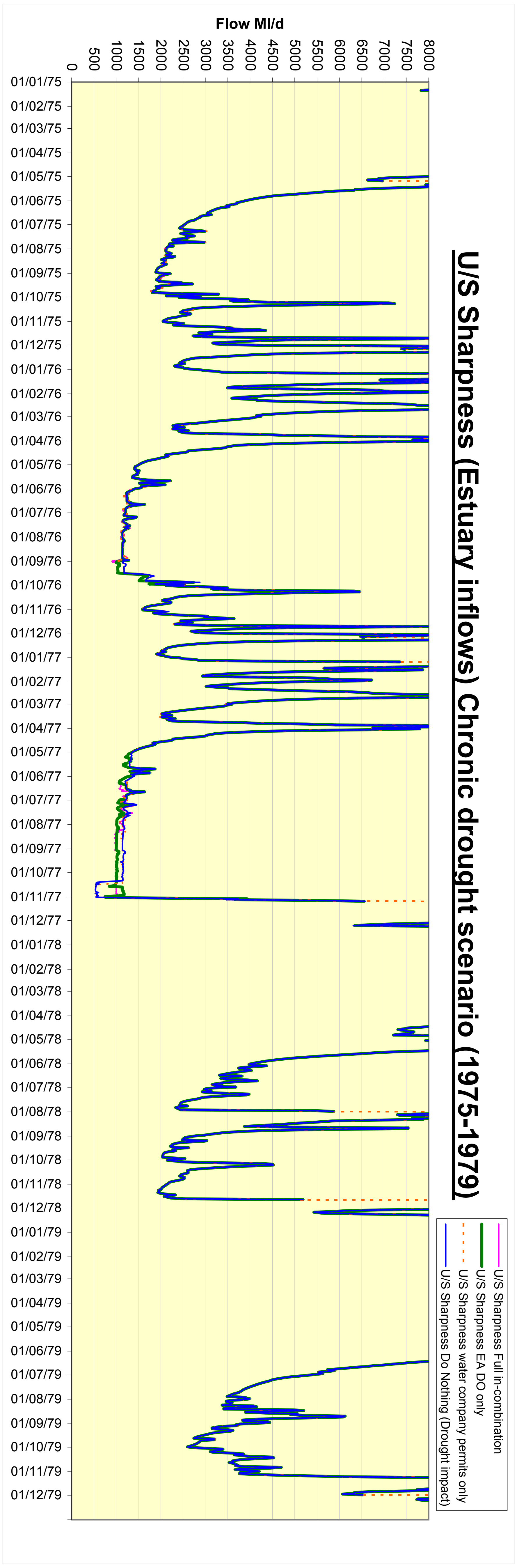
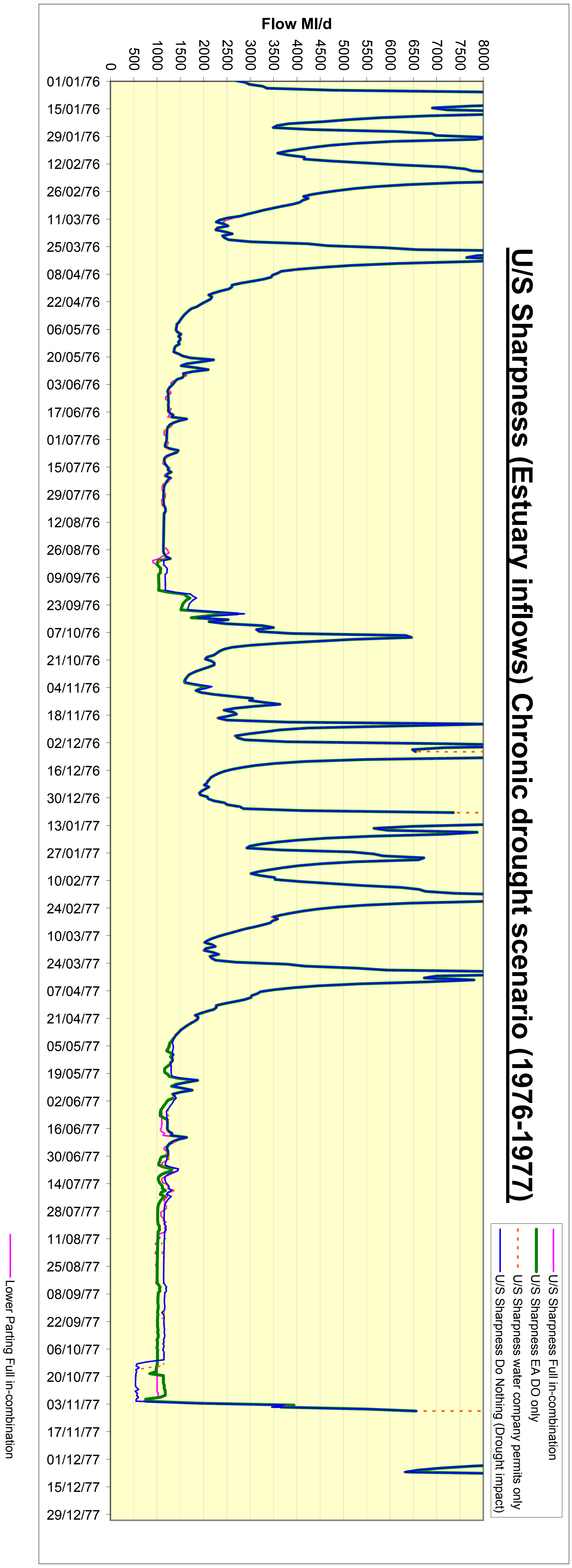
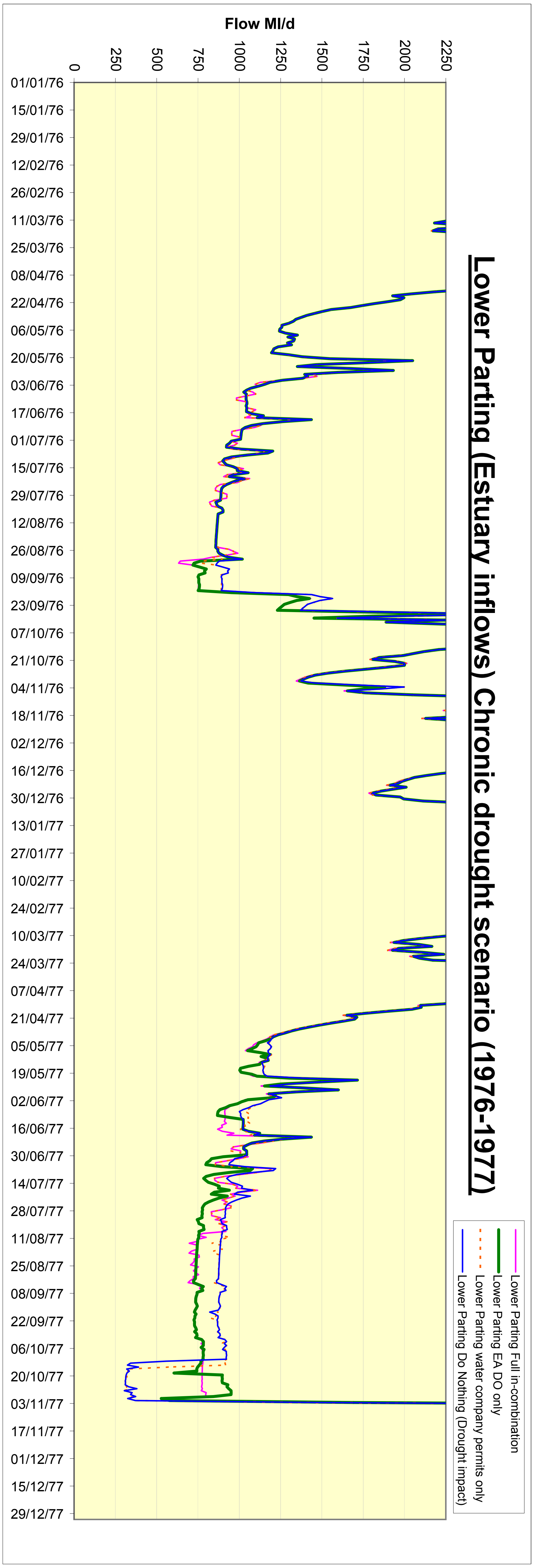
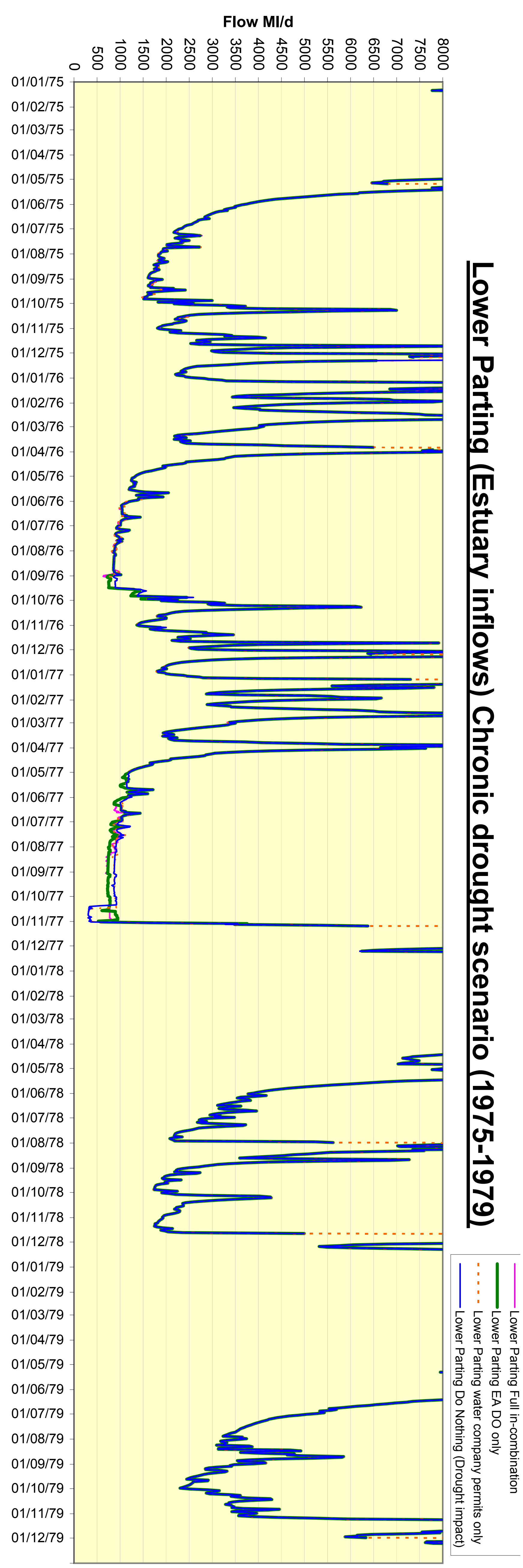
22/09/77
06/10/77
20/10/77
03/11/77
17/11/77
01/12/77
15/12/77
29/12/77
Deerhurst Full in-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing (Drought impact)

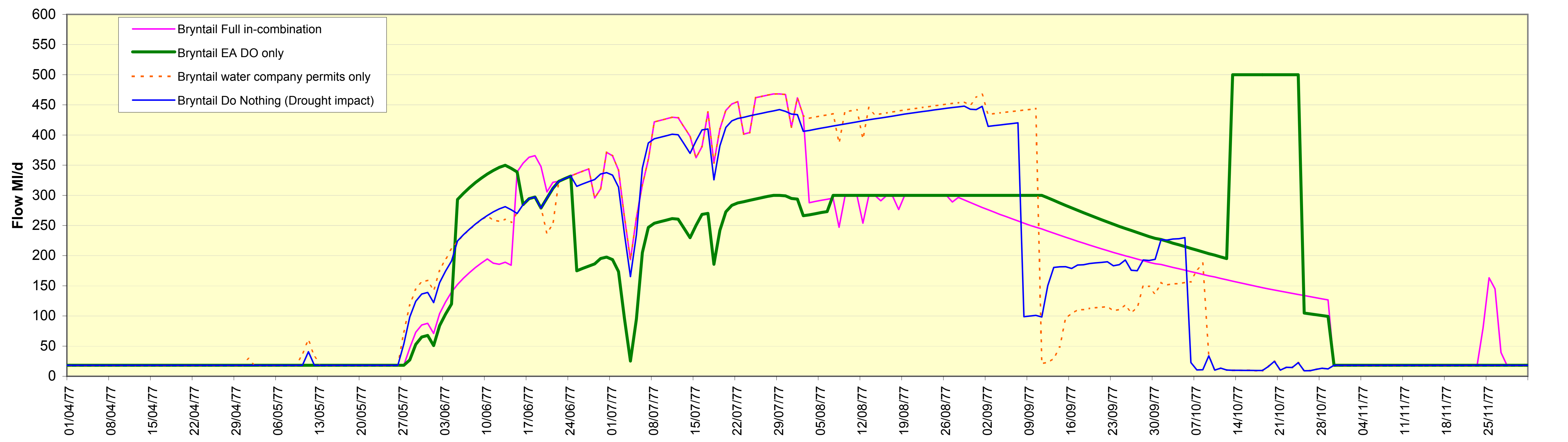

U/S Sharpness (Estuary inflows) Chronic drought scenario (1975-1979)
Flow Ml/d
U/S Sharpness Full in-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only
U/S Sharpness Do Nothing (Drought impact)


U/S Sharpness (Estuary inflows) Chronic drought scenario (1976-1977)
Flow Ml/d
U/S Sharpness Full in-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only
U/S Sharpness Do Nothing (Drought impact)
Lower Parting Full in-combination

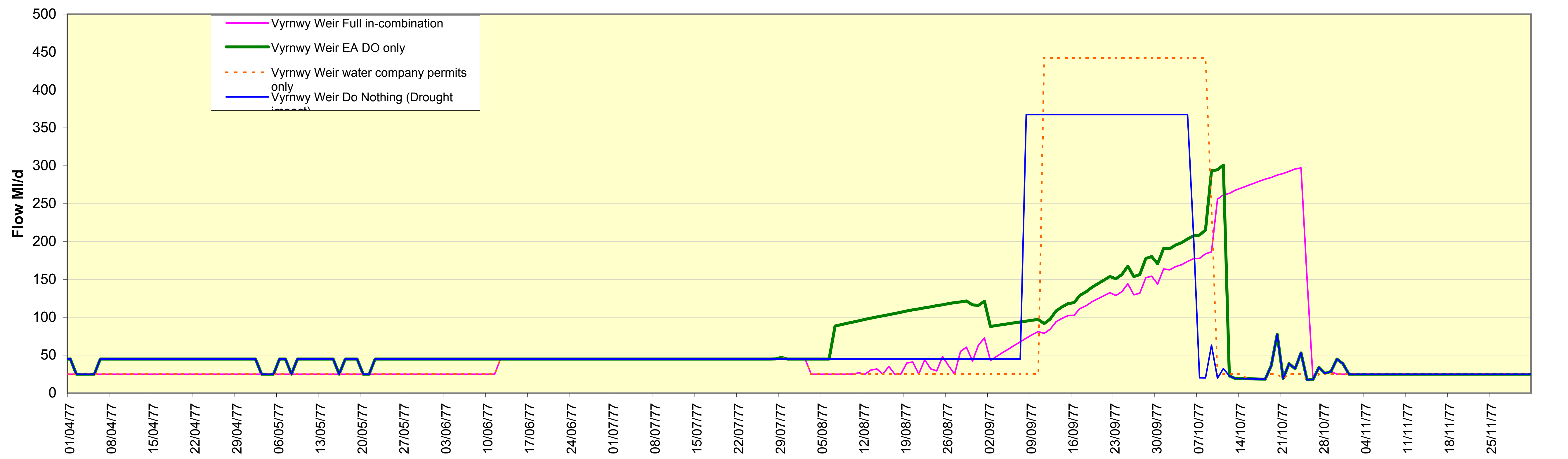

Lower Parting (Estuary inflows) Chronic drought scenario (1976-1977)
Flow Ml/d
Lower Parting Full in-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing (Drought impact)


Lower Parting (Estuary inflows) Chronic drought scenario (1975-1979)
Flow Ml/d
Lower Parting Full in-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing (Drought impact)

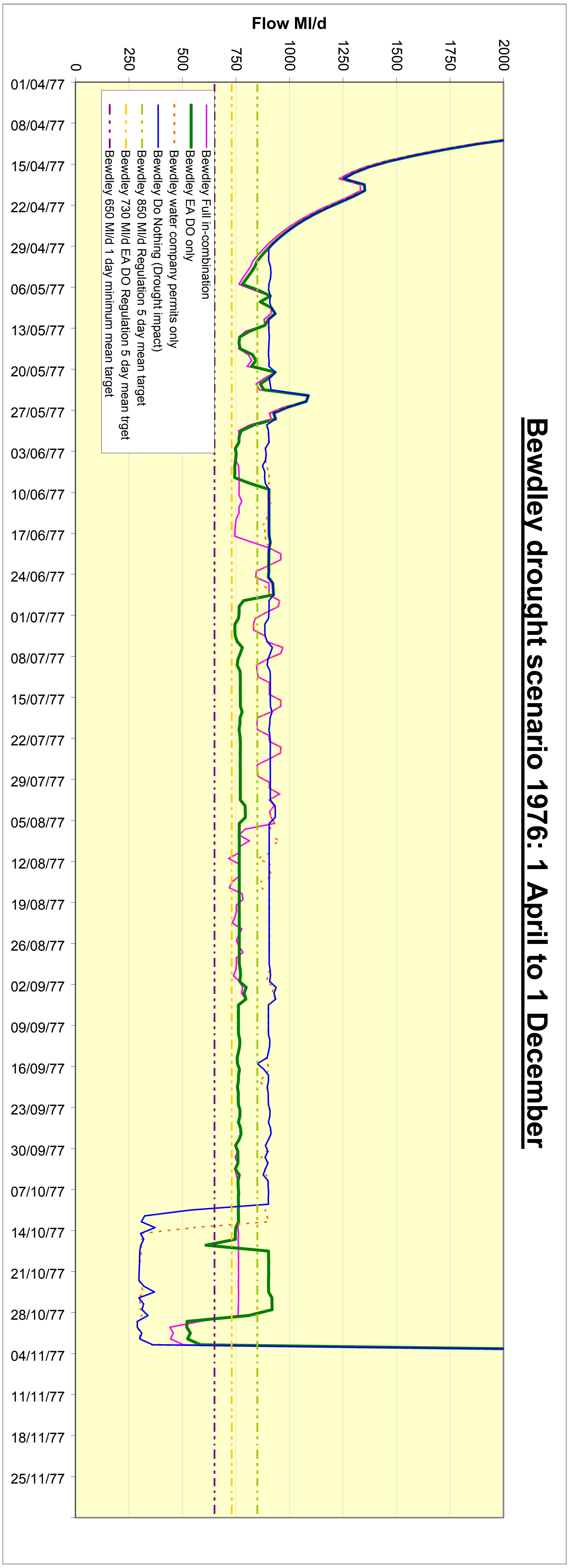
Chronic Scenario - 1977 Close up's

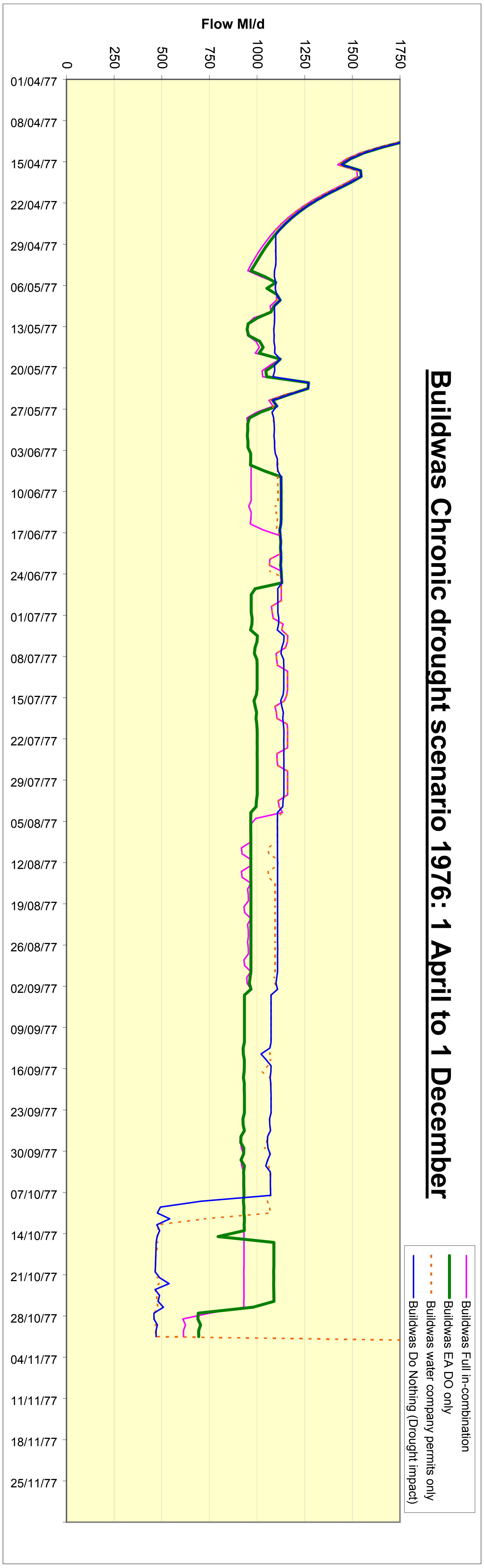


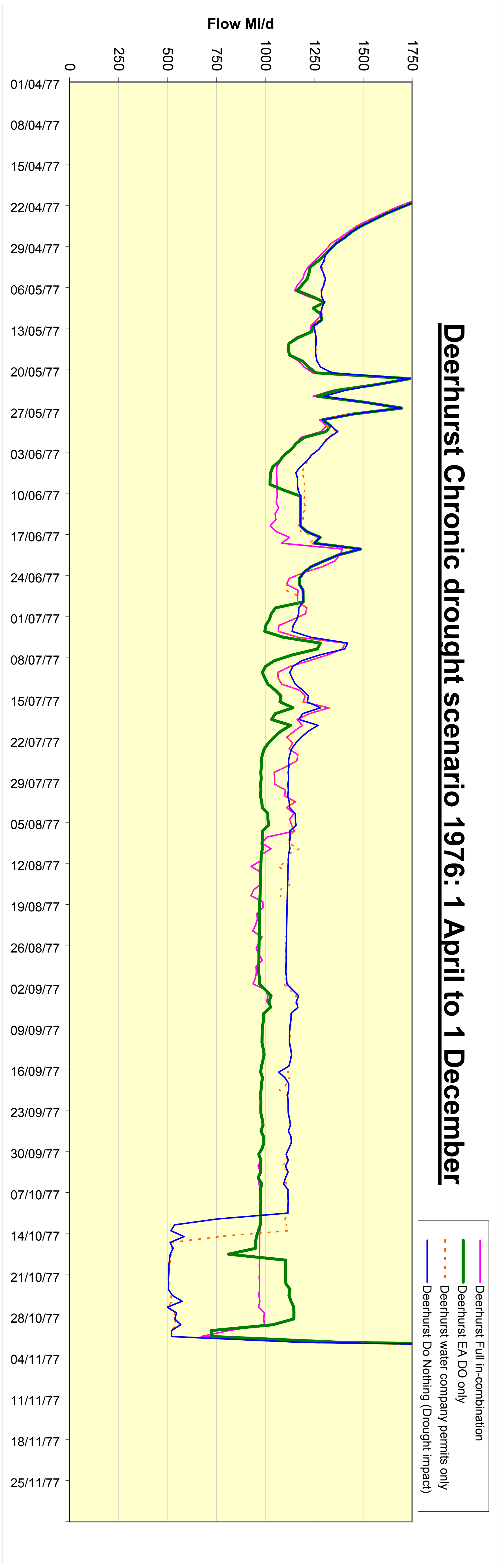
Bryntail (Clywedog) Chronic drought scenario 1976: 1 April to 1 December

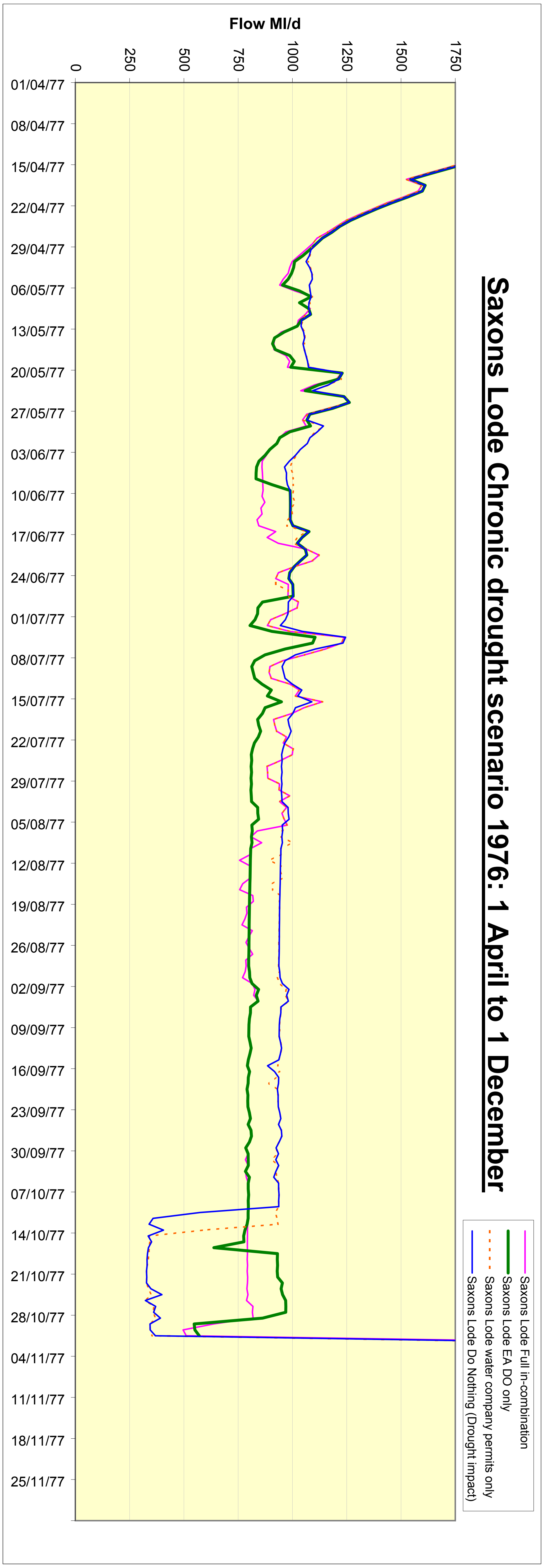


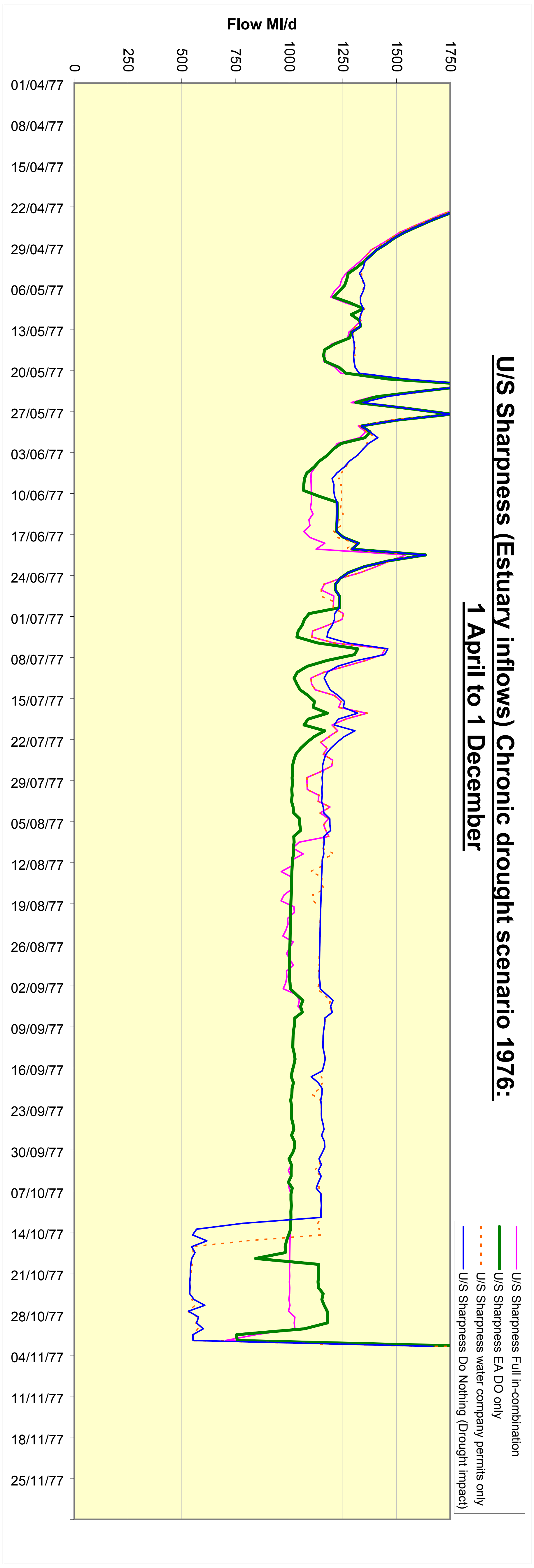
Vyrnwy Weir Chronic drought scenario 1976: 1 April to 1 December


Bewdley drought scenario 1976: 1 April to 1 December
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
2000
01/04/77
08/04/77
15/04/77
22/04/77
29/04/77
06/05/77
13/05/77
20/05/77
27/05/77
03/06/77
10/06/77
17/06/77
24/06/77
01/07/77
08/07/77
15/07/77
22/07/77
29/07/77
05/08/77
12/08/77
19/08/77
26/08/77
02/09/77
09/09/77
16/09/77
23/09/77
30/09/77
07/10/77
14/10/77
21/10/77
28/10/77
04/11/77
11/11/77
18/11/77
25/11/77
Bewdley Full in-combination
Bewdley EA DO only
Bewdley water company permits only
Bewdley Do Nothing (Drought impact)
Bewdley 850 Ml/d Regulation 5 day mean target
Bewdley 730 Ml/d EA DO Regulation 5 day mean trget
Bewdley 650 Ml/d 1 day minimum mean target

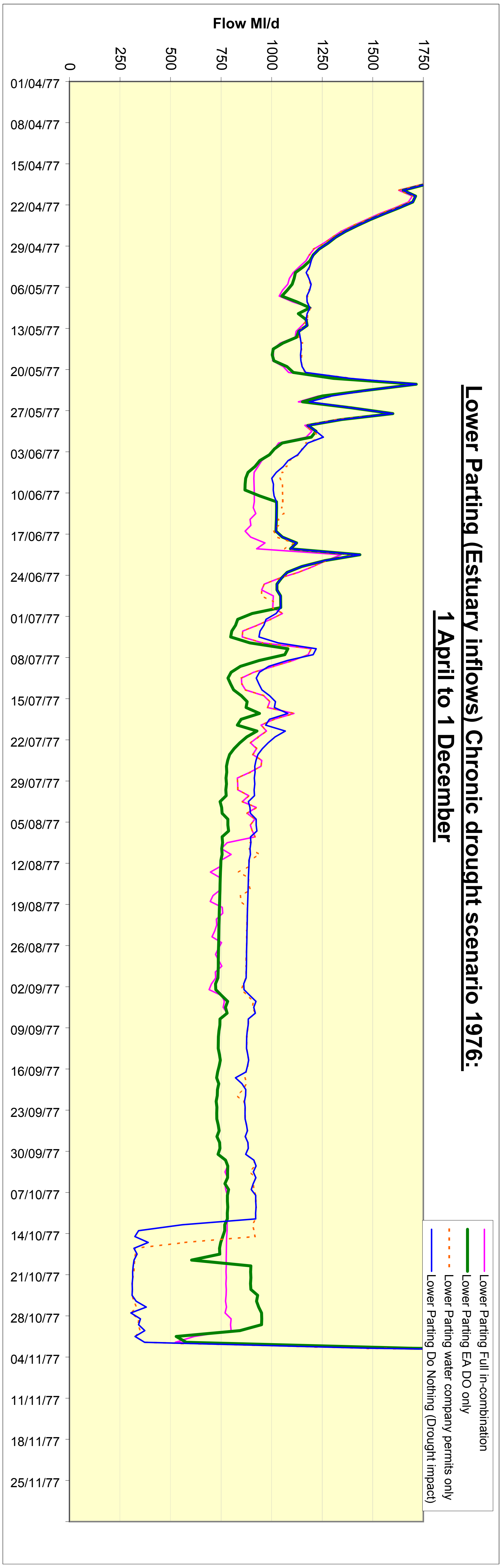

Buildwas Chronic drought scenario 1976: 1 April to 1 December
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
01/04/77
08/04/77
15/04/77
22/04/77
29/04/77
06/05/77
13/05/77
20/05/77
27/05/77
03/06/77
10/06/77
17/06/77
24/06/77
01/07/77
08/07/77
15/07/77
22/07/77
29/07/77
05/08/77
12/08/77
19/08/77
26/08/77
02/09/77
09/09/77
16/09/77
23/09/77
30/09/77
07/10/77
14/10/77
21/10/77
28/10/77
04/11/77
11/11/77
18/11/77
25/11/77
Buildwas Full in-combination
Buildwas EA DO only
Buildwas water company permits only
Buildwas Do Nothing (Drought impact)


Deerhurst Chronic drought scenario 1976: 1 April to 1 December
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
01/04/77
08/04/77
15/04/77
22/04/77
29/04/77
06/05/77
13/05/77
20/05/77
27/05/77
03/06/77
10/06/77
17/06/77
24/06/77
01/07/77
08/07/77
15/07/77
22/07/77
29/07/77
05/08/77
12/08/77
19/08/77
26/08/77
02/09/77
09/09/77
16/09/77
23/09/77
30/09/77
07/10/77
14/10/77
21/10/77
28/10/77
04/11/77
11/11/77
18/11/77
25/11/77
Deerhurst Full in-combination
Deerhurst EA DO only
Deerhurst water company permits only
Deerhurst Do Nothing (Drought impact)


Saxons Lode Chronic drought scenario 1976: 1 April to 1 December
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
01/04/77
08/04/77
15/04/77
22/04/77
29/04/77
06/05/77
13/05/77
20/05/77
27/05/77
03/06/77
10/06/77
17/06/77
24/06/77
01/07/77
08/07/77
15/07/77
22/07/77
29/07/77
05/08/77
12/08/77
19/08/77
26/08/77
02/09/77
09/09/77
16/09/77
23/09/77
30/09/77
07/10/77
14/10/77
21/10/77
28/10/77
04/11/77
11/11/77
18/11/77
25/11/77
Saxons Lode Full in-combination
Saxons Lode EA DO only
Saxons Lode water company permits only
Saxons Lode Do Nothing (Drought impact)



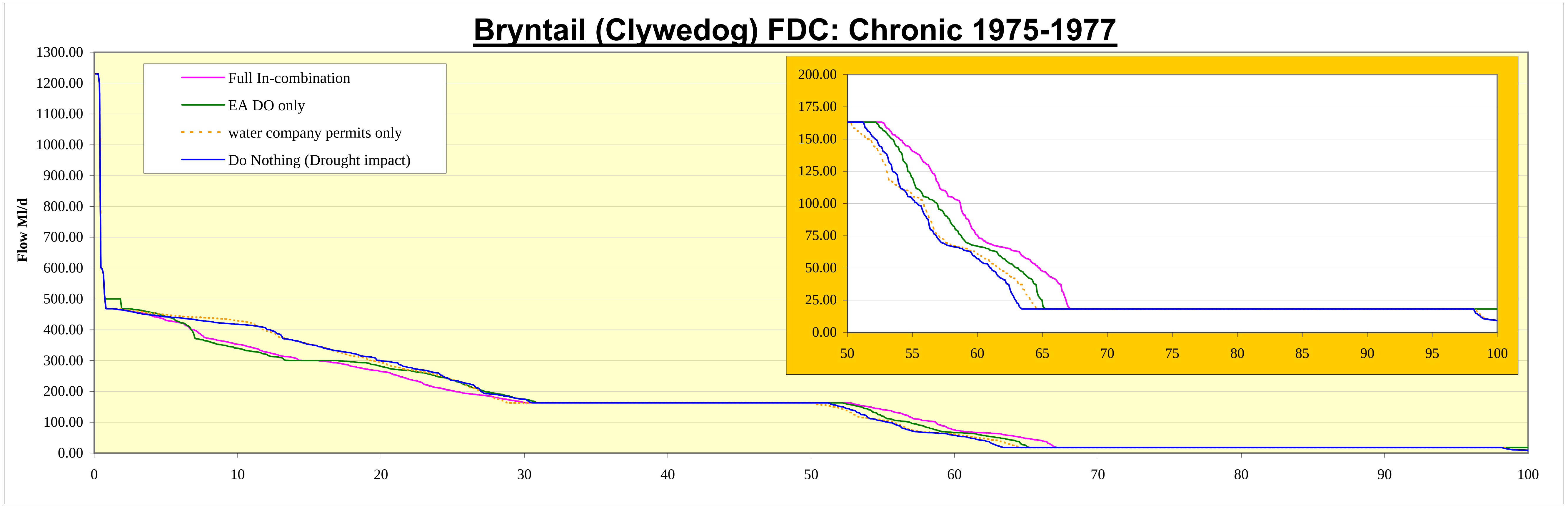
U/S Sharpness (Estuary inflows) Chronic drought scenario 1976:
1 April to 1 December
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
01/04/77
08/04/77
15/04/77
22/04/77
29/04/77
06/05/77
13/05/77
20/05/77
27/05/77
03/06/77
10/06/77
17/06/77
24/06/77
01/07/77
08/07/77
15/07/77
22/07/77
29/07/77
05/08/77
12/08/77
19/08/77
26/08/77
02/09/77
09/09/77
16/09/77
23/09/77
30/09/77
07/10/77
14/10/77
21/10/77
28/10/77
04/11/77
11/11/77
18/11/77
25/11/77
U/S Sharpness Full in-combination
U/S Sharpness EA DO only
U/S Sharpness water company permits only
U/S Sharpness Do Nothing (Drought impact)

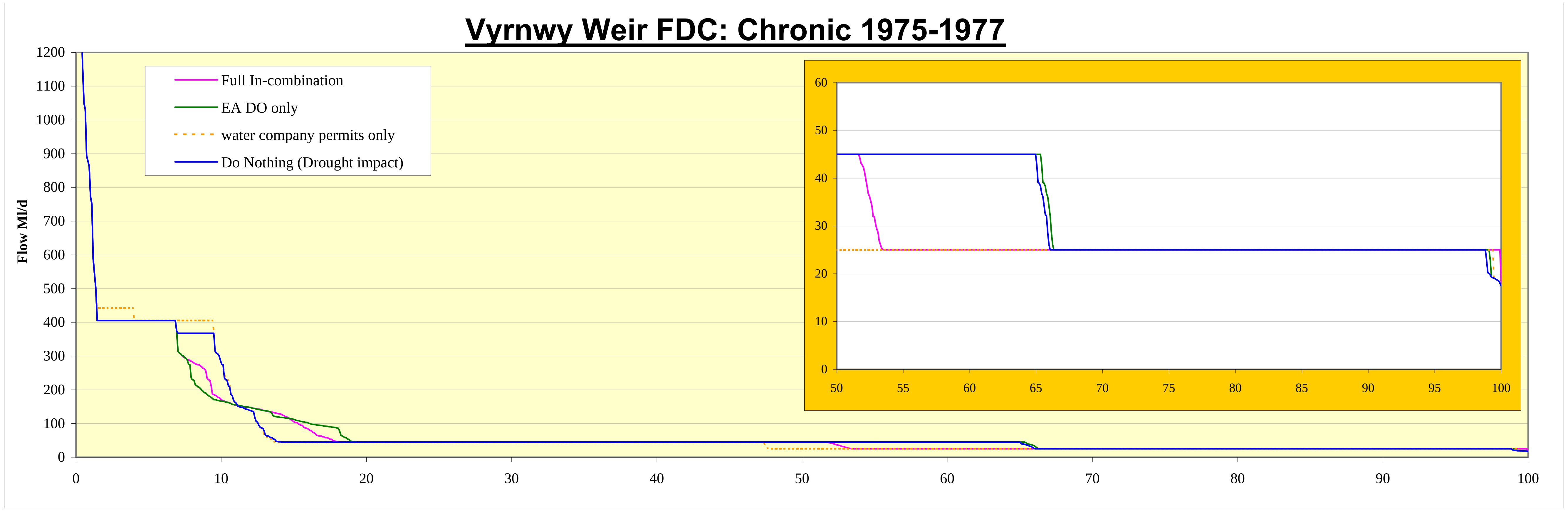


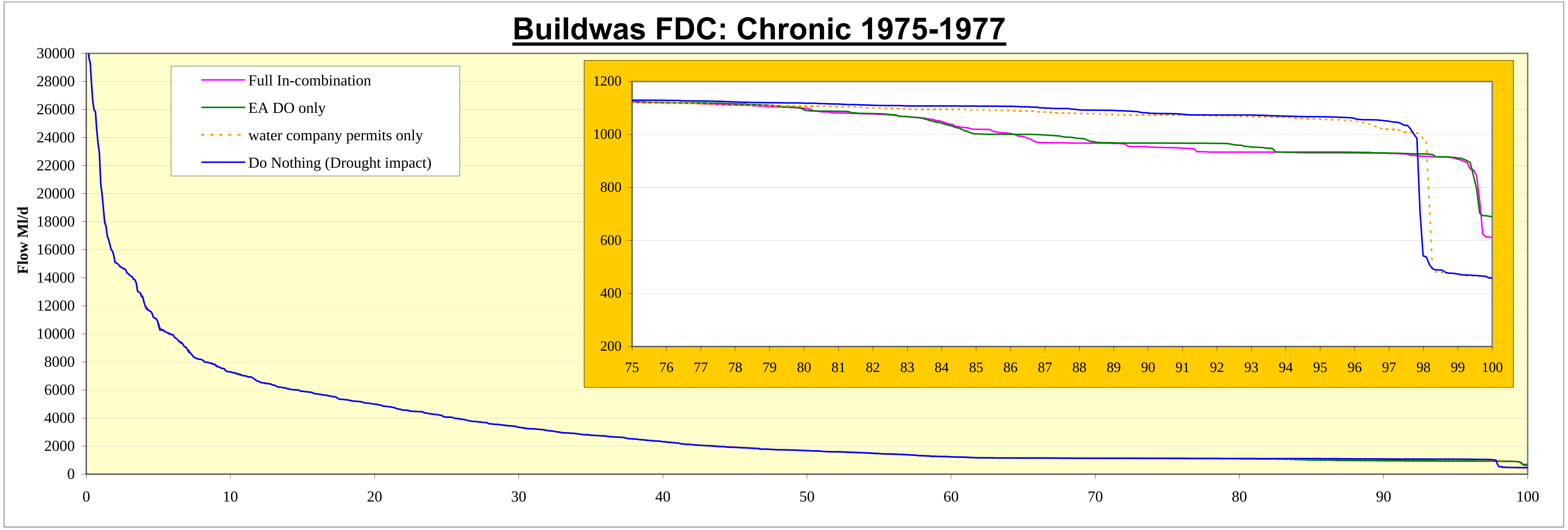
Lower Parting (Estuary inflows) Chronic drought scenario 1976:
1 April to 1 December
Flow Ml/d
0
250
500
750
1000
1250
1500
1750
01/04/77
08/04/77
15/04/77
22/04/77
29/04/77
06/05/77
13/05/77
20/05/77
27/05/77
03/06/77
10/06/77
17/06/77
24/06/77
01/07/77
08/07/77
15/07/77
22/07/77
29/07/77
05/08/77
12/08/77
19/08/77
26/08/77
02/09/77
09/09/77
16/09/77
23/09/77
30/09/77
07/10/77
14/10/77
21/10/77
28/10/77
04/11/77
11/11/77
18/11/77
25/11/77
Lower Parting Full in-combination
Lower Parting EA DO only
Lower Parting water company permits only
Lower Parting Do Nothing (Drought impact)

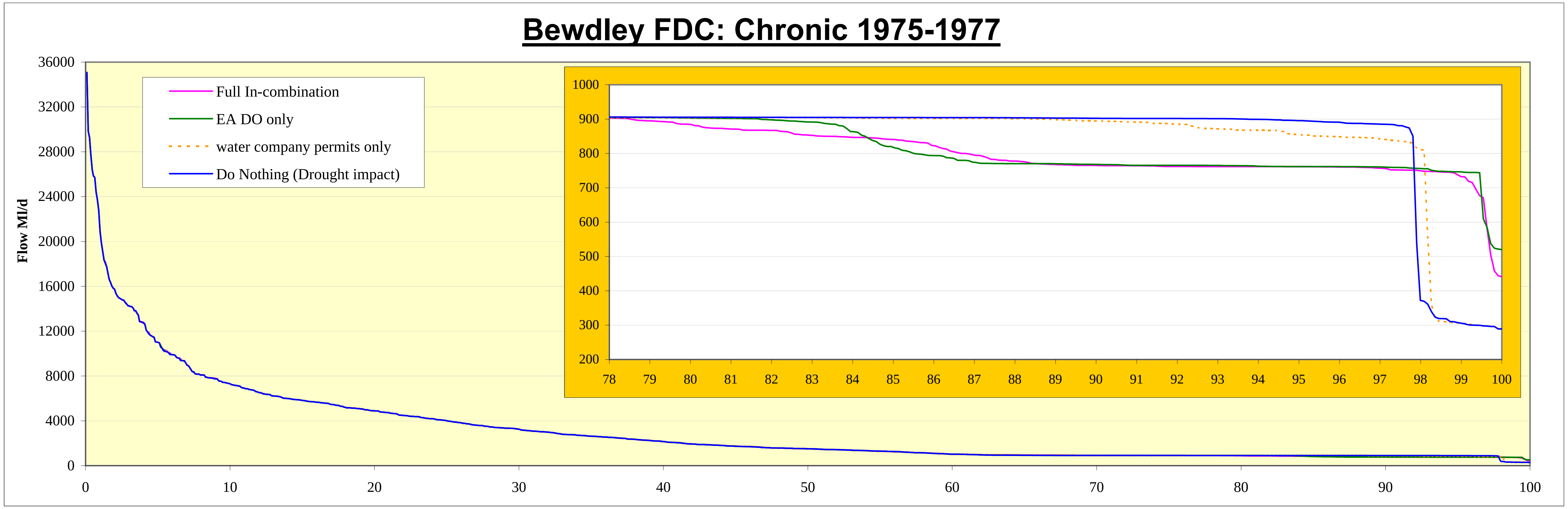
Appendix K.2

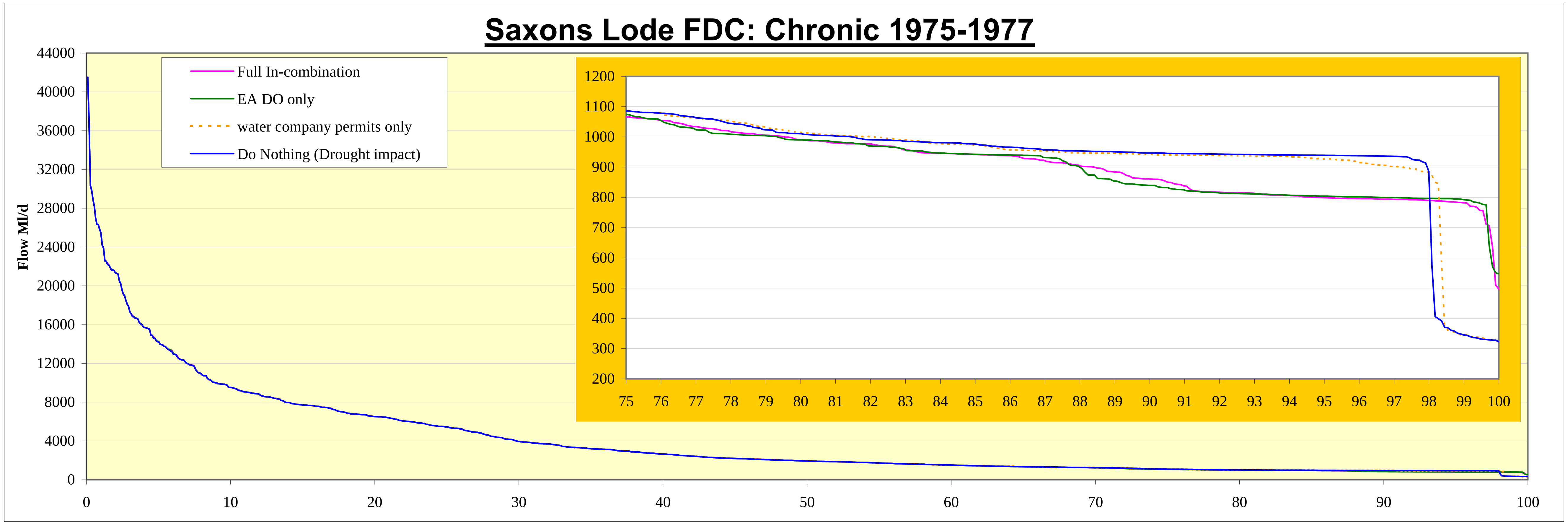
Chronic scenario: Flow Duration Curves

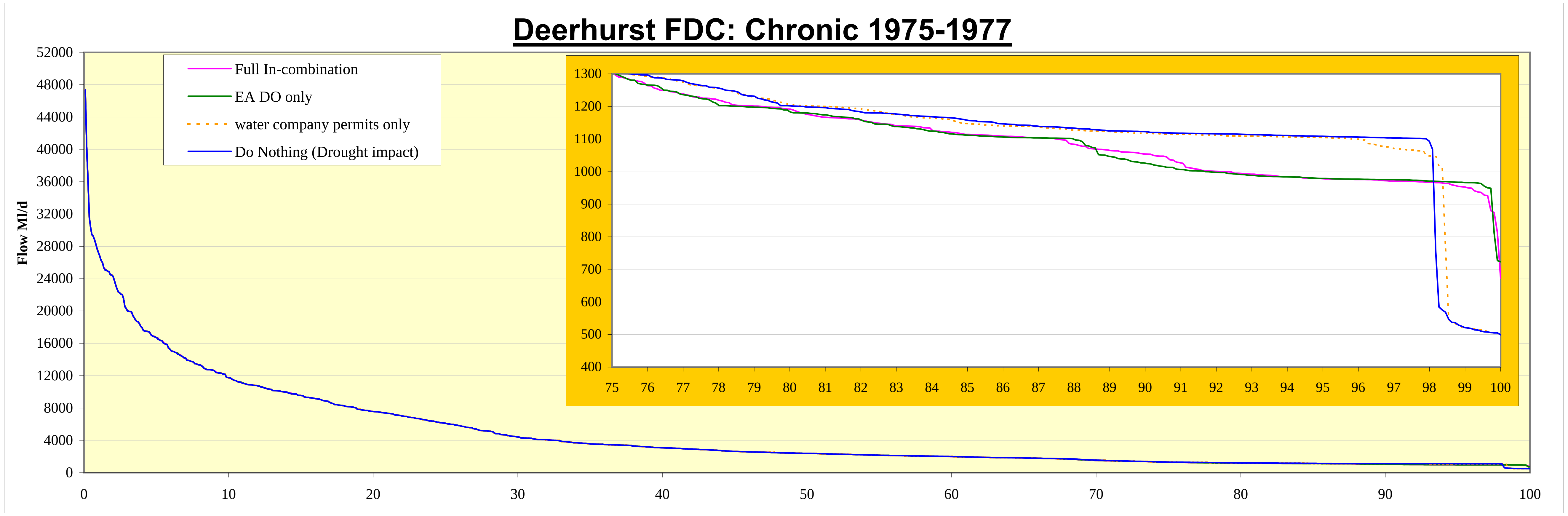

Bryntail (Clywedog) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
1300.00
1200.00
1100.00
1000.00
900.00
800.00
700.00
600.00
500.00
400.00
300.00
200.00
100.00
0.00
0
10
20
30
40
50
60
70
80
90
100
200.00
175.00
150.00
125.00
100.00
75.00
50.00
25.00
0.00
50
55
60
65
70
75
80
85
90
95
100

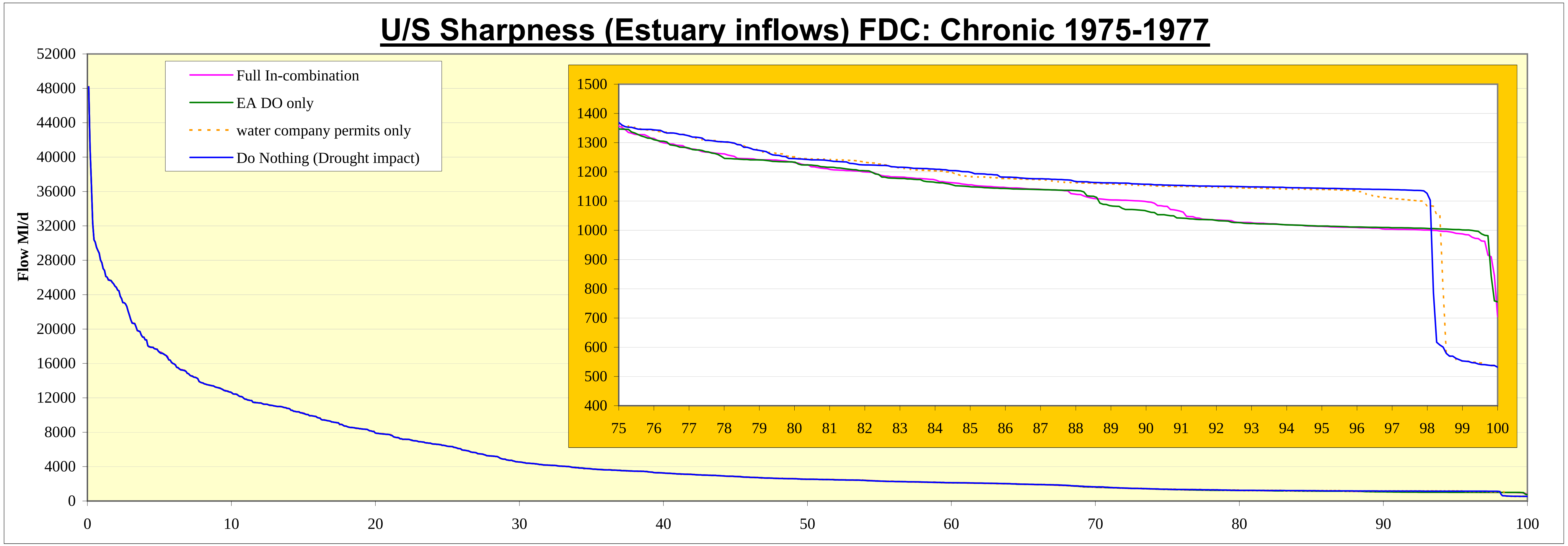

Vyrnwy Weir FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
1200
1100
1000
900
800
700
600
500
400
300
200
100
0
0
10
20
30
40
50
60
70
80
90
100
60
50
40
30
20
10
0
50
55
60
65
70
75
80
85
90
95
100

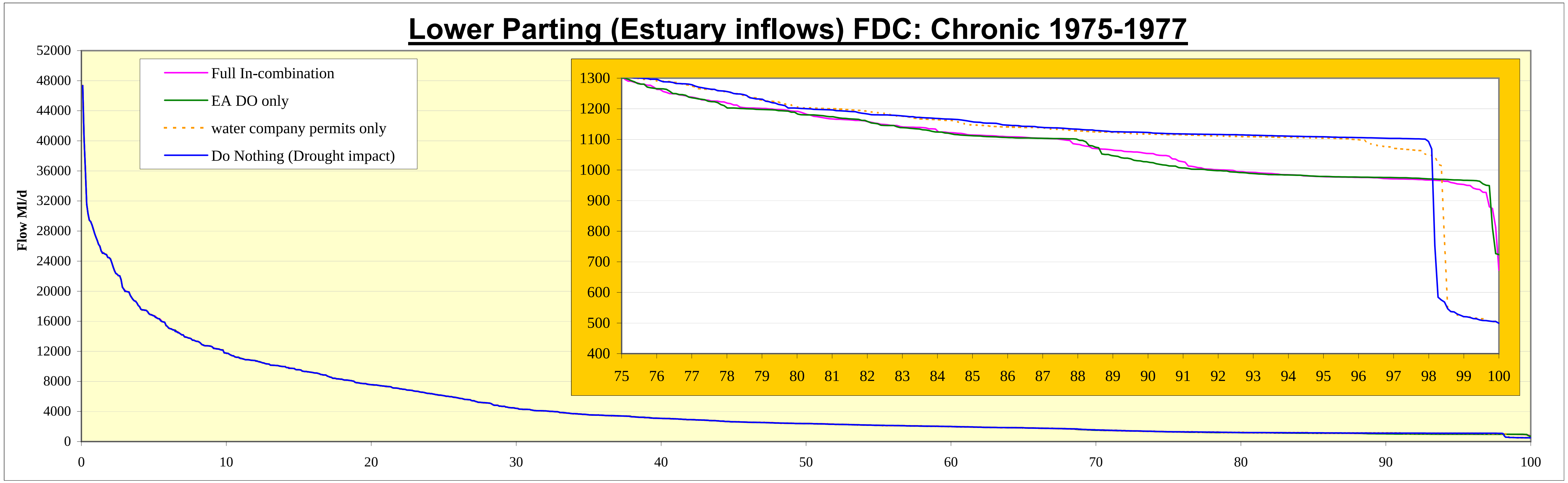

Buildwas FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)


Bewdley FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)


Saxons Lode FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)

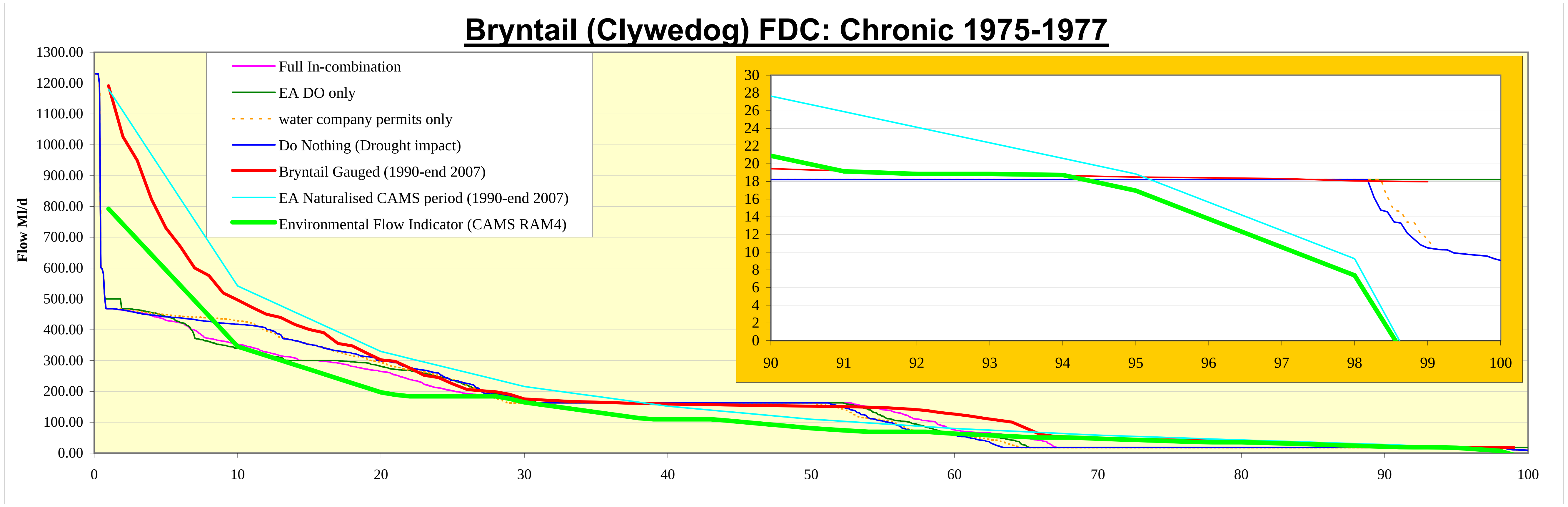

Deerhurst FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)


U/S Sharpness (Estuary inflows) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)

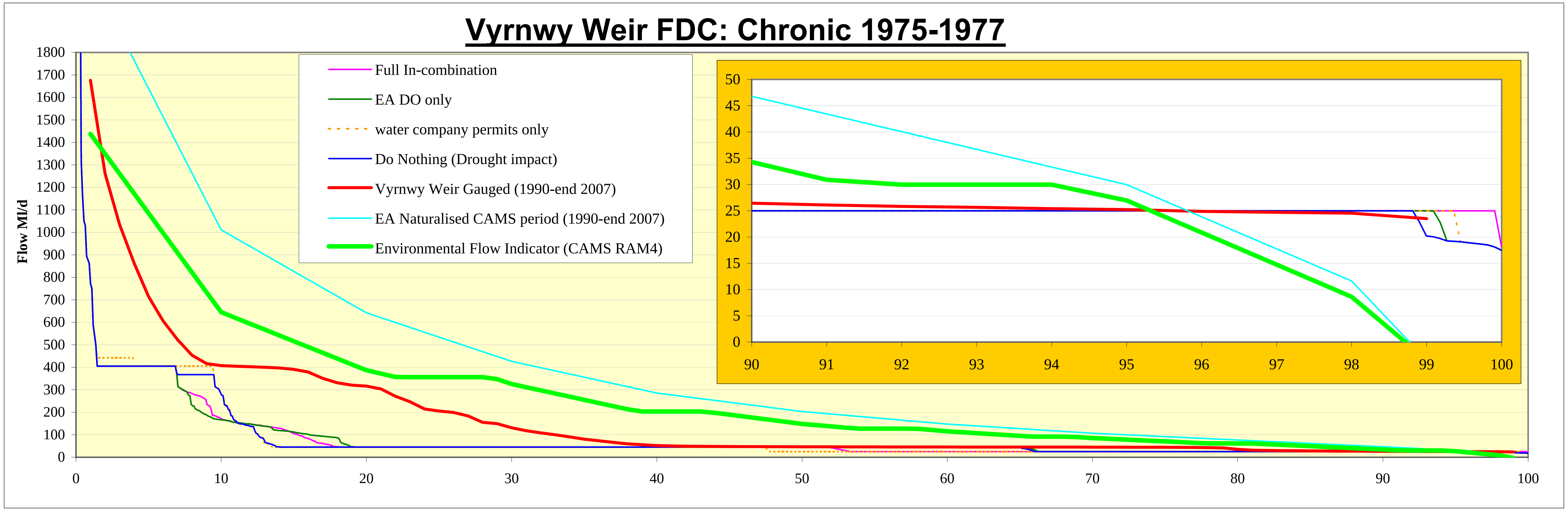

Lower Parting (Estuary inflows) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)

Appendix K.3

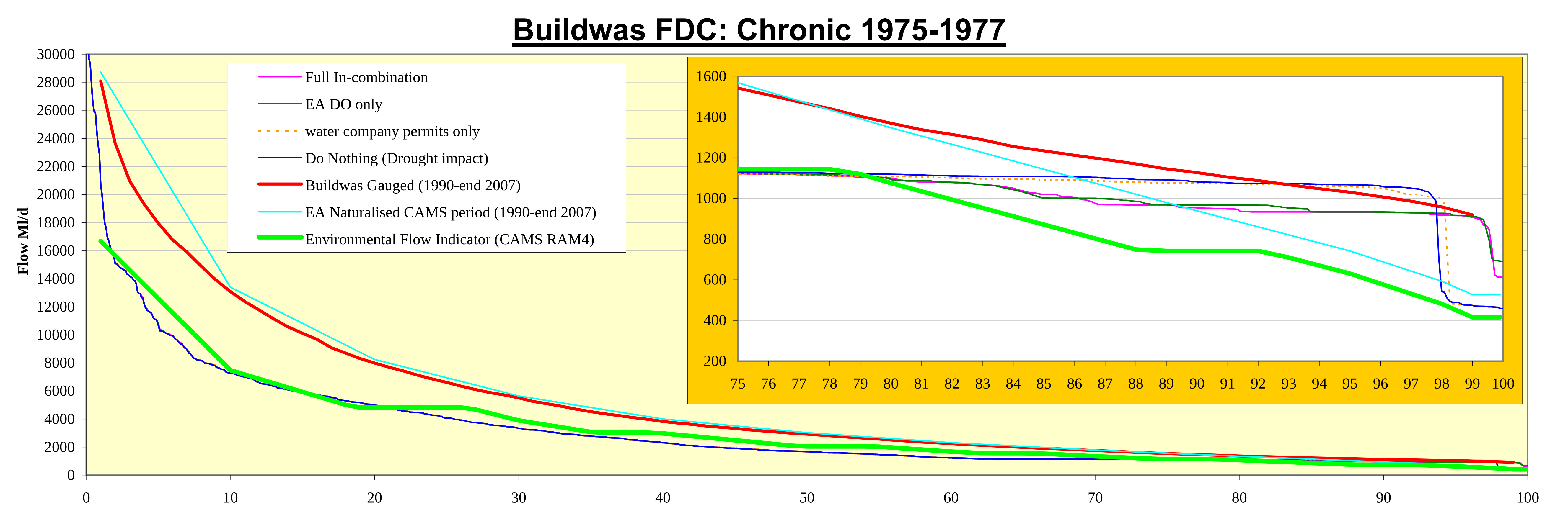
Chronic scenario: Environmental Flow Indicator Flow Duration Curves

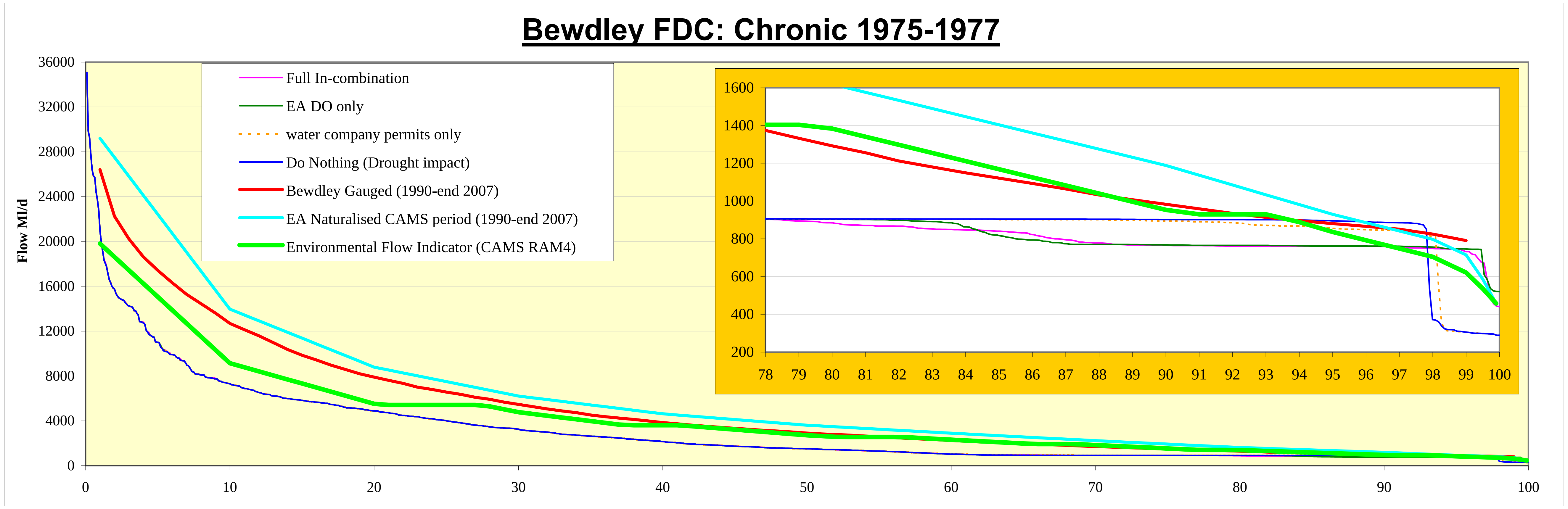


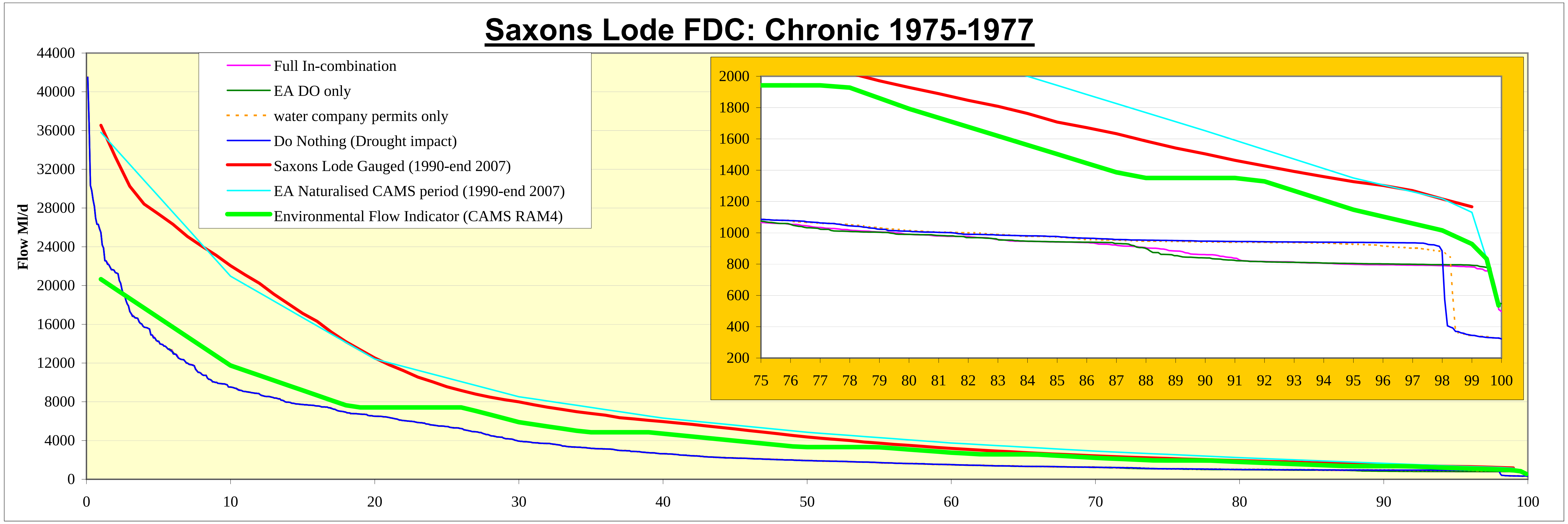
Bryntail (Clywedog) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Bryntail Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)



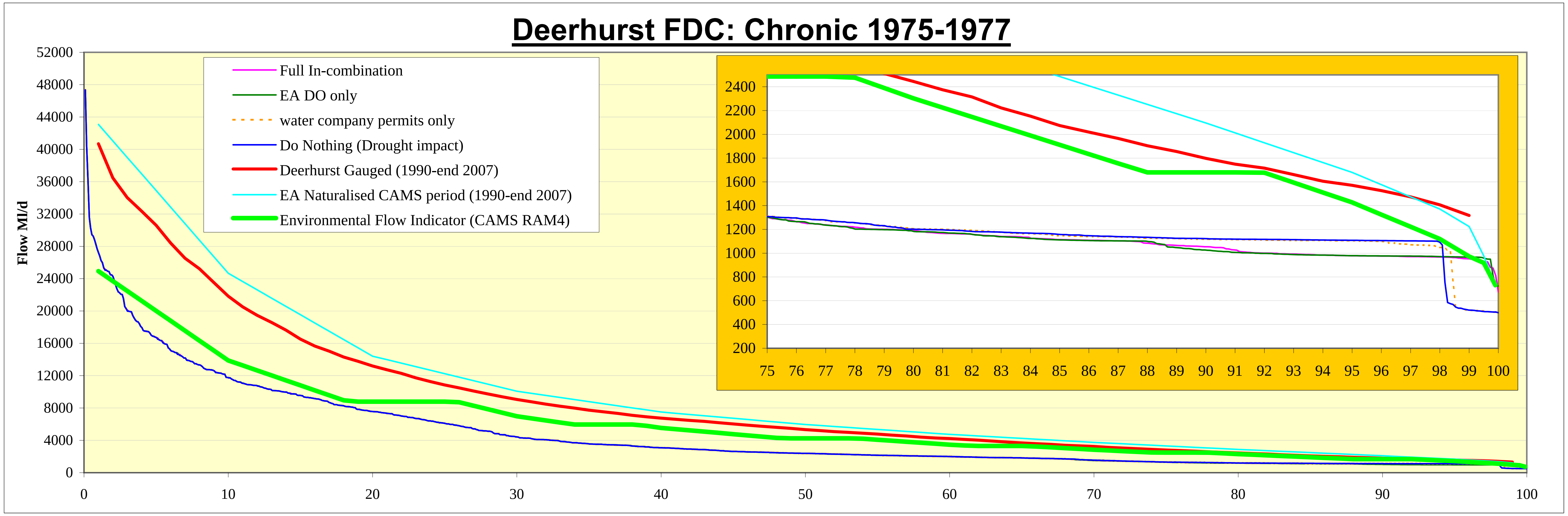
Vyrnwy Weir FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Vyrnwy Weir Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)


Buildwas FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Buildwas Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

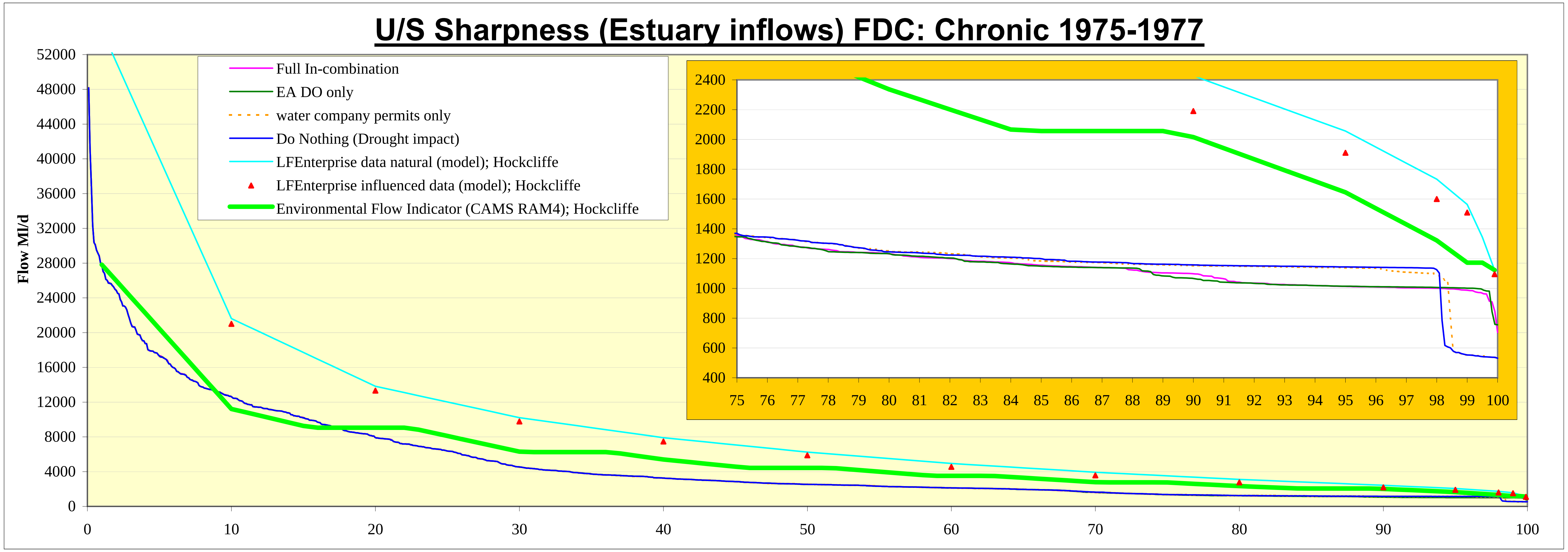

Bewdley FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Bewdley Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

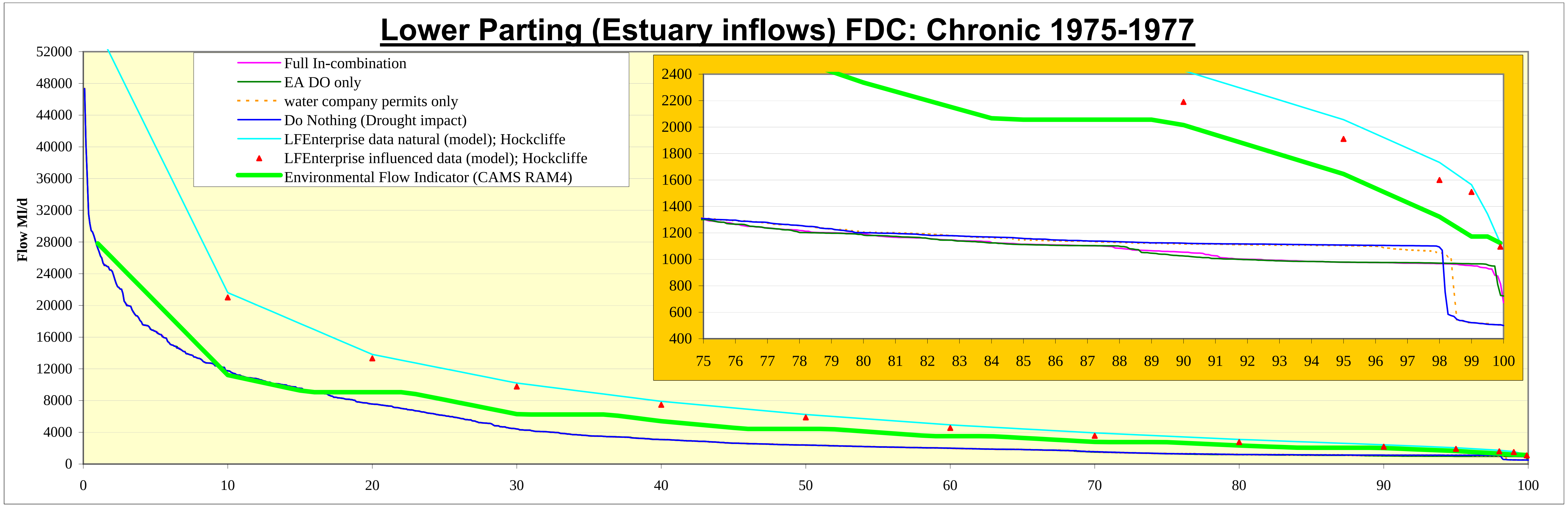


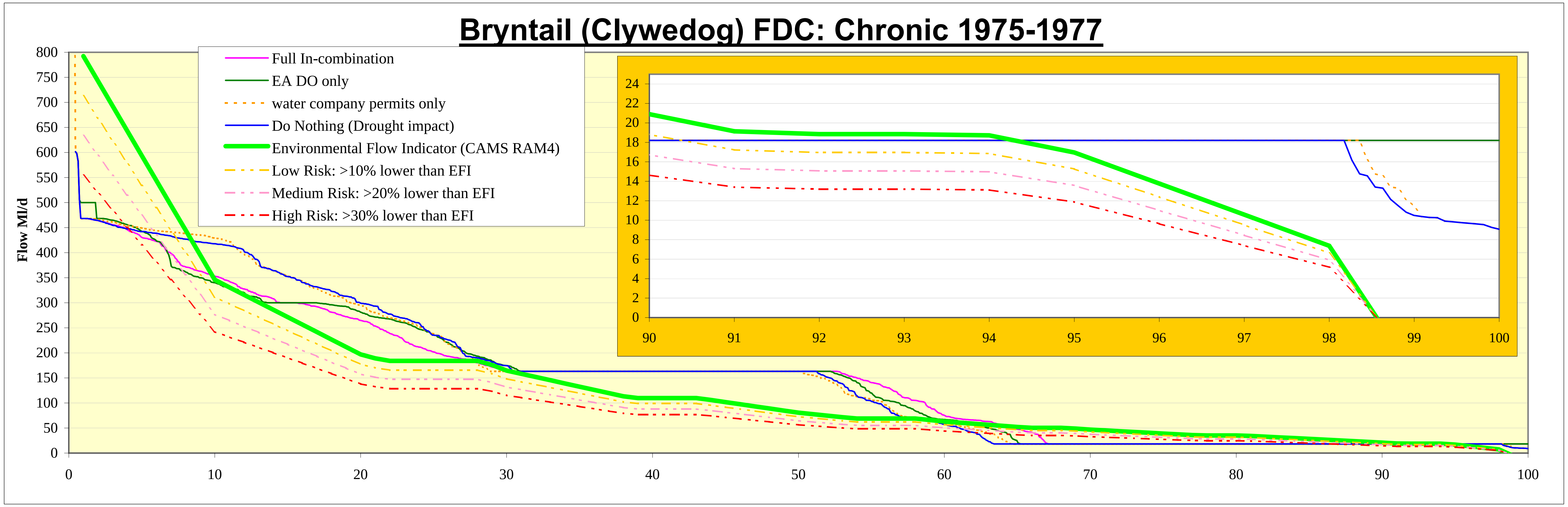
Saxons Lode FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Saxons Lode Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

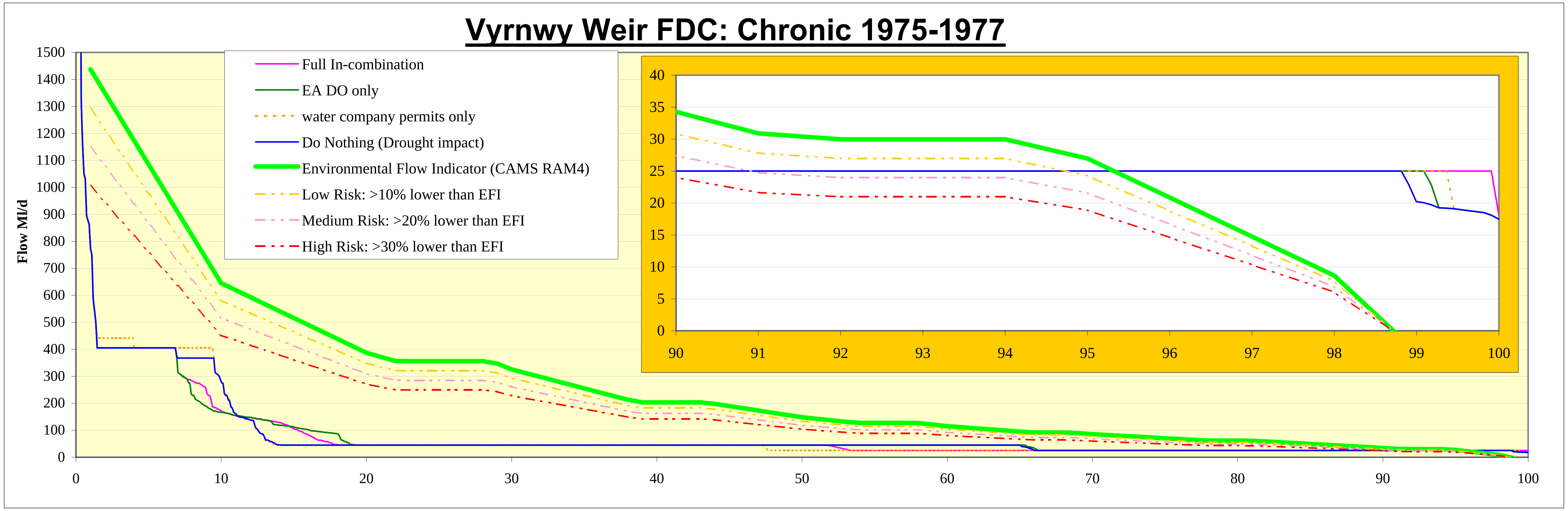


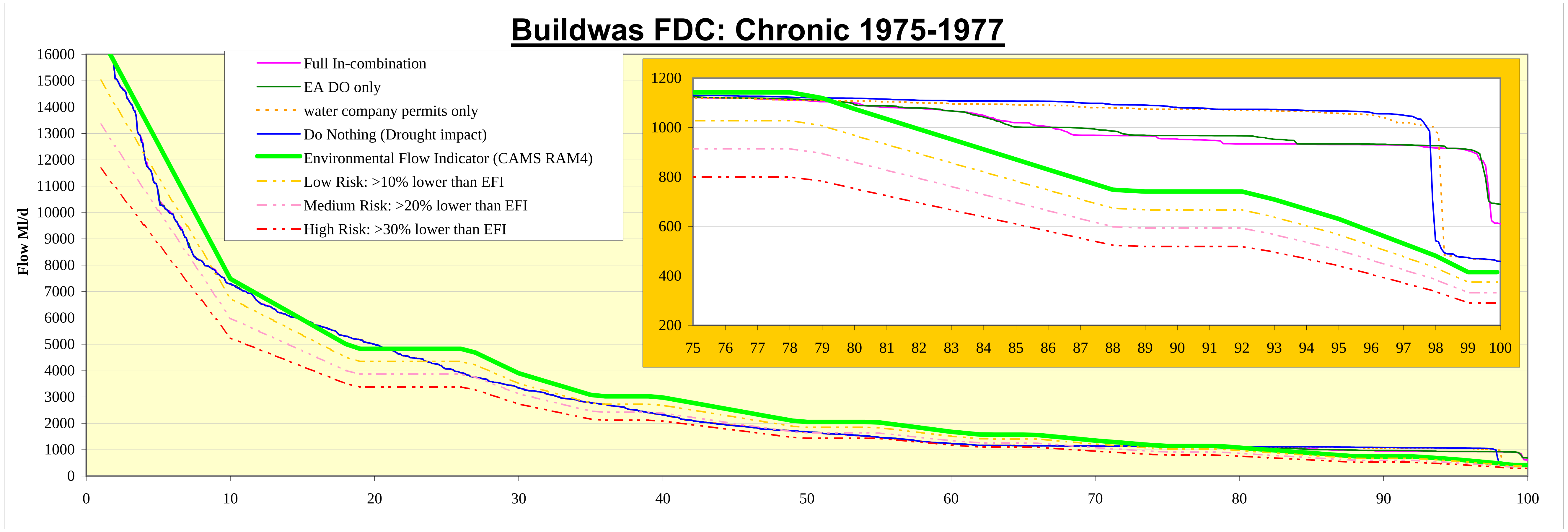
Deerhurst FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Deerhurst Gauged (1990-end 2007)
EA Naturalised CAMS period (1990-end 2007)
Environmental Flow Indicator (CAMS RAM4)

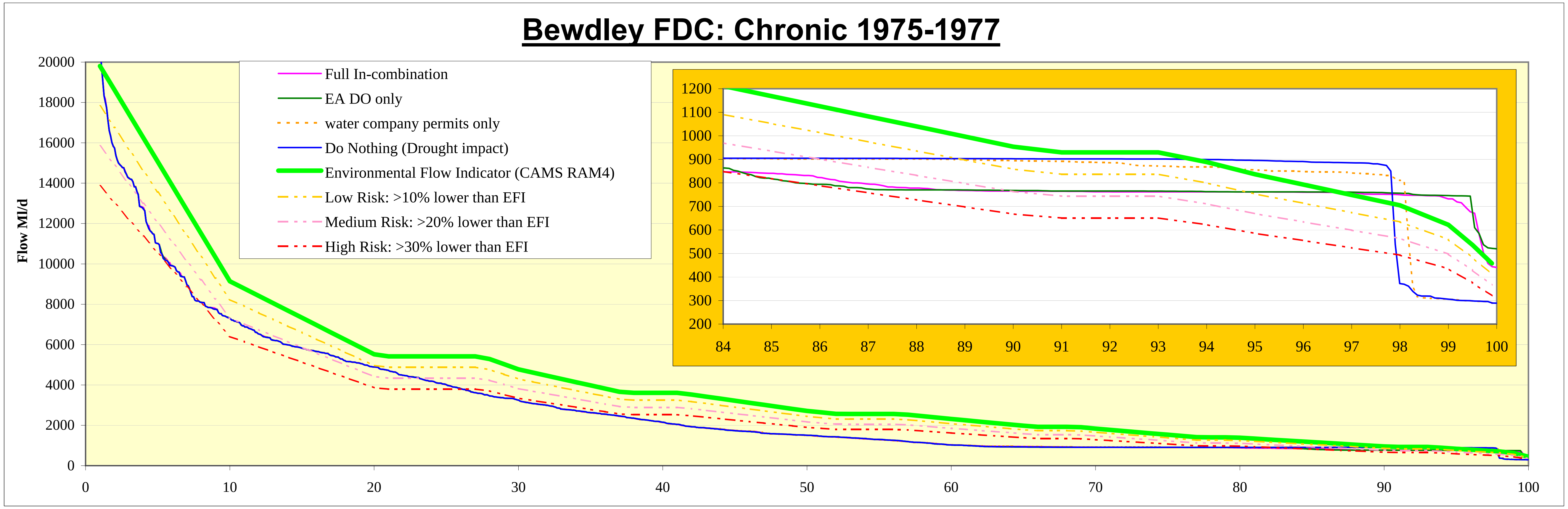

U/S Sharpness (Estuary inflows) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
LFEnterprise data natural (model); Hockcliffe
LFEnterprise influenced data (model); Hockcliffe
Environmental Flow Indicator (CAMS RAM4); Hockcliffe

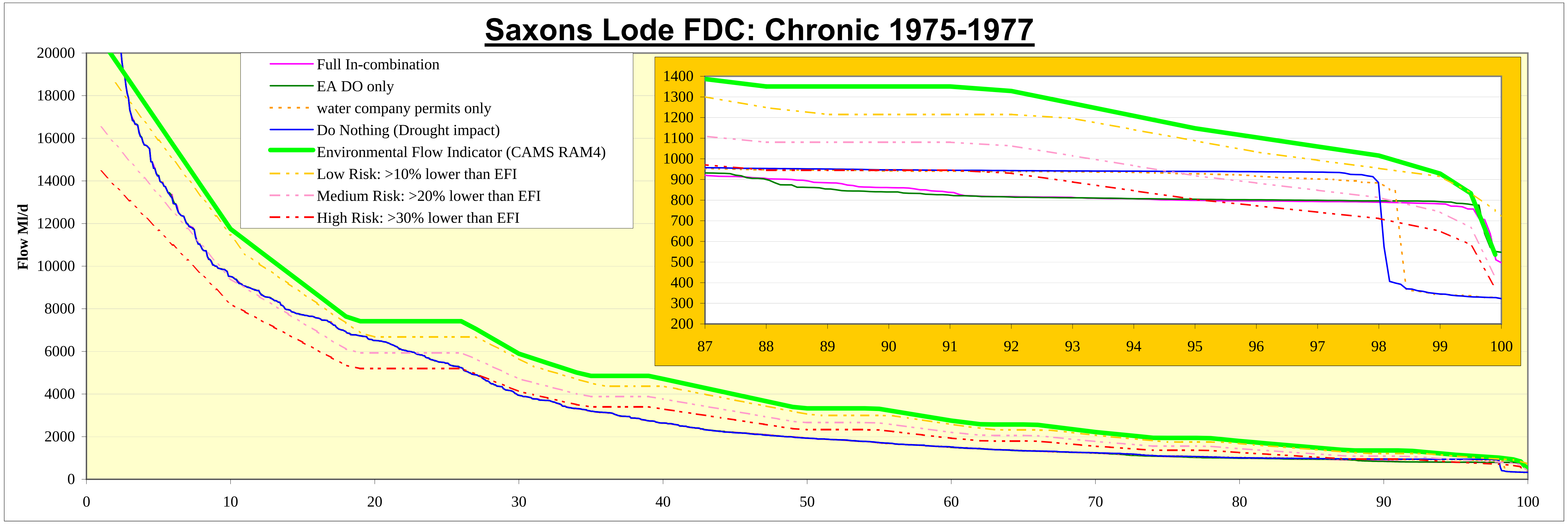

Lower Parting (Estuary inflows) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
LFEnterprise data natural (model); Hockcliffe
LFEnterprise influenced data (model); Hockcliffe
Environmental Flow Indicator (CAMS RAM4)

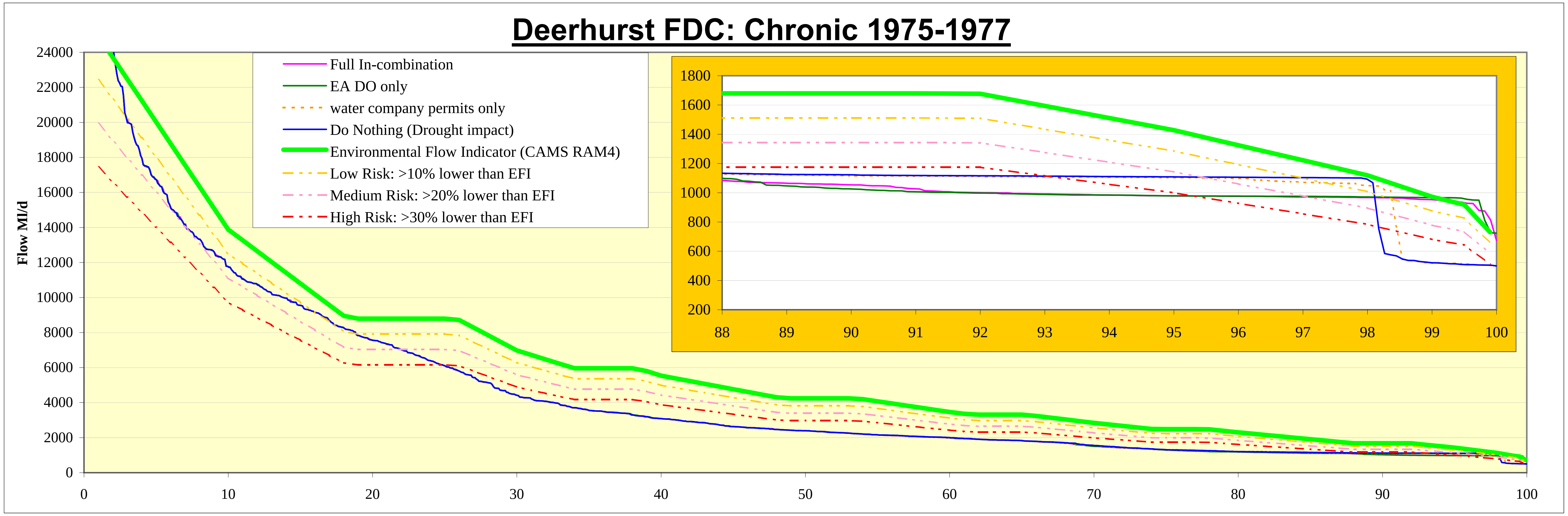

Bryntail (Clywedog) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI

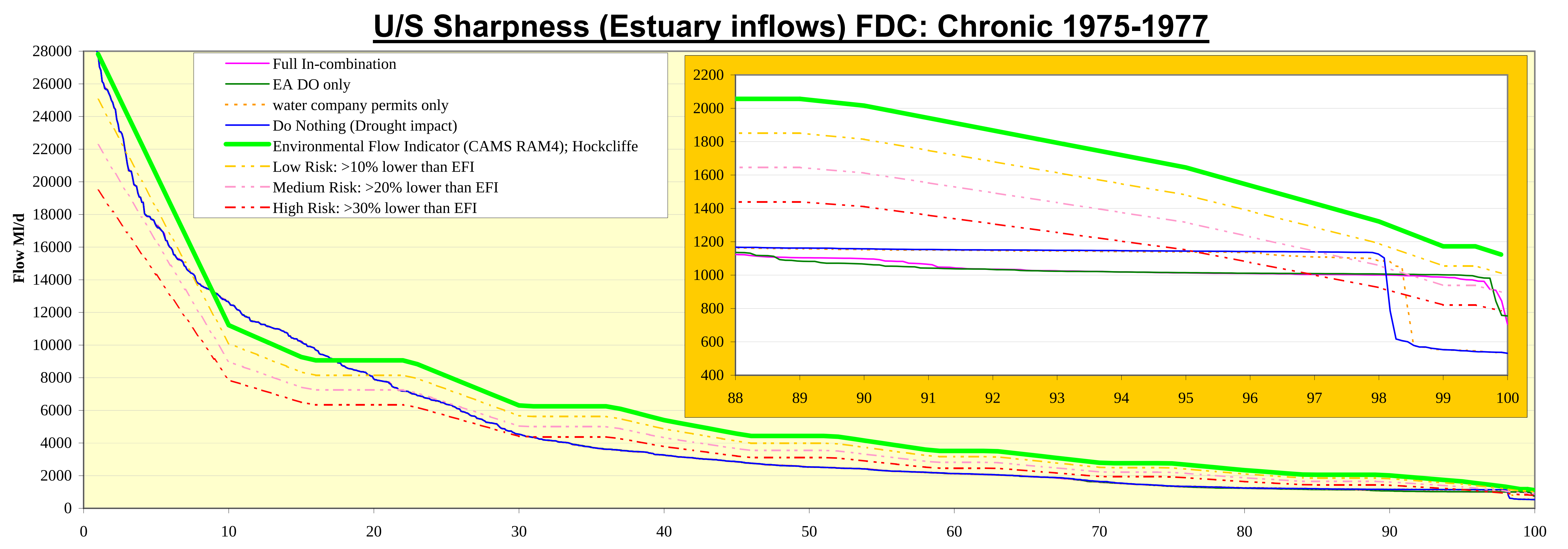

Vyrnwy Weir FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI

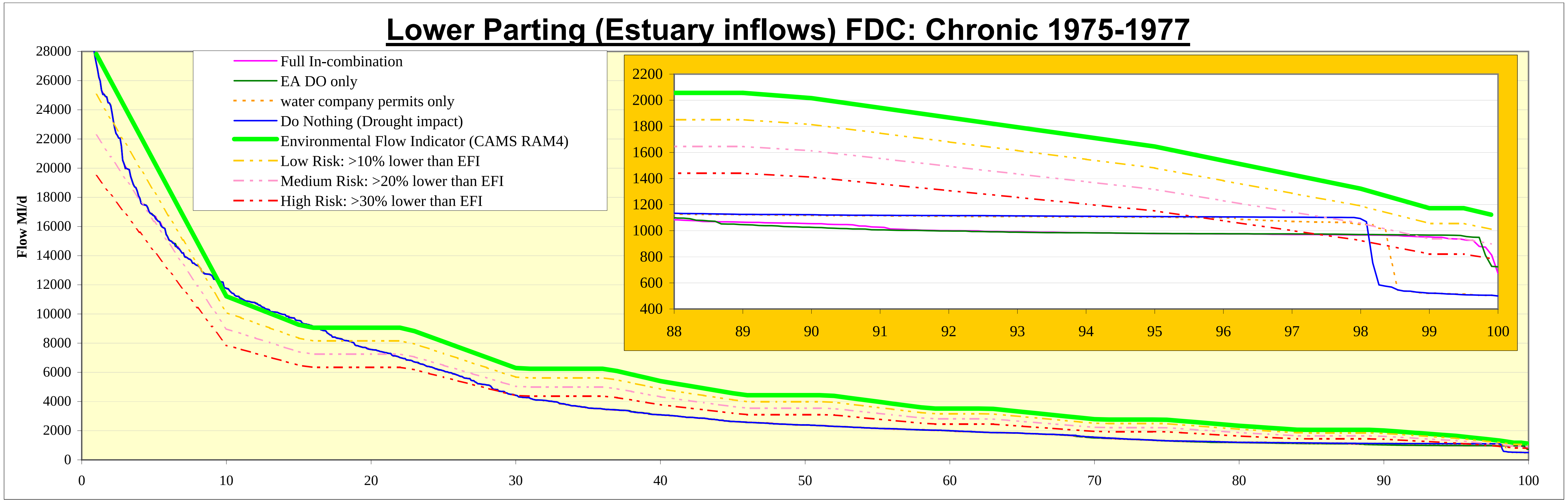

Buildwas FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Bewdley FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Saxons Lode FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Deerhurst FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


U/S Sharpness (Estuary inflows) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4); Hockcliffe
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI


Lower Parting (Estuary inflows) FDC: Chronic 1975-1977
Flow Ml/d
Full In-combination
EA DO only
water company permits only
Do Nothing (Drought impact)
Environmental Flow Indicator (CAMS RAM4)
Low Risk: >10% lower than EFI
Medium Risk: >20% lower than EFI
High Risk: >30% lower than EFI

Appendix K.4

Chronic scenario: Comparison Summary Statistics

Chronic scenario

Severn Regulation system

1975

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Diff. (Ml)	% Diff.	Clywedog releases Ml	Diff. (Ml)	% Diff.	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %	% Diff.
Do Nothing	19004.99			15.69			18989.29			0.00	63		100		71		100	
EA DO in isolation	19004.99	0.00	0	15.69	0.00	0	18989.29	0.00	0	0.00	63	0	100	0	71	0	100	0
Wc Permits only	18052.19	-952.80	-5	96.59	80.90	515	17955.59	-1033.70	-5	0.00	65	2	100	0	71	0	100	0
Full In-combination	18052.19	-952.80	-5	96.59	80.90	515	17955.59	-1033.70	-5	0.00	65	2	100	0	71	0	100	0

1976

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Diff. (Ml)	% Diff.	Clywedog releases Ml	Diff. (Ml)	% Diff.	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %	% Diff.
Do Nothing	59029.62			15594.95			43429.22			5.45	12		98		47		100	
EA DO in isolation	54500.82	#######	-8	15213.55	-381.39	-2	37122.22	-6307.00	-15	2165.05	24	12	98	0	43	-4	100	0
Wc Permits only	58034.12	-995.50	-2	15178.59	-416.36	-3	42848.61	-580.61	-1	6.92	13	1	98	0	48	1	100	0
Full In-combination	53234.59	#######	-10	14758.45	-836.50	-5	36316.58	-7112.64	-16	2159.56	26	14	98	0	44	-3	100	0

1977

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Diff. (Ml)	% Diff.	Clywedog releases Ml	Diff. (Ml)	% Diff.	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %	% Diff.
Do Nothing	66958.50			18085.26			39619.47			9253.77	26.04		89.58		37.09		100.00	
EA DO in isolation	60530.27	#######	-10	15337.05	-2748.21	0	39178.75	-440.72	-1	6014.47	36.71	11	97.47	8	37.10	0	100.00	0
Wc Permits only	70192.90	3234.40	5	18099.03	13.77	0	40197.59	578.12	1	11896.28	26.04	0	89.58	0	39.45	2	100.00	0
Full In-combination	63969.05	#######	-4	17958.20	-127.06	0	38184.59	-1434.88	-4	7826.26	37.70	12	97.81	8	39.46	2	100.00	0

1978

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Clywedog releases Ml	Vyrnwy releases Ml	Min. Clywedog Storage %	% Diff.	Max. Clywedog Storage %	% Diff.	Min. Vyrnwy Storage %	% Diff.	Max. Vyrnwy Storage %	% Diff.
Do Nothing	3064.46			0.00	3064.46	0.00	56		99		73		100	
EA DO in isolation	3064.46	0.00	0	0.00	3064.46	0.00	67	11	99	0	73	0	100	0
Wc Permits only	3064.46	0.00	0	0.00	3064.46	0.00	56	0	99	0	73	0	100	0
Full In-combination	3064.46	0.00	0	0.00	3064.46	0.00	68	12	99	0	73	0	100	0

1979

	Total regulation releases (Ml)	Diff. (Ml)	% Diff.	SGS Ml	Clywedog releases Ml	Vyrnwy releases Ml	Min. Clywedog Storage %	Max. Clywedog Storage %	Min. Vyrnwy Storage %	Max. Vyrnwy Storage %
Do Nothing	16.85			0.00	16.85	0.00	83	100	79	100
EA DO in isolation	16.85	0.00	0	0.00	16.85	0.00	83	100	79	100
Wc Permits only	16.85	0.00	0	0.00	16.85	0.00	83	100	79	100
Full In-combination	16.85	0.00	0	0.00	16.85	0.00	83	100	79	100

Chronic scenario

Minimum Flows

1975

	Bryntail (Clywedog) min. flow Ml/d	Ml/d Diff.	Vyrnwy min. flow Ml/d	Ml/d Diff.	Buildwas min. flow Ml/d	Ml/d Diff.	Bewdley min. flow Ml/d	Ml/d Diff.	Saxons Lode min. flow Ml/d	Ml/d Diff.	Deerhurst min. flow Ml/d	Ml/d Diff.	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Ml/d Diff.	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures	% Diff.
Do Nothing	18.20		25.00		1002.62		891.14		1250.07		1685.23		1808.54		1511.64		0	0	0	
EA DO in isolation	18.20	0	25.00	0	1002.62	0	891.14	0	1250.07	0	1685.23	0	1808.54	0	1511.64	0.00	0	0	0	0
Wc Permits only	18.20	0	25.00	0	975.11	-27.51	836.16	-54.99	1208.44	-41.63	1646.56	-38.67	1773.26	-35.28	1476.36	-35.28	2	0	0	0
Full In-combination	18.20	0	25.00	0	975.11	-27.51	836.16	-54.99	1208.44	-41.63	1646.56	-38.67	1773.26	-35.28	1476.36	-35.28	2	0	0	0

1976

	Bryntail (Clywedog) min. flow Ml/d	Ml/d Diff.	Vyrnwy min. flow Ml/d	Ml/d Diff.	Buildwas min. flow Ml/d	Ml/d Diff.	Bewdley min. flow Ml/d	Ml/d Diff.	Saxons Lode min. flow Ml/d	Ml/d Diff.	Deerhurst min. flow Ml/d	Ml/d Diff.	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Ml/d Diff.	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures	% Diff.
Do Nothing	8.67		25.00		512.05		335.89		398.89		576.92		608.86		382.44		22	21	21	
EA DO in isolation	18.20	9.53	25.00	0	584.12	72.08	409.00	73.11	473.06	74.17	652.15	75.24	684.09	75.24	458.76	76.32	66	26	25	4
Wc Permits only	8.67	0	25.00	0	492.05	-20.00	315.77	-20.13	378.89	-20.00	556.92	-20.00	588.86	-20.00	362.44	-20.00	34	20	20	-1
Full In-combination	18.20	9.53	25.00	0	571.57	59.52	396.58	60.69	460.61	61.72	639.95	63.03	671.89	63.03	446.67	64.23	78	28	24	3

1977

	Bryntail (Clywedog) min. flow Ml/d	Ml/d Diff.	Vyrnwy min. flow Ml/d	Ml/d Diff.	Buildwas min. flow Ml/d	Ml/d Diff.	Bewdley min. flow Ml/d	Ml/d Diff.	Saxons Lode min. flow Ml/d	Ml/d Diff.	Deerhurst min. flow Ml/d	Ml/d Diff.	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Ml/d Diff.	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures	% Diff.
Do Nothing	9.07		17.46		458.88		289.05		322.65		499.35		531.55		303.93		25	24	24	
EA DO in isolation	18.20	9	17.46	0	689.70	231	519.89	231	547.16	225	723.37	224	755.36	224	527.74	224	140	6	6	-18
Wc Permits only	9.07	0	17.46	0	458.88	0	289.05	0	322.65	0	499.35	0	531.55	0	303.93	0	32	21	21	-3
Full In-combination	18.20	9	18.09	1	610.52	152	440.72	152	496.54	174	672.62	173	704.56	173	523.49	220	135	7	5	-19

1978

	Bryntail (Clywedog) min. flow Ml/d	Vyrnwy min. flow Ml/d	Buildwas min. flow Ml/d	Bewdley min. flow Ml/d	Saxons Lode min. flow Ml/d	Deerhurst min. flow Ml/d	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures
Do Nothing	18.20	25.00	969.18	905.04	1423.58	1807.88	1933.58		1735.80	0	0	0
EA DO in isolation	18.20	25.00	969.18	905.04	1423.58	1807.88	1933.58		1735.80	0	0	0
Wc Permits only	18.20	25.00	969.18	905.04	1423.58	1807.88	1933.58		1735.80	0	0	0
Full In-combination	18.20	25.00	969.18	905.04	1423.58	1807.88	1933.58		1735.80	0	0	0

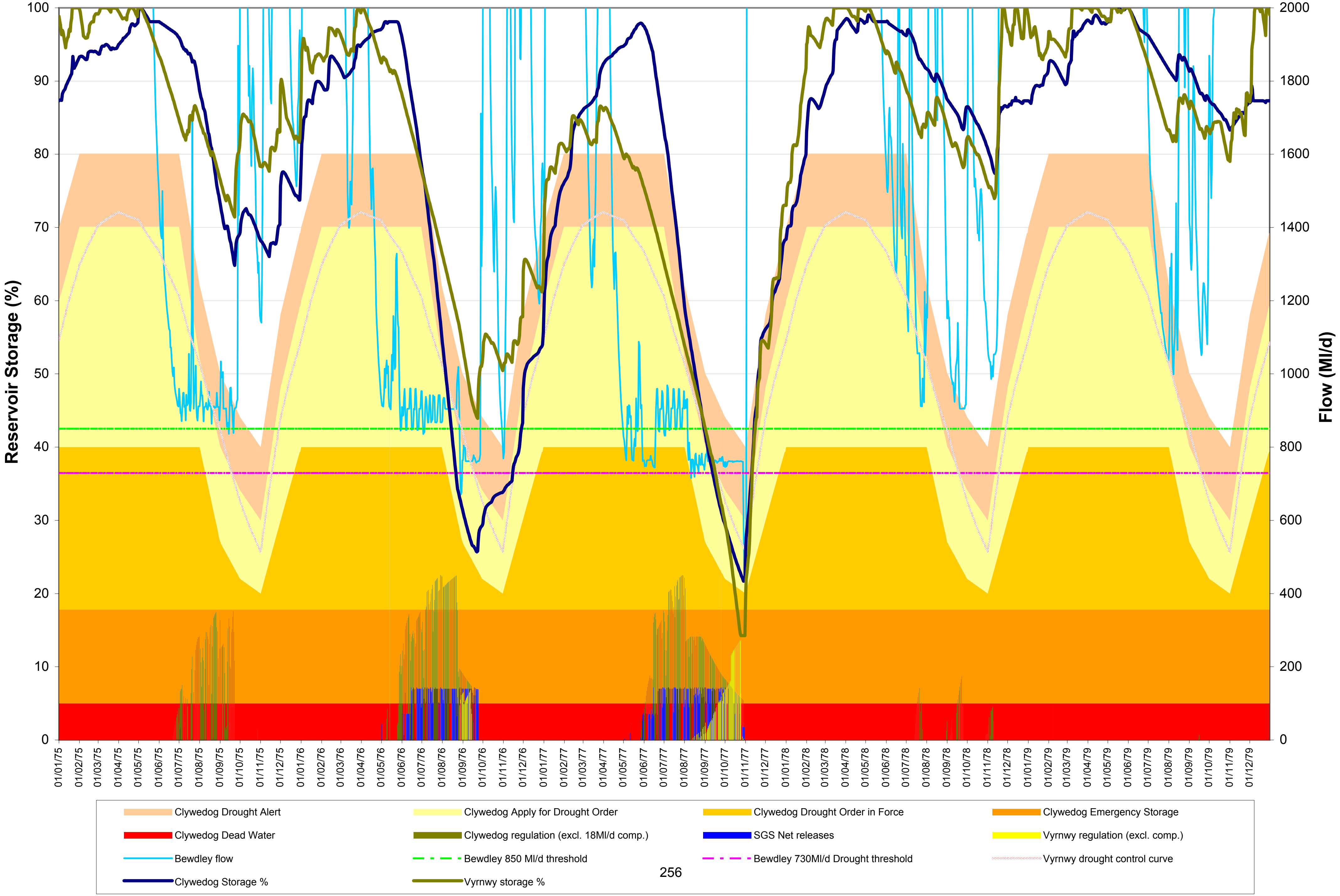
1979

	Bryntail (Clywedog) min. flow Ml/d	Vyrnwy min. flow Ml/d	Buildwas min. flow Ml/d	Bewdley min. flow Ml/d	Saxons Lode min. flow Ml/d	Deerhurst min. flow Ml/d	Sharpness min. flow Ml/d	Ml/d Diff.	Lower Parting min. flow Ml/d	Bewdley Flow Failures: Total 850 Ml/d failures	Total 730 Ml/d failures	Total 650 Ml/d failures
Do Nothing	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0
EA DO in isolation	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0
Wc Permits only	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0
Full In-combination	31.26	25.00	1115.73	998.64	1723.73	2305.45	2597.15		2300.25	0	0	0

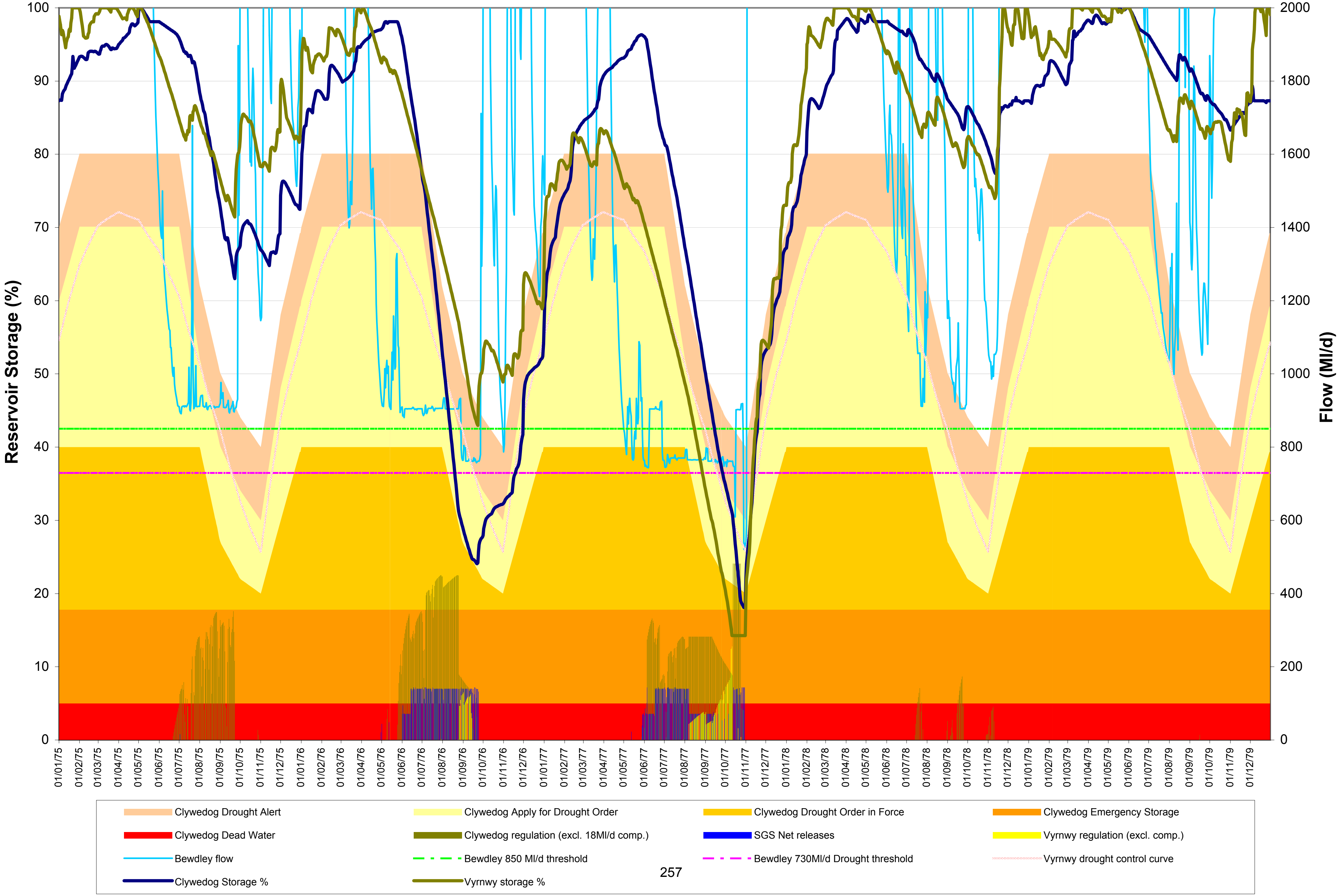
Appendix K.5

Chronic scenario: Reservoir Operations

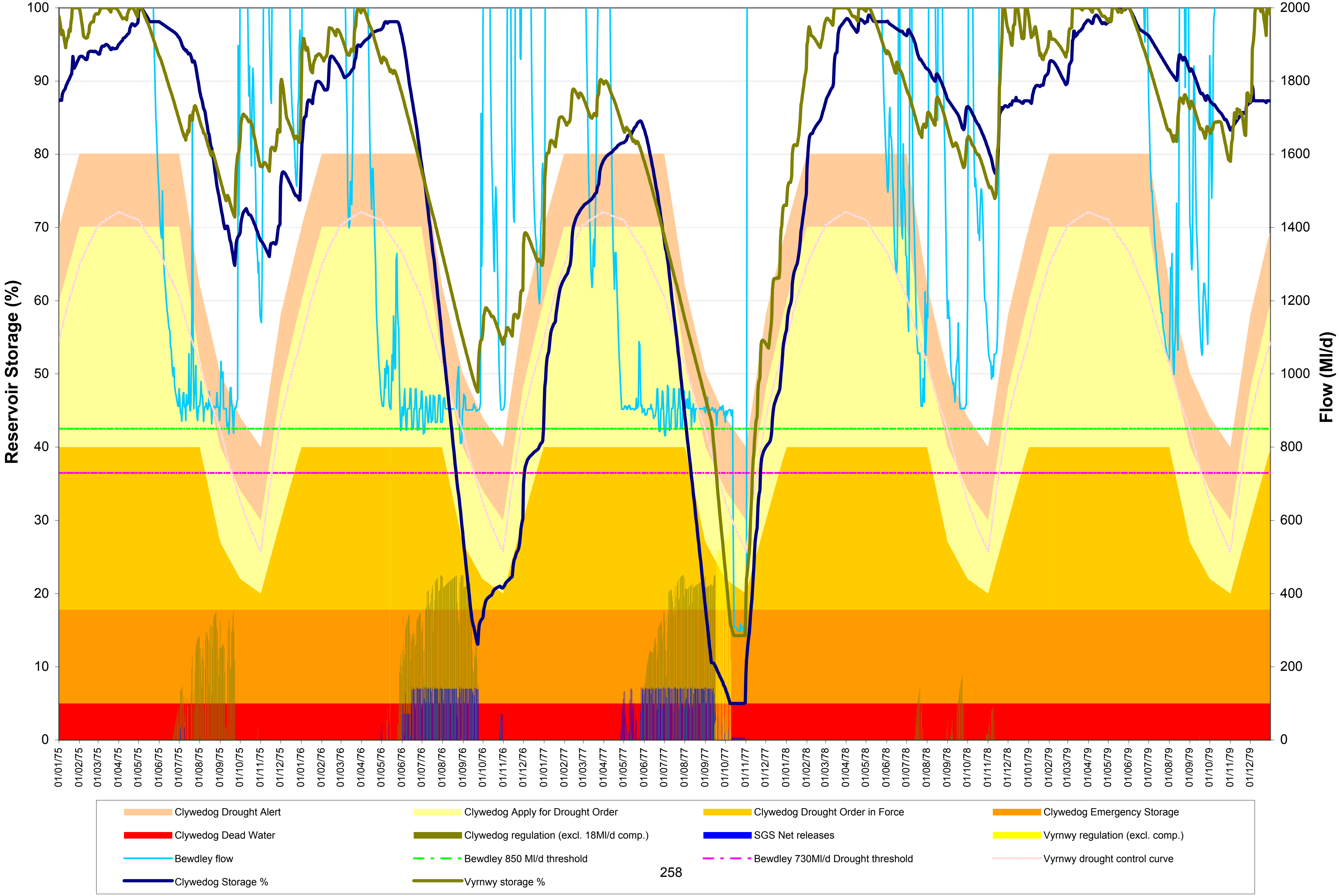
Chronic scenario - Full In-combination (EA Drought Orders & water company Permits): 1975 - 1979



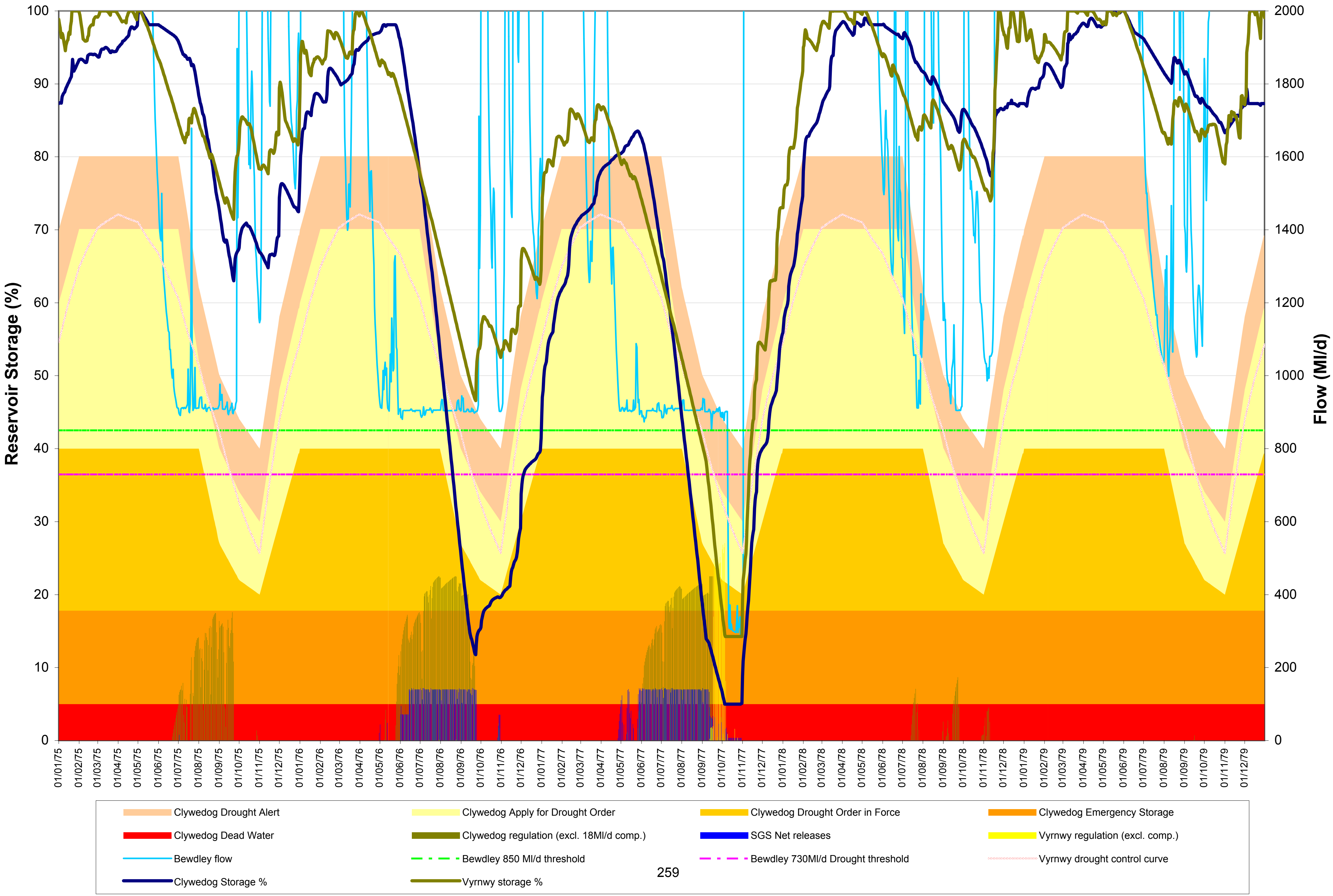
Chronic scenario - EA Drought Order only (no water company Permits): 1975 - 1979



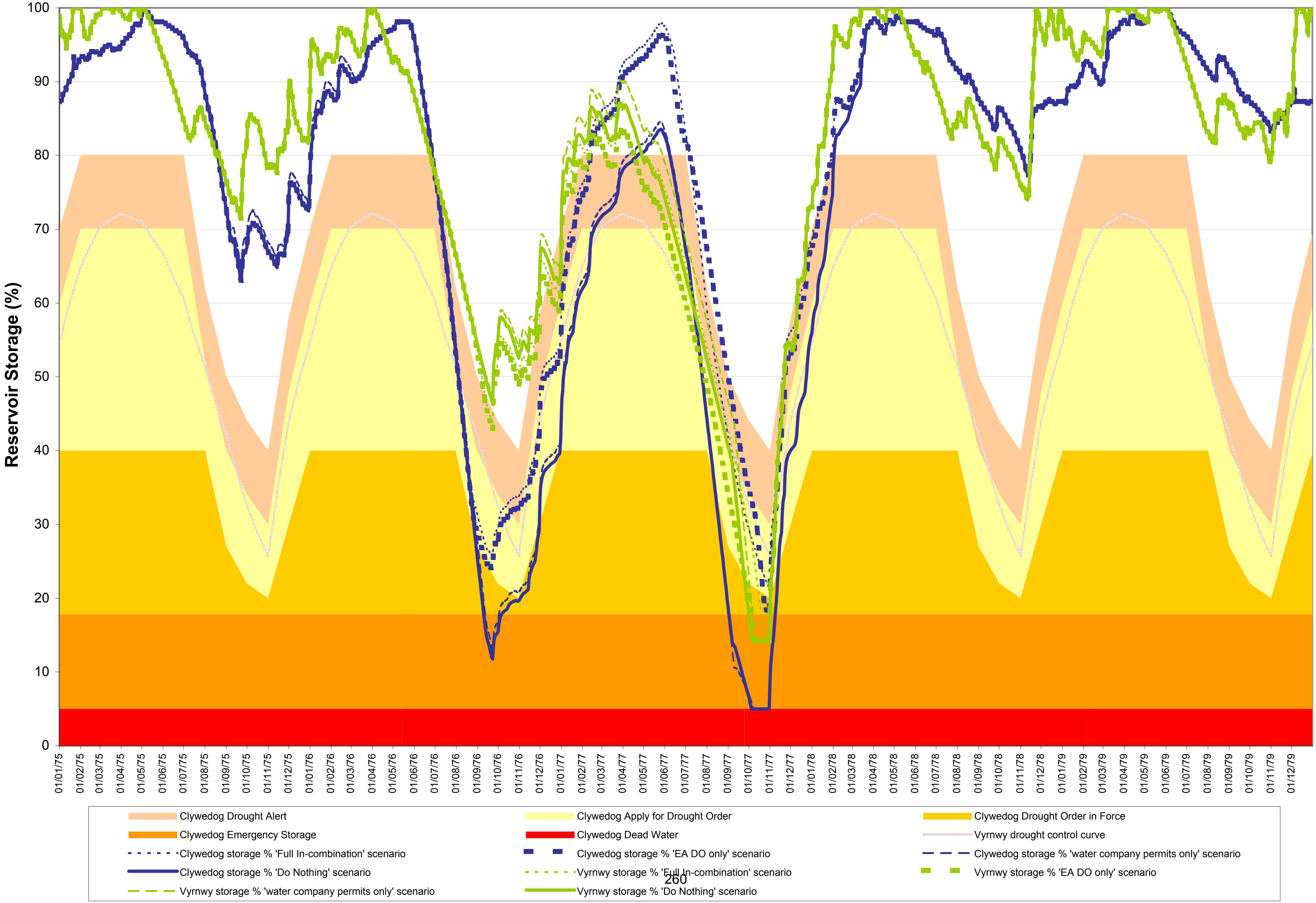
Chronic scenario - EA Water Company Permits only (no EA Drought Orders): 1975 - 1979



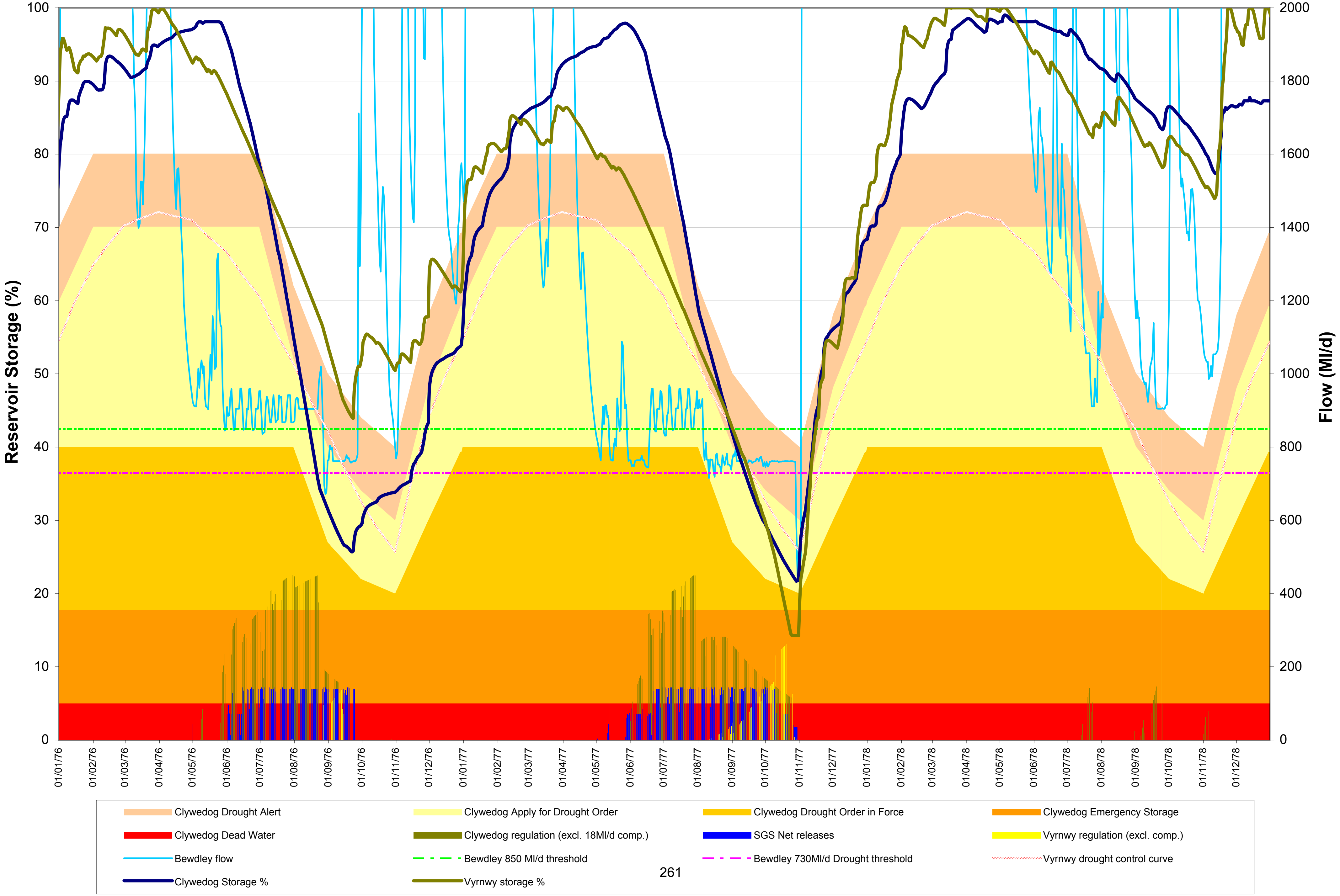
Chronic scenario - Do Nothing (underlying drought impacts): 1975 - 1979

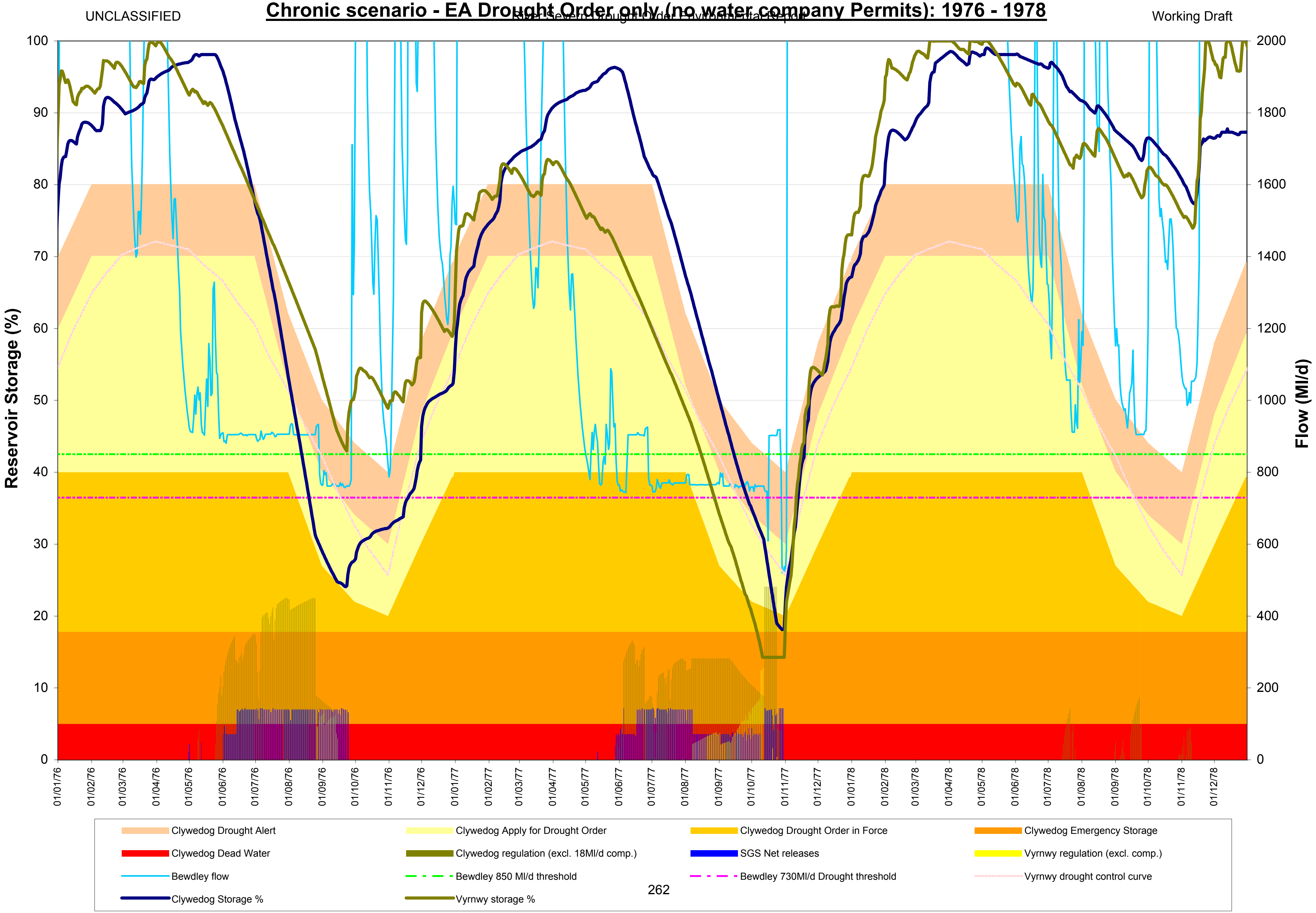


Chronic drought scenario Modelling: Reservoir Storage (only) 1975 - 1979

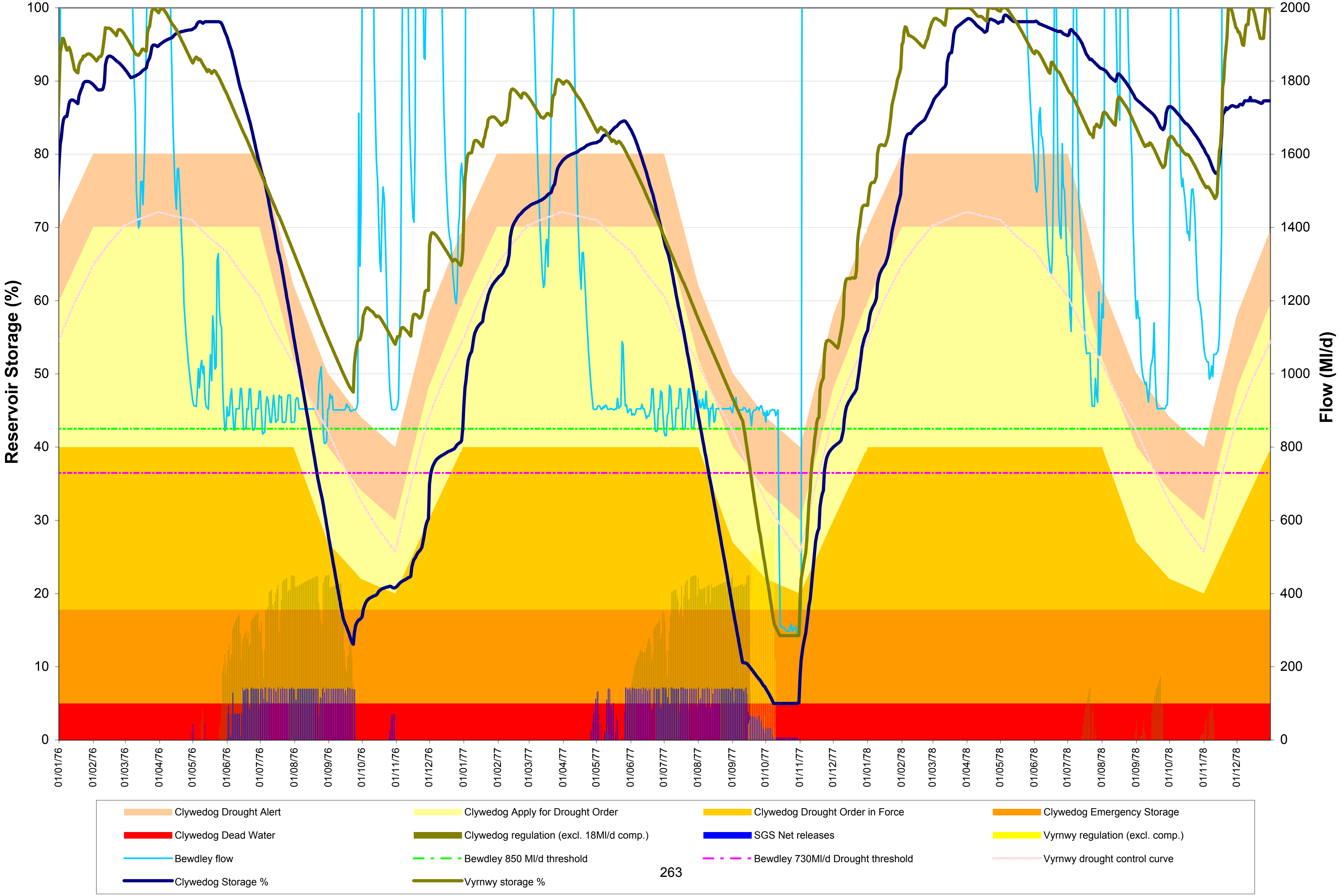


Chronic scenario - Full In-combination (EA Drought Orders & water company Permits): 1976 - 1978

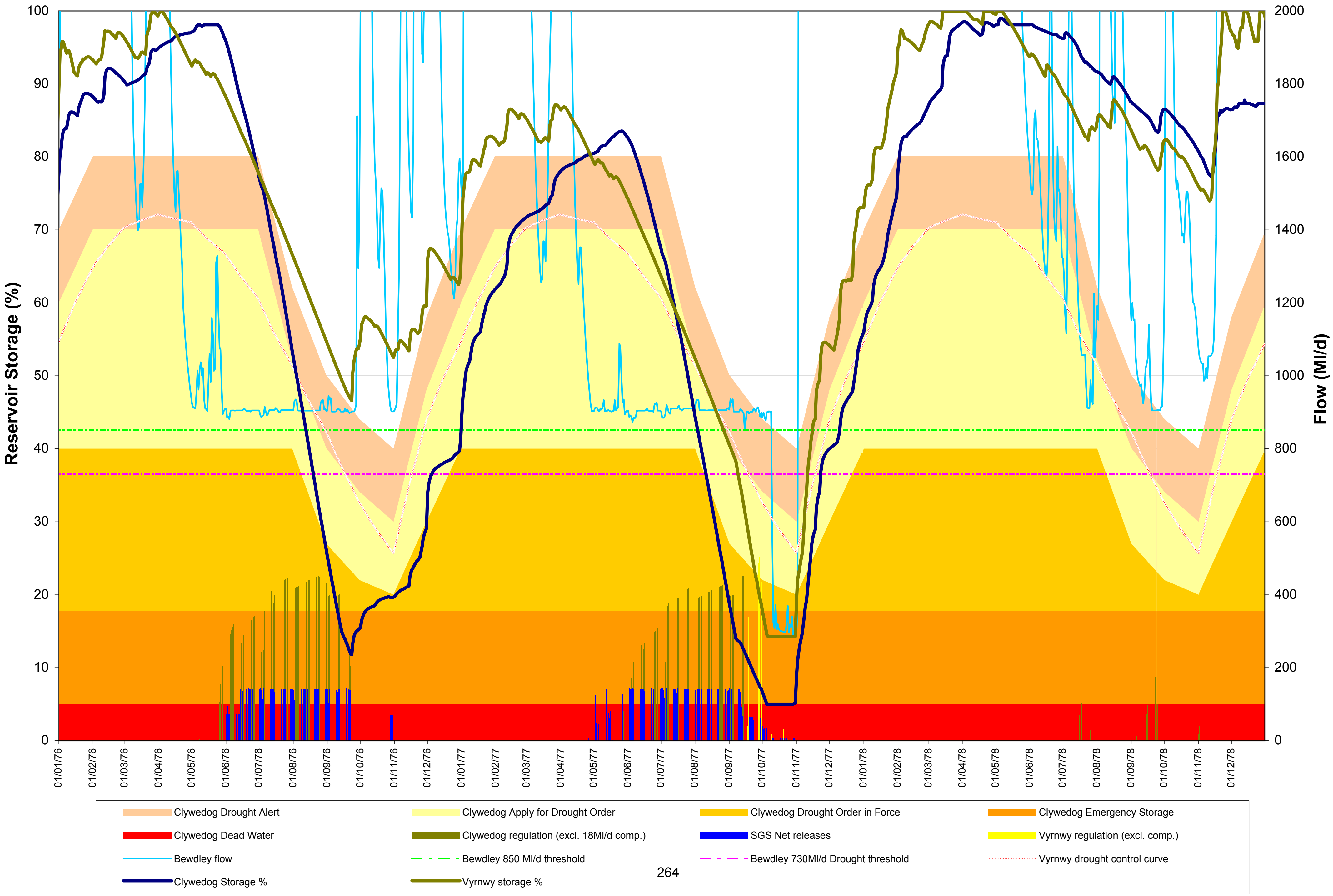



Chronic scenario - EA Drought Order only (no water company Permits): 1976 - 1978
Reservoir Storage (%)
Flow (Ml/d)
0
10
20
30
40
50
60
70
80
90
100
0
200
400
600
800
1000
1200
1400
1600
1800
2000
01/01/76
01/02/76
01/03/76
01/04/76
01/05/76
01/06/76
01/07/76
01/08/76
01/09/76
01/10/76
01/11/76
01/12/76
01/01/77
01/02/77
01/03/77
01/04/77
01/05/77
01/06/77
01/07/77
01/08/77
01/09/77
01/10/77
01/11/77
01/12/77
01/01/78
01/02/78
01/03/78
01/04/78
01/05/78
01/06/78
01/07/78
01/08/78
01/09/78
01/10/78
01/11/78
01/12/78
Clywedog Drought Alert
Clywedog Apply for Drought Order
Clywedog Drought Order in Force
Clywedog Emergency Storage
Clywedog Dead Water
Clywedog regulation (excl. 18Ml/d comp.)
SGS Net releases
Vyrnwy regulation (excl. comp.)
Bewdley flow
Bewdley 850 Ml/d threshold
Bewdley 730Ml/d Drought threshold
Vyrnwy drought control curve
Clywedog Storage %
Vyrnwy storage %

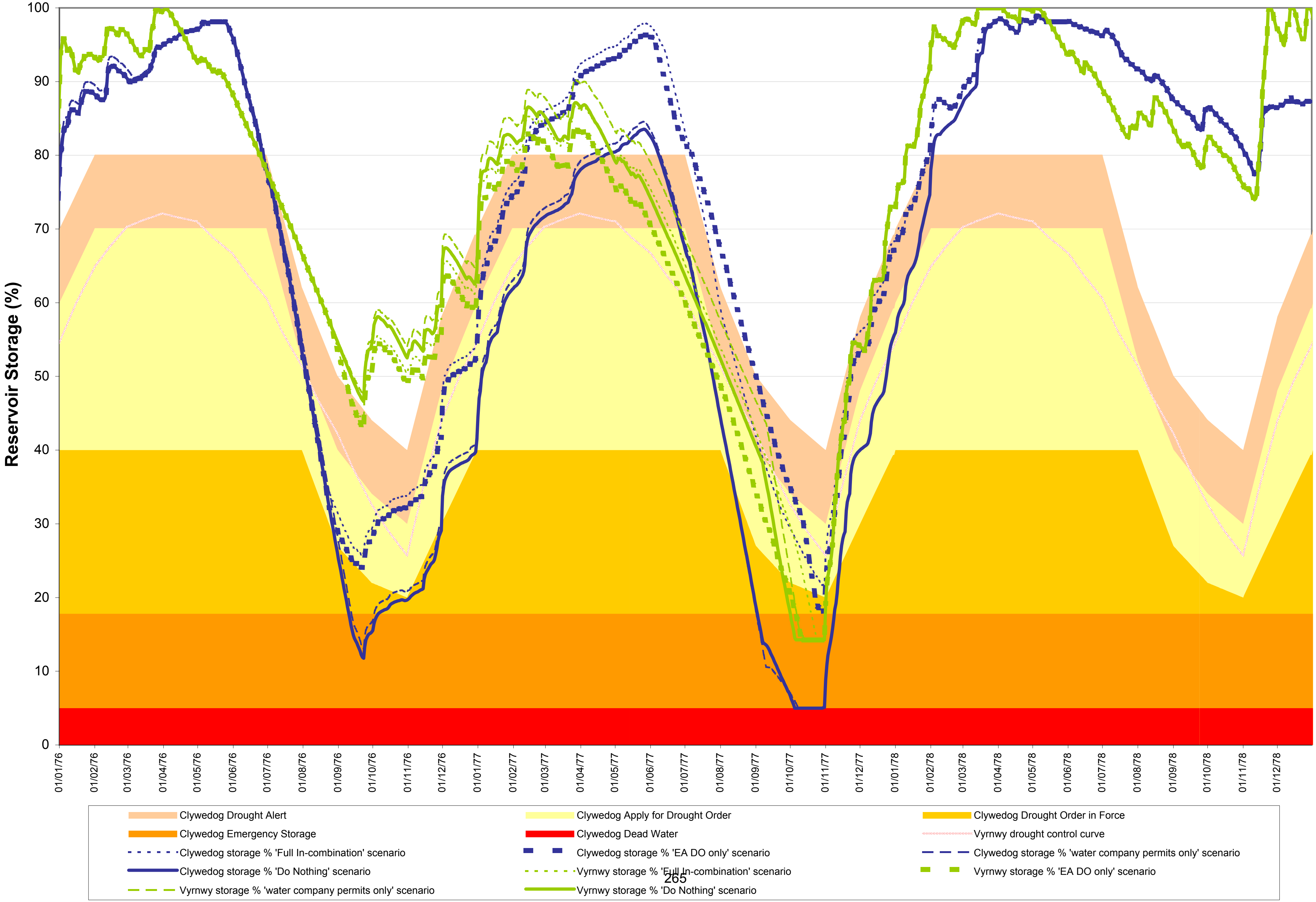
Chronic scenario - EA Water Company Permits only (no EA Drought Orders): 1976 - 1978



Chronic scenario - Do Nothing (underlying drought impacts): 1976 - 1978



Chronic drought scenario Modelling: Reservoir Storage (only) 1976 - 1978



Appendix K.6

Chronic scenario: Critical regulation dates

Critical drought year

1977 Critical regulation stats: Chronic

	Do Nothing	EA DO in isolation	Full In-combination	Wc Permits only
Start of continuous regulation	27/05/1977	28/05/1977	28/05/1977	27/05/1977
Clywedog D. Alert	09/06/1977	31/08/1977	22/07/1977	10/06/1977
DO app. Crossed	27/06/1977	04/10/1977	07/09/1977	29/06/1977
DO in force crossed	13/08/1977	22/10/1977	No	11/08/1977
DO activated	-	**24/02/1977 : 24/06/1977 : 24/10/1977**	**06/03/1977 : 02/08/1977**	-
Emergency storage	02/09/1977	(close!)	No	02/09/1977
min storage	18/09/1977	29/10/1977	29/10/1977	17/09/1977
Dead water	18/09/1977	-	-	17/09/1977
Days in dead water	42	0	0	43
recovery above dead water	30/10/1977	-	-	30/10/1977
recovery above emergency storage	09/11/1977	-	-	09/11/1977
DO turned off	-	**04/06/1977 : 12/10/1977 : 01/02/1978**	**13/06/1977 : 09/11/1977**	-
No. Days DO active	-	**on off on off (110 June-Oct)**	**99 & 99**	-
recovery above D. alert	03/02/1978	23/01/1978	26/01/1978	03/02/1978
Source exhausted	**Yes (dead water)**	**No (not quite em. storage)**	**No (Do app not reached)**	**Yes (dead water)**
Regulation stops	18/09/1977	29/10/1977	29/10/1977	17/09/1977
No. Continuous Regulation days	114	154	154	113
Vyrnwy activated continuously	13/09/1977	07/08/1977	10/08/1977	15/09/1977
Vyrnwy drought control curve	20/08/1977	29/06/1977	16/09/1977	22/09/1977
min storage	06/10/1977	11/10/1977	25/10/1977	14/10/1977
recovery above D.c.curve	09/11/1977	09/11/1977	09/11/1977	09/11/1977
Source exhausted	**No - below Drought CC (14.26%)**	**No - below Drought CC (14.26%)**	**No - below Drought CC (14.26%)**	**No - below Drought CC (14.26%)**
Regulation stops	06/10/1977	11/10/1977 (24/10/1977)	29/10/1977	09/10/1977
No. Continuous Regulation days	23	65	80	24
SGS activated more continuously	26/04/1977	28/05/1977	27/05/1977	26/04/1977
1st halves	12/09/1977	08/08/1977	11/10/1977	15/09/1977
halves again	30/09/1977 & 09/10/1977	increases	26/10/1977	07/10/1977
Source exhausted	**licence limit**	**No**	**licence limit**	**licence limit**
Regulation stops	30/10/1977	30/10/1977	30/10/1977	30/10/1977
No. Regulation days	179	155	156	180
No. Days regulation in total	179	157	161	180
7 Regulation continuous period	179	155	156	180

1977 Critical regulation stats: Chronic

Buildwas	Do Nothing	EA DO in isolation	Full In-combination	Wc Permits only
SDO impacts 1st noticed	-	26/06/1977	04/08/1977	-
Average flow maintained during SDO activation period	1086	961	938	1078
Average Diff from Do Nothing (Ml/d)	-	*minus 125*	*minus 148*	*minus 7*
Flow crash	08/10/1977	26/10/1977	27/10/1977	11/10/1977
Cross over point	-	08/10/1977	08/10/1977	*drops lower 21/10/1977*
Average SDO flow maintained after crash (Ml/d)	481	694	615	472
Average Diff from Do Nothing (Ml/d)	-	*plus 213*	*plus 134*	*minus 9*
No. days crashed AFTER to Do Nothing	-	19	20	4
Min flow date	27/10/1977	28/10/1977	28/10/1977	27/10/1977
flow recovery	01/11/1977	(15/10/1977 till 25/10/1977) 01/11/1977	01/11/1977	01/11/1977
No. days flows crashed	**24**	**6**	**5**	**21**
No. days of impact before benefit realised (lower than Do Nothing)	-	105	66	-
No. days flows maintained above Do Nothing	-	**24**	**24**	**(5 lower than DN)**
FDC impacts noticed				
Q95	1067	934	931	1058
Q99	471	910	904	473
Q99.9	459	691	614	459
EFI failure?				

Bewdley	Do Nothing	EA DO in isolation	Full In-combination	Wc Permits only
SDO impacts 1st noticed	-	28/06/1977	06/08/1977	-
Average flow maintained during SDO activation period	903	764	761	901
Average Diff from Do Nothing (Ml/d)	-	*minus 139*	*minus 142*	*minus 2*
Flow crash	10/10/1977	28/10/1977	29/10/1977	13/10/1977
Cross over point	-	10/10/1977	10/10/1977	*drops lower 23/10/1977*
Average SDO flow maintained after crash (Ml/d)	314	537	462	305
Average Diff from Do Nothing (Ml/d)	-	*plus 224*	*plus 148*	*minus 8*
No. days crashed AFTER to Do Nothing	-	19	20	4
Min flow date	29/10/1977	30/10/1977	30/10/1977	29/10/1977
flow recovery	03/11/1977	(17/10/1977 till 27/10/1977) 03/11/1977	03/11/1977	03/11/1977
No. days flows crashed	**24**	**6**	**5**	**21**

No. days of impact before benefit realised (lower than Do Nothing)	-	105	66	-
No. days flows maintained above Do Nothing	**-**	**24**	**24**	**(5 lower than DN)**
FDC impacts noticed				
Q95	895	762	761	854
Q99	304	745	732	304
Q99.9	289	521	444	289
EFI failure?				
Lower Parting	**Do Nothing**	**EA DO in isolation**	**Full In-combination**	**Wc Permits only**
SDO impacts 1st noticed	-	30/06/1977	08/08/1977	-
Average flow maintained during SDO activation period	888	790	752	886
Average Diff from Do Nothing (Ml/d)	-	*minus 98*	*minus 135*	*minus 2*
Flow crash	12/10/1977	31/10/1977	31/10/1977	15/10/1977
Cross over point	12/10/1977	12/10/1977	12/10/1977	12/10/1977
Average SDO flow maintained after crash (Ml/d)	344	553	570	421
Average Diff from Do Nothing (Ml/d)	-	*plus 208*	*plus 226*	*plus 77*
No. days crashed prior to Do Nothing	-	0	0	0
Min flow date	27/10/1977	31/10/1977	31/10/1977	27/10/1977
flow recovery	02/11/1977	02/11/1977	02/11/1977	02/11/1977
No. days flows crashed	21	2	2	18
No. days of impact before benefit realised (lower than Do Nothing)	-	*modelling errors*	*modelling errors*	-
No. days flows maintained above Do Nothing	-	19	19	-
FDC impacts noticed				
Q95	871	748	753	865
Q99	325	729	719	325
Q99.9	310	578	617	310
EFI failure?				

Appendix L

Water Quality Current Environment Information

WATER QUALITY

Environment Agency
Dawn Karle
Area Environment Planning (Water Quality)

Current Environment: Water Quality

The following sections provide a description of the chemical and nutrient quality of the River Severn.

Water Quality Assessment Schemes

Up until 2009, for over twenty years the Environment Agency used the General Quality Assessment (GQA) scheme to assess river water quality in terms of chemistry, biology and nutrients. This helped drive environmental improvements by dealing with the main sources of pollutants, such as point source discharges from sewage treatment works (STWs).

However, the Water Framework Directive (WFD) has introduced a new approach to assessing the whole water environment, integrating water quality, quantity and physical habitat with ecological indicators that will help direct action to where it is most needed, tackling diffuse as well as point source issues. The WFD water quality assessment uses a new tougher methodology based on a far wider range of assessments than GQA classification. The classification uses a principle of 'one out, all out' which means that the poorest individual result drives the overall classification. It reports on over 30 measures, grouped into ecological status (including biology and physico-chemical such as phosphate and pH) and chemical status. Unlike GQA, WFD incorporates estuaries, coastal waters, groundwater and lakes as well as rivers.

The changes to the way water quality is assessed means that WFD classification appears significantly different to the GQA assessment of water quality. Therefore care needs to be taken when comparing the two schemes. In 2009, both schemes were run in parallel and 2009 was the last year that GQA classification was determined.

The Environment Agency published a River Basin Management Plan (RBMP) for the River Severn District in December 2009, in which WFD baseline classification was made available. A second RBMP will be published in 2015 with updated classification information.

As we have only recently moved from one classification scheme to another, this section will include a discussion of both the GQA and WFD schemes, focusing on the physico-chemical elements.

GQA Assessment Points

The GQA scheme used 23 discrete GQA riverine assessment reaches for the River Severn from the headwaters in the Welsh Hills at Cwm Ricket to the near the tidal limit at Llanthony Weir in Gloucester. A single monitoring point was used to classify each GQA reach.

Table 1 GQA assessment reaches

GQA Reach No.	Reach name	Monitoring point name	Monitoring site number	Grid reference		Length (km)
				From	To	
1	Cwm Ricket Ford to conf A Clywedog	Llanidloes Felindr	00074380	SN 8619 8670	SN 9541 8477	12
2	Conf A Clywedog to conf A Cerist	Dolwen	00072250	SN 9541 8477	SO 0250 9149	15
3	Conf A Cerist to Conf Mochdre Bk	Caersws	00070450	SO 0250 9149	SO 0865 9080	12
4	Conf Mochdre Bk to Newtown STW	Fbr Back Lane	00067800	SO 0865 9080	SO 1397 9275	7.4
5	Newtown STW to conf The Mule	Aberbechan	00065870	SO 1397 9275	SO 1594 9480	3.5
6	Conf The Mule to Welshpool STW	Caerhowel	00064480	SO 1594 9480	SJ 2352 0726	20
7	Welshpool STW to conf A Vyrnwy	Llandrinio	00060200	SJ 2352 0726	SJ 3280 1586	25
8	Conf A Vyrnwy to conf R Perry	Montford Br	00056710	SJ 3280 1586	SJ 4402 1863	19
9	Conf R Perry to Monkmoor STW outfall	Shelton intake	00055140	SJ 4402 1863	SJ 5210 1328	25
10	Monkmoor STW outfall to R Tern conf	Atcham	00052182	SJ 5210 1328	SJ 5532 0915	10
11	Conf R Tern to conf Much Wenlock Bk	Cressage	00049650	SJ 553 091	SJ 641 044	14
12	Conf Much Wenlock Bk to Coalport STW	Coalport	00045702	SJ 641 044	SJ 710 013	12
13	Coalport STW to conf R Worfe	Apley Forge	00044720	SJ 710 013	SO 724 952	6
14	Conf R Worfe to conf R Stour	Bewdley	00038360	SO 724 952	SO 812 707	30
15	Conf R Stour to conf R Salwarpe	Holt Fleet	00034302	SO 812 707	SO 841 601	22
16	Conf R Salwarpe to Worcester STW	Worcester Bridge	00030850	SO 841 601	SO 847 532	3.8
17	Worcester STW to conf R Teme	Depot Bath Road	00030090	SO 847 532	SO 850 521	1.3
18	Conf R Teme to Hatfield Bk	Kempsey	00029500	SO 850 521	SO 846 489	3.4
19	Hatfield Bk to Ripple supply intake	Upton on Severn	00027540	SO 846 489	SO 865 399	13
20	Ripple supply intake to conf R Avon	Tewkesbury	00026230	SO 865 399	SO 888 331	8.5
21	Conf R Avon to conf River Chelt	Hawbridge	00025085	SO 888 331	SO 848 262	10
22	Conf R Chelt to Ashleworth	Ashleworth	00024062	SO 848 262	SO 819 250	3.5
23	Ashleworth to Llanthony Weir	Llanthony Bridge	00021202	SO 819 250	SO 823 182	8.2

WFD Water bodies & assessment points

There are 11 WFD River Water bodies covering the River Severn from source to the tidal limit, these are listed in Table 2. Unlike the GQA scheme, where only one monitoring point per stretch was used for assessment purposes, WFD water bodies can use multiple monitoring points in the water body catchment. Data are used from each monitoring point to calculate a classification for the whole water body by taking the median (the middle value) of all the monitoring point classifications within the water body. This is representative of typical conditions for the water body, not the best or the worst.

WFD water bodies do however incorporate the monitoring points previously used for GQA. Table 3 compares the WFD and GQA monitoring points.

Table 2. River Severn: River Water Bodies

Water Body ID	Water Body Name	Length (kms)
GB109054044790	R Severn - source to conf Afon Dulas	16.33
GB109054049310	R Severn - conf Afon Dulas to conf R Camlad	51.01
GB109054049700	R Severn - conf R Camlad to conf Bele Bk	27.17
GB109054049142	R Severn - conf Bele Bk to conf Sundorne Bk	53.9
GB109054049141	R Severn - Sundorne Bk to conf M Wenlock-Farley Bk	31.53
GB109054049143	R Severn conf M Wenlock-Farley Bk to conf R Worfe	15.92
GB109054049145	R Severn - conf R Worfe to conf R Stour	33.48
GB109054049144	R Severn - conf R Stour to conf River Teme	30.25
GB109054039760	R Severn - conf R Teme to conf R Avon	29.5
GB109054044404	R Severn - conf R Avon to conf Upper Parting	27.57
GB109054032750	R Severn (E Channel) - Horsbere Bk to Severn Est	4.56

Table 3. Comparison of GQA and WFD Monitoring Points

WFD Monitoring Points					GQA point
Water body ID	Monitoring Site	Site Name	Easting	Northing	
GB109054044790	00074380	R.Severn Llanidloes Felindre Bridge	294400	283901	Yes
GB109054049310	00072250	R.Severn Dolwen	299700	285200	Yes
GB109054049310	00070450	R.Severn At Caersws	303200	291700	Yes
GB109054049310	00067800	R.Severn Foot Bridge Back Ln Cp	310520	291640	Yes
GB109054049310	00065870	R.Severn Cil Gwrgan Bridge Aberbechan	314368	293368	Yes
GB109054049310	00064480	R.Severn At Caerhowel Bridge	319670	298150	Yes
GB109054049700	00061340	R.Severn Maginnis Bridge	325890	311510	No
GB109054049142	29949160	Leaton Brook At Leaton	347300	318000	Yes*
GB109054049142	29266040	Rea Brook At Coleham	349700	312262	Yes*
GB109054049142	00060200	R.Severn At Llandrinio	329843	316977	Yes
GB109054049142	00056710	R.Severn Montford Bridge	343200	315300	Yes
GB109054049142	00055460	R.Severn Isle Of Bicton	346800	316400	No
GB109054049142	00055140	R.Severn Shelton Intake	346432	313458	Yes
GB109054049141	25877190	Devil's Dingle Bk - Footbrdg To Bk Ctge	363700	304700	No
GB109054049141	00052182	R.Severn Atcham	354000	309300	Yes
GB109054049141	00049650	R.Severn At Cressage	359380	304550	Yes
GB109054049143	00045702	R.Severn At Coalport	370200	302100	Yes
GB109054049143	00044720	R.Severn At Apley Forge	370674	298325	Yes
GB109054049145	24239020	Borle Brook Conf With R.Severn	375300	281600	Yes*
GB109054049145	00041180	R.Severn Hampton Loade Bridge	374600	287050	No
GB109054049145	00038360	R.Severn At Bewdley	378750	275450	Yes
GB109054049144	22147580	Barbourne Brook B4550 Bridge Blackpole	386850	257850	Yes*
GB109054049144	22146950	Barbourne Brook At Perdiswell Park	385500	257690	Yes*
GB109054049144	22146620	Barbourne Brook At Bilford Road Worcs	385450	257150	Yes*

GB109054049144	22145580	Barbourne Brook At A449 Bridge Gheluvet	384470	256480	Yes*
GB109054049144	00034302	Holt Fleet Meadows Holt Fleet	382330	263400	Yes
GB109054049144	00030850	R Severn Worcester Bridge	384650	254750	Yes
GB109054049144	00030090	R.Severn Rear Of Oil Depot Bath Rd Worcs	385100	252320	Yes
GB109054039760	00029500	R Severn (Upper) Kempsey (Mid)	384690	249280	Yes
GB109054039760	00028400	R Severn (Upper) Severn Stoke	384860	244490	No
GB109054039760	00027540	R Severn - Upton On Severn	385160	240750	Yes
GB109054039760	00026230	R Severn (Upper) Tewkesbury	388870	233720	Yes
GB109054039760	06147180	Norton Brook Ds Morganite Crucible	389420	251020	No
GB109054039760	13397040	Hatfield Brook Kempsey	384910	249030	Yes*
GB109054044404	00025312	R Severn (Lower) Chaceley Stock	386550	229740	No
GB109054044404	00025085	R Severn (Lower) Haw Bridge	384550	227850	Yes
GB109054044404	00024062	R Severn (Lower) Ashleworth	381900	225060	Yes
GB109054044404	00017500	R Severn (Lower) Maisemore Weir	381800	221700	No
GB109054032750	00021202	R Severn (Lower) Severn Rd Foot Bridge	382330	218240	Yes

*these monitoring sites are on a tributary of the River Severn.

GQA Chemistry and Nutrients (Riverine)

An overview of the historical GQA for chemistry and nutrients, and compliance with the River Ecosystem Classification (REC) is provided in the following sections. GQA and REC methodologies are summarised in Appendix M.

Chemistry and nutrient GQA summary data for the periods 1996 (chemistry only), 2000, 2003 and 2006 are summarised in Table 4. REC compliance for 2006 is also given.

In 2007, during the build up towards WFD reporting, the GQA scheme underwent change and fewer statistics produced. The main changes to the scheme were a reduction in monitoring (fewer sites monitored in England) and the removal of Biochemical Oxygen Demand (BOD) monitoring at most sites in England from the beginning of 2008.

GQA monitoring from 2007 onwards is provided in Table 5. Due to the removal of BOD from the assessment, Table 4 and Table 5 cannot be directly compared. Therefore GQA results prior to 2007 have been recalculated with the BOD removed and these are provided in Table 6 along with data post 2007 to allow for direct comparison. The removal of BOD from the assessment can elevate the GQA grade of a stretch if the BOD was previously the poorest element within the assessment.

Overview of Physico-Chemical Quality (Riverine)

From the rural landscape of Wales and flow from clean mountain sources such as the River Vyrnwy and inputs from abandoned mining areas, to the more urbanised impacts of the River Stour which receives effluent from the textile industry of Kidderminster, the river experiences many different impacts on water quality.

Despite this, the Severn remains a clean river, recently recording GQA grades of A and B down to Ashleworth, then dropping to C from Ashleworth to Gloucester (GQA 2009). The river is also a Salmonid designated fishery under the Freshwater Fish Directive from its source to the confluence with the River Vyrnwy and supports Cyprinid fish populations throughout the remainder of its course.

GQA 1996 -2006

Chemistry

All but one of the reaches achieved compliance with the designated REC River Quality Objective (RQO) in 2006. The non-complaint stretch, Newtown STW to confluence of The Mule is only marginally above the target. In terms of GQA chemical quality, the upper reaches of the River Severn down to Newtown STW record mainly grade A, very good quality. A slight decline to good is observed in reach 5 in 2006, downstream of Newton STW, however, quality improves again to very good downstream of Welshpool. The impact of Shrewsbury Monkmoor STW and the Perry and Tern tributaries is evident as GQA grades drop downstream, from very good to good/fairly good for all years. 2006 grades show an improvement from B to A for reaches 13 to 18, Coalport to Kempsey. The final 5 stretches from the Hatfield Brook to Llanthony Weir are on the whole good quality for all years.

Nutrients

Phosphate and nitrate both show the same trend with concentrations increasing with distance downstream.

Levels of nitrates are very low/low in the upper Severn reaches increasing to moderately low in the middle stretches and declining again to moderate downstream of the confluence with the River Worfe and generally remaining at this level down to Llanthony weir.

Phosphates also are very low/low in the upper Severn reaches, with a slight improvement over time observed. Levels increase downstream of Monkmoor; however they have improved over time from very high to high. Another step increase is observed downstream of Coalport where levels stay consistently at very high down to Llanthony weir.

GQA 2007 – to date

Chemistry (removal of BOD element from the GQA assessment)

With the removal of BOD from the classification scheme in 2007, the River Severn is reported as being very good quality from source down to the confluence with the River Avon where it drops to good class B. Deterioration to fairly good is seen from Ashleworth to Llanthony Weir.

Nutrients

Phosphate and nitrate continue to show the same trend as in previous years, with concentrations increasing with distance downstream. No obvious trend is observed in the nitrate grades for each reach, however when comparing grades from 1995 to date, levels of phosphates have decreased for some stretches. Phosphates improve from low to very low for stretches 2 and 4, and GQA grades improve downstream of the Perry confluence, Monkmoor STW and Coalport, due in part to recent improvements in nutrient discharges in a number of sewage treatment works.

Table 4. Chemistry and Nutrient GQA, and RE compliance for the River Severn

GQA Reach No.	Reach name	RQO compliance (2006)	Chemistry				Nutrients					
			1996	2000	2003	2006	P 2000	P 2003	P 2006	N 2000	N 2003	N 2006
1	Cwm Ricket Ford to conf A Clywedog	RE1 Compliant	A	A	A	A	1	2	1	1	1	1
2	Conf A Clywedog to conf A Cerist	RE1 Compliant	A	A	A	A	2	2	2	1	1	2
3	Conf A Cerist to Conf Mochdre Bk	RE1 Compliant	A	A	A	A	2	2	2	2	1	2
4	Conf Mochdre Bk to Newtown STW	RE1 Compliant	A	A	A	A	2	2	2	2	1	2
5	Newtown STW to conf The Mule	RE1 Marginal	B	A	A	B	3	3	2	2	2	2
6	Conf The Mule to Welshpool STW	RE1 Compliant	A	A	A	B	3	3	2	2	2	2
7	Welshpool STW to conf A Vyrnwy	RE1 Compliant	A	A	A	A	3	3	3	3	2	2
8	Conf A Vyrnwy to conf R Perry	RE1 Compliant	B	A	A	A	3	3	3	3	2	2
9	Conf R Perry to Monkmoor STW outfall	RE2 Compliant	B	A	A	A	4	3	3	3	2	3
10	Monkmoor STW outfall to conf R Tern	RE2 Compliant	B	B	C	B	4	4	4	3	3	3
11	Conf R Tern to Much Wenlock Bk	RE2 Compliant	C	B	B	B	5	5	4	4	3	3
12	Conf Much Wenlock Bk to Coalport STW	RE2 Compliant	B	B	B	B	5	5	4	3	3	3
13	Coalport STW to conf R Worfe	RE2 Compliant	B	B	B	A	5	5	5	3	3	3
14	Conf R Worfe to R Stour	RE2 Compliant	B	B	B	A	5	5	5	4	3	4
15	Conf R Stour to conf R Salwarpe	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
16	Conf R Salwarpe to Worcester STW	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
17	Worcester STW to conf R Teme	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
18	Conf R Teme to conf Hatfield Bk	RE2 Compliant	B	B	B	A	5	5	5	4	4	4
19	Hatfield Bk to Ripple supply intake	RE2 Compliant	B	B	B	B	5	5	5	4	4	4
20	Ripple supply intake to conf R Avon	RE2 Compliant	B	B	B	B	5	5	5	4	4	4
21	Conf R Avon to conf R Chelt	RE2 Compliant	B	B	B	B	5	5	5	4	4	4
22	River Chelt confluence to Ashleworth	RE2 Compliant	B	B	B	B	5	5	5	4	4	5
23	Ashleworth to Llanthony weir	RE2 Compliant	B	C	B	B	5	5	5	4	4	4

Table 5. Chemistry and Nutrient GQA, and RE compliance for the River Severn 2007-2009 (modified GQA scheme)

GQA Reach No.	Reach name	Chemistry			Nutrients					
		2007	2008	2009	P 2007	P 2008	P 2009	N 2007	N 2008	N 2009
1	Cwm Ricket Ford to conf A Clywedog	A	A	A	1	1	1	1	1	1
2	Conf A Clywedog to conf A Cerist	A	A	A	1	1	1	2	1	1
3	Conf A Cerist to Conf Mochdre Bk	A	A	A	2	2	2	2	2	1
4	Conf Mochdre Bk to Newtown STW	A	A	A	1	1	1	2	2	1
5	Newtown STW to conf The Mule	A	A	A	2	2	2	2	2	2
6	Conf The Mule to Welshpool STW	A	A	A	2	2	2	2	2	2
7	Welshpool STW to conf A Vyrnwy	A	A	A	3	3	3	2	2	2
8	Conf A Vyrnwy to conf R Perry	A	A	A	2	2	2	2	2	2
9	River Perry Confluence to Monkmoor STW outfall	A	A	A	2	2	2	3	3	2
10	Monkmoor STW outfall to River Tern confluence	A	A	A	3	3	3	3	3	3
11	River Tern confluence to Much Wenlock Bridge	A	A	A	4	4	4	3	3	3
12	Much Wenlock Bridge to Coalport STW	A	A	A	4	4	4	3	3	3
13	Coalport STW to River Worfe Confluence	A	A	A	4	4	4	3	3	3
14	River Worfe confluence to River Stour confluence	A	A	A	4	4	4	3	3	3
15	River Stour confluence to River Salwarpe confluence	A	A	A	5	5	5	4	4	4
16	River Salwarpe confluence to Worcester STW	A	A	A	5	5	5	4	4	4
17	Worcester STW to River Teme confluence	A	A	A	5	5	5	4	4	4
18	River Teme confluence to Hatfield Brook confluence	A	A	A	5	5	5	4	4	4
19	Hatfield Brook confluence to Ripple supply intake	A	A	A	5	5	5	4	4	4
20	Ripple supply intake to River Avon confluence	B	B	B	5	5	5	4	4	4
21	River Avon confluence to River Chelt confluence	B	B	B	5	5	5	4	4	4
22	River Chelt confluence to Ashleworth	B	B	B	5	5	5	4	4	4
23	Ashleworth to Llanthony weir	C	C	C	5	5	5	4	4	4

Table 6. Chemical GQA Grades (1996-2006 recalculated)

GQA Reach No.	Reach name	Chemistry													
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
1	Cwm Ricket Ford to conf A Clywedog	A	A	A	A	A	A	A	A	A	A	A	A	A	A
2	Conf A Clywedog to conf A Cerist	A	A	A	A	A	A	A	A	A	A	A	A	A	A
3	Conf A Cerist to Conf Mochdre Bk	A	A	A	A	A	A	A	A	A	A	A	A	A	A
4	Conf Mochdre Bk to Newtown STW	A	A	A	A	A	A	A	A	A	A	A	A	A	A
5	Newtown STW to conf The Mule	A	A	A	A	A	A	A	A	A	A	A	A	A	A
6	Conf The Mule to Welshpool STW	A	A	A	A	A	A	A	A	A	A	A	A	A	A
7	Welshpool STW to conf A Vyrnwy	A	A	A	A	A	A	A	A	A	A	A	A	A	A
8	Conf A Vyrnwy to conf R Perry	A	A	A	A	A	A	A	A	A	A	A	A	A	A
9	Conf R Perry to Monkmoor STW outfall	B	A	A	A	A	A	A	A	A	A	A	A	A	A
10	Monkmoor STW outfall to conf R Tern	B	A	A	A	A	A	B	A	B	B	B	A	A	A
11	Conf R Tern to Much Wenlock Bk	B	B	A	A	A	A	A	A	B	B	B	A	A	A
12	Conf Much Wenlock Bk to Coalport STW	A	A	A	A	A	A	A	A	B	A	B	A	A	A
13	Coalport STW to conf R Worfe	B	B	A	A	A	A	A	A	B	A	A	A	A	A
14	Conf R Worfe to R Stour	B	A	B	B	B	A	A	B	B	B	A	A	A	A
15	Conf R Stour to conf R Salwarpe	A	A	A	A	A	A	A	A	A	A	A	A	A	A
16	Conf R Salwarpe to Worcester STW	A	B	B	B	B	A	A	C	A	A	A	A	A	A
17	Worcester STW to conf R Teme	B	B	B	B	A	A	A	B	A	A	A	A	A	A
18	Conf R Teme to conf Hatfield Bk	A	B	B	B	A	A	A	B	A	A	A	A	A	A
19	Hatfield Bk to Ripple supply intake	A	B	B	B	B	A	A	B	B	B	B	A	A	A
20	Ripple supply intake to conf R Avon	B	B	B	B	B	B	B	B	B	B	B	B	B	B
21	Conf R Avon to conf R Chelt	B	B	B	A	A	A	B	B	B	B	A	B	B	B
22	River Chelt confluence to Ashleworth	B	B	B	B	A	A	B	B	B	B	A	B	B	B
23	Ashleworth to Llanthony weir	B	C	B	B	A	A	A	A	B	B	A	C	C	C

Water Framework Directive

The WFD sets a number of different environmental objectives for surface waters. These are:

- Prevent deterioration in status for water bodies
- Aim to achieve good ecological and good surface water chemical status in water bodies by 2015
- For water bodies that are designated as artificial or heavily modified, aim to achieve good ecological potential by 2015
- Comply with objectives and standards for protected areas where relevant
- Reduce pollution from priority substances and cease discharges, emissions and losses of priority hazardous substances.

A summary of compliance with good ecological status/potential and good chemical status is given in Table 7.

Table 7. Compliance with WFD Objectives

Water Body ID	Water Body Name	Overall Status/Potential	Ecological Status/Potential	Chemical status
GB109054044790	R Severn – source to conf Afon Dulas	Moderate	Moderate (Status)	Does not require assessment
GB109054049310	R Severn – conf Afon Dulas to conf R Camlad	Poor (Potential)	Poor (Potential)	Fail
GB109054049700	R Severn – conf R Camlad to conf Bele Bk	Moderate (Potential)	Moderate (Potential)	Does not require assessment
GB109054049142	R Severn – conf Bele Bk to conf Sundorne Bk	Moderate (Potential)	Moderate (Potential)	Fail
GB109054049141	R Severn – Sundorne Bk to conf M Wenlock-Farley Bk	Moderate (Potential)	Moderate (Potential)	Good
GB109054049143	R Severn conf M Wenlock-Farley Bk to conf R Worfe	Moderate (Potential)	Moderate (Potential)	Good
GB109054049145	R Severn – conf R Worfe to conf R Stour	Moderate (Potential)	Moderate (Potential)	Does not require assessment
GB109054049144	R Severn – conf R Stour to conf River Teme	Moderate (Potential)	Moderate (Potential)	Does not require assessment
GB109054039760	R Severn – conf R Teme to conf R Avon	Moderate (Potential)	Moderate (Potential)	Good
GB109054044404	R Severn – conf R Avon to conf Upper Parting	Moderate (Potential)	Moderate (Potential)	Fail
GB109054032750	R Severn (E Channel) – Horsbere Bk to Severn Est	Moderate (Potential)	Moderate (Potential)	Does not require assessment

The Directive sets a target of aiming to achieve at least 'good status/potential' in all waters. For surface waters there are two separate classifications for water bodies; ecological and chemical. For a surface water body to be overall 'good', both ecological and chemical status must be at least 'good'. Ecological status is recorded on a scale high, good, moderate, poor and bad; chemical status is recorded as good or fail.

Some surface water bodies are designated as ‘artificial’ or ‘heavily modified’ because they have been created or modified for a particular use such as water supply, flood protection, navigation or urban infrastructure. By definition, artificial and heavily modified water bodies are not able to achieve natural conditions. Instead the classification and objectives for these water bodies, and the biology they represent, are measured against ‘ecological potential’ rather than status. Whilst good ecological status is defined as a slight variation from undisturbed natural conditions in natural water bodies, artificial and heavily modified water bodies are unable to achieve natural conditions. Instead, artificial and heavily modified water bodies have a target to achieve good ecological potential, which recognises their important uses, whilst making sure ecology is protected as far as possible. Ecological potential is also measured on the scale high, good, moderate, poor and bad. The chemical status of these water bodies is measured in the same way as for natural water bodies. All the River Severn water bodies downstream of the confluence with the Afon Dulas are classed as heavily modified.

In the WFD classification scheme, physico-chemical elements are supporting elements. Only biological elements are recorded on the full scale, high to bad. Physico-chemical elements are not reported below moderate status. Table 8 gives the actual status of the physico-chemical elements for each River Severn water body. The status of each element will be in most cases calculated from a number of sample points within the water body.

Table 8. WFD Water Body Physico-Chemical Element Status

Water Body ID	Water Body Name	Ecological Status/Potential	Physico-Chemical Element Status
GB109054044790	R Severn – source to conf Afon Dulas	Moderate	Ammonia – High DO – High pH –High Phosphate – High Temp – High
GB109054049310	R Severn – conf Afon Dulas to conf R Camlad	Poor	Ammonia – High DO – High pH –High Phosphate – High Temp – High
GB109054049700	R Severn – conf R Camlad to conf Bele Bk	Moderate	Ammonia – High DO – High pH –High Phosphate – Moderate Temp – High
GB109054049142	R Severn – conf Bele Bk to conf Sundorne Bk	Moderate	Ammonia – High DO – High pH –High Phosphate – Good Temp – High
GB109054049141	R Severn – Sundorne Bk to conf M Wenlock-Farley Bk	Moderate	Ammonia – High DO – High pH –High Phosphate – Good Temp – High

GB109054049143	R Severn conf M Wenlock-Farley Bk to conf R Worfe	Moderate	Ammonia – High DO – High pH –High Phosphate – Moderate Temp – High
GB109054049145	R Severn – conf R Worfe to conf R Stour	Moderate	Ammonia – High DO – High pH –High Phosphate – Moderate Temp – High
GB109054049144	R Severn – conf R Stour to conf River Teme	Moderate	Ammonia – Good DO – High pH –High Phosphate – Poor Temp – High
GB109054039760	R Severn – conf R Teme to conf R Avon	Moderate	Ammonia – High DO – High pH –High Phosphate – Poor Temp – High
GB109054044404	R Severn – conf R Avon to conf Upper Parting	Moderate	Ammonia – High DO – High pH –High Phosphate – Poor Temp – High
GB109054032750	R Severn (E Channel) – Horsbere Bk to Severn Est	Moderate	Ammonia – High DO – Good pH –High Phosphate – Poor Temp - High

Ammonia levels are high status for all River Severn water bodies except for the water body downstream of the Stour confluence where levels increase and the class drops to good. Dissolved Oxygen status is high from source down to the Horsbere Brook confluence where it drops to good. Temperature and pH are both high status for all. Phosphate status generally decreases from source, from high to poor.

The phosphate and ammonia status of the individual WFD monitoring points on the main River Severn for each water body are provided in Tables 9 and 10.

Table 9. Phosphate Monitoring Point Status

Water Body ID	Site	Site Name	Phosphate Status	Mean	Std Dev	EQS Limit for Good	Start Year	End Year
GB109054044790	00074380	R.Severn Llanidloes Felindre Bridge	High	0.00611	0.0257	0.04	2006	2008
GB109054049310	00072250	R.Severn Dolwen	High	0.00706	0.0163	0.04	2006	2008
GB109054049310	00070450	R.Severn At Caersws	High	0.0163	0.0482	0.04	2006	2008
GB109054049310	00067800	R.Severn Foot Bridge Back Ln Cp	High	0.00518	0.0165	0.04	2006	2008
GB109054049310	00065870	R.Severn Cil Gwrgan Bridge Aberbechan	Good	0.033	0.0257	0.04	2006	2008
GB109054049310	00064480	R.Severn At Caerhowel Bridge	High	0.0285	0.0193	0.05	2006	2008
GB109054049700	00061340	R.Severn Maginnis Bridge	Moderate	0.206	0.919	0.12	2006	2008
GB109054049142	00060200	R.Severn At Llandrinio	Good	0.064	0.0369	0.12	2006	2008

GB109054049142	00056710	R.Severn Montford Bridge	High	0.0445	0.0149	0.12	2006	2008
GB109054049142	00055460	R.Severn Isle Of Bicton	Good	0.0613	0.0308	0.12	2007	2008
GB109054049142	00055140	R.Severn Shelton Intake	Good	0.0523	0.0167	0.12	2006	2008
GB109054049141	00052182	R.Severn Atcham	Good	0.0932	0.0528	0.12	2006	2008
GB109054049141	00049650	R.Severn At Cressage	Moderate	0.148	0.0725	0.12	2006	2008
GB109054049143	00045702	R.Severn At Coalport	Moderate	0.139	0.0633	0.12	2006	2008
GB109054049143	00044720	R.Severn At Apley Forge	Moderate	0.169	0.0849	0.12	2006	2008
GB109054049145	00041180	R.Severn Hampton Loade Bridge	Moderate	0.165	0.0817	0.12	2006	2008
GB109054049145	00038360	R.Severn At Bewdley	Moderate	0.163	0.0889	0.12	2006	2008
GB109054049144	00034302	River Severn Holt Fleet Meadows Holt Fleet	Poor	0.329	0.212	0.12	2006	2008
GB109054049144	00030850	R Severn Worcester Bridge	Poor	0.344	0.237	0.12	2006	2008
GB109054049144	00030090	R.Severn Rear Of Oil Depot Bath Rd Worcs	Poor	0.333	0.225	0.12	2006	2008
GB109054039760	00029500	R Severn (Upper) Kempsey (Mid)	Poor	0.296	0.156	0.12	2006	2008
GB109054039760	00028400	R Severn (Upper) Severn Stoke (New Spt)	Poor	0.364	0.194	0.12	2006	2008
GB109054039760	00027540	R Severn - Upton On Severn	Poor	0.329	0.197	0.12	2006	2008
GB109054039760	00026230	R Severn (Upper) Tewkesbury	Poor	0.31	0.169	0.12	2006	2008
GB109054044404	00025312	R Severn (Lower) Chaceley Stock	Poor	0.286	0.129	0.12	2006	2008
GB109054044404	00025085	R Severn (Lower) Haw Bridge	Poor	0.28	0.125	0.12	2006	2008
GB109054044404	00024062	R Severn (Lower) Ashleworth	Poor	0.394	0.707	0.12	2006	2008
GB109054044404	00017500	R Severn (Lower) Maisemore Weir	Poor	0.289	0.149	0.12	2006	2007

Table 10. Ammonia Monitoring Point Status

Water Body ID	Site	Site Name	Ammonia Status	Mean	StdDev	EQS Limit for Good	Start Year	End Year
GB109054044790	00074380	R.Severn Llanidloes Felindre Bridge	High	0.0117	0.0272	0.3	2006	2008
GB109054049310	00072250	R.Severn Dolwen	High	0.0124	0.0408	0.3	2006	2008
GB109054049310	00070450	R.Severn At Caersws	High	0.0205	0.0312	0.3	2006	2008
GB109054049310	00067800	R.Severn Foot Bridge Back Ln Cp	High	0.0219	0.0396	0.3	2006	2008
GB109054049310	00065870	R.Severn Cil Gwrgan Bridge Aberbechan	High	0.0246	0.0346	0.3	2006	2008
GB109054049310	00064480	R.Severn At Caerhowel Bridge	High	0.0315	0.0432	0.3	2006	2008
GB109054049700	00061340	R.Severn Maginnis Bridge	High	0.0305	0.0355	0.6	2006	2008
GB109054049142	00060200	R.Severn At Llandrinio	High	0.0521	0.0498	0.6	2006	2008
GB109054049142	00056710	R.Severn Montford Bridge	High	0.0305	0.0298	0.6	2006	2008
GB109054049142	00055460	R.Severn Isle Of Bicton	High	0.0394	0.0401	0.6	2007	2008

GB109054049142	00055140	R.Severn Shelton Intake	High	0.015	0.0385	0.6	2006	2008
GB109054049141	00052182	R.Severn Atcham	High	0.0447	0.0545	0.6	2006	2008
GB109054049141	00049650	R.Severn At Cressage	High	0.0558	0.0603	0.6	2006	2008
GB109054049143	00045702	R.Severn At Coalport	High	0.0459	0.0521	0.6	2006	2008
GB109054049143	00044720	R.Severn At Apley Forge	High	0.0542	0.071	0.6	2006	2008
GB109054049145	00041180	R.Severn Hampton Loade Bridge	High	0.0676	0.0808	0.6	2006	2008
GB109054049145	00038360	R.Severn At Bewdley	High	0.0472	0.0513	0.6	2006	2008
GB109054049144	00034302	Holt Fleet Meadows Holt Fleet	High	0.0474	0.034	0.6	2006	2008
GB109054049144	00030850	R Severn Worcester Bridge	High	0.0637	0.0398	0.6	2006	2008
GB109054049144	00030090	R.Severn Rear Of Oil Depot Bath Rd Worcs	High	0.0637	0.0376	0.6	2006	2008
GB109054039760	00029500	R Severn (Upper) Kempsey (Mid)	High	0.0604	0.0435	0.6	2006	2008
GB109054039760	00028400	R Severn (Upper) Severn Stoke (New Spt)	High	0.0695	0.0403	0.6	2006	2008
GB109054039760	00027540	R Severn - Upton On Severn	High	0.0644	0.0596	0.6	2006	2008
GB109054039760	00026230	R Severn (Upper) Tewkesbury	High	0.0518	0.0316	0.6	2006	2008
GB109054044404	00025312	R Severn (Lower) Chaceley Stock	High	0.0701	0.0542	0.6	2006	2008
GB109054044404	00025085	R Severn (Lower) Haw Bridge	High	0.064	0.0502	0.6	2006	2008
GB109054044404	00024062	R Severn (Lower) Ashleworth	High	0.0606	0.0504	0.6	2006	2008
GB109054044404	00017500	R Severn (Lower) Maisemore Weir	High	0.0637	0.0605	0.6	2006	2007

Looking at the individual monitoring point status rather than the water body element status reveals that ammonia is actually high along the entire length of the River Severn. The difference observed between water body element classification and individual monitoring point classification is down to the use of multiple monitoring points for water body classification. Water body GB109054049144 actually incorporates monitoring points on the Barbourne Brook, a River Severn tributary. This is an error and will be corrected in the second cycle of the RBMP; the River Barbourne will be separated and a new water body created. Phosphate class, from Montford Bridge downwards, declines from high to poor. Above Montford Bridge the only monitoring point at less than good status is Maginnis Bridge. Closer inspection of the data used for WFD compliance shows that this is a marginal fail due to one sample taken in 2006, with an unusually high result influencing the calculated phosphate mean result.

Chemical status

Three of the River Severn Water bodies are reported as failing chemical status:

1. GB109054049310 R Severn (conf Afon Dulas to conf R Camlad). Failed for Cadmium and its compounds.

2. GB109054049142 R Severn (conf Bele Bk to conf Sundorne Bk). The reported failure is due to tributyltin. This was a marginal failure (>50 to <75% confidence of failing). Further data analysis predicts this to pass in 2015.
3. GB109054044404 R Severn (conf R Avon to conf Upper Parting). The reported failure is due to tributyltin and PAH. These were both marginal failures (>50 to <75% confidence of failing). Further data analysis predicts these to pass in 2015

River Basin Management Plans
The WFD requires EU member states to formulate RBMPs to deliver the objectives of the Directive. The River Basin Management Plan (RBMP) for the River Severn divides the catchment up into 10 'Management Catchments'

Map 1: River Basin Management Plans

1. Severn Uplands
2. Shropshire Middle Severn
3. Worcestershire Middle Severn
4. Teme
5. Severn Vale
6. Warwickshire Avon
7. Wye
8. Usk
9. South East Valleys
10. Bristol Avon and North Somerset Streams

The water quality of catchments 1 through 6, the River Severn from source to the tidal influence at Gloucester, is discussed in more detail in this appendix.

Severn Uplands catchment

A mostly rural catchment, the Severn Uplands includes the towns of Oswestry, Llanidloes, Newtown and Welshpool. In terms of water bodies, there are 93 river and lake water bodies including Clywedog and Vyrnwy reservoirs, the River Severn and River Vyrnwy.

The RBMP reports 45 per cent of the 97 river and lake water bodies currently achieve good ecological status. With the exception of phosphate, all physico–chemical elements are high or good status for all water bodies in this catchment. 19 water bodies are reported as moderate or poor status for phosphate, including the River Severn water body GB109054049700 River Severn R Severn (conf. R Camlad to conf. to Bele Bk).

There are many designated conservation sites in this catchment, and tributaries support a diverse range of ecology associated with good water quality. However, the headwaters of many streams along the western uplands are impacted by acid runoff or drainage from abandoned metal mines. Sheep dip and sediment run-off cause ecological impacts in several rivers such as the Tanat, Vyrnwy and Cain.

Shropshire Middle Severn catchment

The Shropshire Middle Severn catchment is a largely rural area incorporating the towns of Shrewsbury, Newport, Market Drayton and part of Telford. It contains River Seven tributaries, the River Roden, River Perry and the River Tern. The area is ecologically rich and includes a large number of designated conservation sites, most of which come under the Midlands Meres and Mosses Ramsar Site. There are also several water related Special Areas of Conservation (SACs) in this area.

Abstraction for public supply and irrigation for agriculture can have a major impact on water resources. Several rivers are over abstracted or over licensed at low flows, for example the Coley Brook and rivers Perry and Tern. As part of the Environment Agency’s Restoring Sustainable Abstraction (RSA) programme and the water company’s AMP, there are a number of sites being investigated to assess the impacts of abstraction on the environment.

The RBMP for the River Severn reports that only 6% of the 49 river and lake water bodies currently achieve good ecological status. 37 of these water bodies have one or more physico–chemical element at less than good status.

There are no main River Severn water bodies within this management catchment, however the Tern (water body GB109054049680) has high levels of phosphate (currently poor status) and this impacts on the River Severn downstream of the confluence, this is seen at the WFD monitoring point at Cressage.

The rivers Tern, Roden and the Rea Brook suffer from excessive plant and algal growth due to high levels of nutrients from sewage treatment works (STW) effluent, other industries and agriculture. Subsequently, the River Tern, The Strine/Strine Brook and Aqualate Mere have all be designated sensitive areas eutrophic (SA(E)) under the Urban Waste Water Treatment Directive UWWTD. As a result, phosphate treatment commenced at Market Drayton STW and Newport STW in March 2012, Barnhurst STW in August 2008 and is planned for Telford Rushmoor STW in 2014. This will result in an overall reduction in phosphate concentrations in the catchment.

Worcestershire Middle Severn catchment
This is a predominantly rural catchment but there are a number of large urban areas such as, Kidderminster, Worcester and parts of Wolverhampton, Dudley, and Telford. The main River Severn tributaries are the rivers Stour, Salwarpe and Worfe. These are all subject to unsustainable levels of abstraction at low flows. The area has many water dependent sites protected for their biodiversity, designated Sites of Special Scientific and a number of SACs.

The River Salwarpe and the River Stour with Smestow Brook, suffer from excessive plant and algal growth due to high levels of nutrients from STW effluent, other industries and agriculture. Subsequently, they have been designated SA(E)s under the UWWTD. As a result, phosphate treatment commenced at Kidderminster STW in March 2012 and Roundhill STW in 2008. Trescott STW is planned for 2013 and Lower Gornal STW, Bromsgrove STW and Droitwich STW are all planned for 2014. This will result in an overall reduction in phosphate concentrations in the catchment.

21% of 57 rivers are currently achieving good ecological status/potential. 32 of the water bodies have one or more physico-chemical parameter at less than good status 26% of rivers assessed for biology are at least good biological status now. 90% of rivers assessed are achieving good chemical status and 21% are achieving good status overall.

The four main River Severn water bodies in this management catchment are: GB109054049141 R Severn (Sundorne Bk to conf M Wenlock-Farley Bk). As previously said, this water body is influenced by high levels of phosphate in the Tern. However, in the RBMP, it is good status for phosphate, but this is because the monitoring point at Atcham (above the Perry confluence) is high status and the water body class is determined using multiple monitoring points. The monitoring point downstream of the Tern at Cressage is actually moderate status for phosphate. Phosphate levels in the Tern have reduced significantly since 1996 and will reduce further when phosphate removal is installed at the STWs as described above.

GB109054049143 R Severn (conf Much Wenlock-Farley Bk to conf R Worfe). The two monitoring points on this water body are at Coalport and Apley Forge. Both are moderate status for phosphate; however mean phosphate concentrations are higher at Apley Forge. This is because the River Severn is impacted by Coalport STW and the Much Wenlock-Farley Brook which has poor phosphate status. All other physico-chemical elements are at high status.

GB109054049145 R Severn (conf R Worfe to conf R Stour). In this water body the monitoring points at Bewdley and Hampton Loade are both moderate status for phosphate, however, as with the previous water body, mean phosphate concentrations increase with distance downstream. All other physico-chemical elements are at high status.

GB109054049144 R Severn (conf R Stour to conf R Teme). The three monitoring points on the River Severn are all high status for all physico-chemical elements except phosphate. This water body is discussed in detail in the following section of this report.

River Severn Water Quality between Apley Forge and Worcester
For the purpose of this study additional data have been obtained for the River Severn between Apley Forge and Worcester, the River Stour at Stourport and the River Salwarpe at Hawford. On the River Severn, monitoring data at four sites are examined; Apley Forge; Bewdley; Holt Fleet; and, Worcester. For all of these sites, nutrient data have been obtained from 2000 to 2012. The available data are shown as time series and cusum graphs in Figures 1 to 17.

For sites upstream of the Stour confluence (Apley Forge & Bewdley), physico-chemical quality is high for all parameters except phosphate, which is moderate quality. This moderate status is taken from the WFD classifications in the RBMP published in 2009; based on three years data from 2006 to 2008. The cusum plots in Figures 3 and 6 cover a 10 year period to 2012 and identify step changes (decreases) during this 2006 to 2008 period, however, at present these improvements are still not sufficient to comply with the good status standard. Updated classification will be published in the 2nd cycle of the RBMP in 2015.

Similarly, water quality is generally high status for sites downstream of the Stour confluence (Holt Fleet & Worcester) with the exception of phosphate. However, compared to the upstream sites, phosphate concentrations increase significantly at Holt Fleet where phosphate levels are reported as poor in the RBMP. However, looking at the 10 year time series plots in figures 8 and 11, phosphate levels at both Holt Fleet and Worcester have decreased over time, however, like the sites upstream, these improvements are not sufficient to comply with the good status standard.

The drop from moderate to poor status in phosphate on the Severn can be largely explained by poorer river quality in the Stour and Salwarpe tributaries that join the Severn between Bewdley and Worcester. Figure 14 is a time series plot of phosphate in the Stour at Stourport. This monitoring site is classified as bad status for phosphate in the RBMP, based on monitoring data from 2006 to 2008. However, a steep drop in levels is observed at the end of 2008 and this is due to phosphate removal having been installed at Roundhill STW and Barnhurst STW that same year. Phosphate levels will continue to drop in the River Stour due to the recent commencement of phosphate removal at Kidderminster STW, and planned removal at Trescott STW and Lower Gornal STW. Wombourne STW has now closed and the flows are being pumped to Roundhill STW.

TON concentrations in the Stour (Figure 13) are significantly higher than the River Severn. The continuing high concentrations indicate that other sources of TON, other than effluent inputs at Kidderminster, exist throughout the catchment.

The River Salwarpe enters the Severn between Holt Fleet and Worcester and also contributes to increasing phosphate concentrations in the Severn. Figure 16 is a time series plot of phosphate in the Salwarpe at Hawford, which is at the bottom of the catchment before the Salwarpe enters the Severn. Phosphate status at this monitoring point is also bad, but as with Stourport, concentrations have already reduced (step change in 2006, Figure 17) and will continue to decrease when nutrient removal is introduced at Bromsgrove Fringe Green STW and Droitwich STW in 2014 as a requirement of the UWWTD.

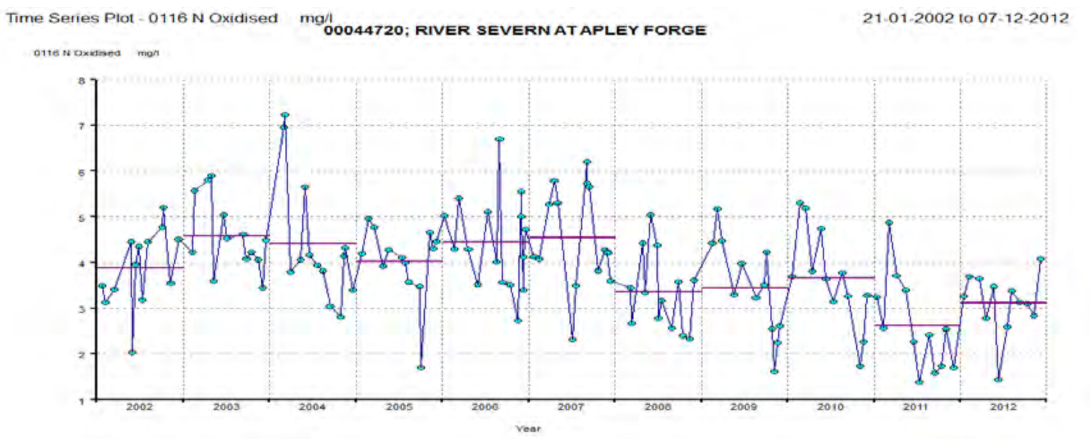


Figure 1: TON River Severn at Apley Forge 2000-20012

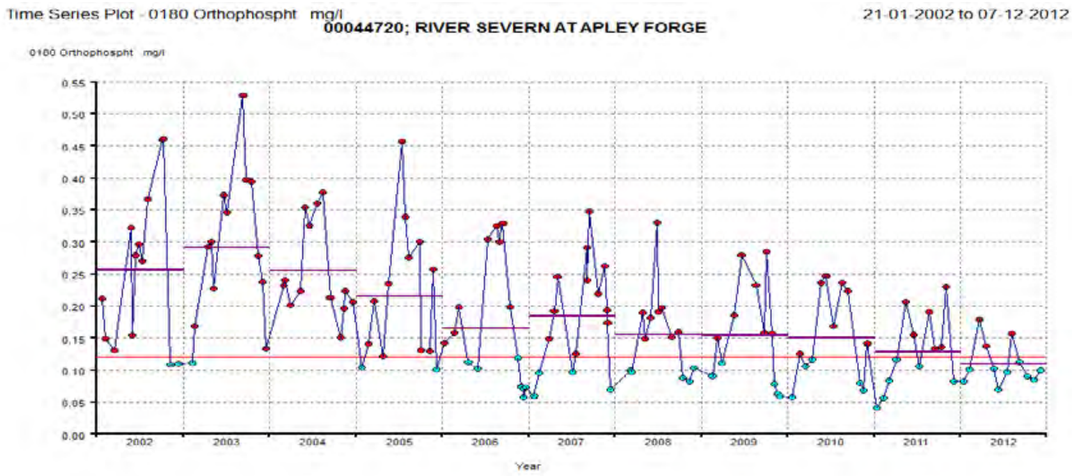


Figure 2: Orthophosphate, River Severn at Apley Forge 2000-2012 (Red line = WFD good status standard)

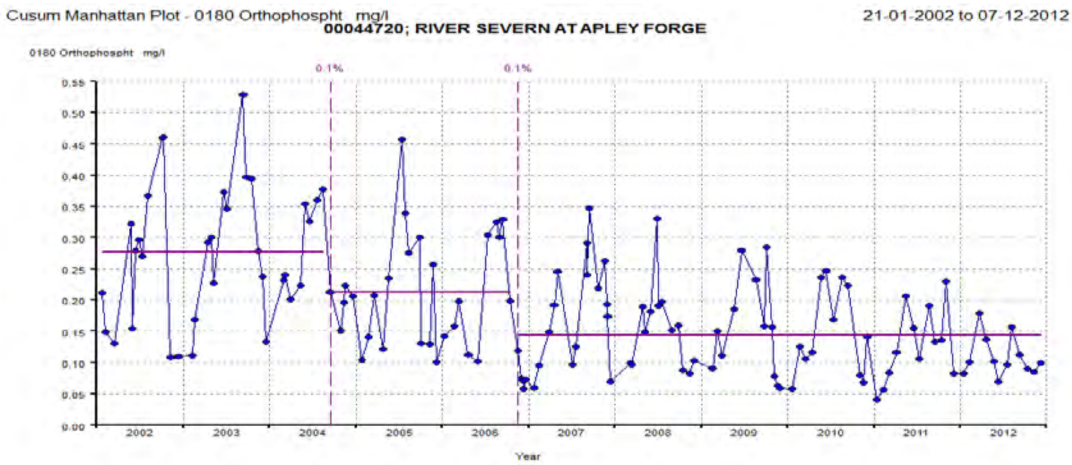


Figure 3: Orthophosphate, Apley Forge. Step changes 2000-2012

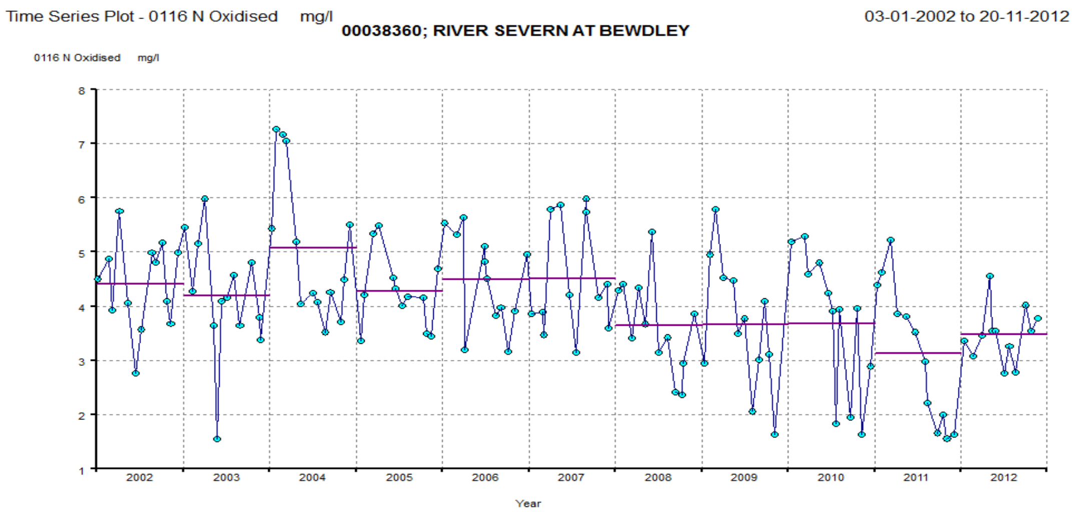


Figure 4: TON, River Severn at Bewdley 2000 to 2012.

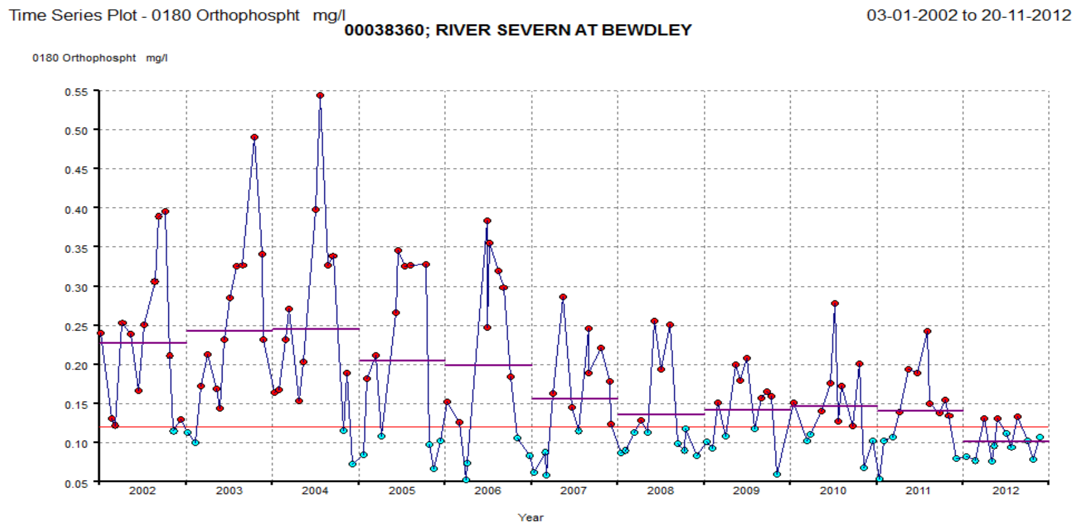


Figure 5: Orthophosphate, River Severn at Bewdley 2000 to 2012. (Red line = WFD good status standard)

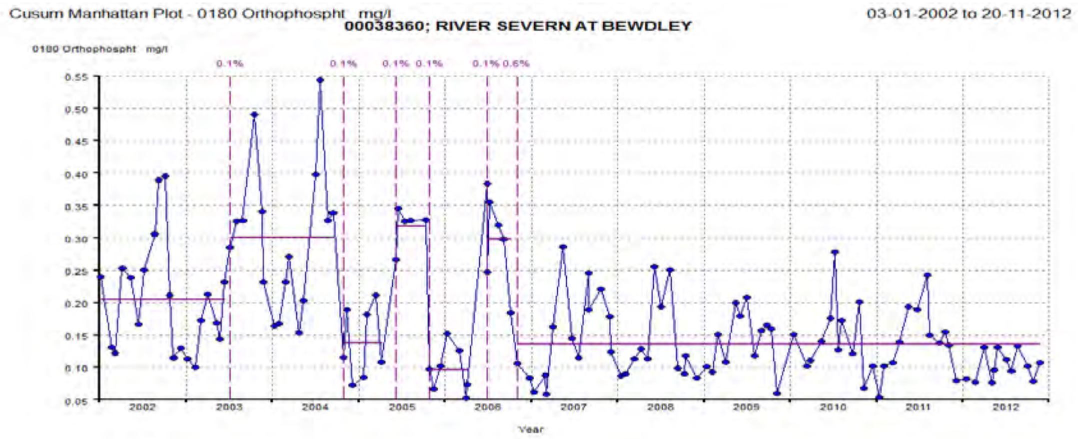


Figure 6: Orthophosphate, Bewdley. Step changes 2000-2012

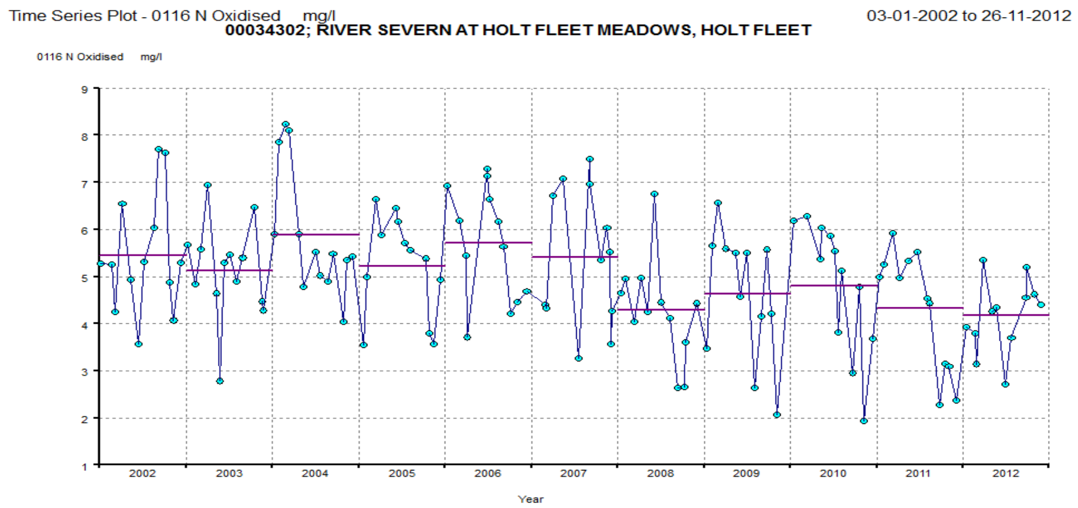


Figure 7: TON, River Severn at Holt Fleet 2000 to 2012.

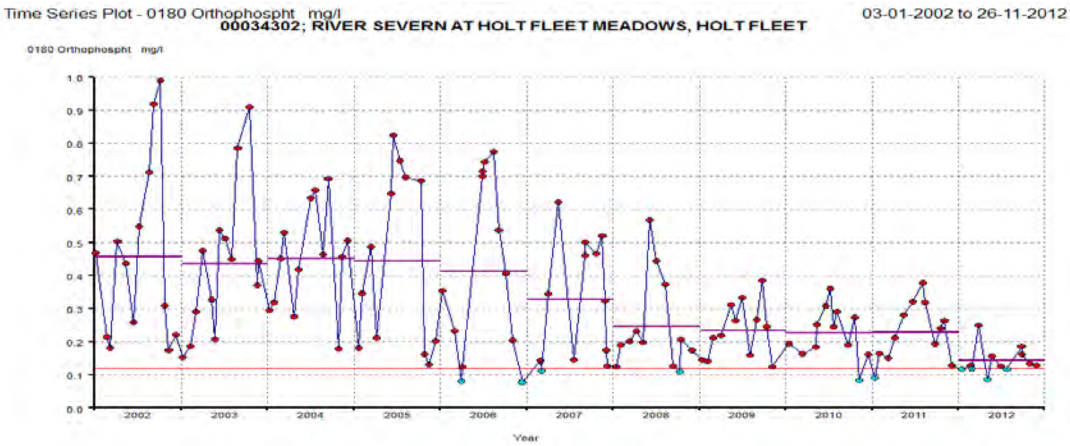


Figure 8: Orthophosphate, River Severn at Holt Fleet 2000 to 2012. (Red line = WFD good status standard)

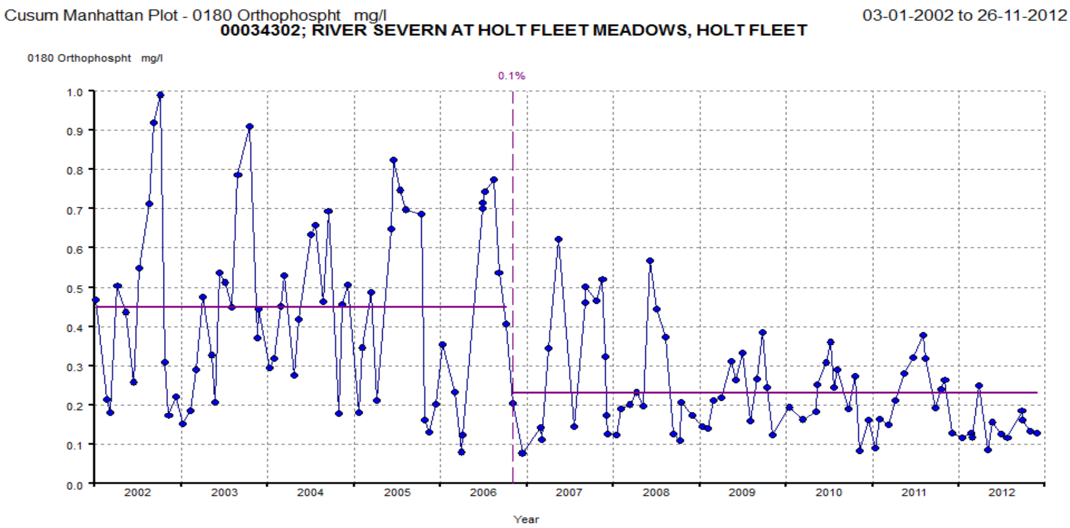


Figure 9: Orthophosphate, Holt Fleet. Step changes 2000-2012

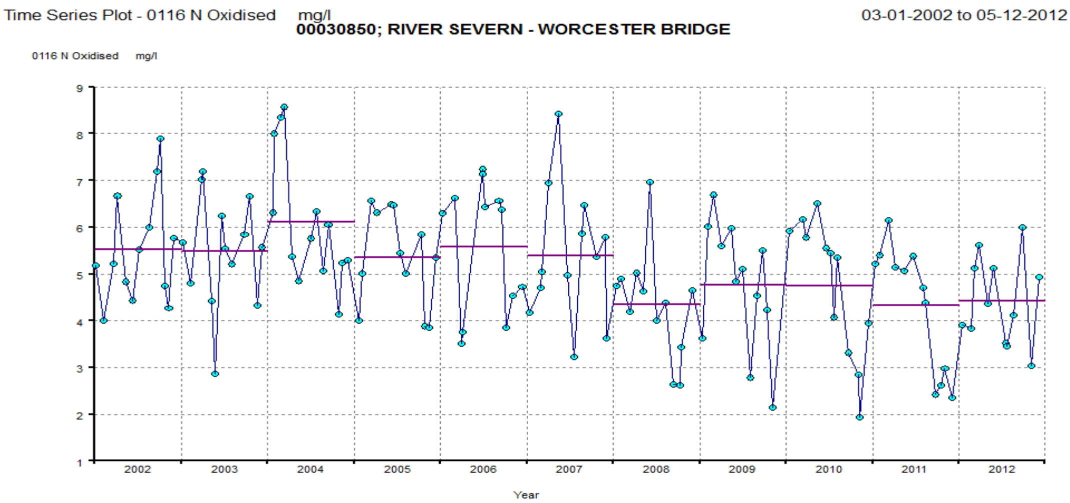


Figure 10: TON, River Severn at Worcester Bridge 2000 to 2012.

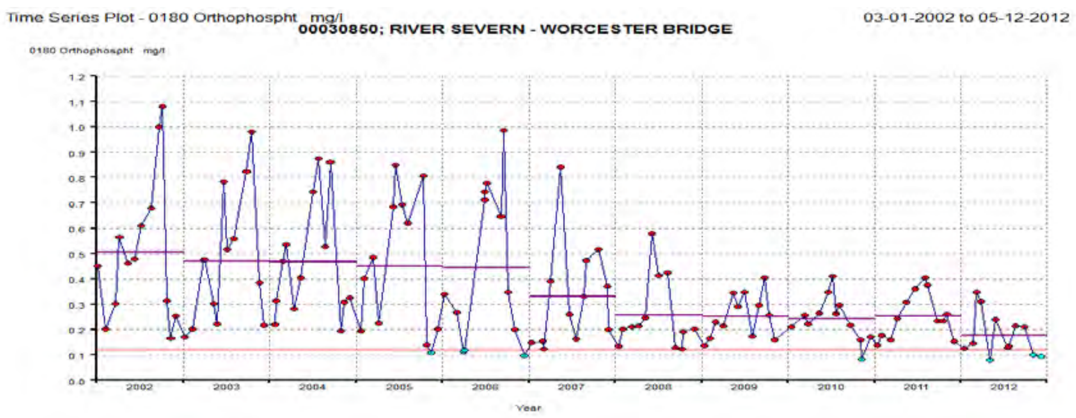


Figure 11: Orthophosphate, River Severn at Worcester Bridge 2000 to 2012. (Red line = WFD good status standard)

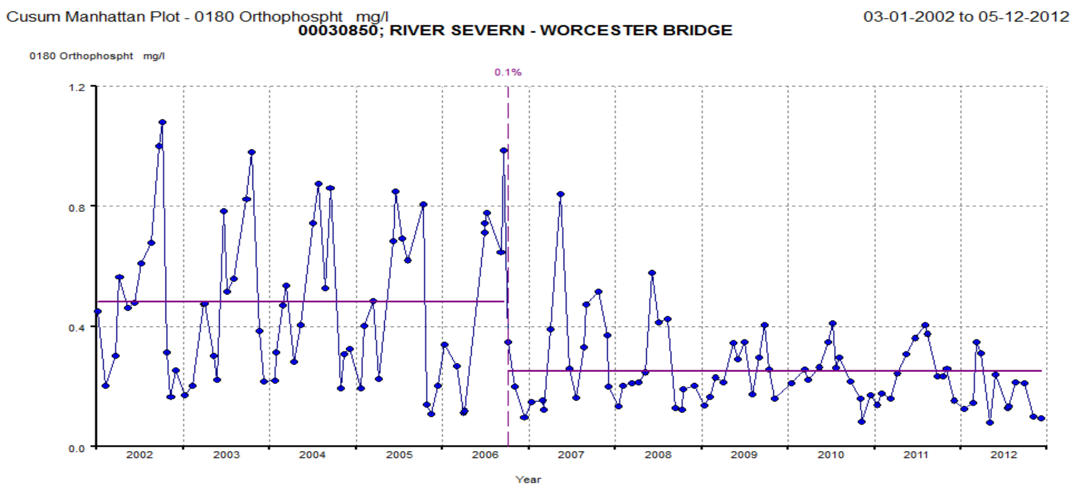


Figure 12: Orthophosphate, Worcester Bridge Step changes 2000-2012.

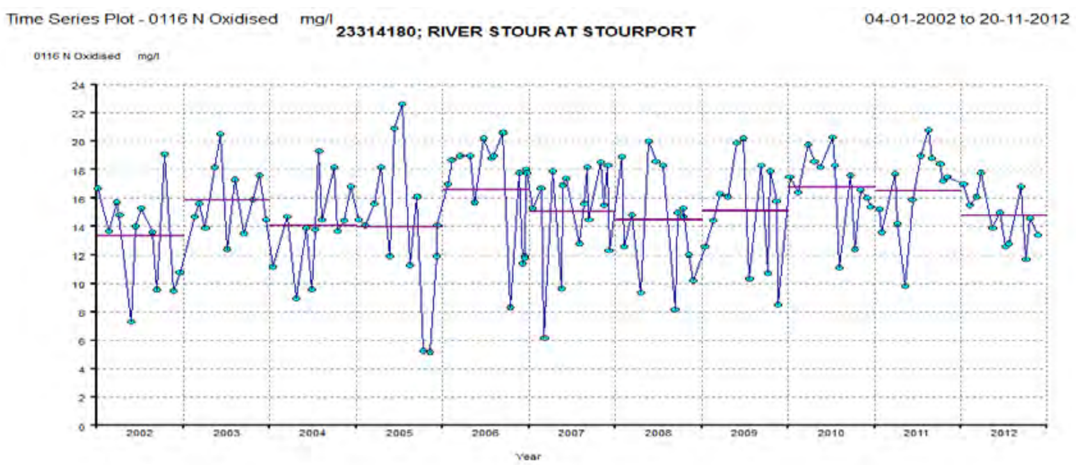


Figure 13: TON River Stour at Stourport 2000 to 2012.

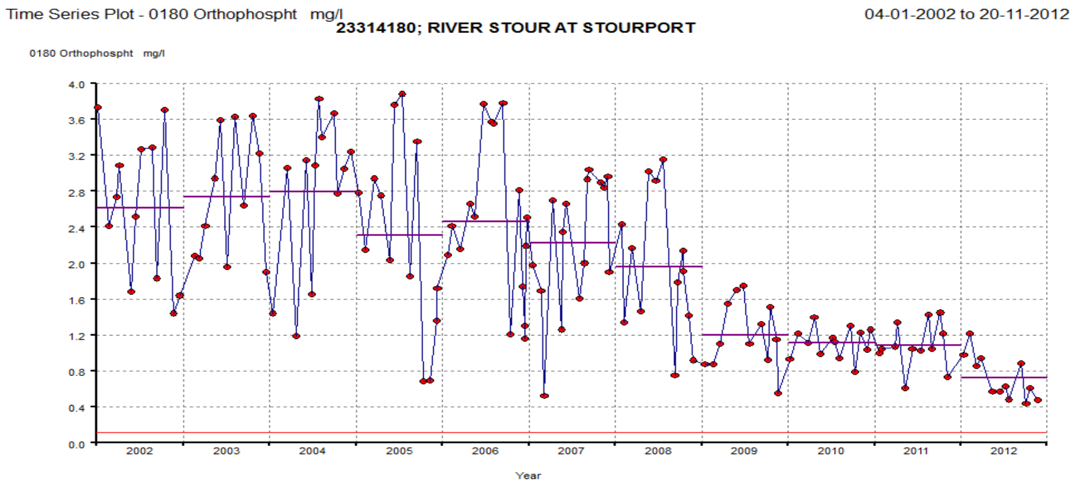


Figure 14: Orthophosphate, River Stour at Stourport 2000 to 2012. (Red line = WFD good status standard)

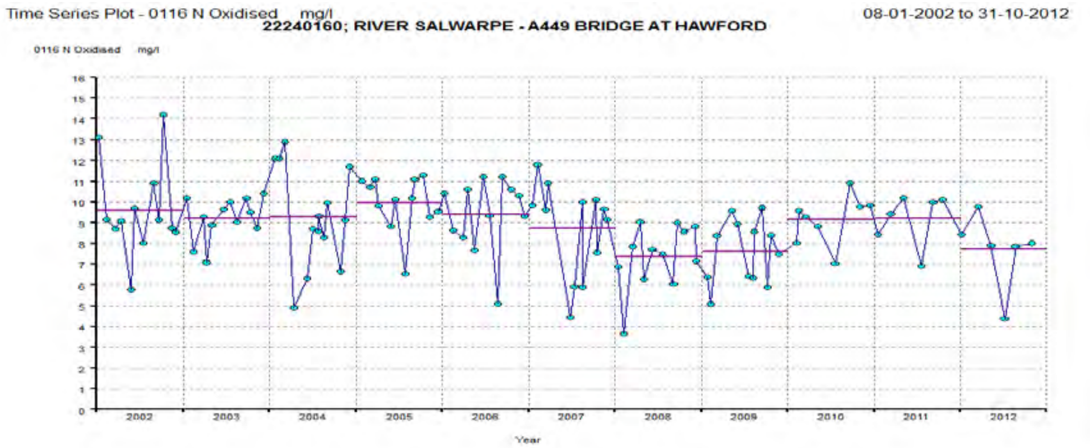


Figure 15: TON, River Salwarpe at Hawford, 2000 to 2012.

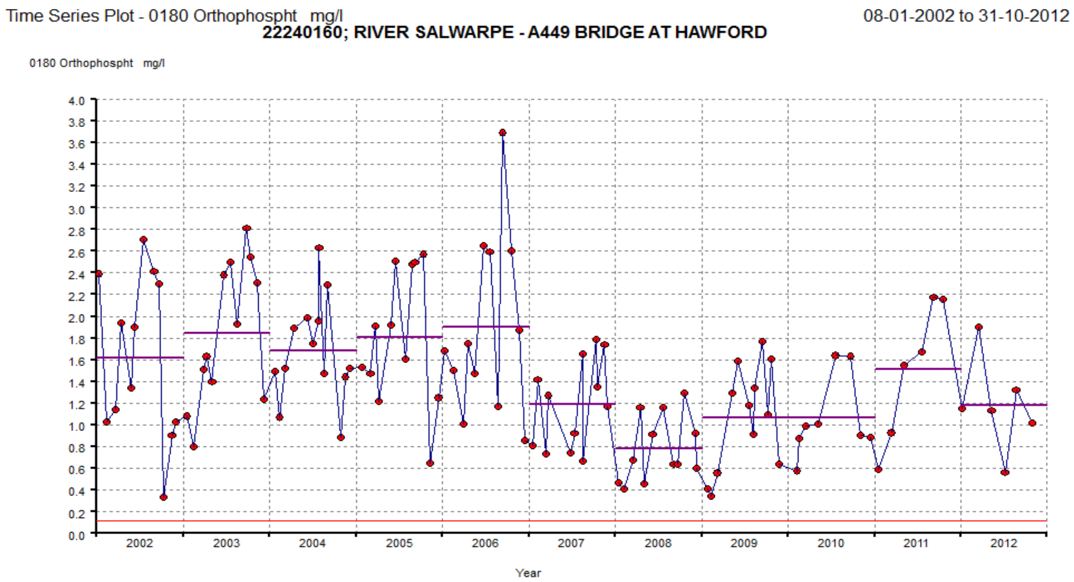


Figure 16: Orthophosphate, River Severn at Hawford, 2000 to 2012. (Red line = WFD good status standard)

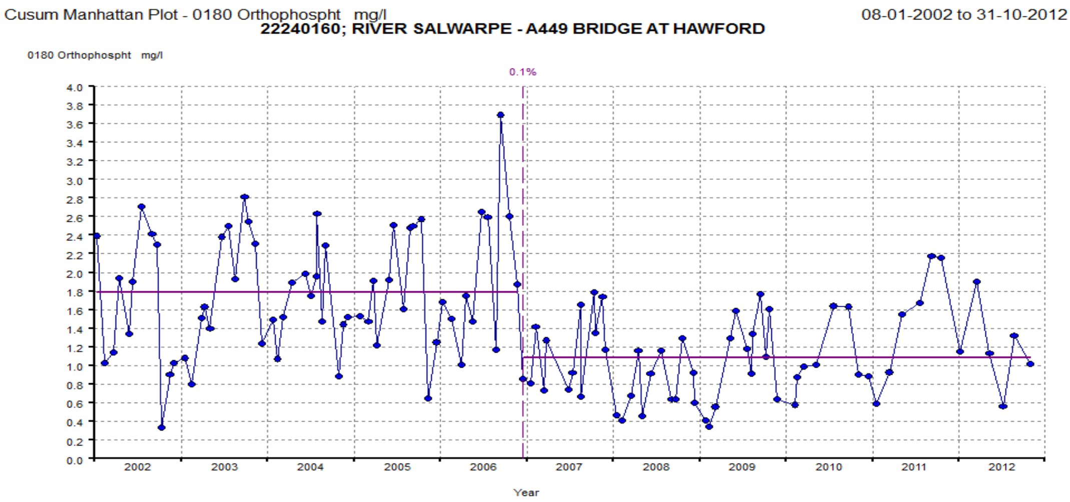


Figure 17: Orthophosphate, Hawford. Step changes 2000-2012.

Teme catchment

The second largest tributary of the River Severn, the Teme is a predominately rural catchment incorporating the market towns of Knighton, Ludlow and Tenbury Wells. Major tributaries include the rivers Clun, Rea, Onny and Corve. The catchment includes two SACs: The Stiperstones and Hollies in the upper reaches of the catchment, and the Downton Gorge on the River Teme between Leintwardine and Ludlow. The lower part of the River Clun to the confluence with the River Teme is also a SAC on the basis of its freshwater pearl mussel population, currently in unfavourable condition, partly due to water quality and sediment. The whole of the River Teme is classed as a SSSI, and Brown trout and migratory Atlantic salmon are found throughout the majority of the Teme catchment and its tributaries provide extensive spawning grounds for both species. The presence of obstacles such as weirs limits the distribution of salmon within the catchment. Water quality in the lower reaches of the catchment is affected by diffuse pollution, mainly by nutrients and sediment; however, overall the river is good quality. Whilst there is adequate supply of surface water in the catchment during the winter months, in the summer the Teme often experiences low flows. Abstraction mainly provides water for irrigation for agriculture, with increased use for trickle irrigation.

In contrast to the other catchments discussed above, 60 of the 48 river water bodies are at good ecological status or potential. The only physico chemical parameter at less than good status is phosphate, and this relates to just 7 of the total water bodies, the others are driven by biological or physical factors.

The Teme was designated a SA(E) under the UWWTD in 1998 and phosphate removal was installed at Tenbury and Ludlow sewage treatment works in 1994. More recently, AMP4 Habitats Directive and Crow Act sewage works improvement schemes have delivered further phosphate reductions from sewage works in the catchment.

Severn Vale catchment
Land use in the Severn Vale is a combination of urban, agricultural and forested areas. The main River Severn tributaries are the River Leadon, the River Chelt, and the River Frome. Downstream of Gloucester is also characterised by numerous small brooks and drainage channels that drain directly to the River Severn. The main urban areas are Gloucester, Cheltenham, Ledbury and Stroud. Arable land dominates the Leadon catchment, which suffers from poor water quality due to excessive quantities of silt and high levels of phosphate and nitrate. Extensive woodlands are present in the Forest of Dean, where there are also water quality problems associated with uncontrolled discharges from former mine workings. These are often acidic and contain metals and other harmful substances that can have significant ecological impacts. Abstraction within the catchment is mainly for public water supply and agriculture. Significant quantities are also used for power generation. The Cinderford and Glynch brooks are over abstracted and groundwater is used to enhance low flows in the Glynch Brook during summer months. Low flows are thought to be adversely affecting fish populations, particularly spawning and nursery areas, in some parts of the area. The Rivers Cam, Frome, Chelt and Leadon all suffer from excessive plant and algal growth due to high levels of nutrients from sewage works effluent, other industries and agriculture. Subsequently, they have been designated SA(E) under the UWWTD and phosphate removal introduced at Coaley, Stroud, Cheltenham (Hayden) and Ledbury sewage works.

There are two River Severn water bodies within this management catchment: GB109054039760 R Severn - conf R Teme to conf R Avon. Phosphate levels remain poor status in this stretch of the Severn. All other physico-chemical elements are high.

GB109054044404 R Severn - conf R Avon to conf Upper Parting. This stretch takes in the largest tributary, the River Avon. Again phosphate levels remain poor status in this stretch of the Severn. All other physico-chemical elements are high. Phosphate levels in the Avon were in the past extremely high, however, since its designation as a sensitive area eutrophic in 1994 and subsequent phosphate stripping at a number of sewage works in the catchments, levels have reduced significantly but they are still at a level to be classed as poor under WFD classification. TON levels are also noticeably higher in the Avon than the Severn (see figures 18 and 19)

Only 7 % of the 67 rivers and lakes in this catchment are currently at good ecological status or potential. 38% are at good or high biological status (50 water bodies assessed), 88 % assessed at good chemical status (16 water bodies assessed) and only 7% at good status overall (chemical and ecological).

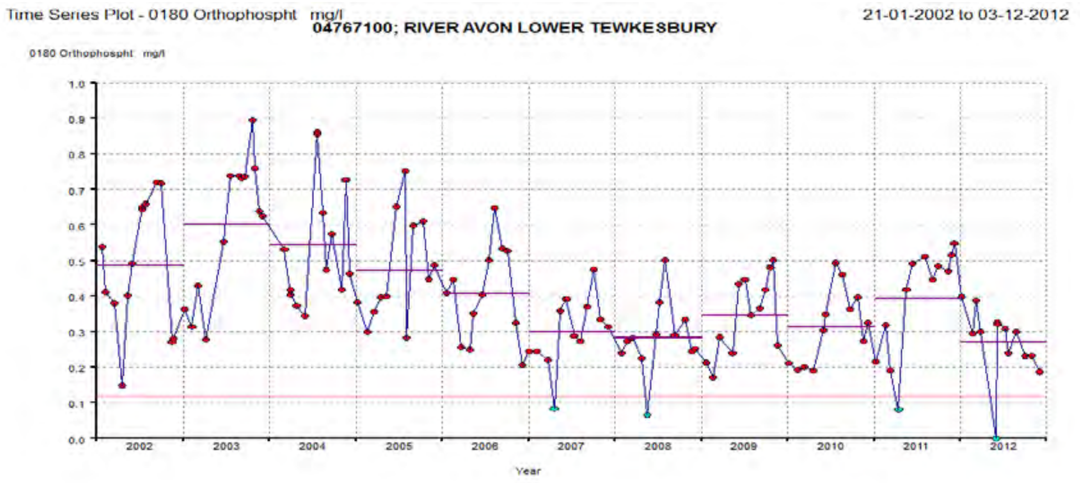


Figure 18: Orthophosphate, River Avon at Tewkesbury 2000 to 2012. (Red line = WFD good status standard)

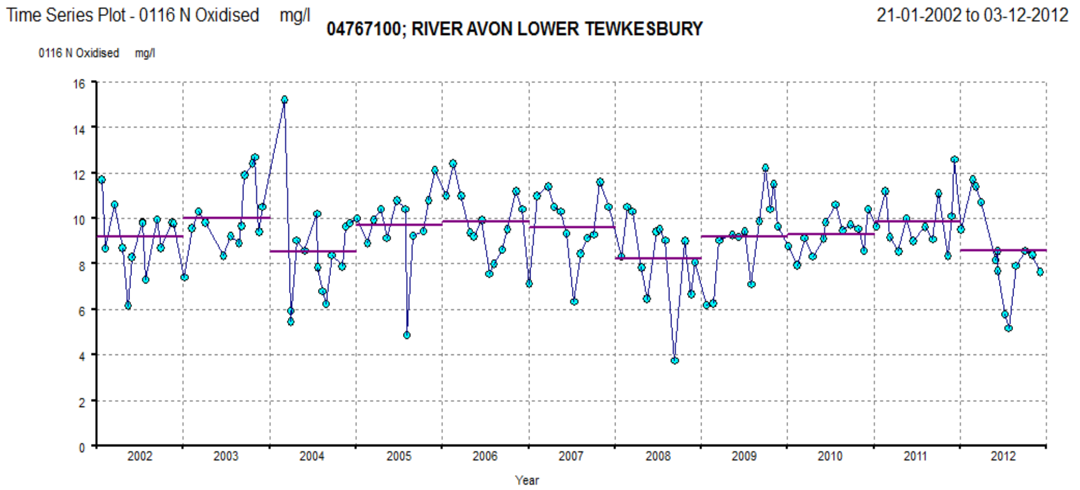


Figure 19:TON River Avon at Tewkesbury 2000 to 2012. (Red line = WFD good status standard)

The River Severn downstream of Gloucester (Maisemore Weir)

The River Severn from the weir at Maisemore to Hock Cliff near Fretherne is not with the Severn Vale management catchment, although water bodies within the Severn Vale catchment drain into it. This stretch of the Severn is named the Severn Upper, GB530905415403 and is a transitional water body type. The only physico-chemical element used in this water body's classification is dissolved oxygen and this is reported as high status.

The River Severn from Hock Cliff near Fretherne to just above the Wye confluence again is not within the Severn Vale management catchment, although water bodies within the Severn Vale catchment drain into it. This stretch of the Severn is named the Severn Middle, GB530905415402 and is a transitional water body type. The only physico-chemical elements used in this water body's classification are dissolved oxygen (reported as high status) and dissolved inorganic nitrogen, which is moderate status (uncertain).

Below the Wye confluence is the Severn Lower water body, ref GB530905415401. The only physico-chemical elements used in this water body's classification is dissolved oxygen, reported as high status, and dissolved inorganic nitrogen, which is moderate status (uncertain).

Warwickshire Avon

The catchment includes the River Avon and its various tributaries. Coventry is the largest urban area in the catchment and other towns include Rugby, Leamington Spa, Warwick, Stratford-upon-Avon, Evesham, Redditch and Tewkesbury. Agriculture accounts for a high proportion of the land use including arable, livestock, horticulture and market gardening and fruit and vegetable production around Evesham. The catchment has a high value for wildlife and there are a large number of designated sites. The River Avon is navigable and a major resource for recreational activities such as boating, canoeing, fishing and walking. Water is abstracted primarily for public water supply, agriculture and industry. Water quality in the headwaters of the main tributaries is generally good. Elsewhere water quality problems are due to a mixture of the impact of sewage discharges, diffuse (urban and agricultural) run off leading to nutrient enrichment and other pollution.

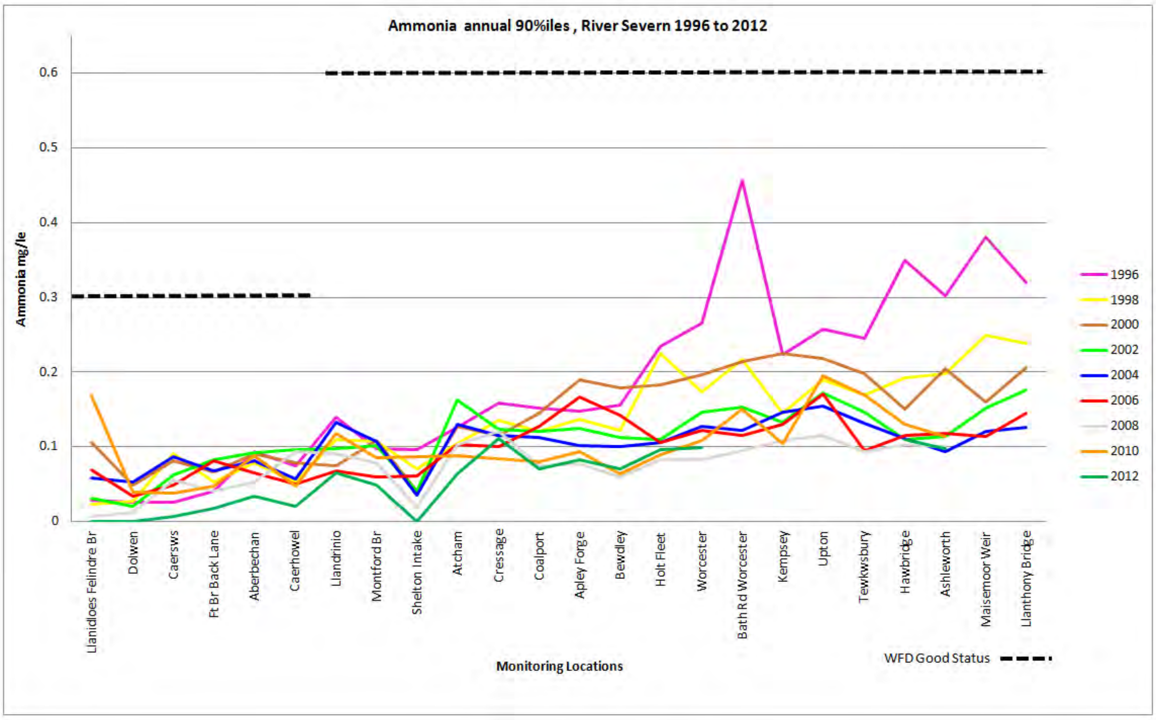
There are 91 river water bodies and 3 lakes in the catchment. 11 per cent of rivers currently achieve good ecological status. 35 per cent of rivers assessed for biology are at least good biological status now.

Summary

For most physico-chemical parameters, the River Severn is high quality. All of the River Severn WFD water bodies examined meet WFD high status for both temperature and pH. Dissolved oxygen achieves WFD high status for all water bodies except GB109054032750 River Severn (East Channel Horsbere Brook to Severn Estuary) where it drops to good status.

Ammonia levels in the river, although increasing from source, stay within the WFD good status standard of 0.3-0.6 mg/l (90%ile). Improvements at many of the sewage works with the Severn Basin district have contributed to the overall reduction in ammonia levels since 1996.

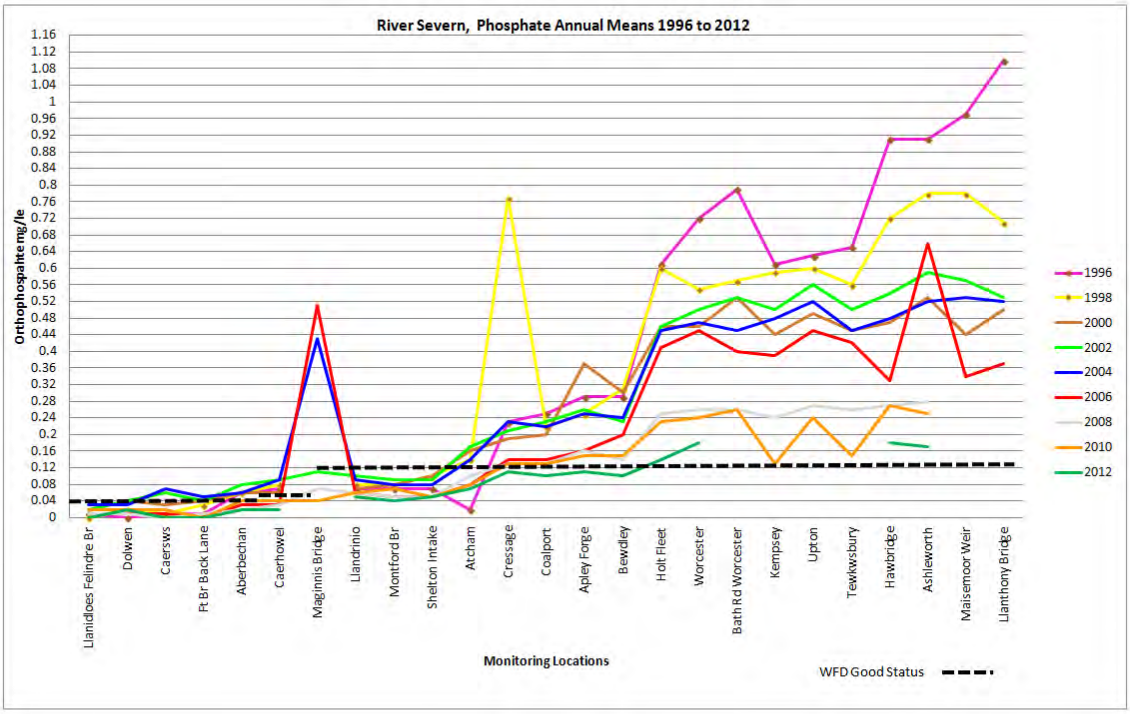
Figure 20



Phosphate levels show a general increasing trend with distance downstream. However, improvements at many sewage works within the River Severn catchment have contributed significantly to the overall reduction in phosphate levels since 1996. Even with these notable improvements, phosphate is the physico-chemical element contributing to WFD River Severn water body failures.

Apart from WFD water body GB109054049700 (River Severn, confluence River Camlad to confluence Bele Brook), phosphate levels are meeting WFD phosphate good status standard down to Atcham, which is above the Tern confluence. The moderate status of GB109054049700 is due to a single high orthophosphate result in September 2006, with this individual sample result removed, the water body would have achieved good status for phosphate. Subsequent annual means at this monitoring point are below the good status standard therefore it is likely that this will be a compliant parameter in the next RBMP classification. Below the Tern confluence, the WFD 0.12 mg/l good status standard is exceeded at all monitoring sites down to Llanthony Bridge up to 2010. 2012 shows some improvement to Bewdley, however downstream of the Stour, levels are still in excess of the WFD standard for good status. This is examined in more detail in Appendix 5.1

Figure 21



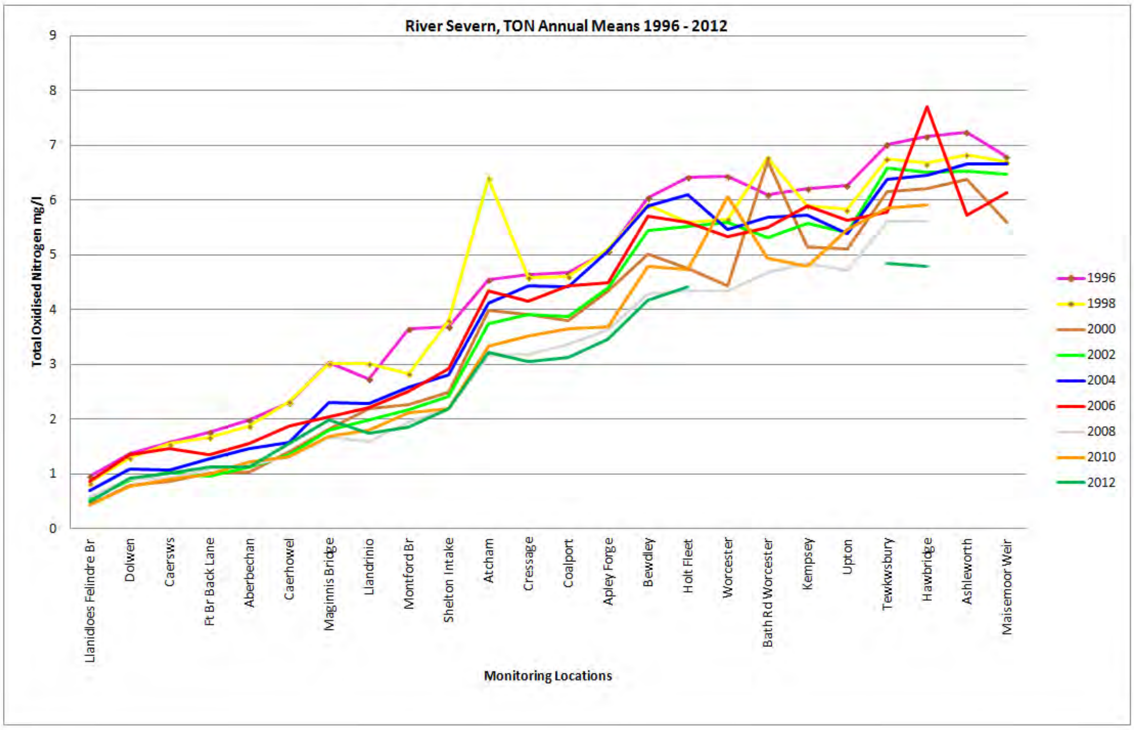
Nutrient Enrichment

As with ammonia and phosphate, nitrate concentrations show a general increasing trend with distance downstream, and overall levels have decreased, but not to the same extent. Nitrate is not used as a physico-chemical element in WFD classification and there is no associated environment quality standard.

Most of the east side of the River Severn catchment below Montford Bridge and parts of the west side is designated as a Nitrate Vulnerable Zone (NVZ) under the EC Nitrates Directive (see figure 24). This should contribute to reduced diffuse nitrate pollution, through restrictions in the use and storage of nitrate fertilisers for farms located within the NVZ.

A detailed assessment of water quality was carried out by the Environment Agency in relation to an unsuccessful proposal to designate a large proportion of the River Severn as a Sensitive Area (Eutrophic) under the E.C. Urban Waste Water Treatment Directive (UWWTD). The stretch under consideration was downstream of the Monkmoor Sewage Treatment Works (STW) to the tidal limit of the river at Maisemore, to the west of Gloucester. This report concluded that the River Severn becomes more eutrophic as the river flows downstream. Many of the STWs increase phosphate levels but diffuse sources also contribute to nutrient enrichment, particularly in the Upper Severn catchment.

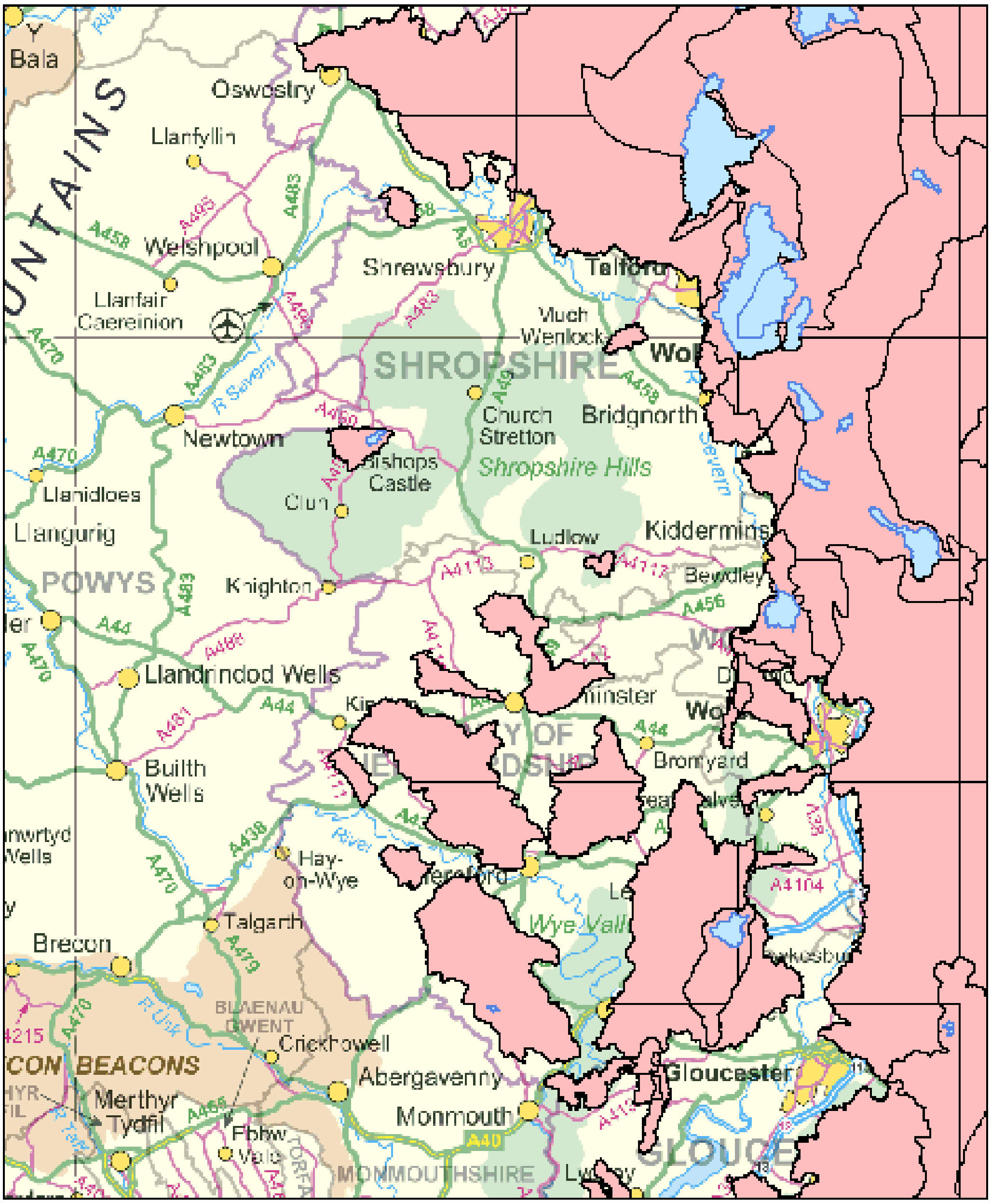
Figure 22



As many of the River Severn tributaries are already designated sensitive areas eutrophic, there has been considerable improvements to the phosphate content of many of the larger sewage works, delivered as part of the water companies Asset Management Plan (AMP). Other AMP drivers such as improvements to discharges impacting on SSSIs and Habitat Directive sites have also required the reduction in sewage discharge phosphate levels.

Despite all these improvements and planned future reductions, phosphate levels will still exceed the WFD good status standards. The RBMP will therefore have to address the diffuse contribution and investigate further options for point source discharges.

Figure 24


Bala
Oswestry
Llanfyllin
Welshpool
Llanfair Caereinion
Shrewsbury
Telford
Much Wenlock
SHROPSHIRE
Church Stretton
Bridgnorth
Shropshire Hills
Newtown
Bishops Castle
Clun
Llanidloes
Llangurig
POWYS
Knighton
Ludlow
Kidderminster
Bewdley
Llandrindod Wells
Builth Wells
Bromyard
Hay-on-Wye
Talgarth
Brecon
Crickhowell
Abergavenny
Monmouth
Merthyr Tydfil
Gloucester
MONMOUTHSHIRE
BLAENAU GWENT
R Severn
Wye Valley

Water Discharges

There are numerous sewage and other trade effluent discharges into the River Severn. All discharges of sewage and trade effluent require the consent of the Environment Agency. The consent limits are set on both the quantity and quality of the discharge according to the amount of water available to dilute the effluent at the point of discharge without causing significant deterioration in the quality of the watercourse. Also, the limits aim to ensure that the discharge does not compromise downstream uses of the river and that the resulting downstream water quality conforms to the relevant environmental quality standards.

The majority of industrial discharges that directly enter the Severn are not of sufficient size to present any threat to the receiving watercourse. One of the largest discharges is clean cooling water from the Ironbridge Power Station, where a volume of 16 Ml/d is consented for discharge. The power station is closed down for a six week period during the summer during which period there will be no abstraction or discharge. This has been taken into consideration by the Environment Agency during the development of the various drought order management scenarios.

The major STWs that discharge to the River Severn are presented in Table 7 below. The Environment Agency reports that compliance with consent conditions is good and the most recent Catchment Abstraction Management Strategy (CAMS) for the River Severn does not identify any water quality issues directly associated with failure of consent conditions at sewage treatment works. However, STWs can have a significant impact during periods of low flow.

Table 7: Major STWs Discharges to the River Severn (direct and indirect)

Name of discharge	Direct / Indirect	NGR	Consented Volume (M^3/d)
Gloucester (Netheridge) STW	Direct	SO 80961594	42800
Worcester STW	Direct	SO 8449 5340	33000
Shrewsbury Monkmoor STW	Direct	SJ 5240 1357	20838
Coalport STW	Direct	SJ 7094 0134	17700
Malvern Barnards Green STW	Direct	SO 8009 4475	13400
Newtown Powys STW	Direct	SO 1380 9245	3700
Bridgnorth (Slads) STW	Direct	SO 7341 9104	2954
Coventry Finham STW	Indirect (via R Avon)	SP 3361 7379	115000
Roundhill STW	Indirect (via R Stour)	SO 8698 8365	59836
Barnhurst STW	Indirect (via Staff/Worcs)	SJ 9020 0176	47500
Warwick STW	Indirect (vu- R Avon)	SP 2777 6290	36000
Cheltenham Hayden STW	Indirect (via R Chelt)	SO 9060 2310	35000
Redditch Spernal STW	Indirect (via R Arrow)	SP 0846 6263	27500
Kidderminster STW	Indirect (via R Stour)	SO 8256 7375	26504
Stanley Downton (Stroud) STW	Indirect (via R Frome)	SO 7910 0480	24300
Telford Rushmoor STW	Indirect (via R Tern)	SJ 6130 1354	23523
Rugby Newbold STW	Indirect (via R Avon)	SP 4942 7635	21600
Stratford Milcote STW	Indirect (via R Avon)	SP 1805 5297	13110
Bromsgrove Fringe Green	Indirect (via R Salwarpe)	SO 9596 6834	11500
Lower Gornal STW	Indirect (via Bobs Bk)	SO 9030 9075	8500
Droitwich STW	Indirect (via R Salwarpe)	SO 8626 6166	7183

Coaley STW	Indirect (via R Cam)	SO 7562 0217	6680
Trescott STW	Indirect (via Smestow Bk)	SO 8549 9763	6460
Evesham STW	Indirect (via R Avon)	SP 0318 4467	5797
Tewkesbury STW	Indirect (via Mill Avon)	SO 8812 3186	5192
Oswestry Mile Oak STW	Indirect (via R Morda)	SJ 3024 2713	4890
Redditch Priest Bridge STW	Indirect (via Bow Bk)	SO 9926 5983	3576
Ludlow STW	Indirect (via R Teme)	SO 5163 7310	3500
Market Drayton STW	Indirect (via R Tern)	SJ 6685 3320	3400
Brockhampton STW	Indirect (via Hyde Bk)	SO 9462 2593	3360
Wombourne STW	Indirect (via Wom Bk)	SO 8575 9213	3289
Itchen Bank STW	Indirect (via R Itchen)	SP 4069 6281	2881
Blackminster STW	Indirect (via Badsey Bk)	SP 0661 4464	2756
Newport STW	Indirect (via Strine Bk)	SJ 7358 1924	2500
Tenbury Wells STW	Indirect (via R Teme)	SO 6044 6848	1247

Summer storms following periods of dry weather can cause catastrophic pollution and resultant fish kills, either through STWs stormwater overflows or through the flushing-out of urban pollution. Most of the large public sewerage systems have storm overflows that operate within the system or at the sewage treatment works at times of heavy rainfall. The majority of the overflows operate without causing nuisance, although it is reported that those situated in areas of high public amenity do give rise to some complaint. Pollution incidents associated with storm overflows are generally of short duration, but can have serious long term effects on the biological and aesthetic quality of the river.

STWs that serve a population in excess of 2000 people (or population equivalent) must also comply with the minimum standards required by the UWWTD.

As part of the water industry AMP, improvements have been delivered at a number of unsatisfactory continuous and intermittent discharges since 2000. The STWs and receiving watercourses which have benefited from this programme are summarised in Tables 8 and 9. These improvements, which include tightening of discharge consents to reduce discharges of ammonia, phosphate and organic matter, have been driven by non-compliance with RQOs and by a number of Directives (i.e. Freshwater Fish Directive, Habitats Directive, and UWWTD).

Further improvements are underway for the current AMP programme running from 2010 to 2015. New drivers have been added such as WFD. These schemes are summarised in Table 10.

TABLE 8: SUMMARY OF IMPROVEMENT WORKS CARRIED OUT UNDER THE WATER INDUSTRY AMP (2000-2005)

WFD Management Catchment	Discharge Name	Discharge Type	Receiving Watercourse	Completion date
Worcestershire Middle Severn	Albrighton	Continuous	Albrighton Brook	31.03.05
	Ombersley	Continuous	Hadley Brook	31.03.05
	Droitwich	Continuous	River Salwarpe	31.03.01
	Bromsgrove	Continuous	Sugar Brook	31.03.03
	Coven Heath	Continuous	Staff/Worcester Canal	31.03.05
	Bagley Street	Intermittent	River Stour	31.03.03
	Wellmeadow	Intermittent	River Severn	31.03.02
	Hayes Lane	Intermittent	River Stour	31.03.04
	Hagley Road	Intermittent	River Stour	31.03.03
	The Kingsway P/S	Intermittent	River Stour	31.03.03
	Stourville Road	Intermittent	River Stour	31.03.04
	Enville Street	Intermittent	River Stour	31.03.04
Severn Vale	Ledbury STW	Continuous	River Leadon	31.12.04
	Little Marcle Road PS	Intermittent	River Leadon	31.03.05
	Staunton STW (Pitsmill)	Intermittent	River Leadon	31.03.03
	Malvern (Barnards Green) STW	Intermittent	River Severn	31.03.03
	Ashleworth Quay	Continuous	River Severn	31.03.05
	Stanley Downton STW	Continuous	River Frome	31.12.04
	Coaley STW	Continuous	River Cam	31.06.03
	Cheltenham STW	Continuous	River Chelt	31.12.04
	Dunkirk Mills	Intermittent	Nailsworth Stream	31.03.03
	Malakoff Inn	Intermittent	River Frome	31.03.03
	Wallbridge PS	Intermittent	River Frome	31.03.04
	Lodgemoor Mills	Intermittent	River Frome	31.03.03
	King Stanley East	Intermittent	River Frome	31.03.03
	Ocean Bridge	Intermittent	River Frome	31.03.05
	Stanley Downton STW	Intermittent	River Frome	31.03.05
	Coaley STW	Intermittent	River Cam	31.03.05
	Listers Car Park	Intermittent	River Cam	31.03.04

TABLE 9: SUMMARY OF IMPROVEMENT WORKS CARRIED OUT UNDER THE WATER INDUSTRY AMP (2005-2010)

WFD Management Catchment	Discharge Name / location	Effluent type	Receiving water name	Delivery Date
Severn Uplands	Coleham SPS	Intermittent	River Severn	31.03.09
	Hanwood SPS	Intermittent	Rea Brook	31.03.08
	The Flash CSO, Shrewsbury	Intermittent	River Severn	Not required
Severn Vale	Cheltenham Hayden STW	Continuous	River Chelt	31.03.09
	Ellwood SPS	Intermittent	Trib Cannop Bk	31.03.07
	Shuttlefast Farm CSO, Malvern	Intermittent	Merebrook Pool	31.03.08
Shropshire Middle Severn	Betton Byeways STW	Continuous	River Tern	31.03.07
	Maer Village Drain	Continuous	River Tern	31.03.12
	Newport STW	Continuous	Strine Brook	31.03.08
	High Ercall CSO (Shop lane)	Intermittent	Shirlowe Brook	31.03.09
	Bishops Castle STW	Continuous	Snakes Croft Brook	31.03.07
	Blundell Hall Bishops Castle STW	Continuous	Trib River Kemp	31.03.07
	Bucknell STW	Continuous	River Redlake	31.03.08
	Church Stretton STW	Continuous	Quinny Bk	31.03.11
	Church Stretton STW Storm Tanks	Intermittent	Quinny Brook	31.03.10
	Clun STW	Continuous	River Clun	Not required
	Craven Arms STW	Continuous	River Onny	31.03.11
	Knighton STW	Continuous	River Teme	01.03.10
	Lydbury North STW	Continuous	River Kemp	Not required
	Wichenford Queens SPS	Emergency Overflow	Trib of Laughern Brook	31.03.08
Warwickshire Avon	Astwood Bank STW	Continuous	Doe Bank Brook	31.03.10
Worcestershire Middle Severn	Bath Rd./ Stanley St. CSO Worcester	Intermittent	Duck Brook (trib of River Severn)	31.03.09
	Batten Hall Rd/St. Dunstans Cres. CSO, Worcester	Intermittent	Duck Brook (trib of River Severn)	31.03.06
	Belle Vue Storm Tanks	Storm Tank	River Stour	31.03.07
	Blakedown STW	Continuous	Blakedown Brook,	31.03.09
	Bridge Road CSO	Intermittent	Benthall Brook, trib River Severn	31.03.09
	Bromsgrove STW	Continuous	Sugar Brook (River Salwarpe)	31.03.10
	Diglis Syphon, Worcester	Intermittent	River Severn	31.03.09
	Grandstand Road, Worcester	Intermittent	River Severn	31.03.07
	Ladywood SPS on B4377 Ironbridge	Intermittent	River Severn	31.03.07
	Much Wenlock STW Storm Tanks	Intermittent	Much Wenlock Brook	31.03.07
	Newport Road CSO, Albrighton	Intermittent	Albrighton Brook	31.03.08
	Pine Grove SPS	Intermittent	Sugar/Spadesbourne Brook	31.03.07
	Roundhill STW - Outlet B	Continuous	Gallows Brook	31.03.10
	Roundhill STW - OutletA	Continuous	River Stour	31.12.08
	Springfield SPS, Worcester	Intermittent	Duck Brook	31.03.07
	Worcester STW Storm Tanks	Intermittent	River Severn	31.03.10

TABLE 10: SUMMARY OF IMPROVEMENT WORKS UNDER THE WATER INDUSTRY AMP (2010-2015)

WFD Management Catchment	Scheme Name/Name of Discharge/Investigation	Effluent type	Name of Water body	Completion date
Severn Uplands	Llanfyllin STW	Continuous	A. Cain	Planned 31.03.15
	West Felton STW	Continuous	Weir Brook	Planned 31.03.15
Severn Vale	Longhope STW	Continuous	Longhope Bk	Planned 31.03.15
	Coaley STW	Continuous	R Cam	Planned 31.03.15
Shropshire Middle Severn	Newport STW	Continuous	Strine Bk	31.03.12
	Rushmoor STW	Continuous	R Tern	Planned 30.09.14
	Market Drayton STW	Continuous	R Tern	31.03.12
	Oswestry (Drenewydd) STW	Continuous	Common Bk	22.12.12
	Edgmond	Continuous	Strine Bk	22.12.12
Teme	Hallow STW	Continuous	Laughern Brook	Planned 31.03.15
Warwickshire Avon	Kimcote STW	Continuous	R Swift	Planned 31.03.15
	Swinford STW	Continuous	River Avon	Planned 31.03.15
	Brinklow STW	Continuous	Smite Bk	Planned 31.03.15
	Kineton-STW	Continuous	R Dene	Planned 31.03.15
	Gaydon STW	Continuous	R Dene	Planned 31.03.15
	Norton Lindsey STW	Continuous	Sherbourne Bk	Planned 31.03.15
	Whichford STW	Continuous	R Stour	Planned 31.03.15
	Cherington STW	Continuous	R Stour	Planned 31.03.15
	Broadway STW	Continuous	Badsey Bk	Planned 31.03.15
	Lutterworth STW	Continuous	R Swift	Planned 30.09.14
	Itchen Bank STW	Continuous	R Itchen	31.03.12
	Blackminster STW	Continuous	Badsey Brook	Planned 30.09.14
Worcestershire Middle Severn	Cutnall Green STW	Continuous	Hadley Brook	Planned 31.03.15
	Chaddesley Corbett-STW	Continuous	Hadley Brook	Planned 31.03.15
	Trescott STW	Continuous	Smestow Brook	Planned 31.03.13
	Kidderminster STW	Continuous	R Stour	31.03.12
	Wombourne STW	Continuous	Smestow Brook	31.03.13
	Droitwich STW	Continuous	R Salwarpe	Planned 30.09.14
	Bromsgrove Fringe Green STW	Continuous	Sugar Brook	Planned 30.09.14
	Lower Gornal STW	Continuous	Bobs/Holbeche Brook	Planned 30.09.14
	Lower Penn STW	Continuous	Merryhill Brook	22.12.12

Appendix M

Physico-Chemical Water Quality

Physico-Chemical Water Quality

GQA – Chemistry and Nutrients

The EA has a duty to monitor and report on the quality of the water environment for a range of statutory (e.g. EC directives, statutory regulations, international conventions etc) and non-statutory (e.g. General Quality Assessment (GQA)) drivers. The GQA scheme is designed to provide an accurate and consistent assessment of the state of water quality and changes over time. This assessment is described in terms of chemical, nutrient, aesthetic and biological quality. This section provides an overview of chemical and nutrient quality only[1].

Sites are sampled a minimum of 12 times a year. The data collected over three years are used to determine average concentrations to reduce any non-seasonal variation due to unusual weather conditions. All the results collected over the three years are included. No extreme data values are excluded.

The Chemical GQA describes quality in terms of chemical measurements which detect the most common types of pollution (i.e. dissolved oxygen, biochemical oxygen demand and ammonia). It allocates one of six grades (A to F) to each stretch of river, using the same, strictly defined procedures, throughout England and Wales (0). The overall GQA grade assigned to a reach is determined by the worst of the three grades for the individual determinands.

Table C.1 GQA chemical standards

GQA grade	DO (% saturation) 10-percentile	BOD (mg/l) 90-percentile	Ammonia (MgN/l) 90-percentile
A (Very Good)	80	2.5	0.25
B (Good)	70	4	0.6
C (Fairly Good)	60	6	1.3
D (Fair)	50	8	2.5
E (Poor)	20	15	9.0
F (Bad)	<20	-	-

The GQA for nutrients describes quality in terms of phosphate and nitrate. A grade from 1 to 6 is allocated for both phosphate and nitrate (Table C.2). These are not combined into a single nutrient grade. In this respect it differs from the chemical classifications which combine factors into a single grade.

There are no formally prescribed 'good' or 'bad' concentrations for nutrients in rivers comparable to those used to describe chemical and biological quality. Rivers in different parts of the country have naturally different concentrations of nutrients. However, by considering man made nutrient sources and influences against ideal targets for the river environment present, or aspired to, it is possible to determine whether the nutrient status is appropriate.

1 Aesthetic quality was not considered in this study

Table C.2 GQA standards for Nitrate and Phosphate

Grade	Nitrate		Phosphate	
	Grade Limit (mg NO_3/l) average	Description	Grade Limit (mg P/l) average	Description
1	<5	Very low	<0.02	Very low
2	>5 to 10	Low	>0.02 to 0.06	Low
3	>10 to 20	Moderately low	>0.06 to 0.1	Moderate
4	>20 to 30	Moderate	>0.1 to 0.2	High
5	>30 to 40	High	>0.2 to 1.0	Very high
6	>40	Very High	>1.0	Excessively high

WFD Surface Waters

For surface waters, good status is a statement of ‘overall status’, and has an ecological and a chemical component. Good ecological status is measured on the scale high, good, moderate, poor and bad. Physico-chemical elements are a supporting element in the classification of ecological status. Chemical status is measured as good or fail. Good ecological status applies to natural water bodies, and is defined as a slight variation from undisturbed natural conditions.

A Environment Agency document explaining the classification process in more detail can be found at: http://www.environment-agency.gov.uk/static/documents/Research/Classification_Method_Statement_FINAL.pdf

UKTAG guidance on classification:
http://www.wfduk.org/UKCLASSPUB/LibraryPublicDocs/sw_status_classification

UKTAG guidance on classifying heavily modified and artificial water bodies
http://www.wfduk.org/UKCLASSPUB/LibraryPublicDocs/gep_hmwb_final

UKTAG environmental standards documents
http://www.wfduk.org/UK_Environmental_Standards/

Appendix N

SIMCAT Water Quality Modelling Technical Report – River Severn Drought Order

River Severn Drought Order – WQ Modelling Summary

Environment Agency
Damon Llewellyn
Midlands Environment Planning (Water Quality)

As the only current water quality modelling tool available that includes the River Severn corridor from source to estuary, including the ability to model the inputs from all tributaries and the flow control measures at Vyrnwy and Clywedog reservoirs, the newly constructed River Severn River Basin District SIMCAT model represented the best option for assessing the Severn Drought Order options.

SIMCAT is a proven modelling tool for water quality planning and has been used by the Environment Agency for over two decades. It has been developed as a software package that can represent point and diffuse source inputs as well as in-river decay. SIMCAT is and can be used for the calculation of water quality statistics (usually mean and 90th percentiles) and for the determination of discharge consent conditions.

The model, rebuilt in 2009 using the most up to date data available, was deemed fit for purpose in terms of both quality and quantity calibration at the time of it's completion. SIMCAT models are constructed using mean and standard deviation quality data and mean and 95% low flow data for flow.

The model operates on the relatively simple principles of mass balance calculations in which upstream loads and discharge loads are mixed to provide a downstream estimate of load, it is possible that it does not necessarily represent the best way of assessing extreme low flows as experienced during drought conditions. It is, however, the best suited water quality modelling tool available for a whole catchment assessment and, as such, the best available tool for the Severn Drought Order water quality assessment.

In terms of flow data, the model has been built on data provided from 57 flow gauges throughout the catchment and daily mean flow data provided by Severn Trent Water where available for the discharges included in the model. Where actual data was not available, the permitted discharge volumes were used.

Major abstractions are also included in the SIMCAT model where it was felt they had a significant impact upon the flows in the environment (29 sites in total). Where applicable, the appropriate hands-off flows can be incorporated in order to limit how much water can be taken from the environment at times of very low flow. The model, however, does not incorporate drought permit requirements at any features.

The quality data used to build the final SIMCAT model came from a variety of sources including a total of 499 river quality sites, 334 sewage treatment works and 50 industrial discharge sites.

A series of correlation exercises were completed to determine the degree of relationship between certain model parameters. These included investigating the relationship between river flow and river quality, effluent flow and quality and effluent flow and river flow. How each parameter relates to each other was then incorporated into the final model.

In terms of flow calibration, all sites satisfied the primary goal of predicting mean and 95%ile river flows within one standard deviation of the measured data provided during the model build. Calibration against the secondary, and more stringent, test of remaining within 10% of the observed data was less successful, however, only seven of the 57 flow gauge locations failed to achieve this criteria. Many of these sites were in areas of low flow meaning that any small error is often exaggerated in term of percentage error but that the actual difference between calculated and observed values are often quite small.

Locations of poorer calibration of most interest with regards to the output of this assessment are as follows:

1. River Severn, Buildwas – -13.2% difference in 95%ile (predicted = 779.3Ml/d, Observed = 897.3Ml/d)
2. River Severn, Bewdley – 16.4% difference in Mean (predicted = 6054.5Ml/d, Observed = 5202.0Ml/d)
3. River Severn, Saxons Lode – -16.2% difference in 95%ile (predicted = 1324.1Ml/d, Observed = 1580.0Ml/d)

Table 1 – Percentage of water quality points calibrated to within one standard deviation

Parameter	Statistic	No. of Water Quality Points	% of Water Quality Points within Criteria
BOD	Mean	483	92
BOD	95%ile	483	60
Ammonia	Mean	486	72
Ammonia	95%ile	486	43
Dissolved Oxygen	Mean	486	95
Dissolved Oxygen	95%ile	486	80
Phosphate	Mean	485	78
Phosphate	95%ile	485	41
Nitrogen	Mean	486	81
Nitrogen	95%ile	486	54

These figures represent the results from manual calibration and, in terms of theoretical water quality modelling, can be regarded as having a achieved a ‘good match’. The performance of the model was further improved, however, through the use of auto-calibration where the model automatically adds or removes load from the model in order to improve the match between predicted and observed data.

In terms of the use of the model for the assessment of the Severn Drought Order, however, the manually calibrated model was used to assess the relative performances of the different scenarios to be tested. Although this may appear strange given the improved nature of the model following auto-calibration, there were two key reasons for this decision:

1. When running what-if scenarios in an auto-calibrated model, it is very difficult to eliminate the effects of the ‘adjusted’ loads from all locations in the model. It is often unknown why this should occur and so, as a safeguard, it was decided to use the manually calibrated model in this assessment.

2. As the assessment of the Severn Drought Order options was a straight forward comparison of river quality as opposed to an assessment of compliance or an exercise to set permit limits, it was felt that perfect calibration was not required, especially given the potential errors that could occur as detailed in 1 above.

The original modelling brief involved a two stage process:

Stage 1: Representation of drought conditions in the model under an acute and chronic scenario

Stage 2: Modelling the impact of invoking the Environment Agency’s Severn Drought Order for both stage 1 scenarios

Stage 1 – Representation of drought conditions in SIMCAT

From a starting point of the original model representation of mean and Q95 low flows, the original aim was to reduce flows to match those modelled in Aquator, simulating two theoretical drought events of greater magnitude than the 1976 drought.

This was to be achieved through a catchment-wide reduction in flows in line with prescribed ratios derived from the Aquator flow modelling scenario's. A full table of the adjustment factors can be found in Table 2 below:

Table 2 – Drought condition adjustment factors

Headwater reference location			Flow headwater adjustments			
			Acute		Chronic	
			mean	95%	mean	95%
2001	Bewdley	R.Severn_13	8.39	8.43	1.64	1.68
2003	Vyrnwy Weir	R.Vyrnwy	see below			
2032	Saxon's Lode	R.Severn	8.39	8.43	1.64	1.68
2057	Haw Bridge	R.Severn	8.07	6.36	1.46	1.97
2109	Bryntail	R.Clywedog	see below			
2134	Buildwas H	R Severn	18.13	6.77	3.12	2.36
2134	Buildwas S	R. Severn	6.48	5.23	1.77	1.79
2606	Deerhurst	R.Severn	8.07	6.36	1.46	1.97
n/a	Hook Cliffe	R. Severn	8.07	6.36	1.46	1.97

Having assigned all headwater flows included in the SIMCAT model to the relevant flow gauge included in Table 2, the appropriate flow was reduced by the corresponding factor in the same table, depending upon the severity of drought condition being modelled (acute or chronic).

The same process was applied to diffuse flows entering the model and also tributary flows included in the model but not specifically modelled for water quality.

In order to further represent the drought conditions, all discharge inputs to the model were reduced to represent just their dry weather flow as opposed to the inclusion of storm water runoff. This was further enhanced by the reduction of the standard deviation of this data to zero in order to represent a prolonged dry period.

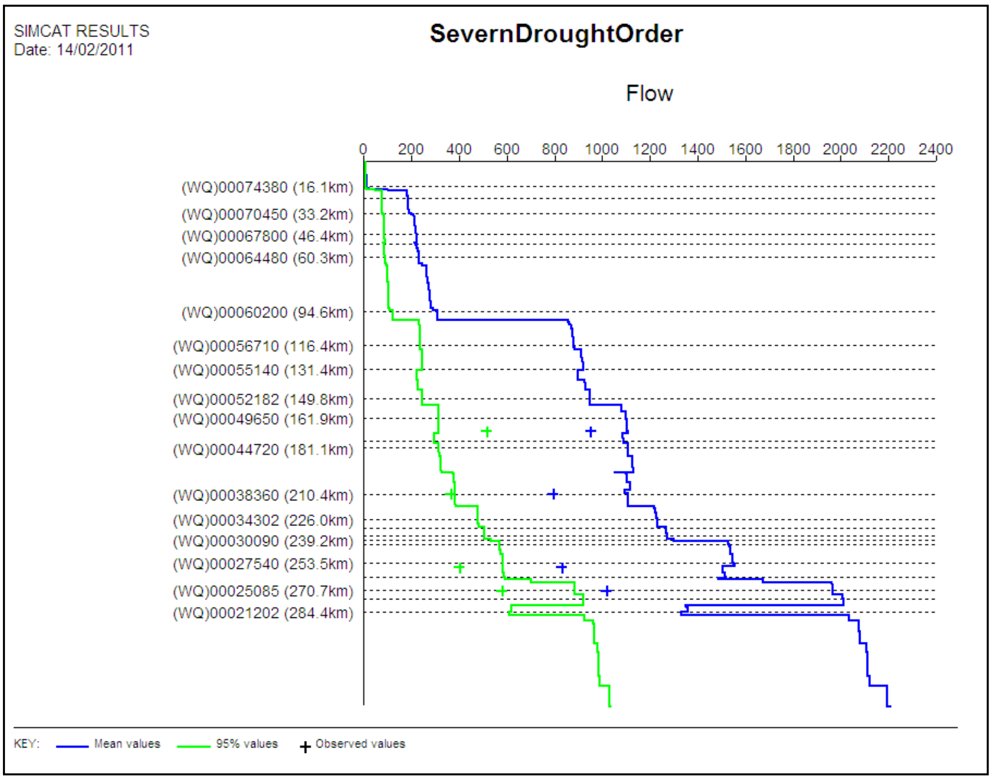
The intention of these initial reductions was to match the prescribed flows detailed in Table 3 below:

Table 3 – Prescribed Flow Gauge flows based on Modelled drought scenario's

River Flows	Acute				Chronic (2nd summer)			
	With DO		Do Nothing scenario		With DO		Do Nothing scenario	
	mean	95%	mean	95%	mean	95%	mean	95%
Clywedog Reservoir	142.03	75.88	222.83	8.87	253.32	18.20	108.07	12.39
Vyrnwy Reservoir	145.03	45.00	145.03	45.00	82.55	25.00	58.16	25.00
Buildwas C Flow	869.87	605.93	950.07	512.69	1020.02	911.19	1610.17	638.01
Bewdley C Flow	727.42	456.77	791.23	363.30	834.82	711.14	1441.64	443.60
Saxon Loade CF	774.46	513.60	828.93	400.10	956.04	765.21	1719.37	581.90
Haw Bridge C Flow	962.64	692.35	1014.77	577.05	1173.54	915.96	2057.80	794.55
Lower Part CF	746.99	499.15	789.42	371.34	997.70	693.29	1870.58	532.95

Figure 1 below represents the results of this initial adjustment under acute, non drought order conditions with the coloured crosses representing the target flows listed in Table 2.

Figure 1 – SIMCAT output following initial flow adjustments



It is clear from the SIMCAT output in Figure 1 that the initial adjustments made failed to achieve the required flow reduction throughout the model. Although flow representation in the upper Severn corridor matched prescribed flows accurately enough, an ever increasing margin of error was evident with distance downstream.

Consultation with the originators of the forecasted flows suggested that the model may be wrongly estimating the many abstractions that occur between Buildwas and Bewdley and that these should be checked to ensure the abstracted volumes were correct.

Completion of this exercise showed that the model represented the full licensed volumes and, therefore, the worst possible impact in terms of flow reduction. Removal of the hands-off flows associated with these abstractions was trialled although this further complicated the results with a practical ‘bottoming-out’ of the Q95 flow and a persistent over-estimation of the mean flow. Specific drought permit parameters cannot be integrated into the SIMCAT model and as such, will not be a factor in the calibration of the drought condition model.

Further investigation into the input flow data showed up obvious areas of error that could be approached to try to improve the match between predicted and observed data. These are included in Table 4 below:

Table 4 – SIMCAT/AQUATOR Prediction errors

Tributary Name	SIMCAT Predicted Flow (Ml/d)	AQUATOR Predicted Flow (Ml/d)
Afon Vyrnwy	547.0Ml/d	145.0Ml/d
River Stour	111.5Ml/d	85.1Ml/d
River Teme	233.3Ml/d	6.11Ml/d
River Avon	439.8Ml/d	239.9Ml/d

Further investigation into the four key tributaries showed no immediate errors so an exercise to further reduce the headwater and diffuse flows was undertaken to try to create a better match between predicted and observed data.

Problems were immediately encountered on the River Stour where it became apparent that population growth in the catchment since the mid 1970s had been considerable and that discharge flows under dry weather conditions alone exceeded the target flow suggested by AQUATOR.

Assuming this would be the case throughout the model, it became further apparent that trying to achieve the target flows in the River Severn corridor would entail making adjustments in flow that would not represent reality and would no longer be defendable in terms of the Severn Drought Order justification.

Consequently, it was decided to just make logical adjustments to the Severn River Basin District SIMCAT model flow parameters which could be backed up and fully justified. These can be summarised as:

1. Adjustment of headwater, diffuse and tributary flow inputs in line with the Table 2 adjustment factors

2. Reduction in licensed discharge volumes to the measured dry weather flows

3. Reduction of the discharge standard deviations to zero.

Figure 2 below illustrates the final acute, non-drought order representation of flows whilst Figures 3 (mean flow) and 4 (Q95 flow) compares this final situation with the flow conditions represented in SIMCAT during non-drought periods.

Figure 2 – final acute drought condition representation

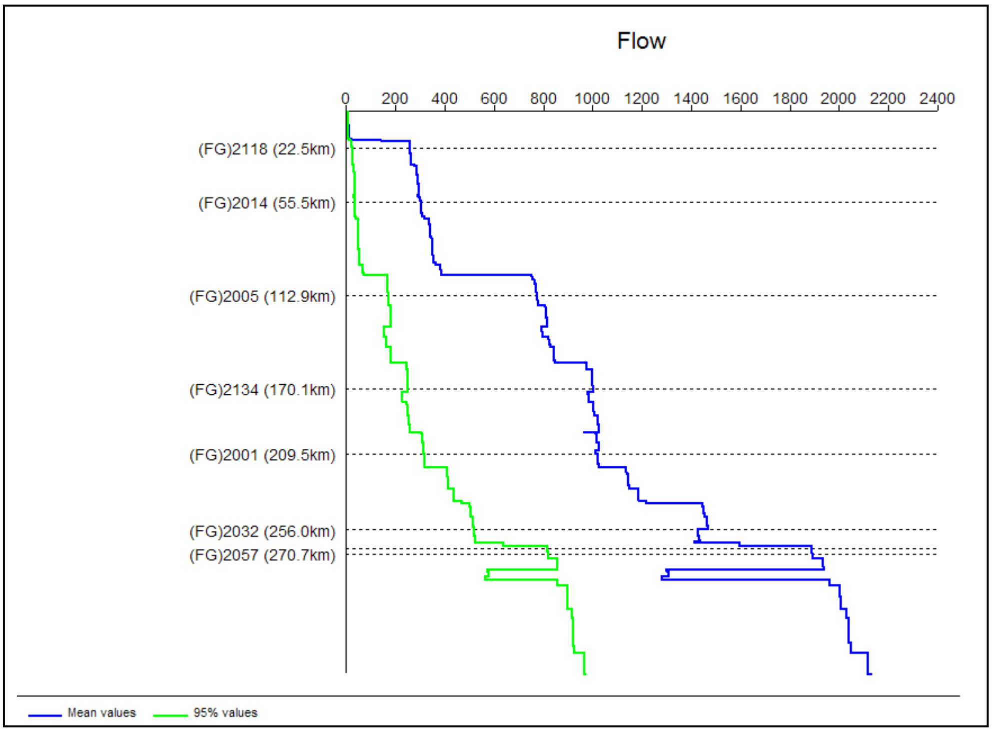


Figure 3 – Acute drought / Non-drought mean flow condition comparison

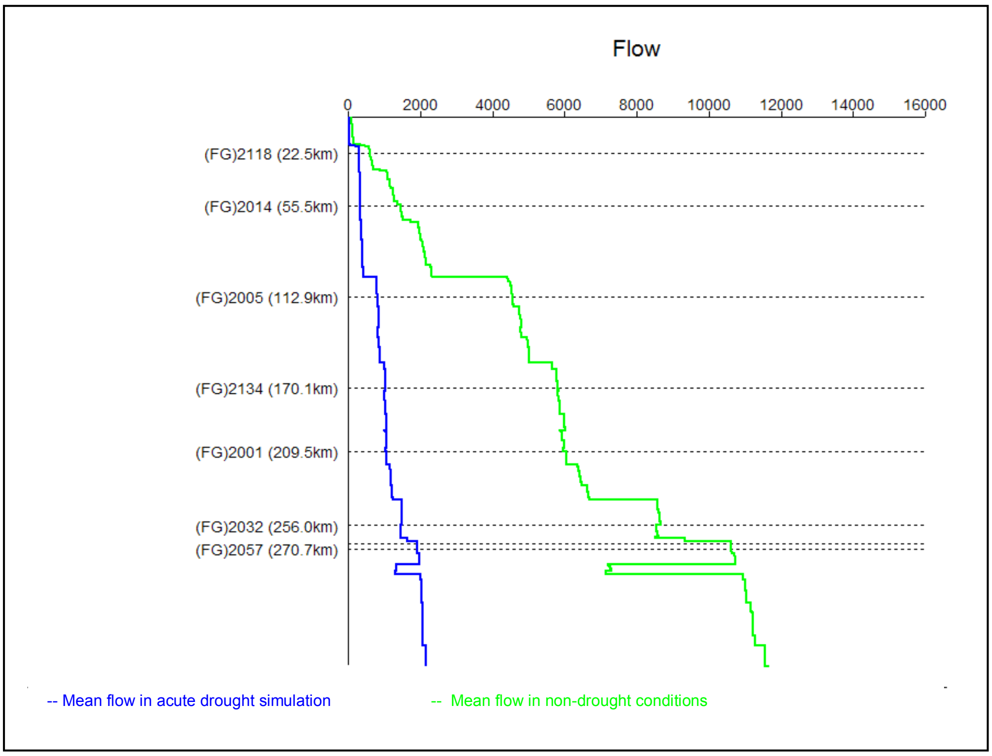
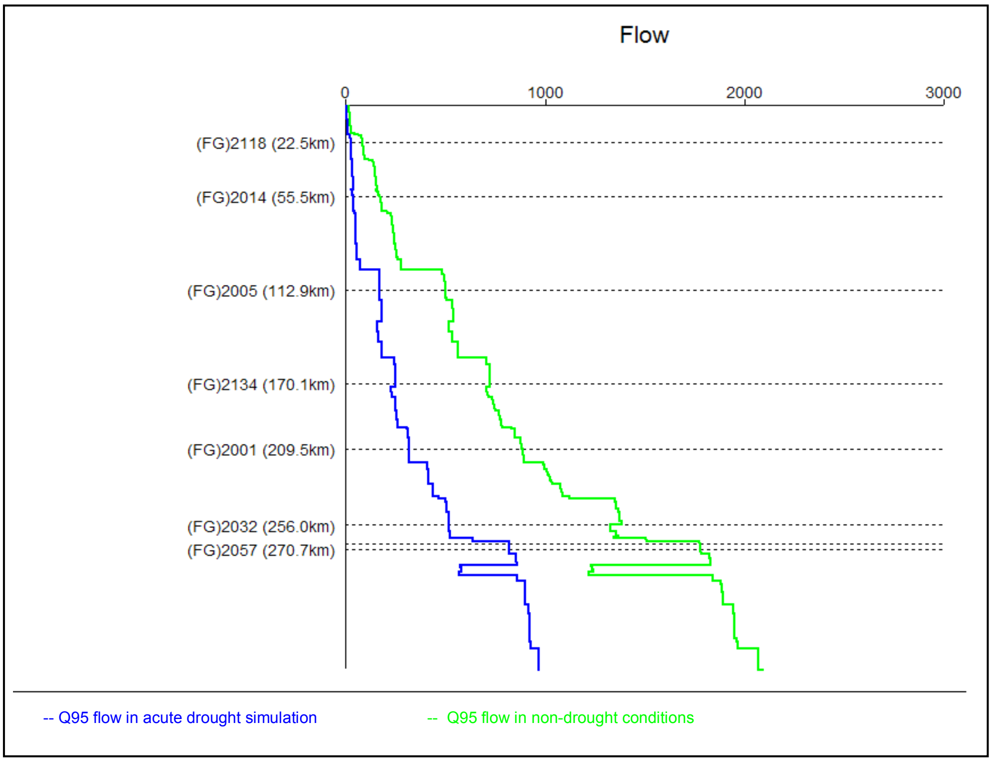


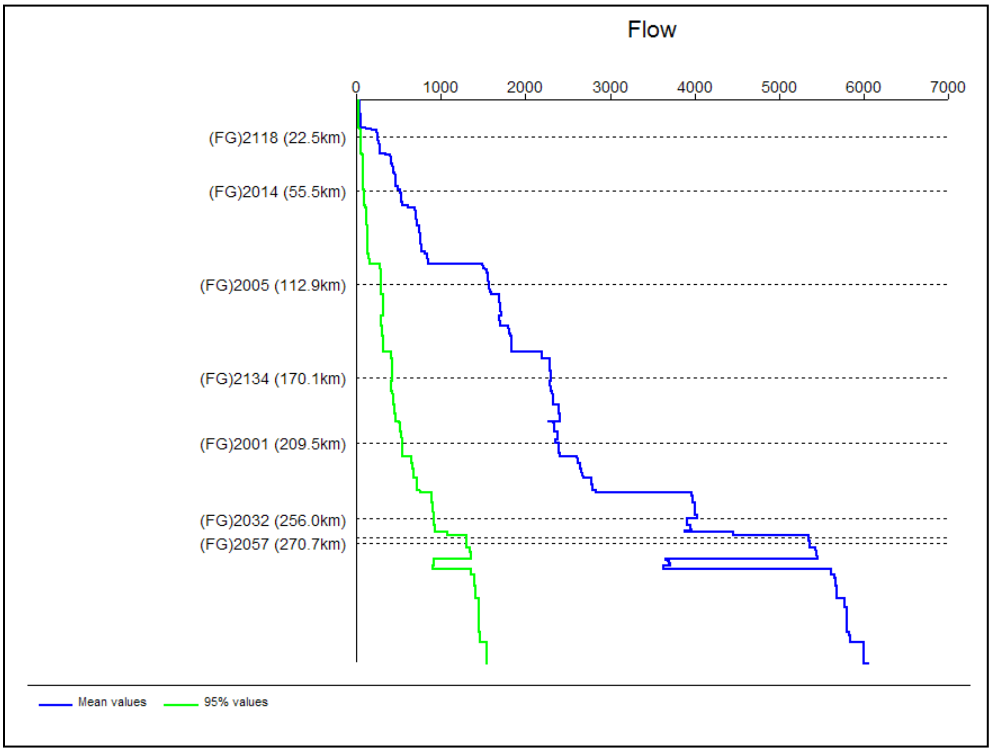
Figure 4 – Acute drought / Non-drought Q95 flow condition comparison



Having established that further refinement of the model was unrealistic and undefendable, work could also progress on the chronic drought condition representation in SIMCAT. The same process was followed to establish the non-drought order scenario, using the chronic mean and Q95 adjustment factors from Table 2 in place of the corresponding acute scenario figures.

Figure 5 below represents the final, adjusted SIMCAT flows for chronic drought conditions.

Figure 5 – final chronic drought condition representation



Similar to the graphs produced for the acute drought situation, Figures 6 (mean flow) and 7(Q95 flow) compares the final acute situation with the flow conditions represented in SIMCAT during non-drought periods.

Figure 6 – Chronic drought / Non-drought Mean flow condition comparison

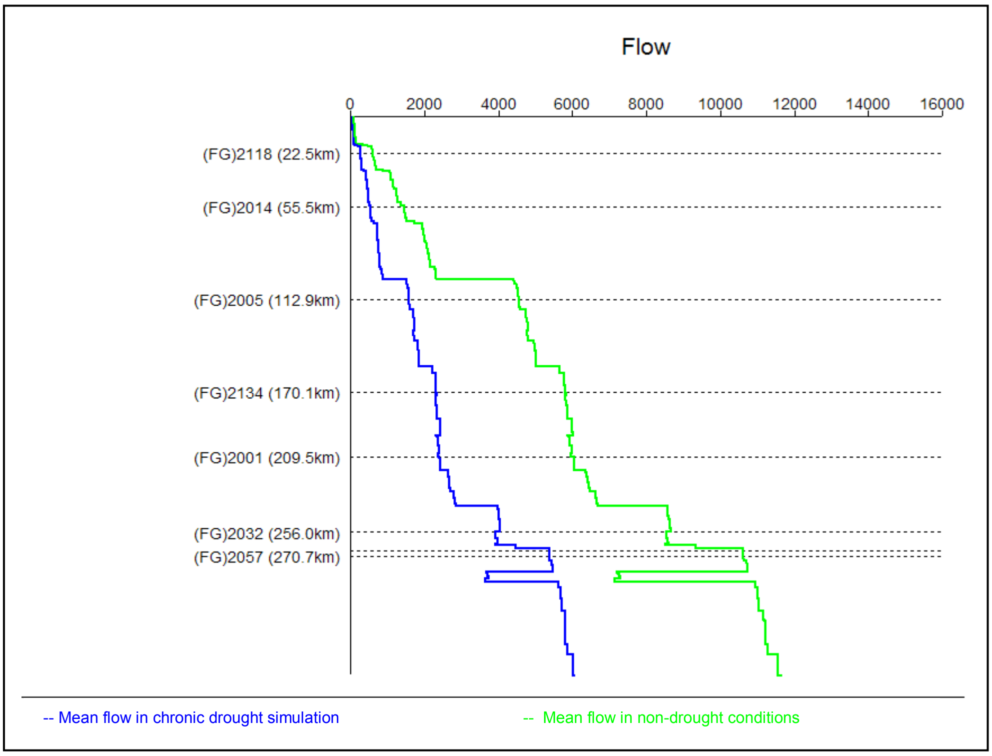
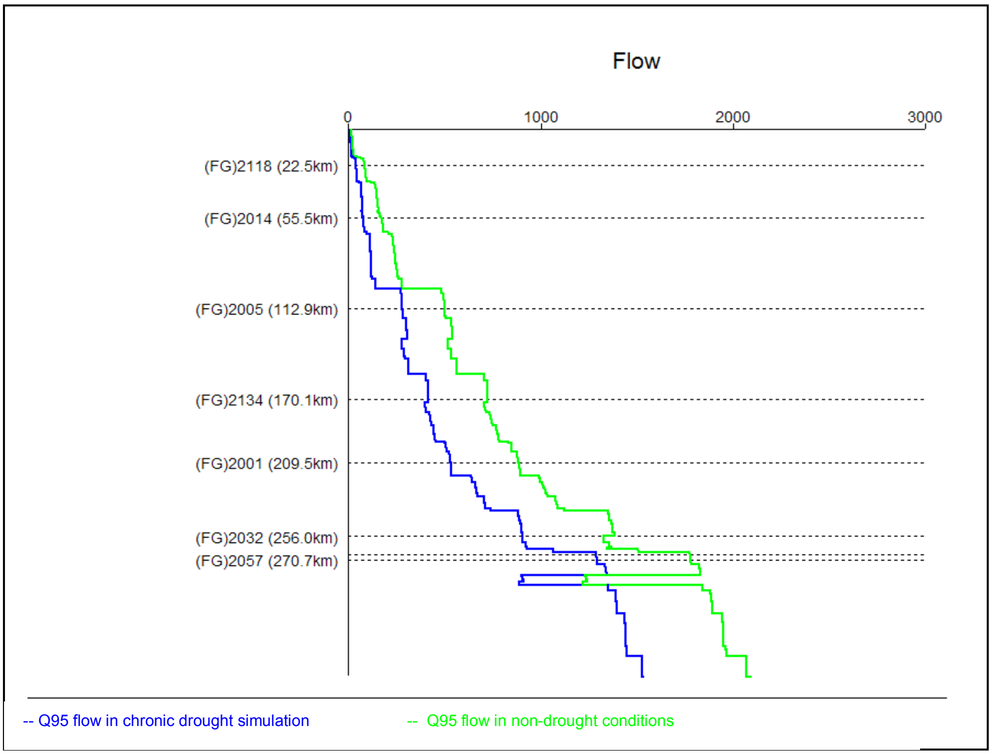


Figure 7 – Chronic drought / Non-drought Q95 flow condition comparison



Despite the assumption that the adjustments made to the model to reduce flows to represent drought conditions have been accepted as the best possible attempt whilst remaining within realistic bounds, it was also decided to simulate a worst possible flow scenario in SIMCAT by reducing all natural flows to zero.

By reducing all headwater flows and all diffuse inflows to the Severn catchment to zero, the modelling exercise effectively simulated a situation where flows comprised of just treated effluent discharges and the releases from Vyrnwy and Clywedog reservoirs.

Figures 8 and 9 below illustrate how these changes are reflected in the model for both acute and chronic flow scenarios compared with the predicted Aquator flows.

Figure 8 - Acute Drought Scenario, Zero Natural Flow

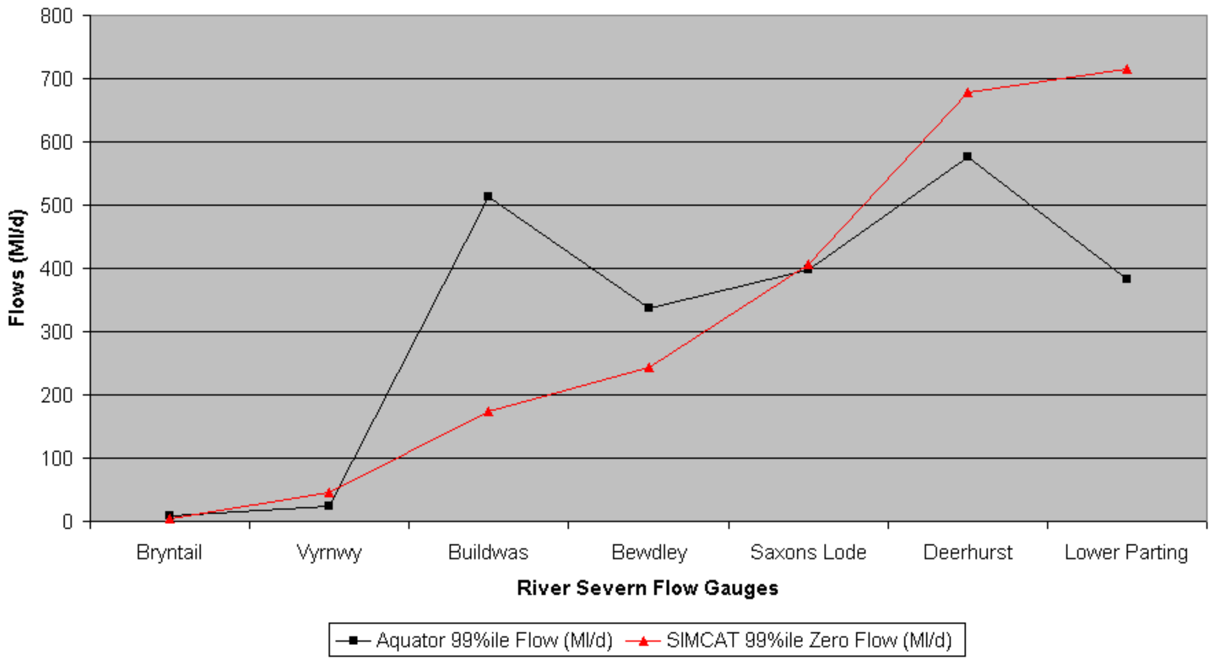
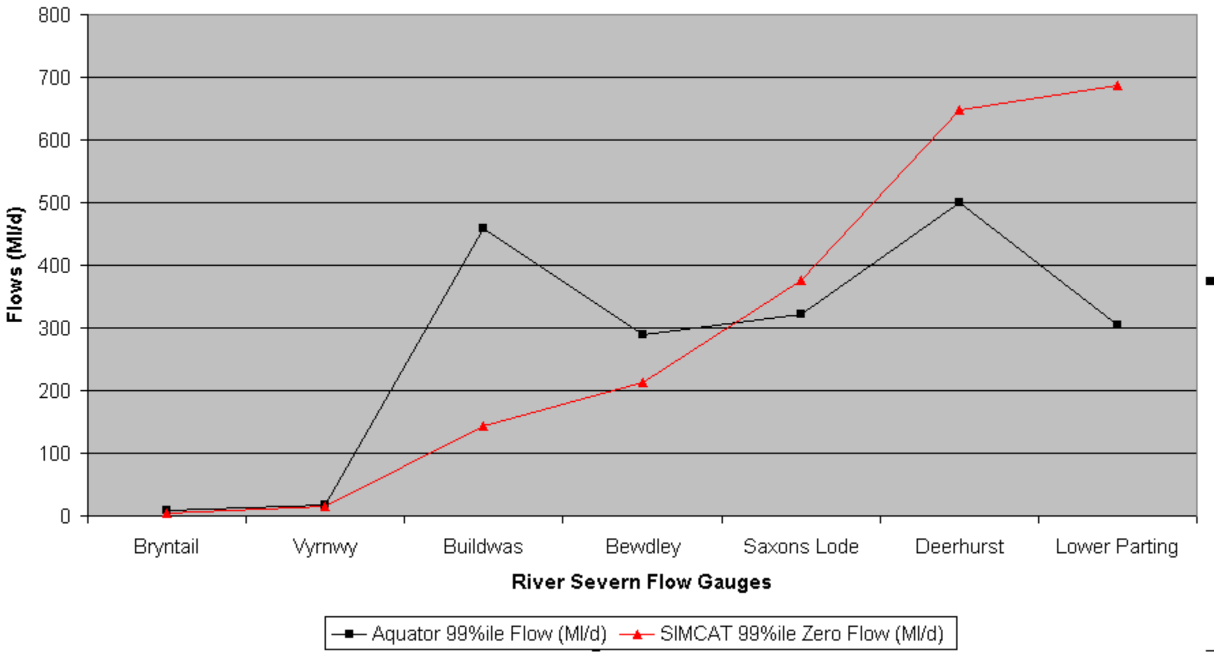


Figure 9 - Chronic Drought Scenario, Zero Natural Flow



Despite remaining in excess of the predicted Aquator flows beyond Saxons Lode in both cases, the overall difference is much reduced and flows predicted by SIMCAT at the head of the Severn Estuary are much lower compared with the previous calibration attempts.

This would appear to better represent the required flows throughout the model but it should be recognised that the adjustments made are unrealistic and should only be applied for the purpose of portraying a worst case water quality scenario.

Stage 2 – Water Quality Assessment following application of the Environment Agency's Drought Order

Having previously established the SIMCAT data files to represent both acute and chronic drought conditions throughout the River Severn catchment, the only alterations required to the data files in order to simulate the impact of the drought order were changes to the key control locations at Vyrnwy and Clywedog reservoirs.

Table 5 below summarises in bold the key changes required in order to represent the varying control measures in the catchment. In both reservoir cases, the required flows were represented by making factored changes to the headwater and diffuse flow inputs in order to match the Table 5 flow figures at Bryntail (for Clywedog) and Vyrnwy Reservoir flow gauges.

Table 5 – Drought Order Flow Gauge Measurements

River Flows	Acute				Chronic (2nd summer)			
	With DO		Without DO		With DO		Without DO	
	mean	95%	mean	95%	mean	95%	mean	95%
Clywedog Reservoir	**142.03**	**75.88**	222.83	8.87	**253.32**	**18.20**	108.07	12.39
Vyrnwy Reservoir	**145.03**	**45.00**	145.03	45.00	**82.55**	**25.00**	58.16	25.00

Representation of the revised releases and their impact on flows throughout the River Severn corridor can be seen in Figures 8 to 11 below.

With regards to the acute drought scenario in figures 10 and 11, the managed and reduced mean reservoir release from Clywedog results in a reduction in the mean flow throughout the river corridor (no drought order in blue, drought order in green) whilst the increase in the released Q95 flow sees an improved situation along the same length of river.

Figure 10 – Acute drought comparison including drought order operation (mean flow)

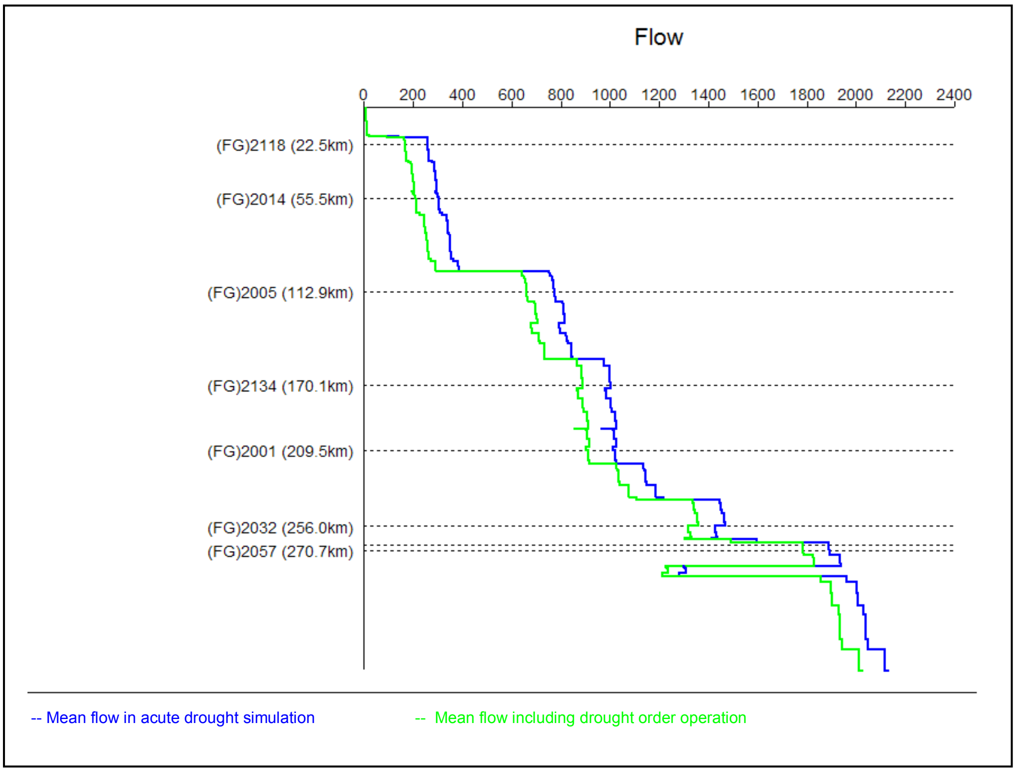
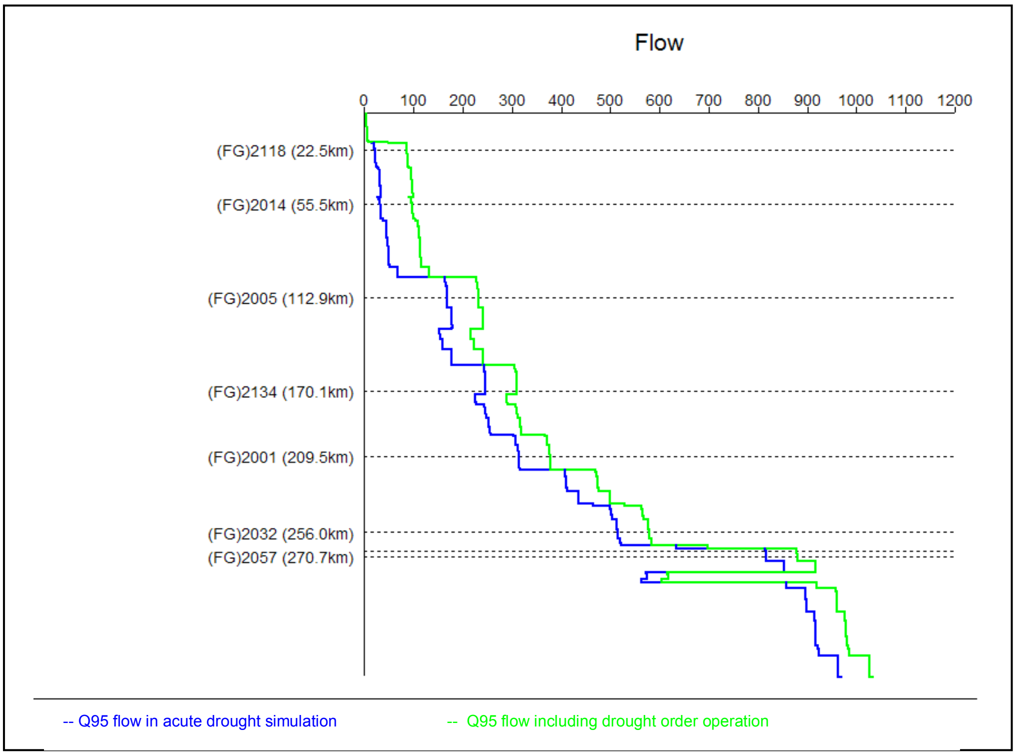


Figure 11 – Acute drought comparison including drought order operation (Q95 flow)



Applying the same logic to the changes required for the chronic drought scenario (Figures 12 & 13 – no drought order, blue, drought order, green), the comparison shows barely any difference in the Q95 flows (the managed scenario effectively tracks the drought conditions) whereas the chronic mean flows show significant benefit from the increased releases from both reservoirs.

Figure 12 – Chronic drought comparison including drought order operation (mean flow)

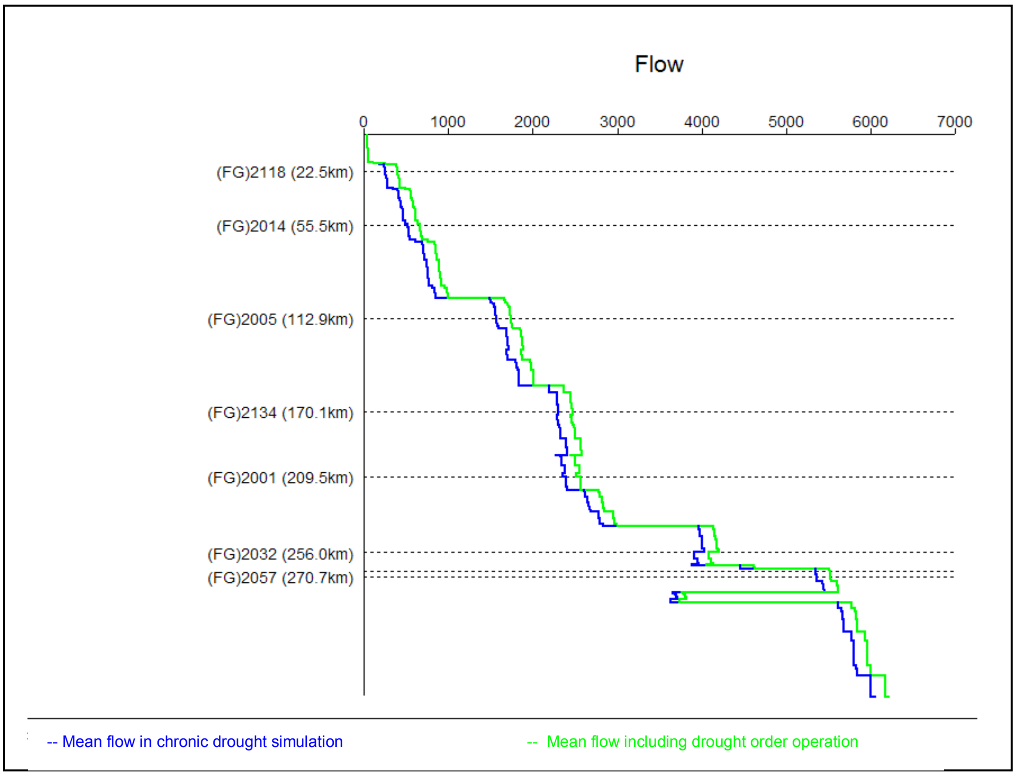
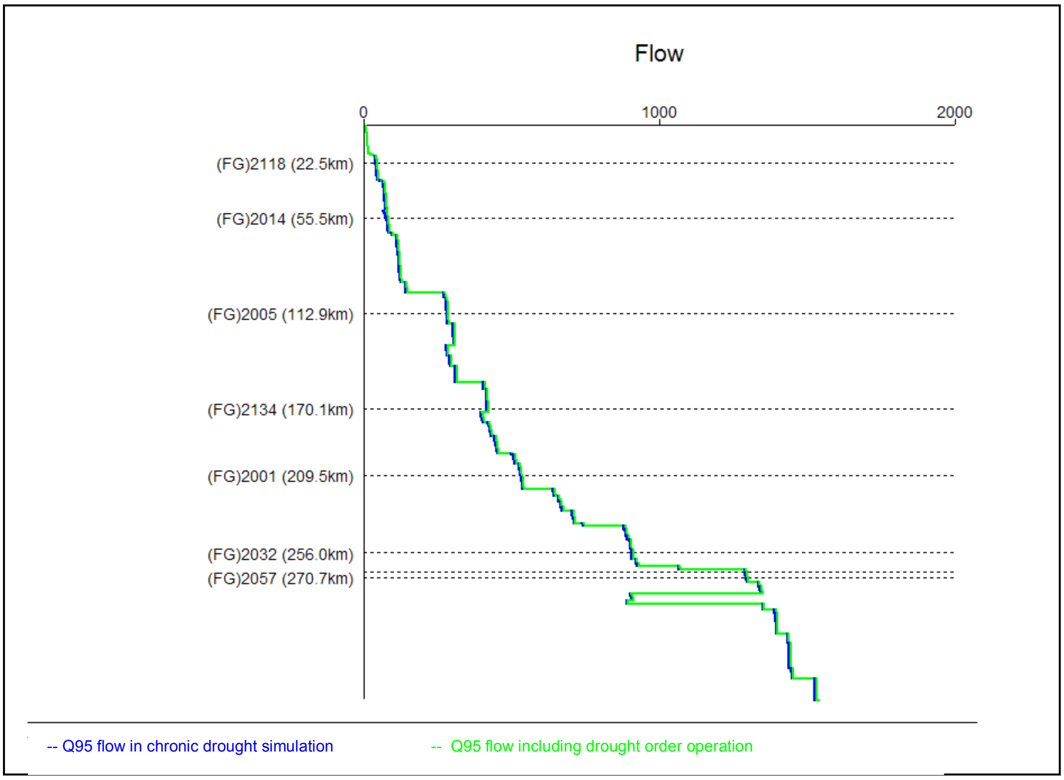


Figure 13 – Chronic drought comparison including drought order operation (Q95 flow)



In order to fully assess the impact of the operation of the drought order on water quality, an assessment of compliance against both Water Framework Directive targets and Fundamental Intermittent Standards was carried out for phosphates, ammonia and biochemical oxygen demand (BOD). A comparative assessment of Total Oxidised Nitrogen is also included for reference.

From the same graphs, it is possible to determine the relative impact in terms of water quality concentration as a result of the operation of the drought order.

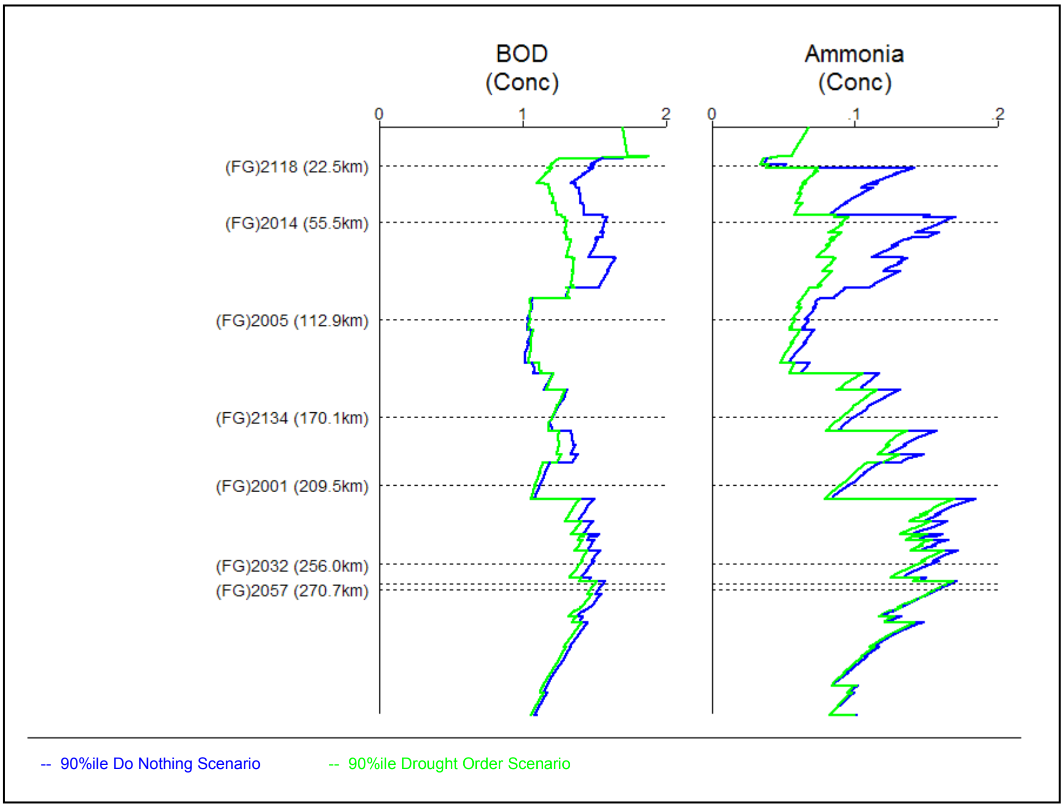
The relative standards for the various sections of the River Severn corridor can be found in Table 6 below.

Table 6 – Water Framework Directive Targets and Fundamental Intermittent Standards

River Severn Stretch	Parameter	WFD Good (mg/l)	FIS 99%ile (mg/l)
Llanidloes Felindre Bridge to Caerhowell	Ammonia	0.3	0.6
Caerhowell to Llandrinio	Ammonia	0.6	0.6
Llandrinio to Gloucester	Ammonia	0.6	1.5
Llanidloes Felindre Bridge to Llandrinio	BOD	4	5
Llandrinio to Gloucester	BOD	5	9
Llanidloes Felindre Bridge to Aberbechan	Phosphate	0.04	n/a
Aberbechan to Gloucester	Phosphate	0.12	n/a

Figure 14 below displays both BOD and ammonia concentrations throughout the River Severn corridor for the Acute scenario and compares the relative water quality under the 'Do Nothing' (blue line) and EA Drought Order (green line) scenarios. The first obvious observation is that there are only very limited areas of deterioration as a result of the drought order operation and that, generally, water quality in the drought order scenario (green line) is improved compared with the unmanaged situation.

Figure 14 - 90%ile assessment for BOD and Ammonia in acute drought conditions



The only areas of minor deterioration in either determinand can be summarised as follows:

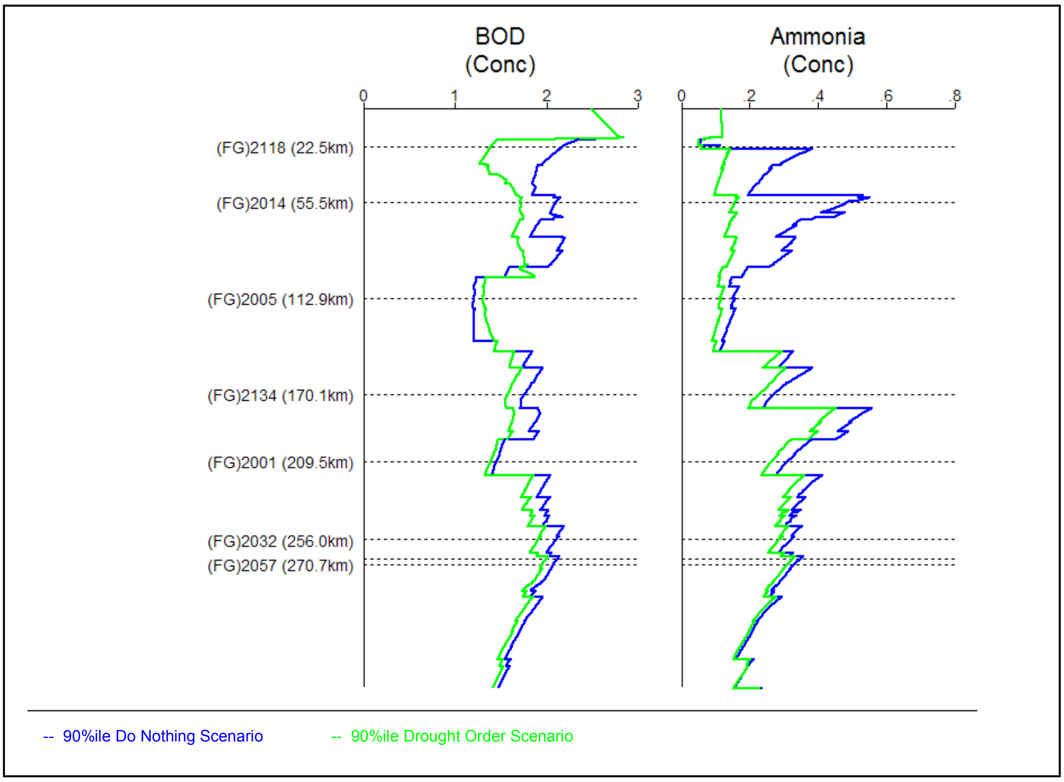
- BOD - Maximum 5% deterioration between Montford Bridge and Cross Houses on the River Severn
- BOD - Minor deterioration at Caerhowell on River Severn (1.5%)
- Ammonia – 25% increase in concentrations on the Afon Vyrnwy d/s of Llansantffraid

In none of the above locations, however, was the deterioration great enough to cause any failure of WFD targets. In fact, Figure 14 above illustrates that no failures of the respective WFD target would be recorded in either the managed or un-managed drought scenario.

Figure 15 below displays the same two determinands (BOD and ammonia) as 99 percentiles. Use of such high percentiles allows a direct application of the results to extreme conditions. For example, Figure 15 effectively represents the concentrations which are exceeded for just 1% of the time or, the equivalent of just 3.65 days/year.

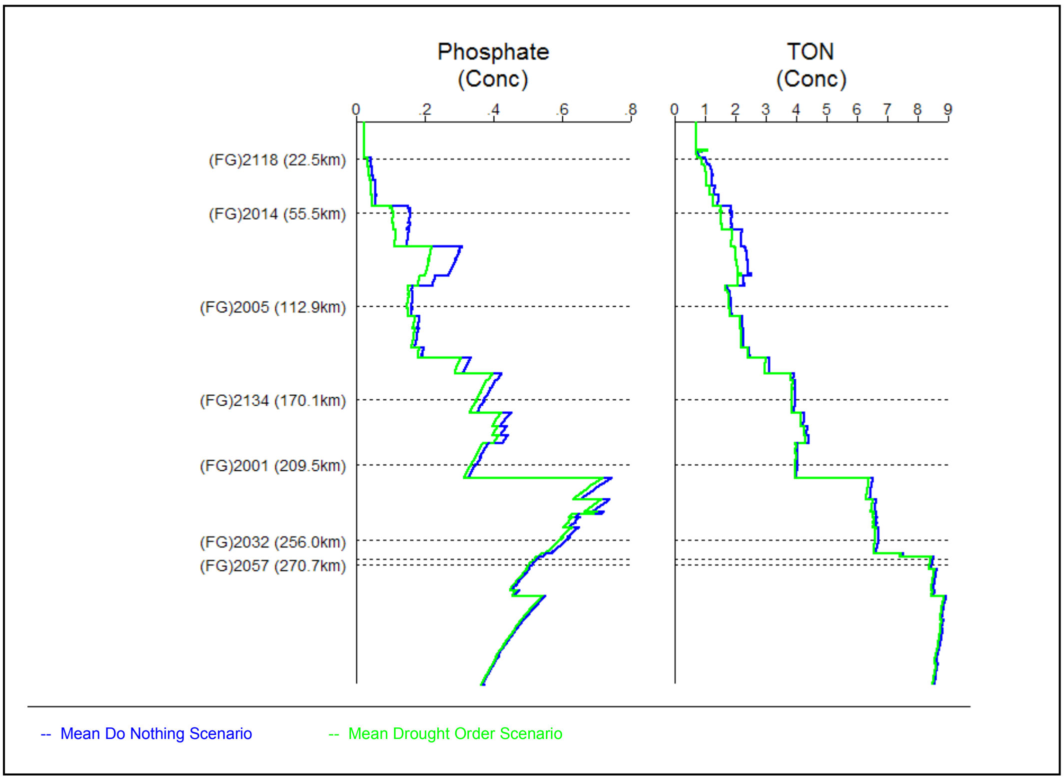
Use of such standards allows assessment of potential worst case scenarios when, one could assume, river flows are at their lowest and dilution conditions for discharges to the river are at their worst.

Figure 15 – 99%ile assessment for BOD and Ammonia in acute drought conditions



Comparison of the results portrayed in Figure 15 with the required standards in Table 6 shows that at no point on the River Severn are concentrations predicted to exceed the 99th percentile regarded as representing a threat to the aquatic environment.

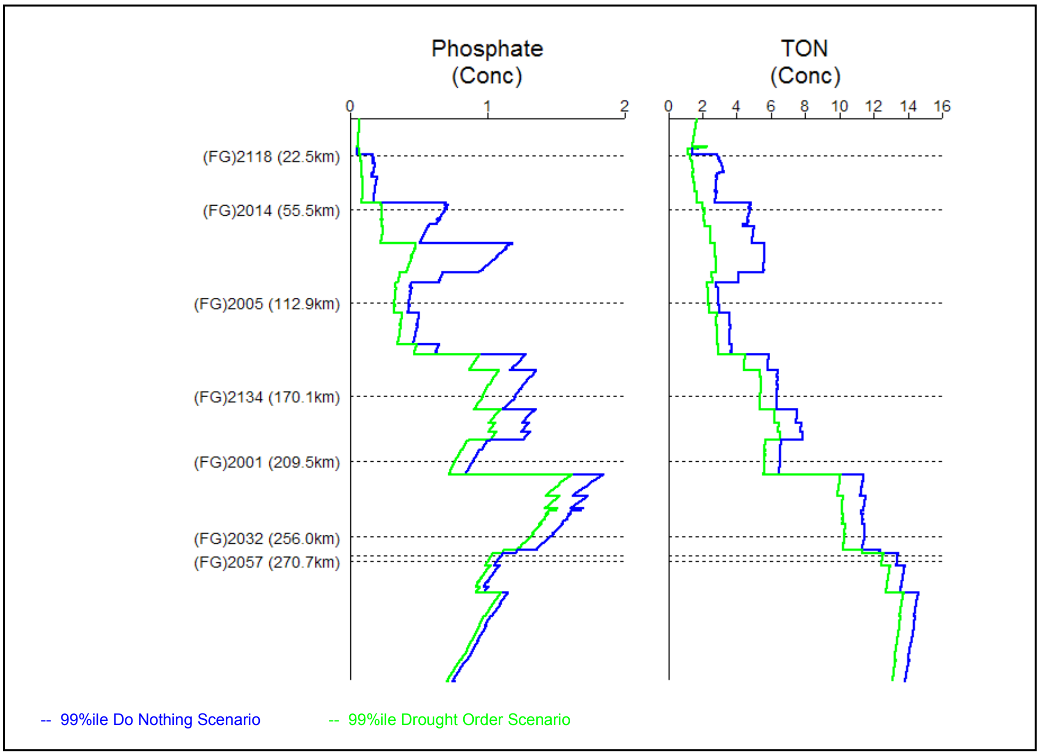
Figure 16 – Mean assessment for Phosphate and TON in acute drought conditions



Although it is immediately evident that phosphate concentrations exceed WFD standards in both acute drought scenarios, this is of lesser concern considering WFD compliance for phosphate along the River Severn corridor is currently less than good at all locations downstream of Cressage. On the graph in Figure 16 this effectively equates to locations downstream of FG2005 (Montford Bridge).

Consequently, there would appear to be a significant length of new WFD standard failure for phosphate in the River Severn during drought conditions but crucially, operation of the drought order generally improves concentrations throughout the Severn corridor compared with the unmanaged scenario.
The same can be said for Total Oxidised Nitrogen concentrations in that they do not appear to deteriorate following commencement of the drought order operations.

Figure 17 – 99%ile assessment for Phosphate and TON in acute drought conditions

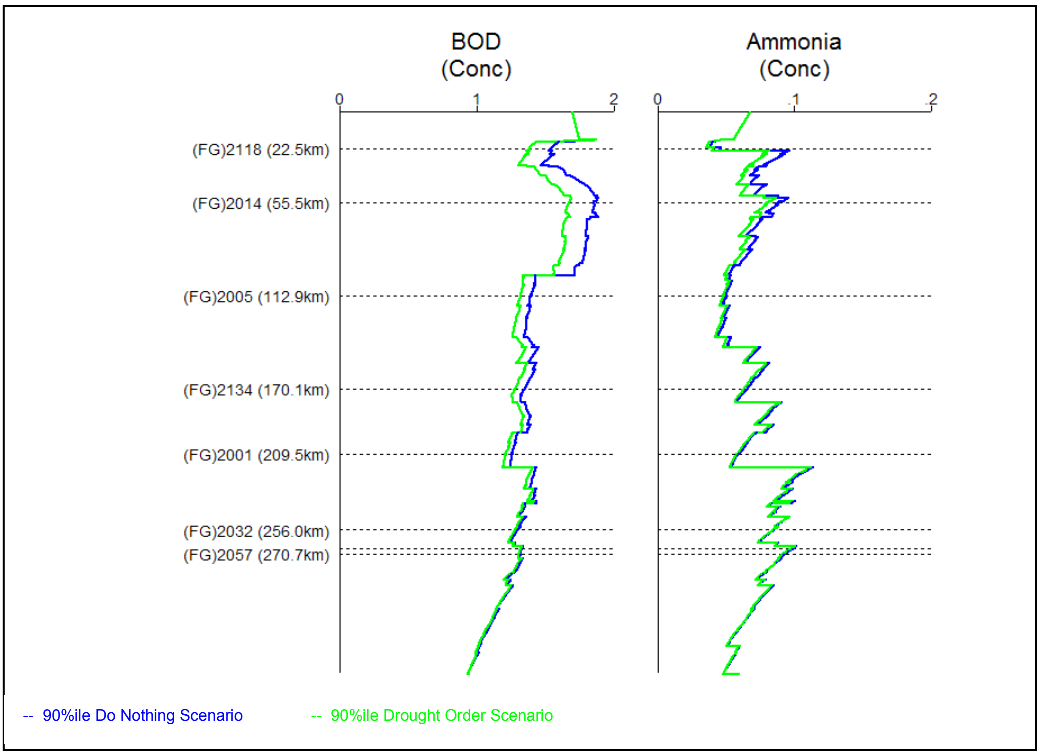


In terms of an almost worse case scenario, Figure 17 demonstrates that concentrations of both nutrients will reach quite high levels during the lowest flow situations. This is inevitable given the lack of dilution in these cases but, once again, it is noticeable that the Severn drought order operation will only help to improve the situation and reduce the potential impact on the aquatic ecosystems.

Consideration of the chronic drought scenario shows a very similar situation. Figures 18 to 20 below demonstrate no significant deterioration in any determinand at any point in the Severn or Vyrnwy catchments as a result of the revised releases from Vyrnwy and Clywedog Reservoirs under operation of the drought order.

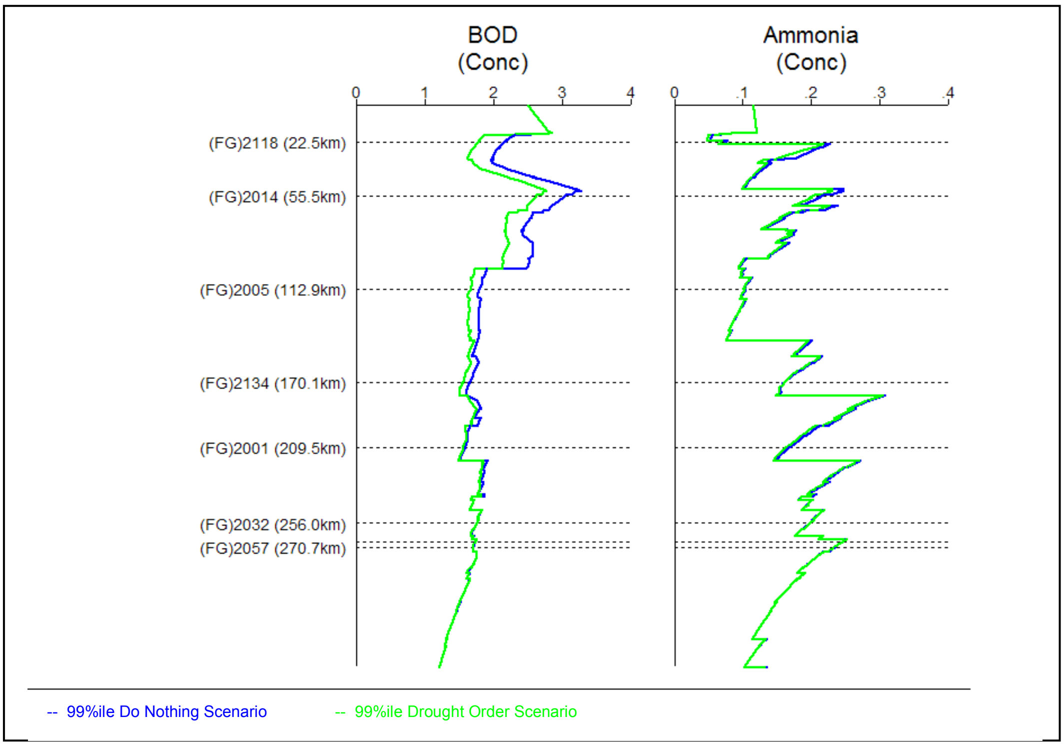
This is of no real surprise given the increased flows assessed throughout the catchment as part of this drought scenario and the fact that operation of the drought order would result in greater mean and Q95 flows released from Clywedog and mean flows from Vyrnwy.

Figure 18 - 90%ile assessment for BOD and Ammonia in chronic drought conditions



As with the acute drought scenario, no new WFD failures are recorded in either BOD or ammonia as a result of the environment experiencing drought conditions. The same is true of the 99 percentile standard applicable to River Severn corridor as demonstrated in Figure 19 below where the maximum concentrations predicted in the worst case scenario both largely remain below 3mg/l and 0.3mg/l for BOD and ammonia respectively (tightest applicable targets = 5mg/l and 0.6mg/l)

Figure 19 – 99%ile assessment for BOD and Ammonia in chronic drought conditions



Not unexpectedly, achievement of WFD Good Status for phosphates is made harder during the modelled periods of drought with a general increase in nutrient concentrations across the board (Figure 20). As with the acute conditions, however, the biggest comfort remains that application of the drought order marginally improves the situation with increased dilution reducing both phosphate and TON concentrations (Figures 20 & 21).

Figure 20 – Mean assessment for Phosphate and TON in chronic drought conditions

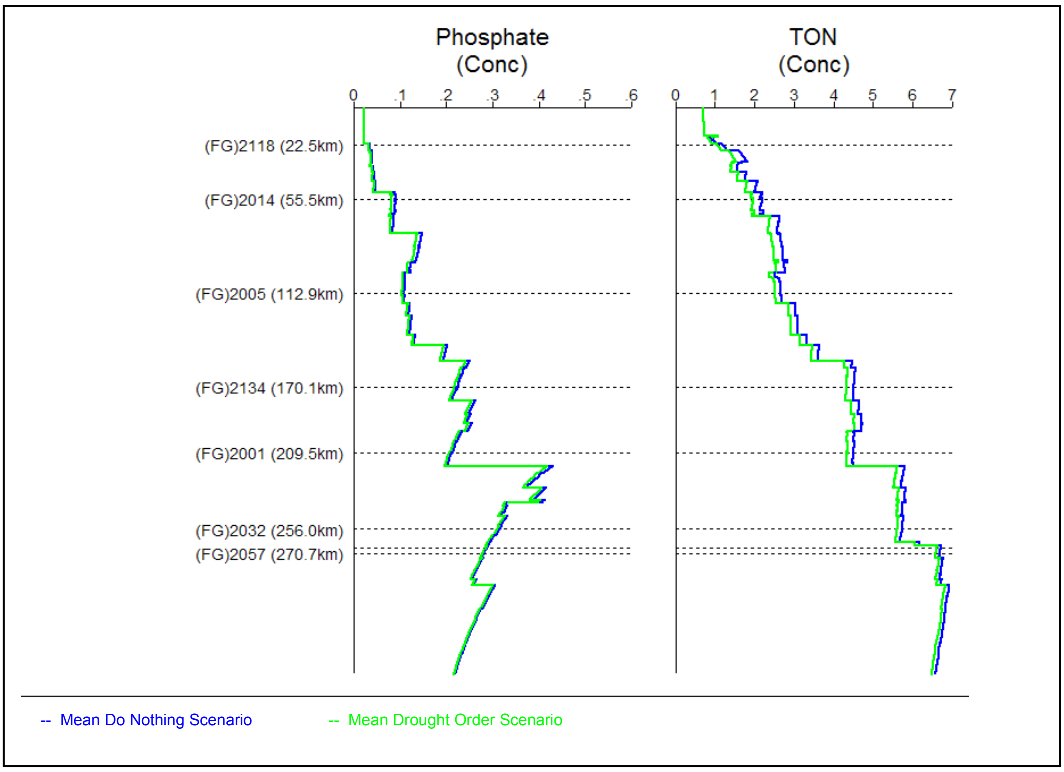
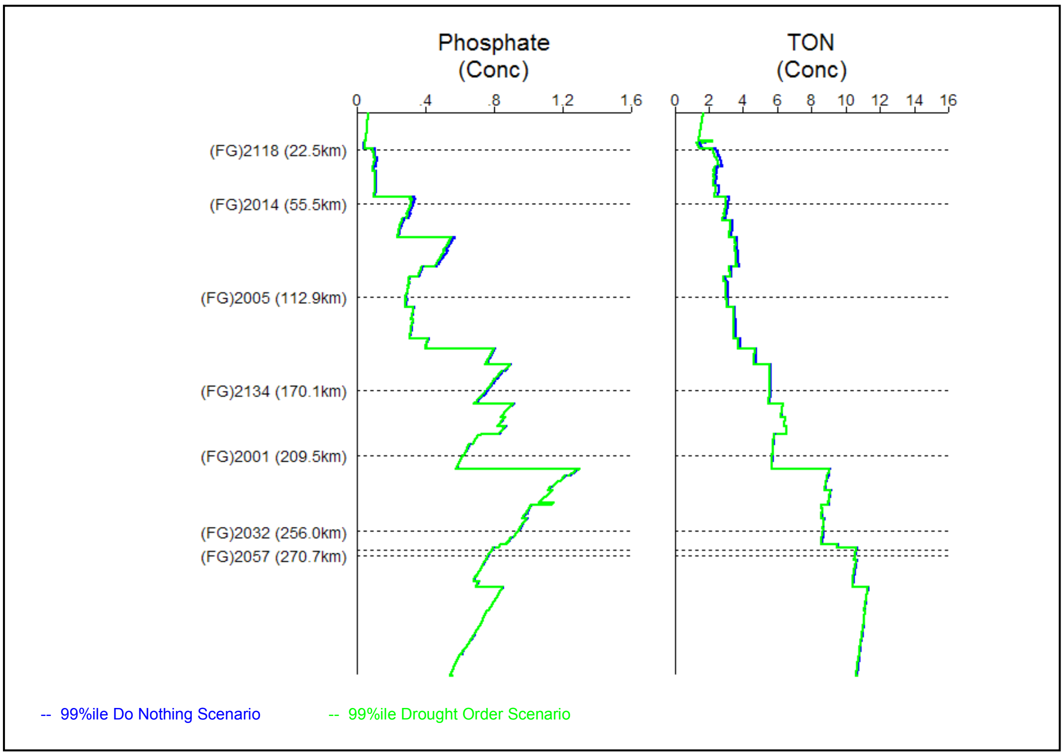


Figure 21 – 99%ile assessment for Phosphate and TON in chronic drought conditions



Consideration of the zero natural flow scenario shows a similar situation for both ammonia and BOD in both acute and chronic drought conditions. Comparison with the previous work (Figures 15 & 19) suggests that predicted concentrations for both determinands in this scenario are not particularly elevated and, as such, do not record failures of the required Water Framework Directive Standards. This is reassuring considering the lack of natural dilution, even when measured at the 99%ile (Tables 7 & 8) and additional comfort is offered by the prediction that application of the drought order only improves the predicted water quality.

Table 7 – BOD and Ammonia predicted concentrations in acute drought conditions with no natural flows

		No Drought Order		Drought Order	
Flow Gauge Location	**FG Ref**	**BOD 99%ile (mg/l)**	**Ammonia 99%ile (mg/l)**	**BOD 99%ile (mg/l)**	**Ammonia 99%ile (mg/l)**
Bryntail	2109	1.6	0.05	1.6	0.05
Vyrnwy	2003	1.67	0.03	1.67	0.03
Buildwas	2134	2.13	0.36	1.84	0.31
Bewdley	2001	1.61	0.47	1.36	0.36
Saxons Lode	2032	2.32	0.45	2.1	0.38
Deerhurst	2057	2.28	0.39	2.17	0.36
Lower Parting		2.08	0.35	1.96	0.33

Table 8 – BOD and Ammonia predicted concentrations in chronic drought conditions with no natural flows

		No Drought Order		Drought Order	
Flow Gauge Location	**FG Ref**	**BOD 99%ile (mg/l)**	**Ammonia 99%ile (mg/l)**	**BOD 99%ile (mg/l)**	**Ammonia 99%ile (mg/l)**
Bryntail	2109	1.6	0.05	1.6	0.05
Vyrnwy	2003	1.67	0.03	1.67	0.03
Buildwas	2134	2.42	0.43	1.88	0.35
Bewdley	2001	1.73	0.48	1.42	0.37
Saxons Lode	2032	2.44	0.46	2.18	0.4
Deerhurst	2057	2.35	0.41	2.23	0.37
Lower Parting		2.12	0.36	2	0.33

The application of the drought order can also be seen to improve water quality in terms of nutrient concentrations in the zero natural flow scenarios. Although maximum concentrations are predictably higher in this situation compared with the more realistic scenarios discussed earlier (Figures 17 & 21), it is noticeable in Tables 9 and 10 below that concentrations are reduced once revised regulation of the flows from Clywedog and Vyrnwy are employed.

Table 9 – Predicted nutrient concentrations in acute drought conditions with no natural flows

		No Drought Order		Drought Order	
Flow Gauge Location	**FG Ref**	**Phosphate 99%ile (mg/l)**	**TON 99%ile (mg/l)**	**Phosphate 99%ile (mg/l)**	**TON 99%ile (mg/l)**
Bryntail	2109	0.06	1.07	0.06	1.07
Vyrnwy	2003	0.06	0.58	0.06	0.58
Buildwas	2134	1.39	7.14	1.27	5.93
Bewdley	2001	1.07	6.69	0.97	6.1
Saxons Lode	2032	1.69	12.95	1.6	11.73
Deerhurst	2057	1.21	15.73	1.17	15.01
Lower Parting		1.11	15.56	1.07	15.04

Table 10 – Predicted nutrient concentrations in chronic drought conditions with no natural flows

		No Drought Order		Drought Order	
Flow Gauge Location	**FG Ref**	**Phosphate 99%ile (mg/l)**	**TON 99%ile (mg/l)**	**Phosphate 99%ile (mg/l)**	**TON 99%ile (mg/l)**
Bryntail	2109	0.06	1.07	0.06	1.07
Vyrnwy	2003	0.06	0.58	0.06	0.58
Buildwas	2134	1.61	8.18	1.4	6.52
Bewdley	2001	1.21	7.4	1.05	6.6
Saxons Lode	2032	1.79	13.49	1.66	12.34
Deerhurst	2057	1.24	16.02	1.19	15.16
Lower Parting		1.14	16.06	1.09	15.28

Summary

Acute Flow Scenario

- Application of the drought order generally results in an improvement in the water quality. There are some local areas of deterioration, notably
    - Phosphate - Afon Vyrnwy d/s of Llansantffraid - 33% increase in concentrations - no resultant failure of WFD targets.
    - BOD - Maximum of 5% deterioration between Montford Bridge and Cross Houses. Minor deterioration at Caerhowell on River Severn (1.5%) - no new WFD failures.
    - Ammonia - Afon Vyrnwy d/s of Llansantffraid - 25% increase in concentrations - no resultant failure of WFD targets.
    - Nitrogen - General deterioration in concentrations throughout the Vyrnwy catchment.
- No new failures to achieve Water Framework Directive good ecological status for ammonia or BOD although widespread phosphate failures persist.
- No failures of the 99% targets associated with the river reach classes imposed under the River Ecosystem Classification and representative of extreme events

- Even under zero natural flow scenarios, maximum ammonia concentrations are predicted to equal 0.47mg/l with BOD pollution topping out at 2.32mg/l, both well within the WFD 90%ile standards.
- Nutrient concentrations continue to breach the required standards and are, indeed, elevated further without the benefit of any natural dilution flow for the treated effluent discharges.
- In all four cases, however, application of the drought order improves concentrations throughout the Severn catchment.

Chronic Flow Scenario

- No significant deterioration for any determinands at any point in the Severn or Vyrnwy catchments as a result of the drought order.
- No new failures to achieve Water Framework Directive good ecological status for ammonia or BOD although widespread phosphate failures persist.
- No failures of the 99% targets associated with the river reach classes imposed under the River Ecosystem Classification and representative of extreme events even under the worst case scenario of zero natural flow.

Severn Estuary – Water Quality and Flow assessment.

It has proved impossible to accurately calibrate the flows in the SIMCAT model to match the prescribed flows from the freshwater River Severn system to the Severn Estuary. The original attempt to adjust the model flows in accordance with ratio'd headwater flows and diffuse flows resulted in an over-estimation of almost 1250Ml/d in the mean flow at Lower Parting at the head of the estuary and bottom of the SIMCAT model. This modelling error manifested itself as an error of almost 350Ml/d at low flows, giving a predicted SIMCAT flow at almost twice the value suggested by AQUATOR.

The margin of error was duplicated in the second calibration exercise when all natural flows were removed from the SIMCAT model. This would suggest that treated effluent discharges into the catchment alone would contribute more flow to the head of the estuary than is expected by the AQUATOR modelling.

Given that the discharge flow figures were based on actual measured volumes during dry weather, it would appear that the SIMCAT model is incapable of achieving the prescribed freshwater flows to the estuary without forcing a fit through use of unrealistic abstraction and discharge data.

In terms of water quality impact on the estuary, however, given that the drought flows represent an 82% reduction in mean flows and a 56% reduction in low flows compared with the baseline model output, the deterioration in water quality at the 95%ile concentration is relatively slight. Phosphate concentrations increase from a non-compliant 0.58mg/l to 0.78mg/l whilst the deterioration in ammonia is just 0.04mg/l compared with a baseline of 0.14mg/l. Both concentrations being compliant with WFD Good Ecological Status requirements. Changes in BOD concentration actually see a predicted 40% improvement.

Extrapolating this data forward to the much lower flows predicted by AQUATOR, it could be suggested that any further deterioration in quality would be equally slight and would be unlikely to cause any new failures of desired water quality standards. It is possible, however, that the increasing nutrient concentrations could result in eutrophic conditions given the right physical conditions in which macrophyte and algal growth could establish.

The worst case, zero natural flow scenario would tend to support this assumption. Considering this scenario represented almost zero dilution for treated sewage effluent discharges, the concentrations predicted at Lower Parting in tables 7 and 8 represent little concern with regards to the sanitary determinands, BOD and ammonia. As discussed above, the elevated nutrient concentrations could be of concern if appropriate growing conditions allow excessive plant growth to occur.

Referring the findings of this modelling to an actual historic situation, the 1976/77 drought, it is re-assuring to read that the quality of the River Severn during the drought event caused very few concerns, despite the increased percentage of flow originating from sewage effluents. It should be noted, however, that temperatures recorded during the 1976/77 event were very high which aided the biological treatment of polluting loads in terms of both in-river purification and at treatment facilities. It is possible that should a drought period be experienced without these high temperatures then water quality deterioration could be more pronounced.

Of greater concern in terms of water quality is the possibility of conditions of high saline intrusion, elevated suspended solids and, as a result, reduced dissolved oxygen levels that could occur if residual freshwater flow to the estuary were severely reduced. Such conditions could prevail where residual flows are insufficient to prevent the landward movement of the area of maximum turbidity which is responsible for the drop in dissolved oxygen.

Mitigation options

Judging by the fact that water quality is not predicted to significantly deteriorate under the perceived worst case scenario of zero natural flows and that, under the same conditions, the predicted 99%ile quality remains within WFD concentration criteria for ammonia and BOD, there appears to be little benefit in employing mitigation measures for water quality in drought conditions.

With regards to phosphate and nitrogen, the drought is likely to cause a further increase in concentrations. As water quality standards are already breached and environmental damage is already likely to be occurring in non-drought conditions, continuation of the current regime of work to reduce nutrient enrichment is seen to be the best way forward with no further mitigation measures required.

Are there any suggestions for the WQ element of a drought? Would it require any mitigation or would it be best left to nature? Ok for you to say that, ecology will hopefully highlight key periods when we could aim to mitigate the situation (e.g. high tides etc).

Modelling Limitations

Throughout the exercise to determine the impact of drought conditions on the water quality of the River Severn corridor and also the impact of managing the flows through implementation of the Severn Drought Order, it became obvious that the SIMCAT models at our disposal were not necessarily the right tools for the job.

The verification exercise initially attempted to match predicted and observed drought flows at the various assessment points proved to be fraught with difficulty and was eventually abandoned in favour of a number of logical assumptions. This was predominantly due to the fact that the current SIMCAT models are based on current day populations rather than those present at the time of the drought situations attempting to be matched (1976/77).

Being a spatial rather than a temporal model, it also proved impossible to provide the data for ecological appraisal in the form that was required. Whereas the ecological impact would be best assessed using an indication of the varying ammonia and BOD concentrations at one location with time and flow (temporal model), SIMCAT was only able to provide a worst case scenario for the entire length of river with no immediate link to the flows at the corresponding time. In other words, an assumption had to be made that the 99th percentile value for each determinand represented the worst case scenario when, in fact, higher concentrations would be present for a maximum of 4 days in a year.

SIMCAT is also a tool more suited to representing more stable conditions and can struggle to represent prolonged, extreme events such as droughts. By it's nature of representing mean and standard deviation statistical input, it is not inherently designed to predict environmental conditions in extreme, worst case scenarios.

Although a specific modelling tool cannot be recommended, any tool which is better suited at representing a temporal link between flow and pollutant concentration would probably be better suited to the tasks required in this water quality assessment.

The SIMCAT model itself could be improved by more sophisticated and numerous water quality and flow monitoring. Currently, the model is based upon the known input data, in other words measured data from flow gauges, water quality monitoring points, measured discharge volumes and quality. From this data, the model must make assumptions on the source of any errors that may occur following mixing of all the known data.

Without enhanced monitoring, much larger data sets encompassing all possible sources of pollution and diffuse flow inputs and highly detailed knowledge of the catchment, this calibration process can be fraught with problems. The SIMCAT models employed in this assessment have been signed off and accepted as the best possible representation of the environment given the data available but it also has to be recognised that the model contains numerous locations where accurate representation of the environment was not possible. Calibration errors such as this can only successfully be rectified through the use of greater amounts of top quality monitoring of all potential sources of pollution and flow.

Future Recommendations & Monitoring Requirements

The underlying SIMCAT model used to predict the baseline water quality can always be improved through a thorough investigation of all polluting or diluting sources and subsequent data collection exercise of the entire catchment, focussing predominantly on the areas highlighted as being of poor calibration.

Such an exercise is likely to improve the model calibration but it would not be a foregone conclusion given the complicated nature of environmental interactions and the fact that it is notoriously difficult to balance a large catchment model. Quite often, what would appear to be an improvement in data quality in one location can deteriorate calibration in other locations in the catchment.

In terms of the Severn Drought Order, the report earlier highlighted the limitations of the SIMCAT model in terms of flow and water quality at strategic locations on the River Severn. Improvement of this calibration is, unfortunately, not as easy as improving data quality at the same locations as, quite often, it is a lack of data from feeding tributaries that impose a greater influence on the model. As discussed above, the model needs to be seen as a holistic tool where data quality and catchment knowldge would need to be improved at all locations in order to achieve a better calibration.

With regards to the improved representation of drought conditions, SIMCAT would need to be fundamentally changed to be able to better represent the intricate operation of the major abstractions in terms of hands of flows and drought orders. In most cases, the model is already built based on measured abstracted flows although the representation of this data could probably be improved.

In short, it is not felt that SIMCAT is the best modelling tool for the job given the limitations discussed earlier in the report. In order to fully understand and better replicate the impacts of drought flows, a specifically developed water resource model capable of accurately representing current and drought conditions would be the recommended way forward. Perhaps a water quality function could be incorporated within AQUATOR?

All SIMCAT models are initially calibrated for flow followed by a water quality calibration exercise based upon the accurate representation of the flow characteristics. Any work beyond this point tends to be in the form of ‘what-if’ scenarios. In other words, what will happen to the quality if we halve the flow?

Providing the initial calibration is as accurate as possible, any change in the model with regards to flow should give a suitably accurate prediction of the impact on quality. What is lacking in SIMCAT is the functionality to represent the complicated flow controls in the River Severn. If this could be rectified in SIMCAT (or any other model for that matter, then an accurate water quality prediction in drought conditions should be possible.

In an ideal modelling world, a tool capable of predicting both temporal and spatial changes in water quality and flow would be available with the capability to represent any number of different flow situations. Providing it was then fully calibrated in terms of water quality in ‘normal’ conditions, reactive predictions in water quality at any location or time could be possible.

What are your monitoring suggestions? (sorry!) What, where and how frequent? Be specific to the SDO project e.g. you said Buildwas, Bewdley and Saxon’s Lode had the highest SIMCAT errors – what monitoring could be done to improve this?

Develop a combined flow and WQ model to capture both water resource impacts on volume of flow, and how this in turn impacts on water quality?

Address temporal capabilities somehow?

Develop a predictive WQ model (ideally as part of the combined flow and WQ model) to enable flow manipulation so we can test climate change and Drought Order/Permit impacts more readily.

Appendix O

Ecological Technical report - River Severn Drought Order

ECOLOGICAL TECHNICAL REPORT - RIVER SEVERN DROUGHT ORDER

Environment Agency
Lucy Morris
Analysis and Reporting

ECOLOGICAL MODELLING AND ASSESSMENT

A number of ecological assessment tools and methodologies were used to both assess the current environment, and possible impacts of the River Severn Drought Order alone or in-combination:

- **Water Framework Directive (WFD) classification** - classifies each surface water body in terms of ecological and chemical quality.
- **River Habitat Surveys (RHS)** - provide an assessment of the morphology of a 500m reach of river, recording both modifications, natural features and giving an idea of habitat quality and diversity.
- **Biological Monitoring Working Party (BMWP) -** score classifies families of invertebrates according to their tolerance of organic pollution.
- **Average Score Per Taxon (ASPT)** – derived from the BMWP, this gives a more precise reflection of the pollution tolerance of the invertebrates found and therefore of water quality.
- **River InVertebrate Prediction And Classification System (RIVPACS)** – the programme predicts the probability of capture of taxa from the sites physiochemical characteristics.
- **Lotic-invertebrate Index for Flow Evaluation (LIFE)** method - recognised flow associations of different macro-invertebrate species and families allow the measurement of ecological effects from low flows.
  - **LIFE O:E -** Observed LIFE (O) scores are divided by Expected (E (calculated by RIVPACS)) life scores to get a ratio and assess potential flow stress.
- **Proportion of Sediment-sensitive Invertebrates (PSI)** biotic index - used for assessing sediment pressures.
- **Hydroecological Validation (HEV)** tool - uses ecological and hydrological data to assess the ecological response of a site to river flow.

Of all the biological elements, the invertebrates are the most sensitive to changes in flow and therefore have been considered in the greatest depth for the River Severn Drought Order impact assessment.

Water Framework Directive classification

The Water Framework Directive (WFD) requires all surface water bodies to be classified in terms of ecological and chemical quality. For those water bodies not designated as heavily modified or artificial, this ecological quality is described in terms of 'ecological status'. This is an expression of the quality of the structure and functioning of surface water ecosystems as indicated by the condition of a number of 'quality elements'. The WFD uses the term 'quality elements' to refer to the different indicators of ecological quality making up its ecological status classification schemes.

There are five classes of ecological status, defined in terms of how much the ecological quality deviates from natural conditions. These are high, good, moderate, poor or bad. High status means that the water body is unaffected or virtually unaffected by human activity. A good status water body shows some signs of damage, such as slight alterations in the balance of aquatic species (biological quality elements) that would be expected in a water body unaffected by human activity. The quality elements used to assess ecological status are:

- biological quality elements (diatoms, macrophytes, invertebrate and fish);
- chemical and physicochemical elements; and
- hydromorphological quality elements

The ecological status of a water body is determined by combining assessment results for biological, chemical and physicochemical quality elements; with the quality element most severely affected by human activity determining the overall ecological status. This is called the ' *one out - all out principle'*.

For a water body to achieve good ecological status, the biological quality elements must show only slight signs of disturbance caused by human activity. Among other things, this requires the chemical, physicochemical and hydromorphological quality of the water body to achieve the standards and conditions necessary to support the biological quality elements at good status.

Chemical status is either 'good' or 'failing to achieve good'. 'Good' means that none of the environmental quality standards established for priority substances and other dangerous substances identified at EU-level is being exceeded.

Artificial and heavily modified waters

Some surface water bodies are designated as 'artificial' or 'heavily modified'. This is because they may have been created or modified for a particular use such as water supply, flood protection, navigation or urban infrastructure. By definition, artificial and heavily modified water bodies are not able to achieve natural conditions. Instead the classification and objectives for these water bodies, and the biology they represent, are measured against 'ecological potential', with the same five categories of high, good, moderate, poor and bad, rather than status. For an artificial or heavily modified water body to achieve good ecological potential, the chemistry of the water body must be good. In addition, there must be no structural or physical changes that could impact upon biology other than those that are essential to maintain the valid uses of the water body. All non essential modifications have had to be removed or changed so that there is potential for biology to be as close as possible to that of a similar natural water body. Often though, the biology will still be impacted and biological status of the water body may be less than good. The chemical status of these water bodies is measured in the same way as natural water bodies.

The overall status for heavily modified waterbodies are not calculated in quite the same way as for normal surface water status. Firstly an assessment is made of whether the flow condition for supporting good status has failed. If this is the case, ecological potential is determined by the worst of the mitigation measures assessment or status as shown by fish, invertebrates, macrophytes diatoms or supporting physico chemistry. All the biological quality elements are used because they are all sensitive to flow pressure.

If the flow condition for supporting good ecological status has passed, ecological potential is based on mitigation measures and the status result from non sensitive (to morphological pressure) quality elements e.g. diatoms and supporting phys chem. Otherwise, heavily modified and artificial water bodies that are polluted from other pressures would be incorrectly labelled as being of good ecological potential because morphological mitigation is in place.

Table 3: Water Framework Directive (WFD) status of water bodies on the Severn.

Waterbody		Water Framework Directive Quality Elements					
Id number and Name	**Overall Status/Potential**	**Physico-chemistry**	**Annex 8/10**	**Diatoms**	**Macrophytes**	**Invertebrates**	**Fish**
GB109054049880 R Vyrnwy – Lake Vyrnwy to conf Afon Cownwy	**MODERATE POTENTIAL**	HIGH	MODERATE				
GB109054049720 Afon Vyrnwy – conf Afon Cownwy to Afon Banwy	**MODERATE POTENTIAL**	HIGH	MODERATE			HIGH	MODERATE
GB109054049850 Afon Vynwy – conf Afon Gam to conf Afon Tanat	**MODERATE POTENTIAL**	HIGH	MODERATE			MODERATE	HIGH
GB109054049800 Afon Vyrnwy – conf Afon Tanat to conf R Severn	**MODERATE POTENTIAL**	MODERATE	HIGH			GOOD	MODERATE
GB109054044760 Afon Clywedog – Clywedog dam to R Severn	**MODERATE POTENTIAL**	HIGH	MODERATE			GOOD	GOOD
GB109054044790 R Severn – source to conf Afon Dulas	**MODERATE STATUS**	HIGH	MODERATE	HIGH	HIGH	GOOD	GOOD
GB109054049310 R Severn – conf Afon Dulas to conf R Camlad	**POOR POTENTIAL**	HIGH	MODERATE	POOR		HIGH	POOR
GB109054049700 R Severn – conf R Camlad to conf Bele Bk	**MODERATE POTENTIAL**	MODERATE	HIGH			MODERATE	BAD
GB109054049142 R Severn - conf Bele Bk to conf Sundorne Bk	**MODERATE POTENTIAL**	GOOD	MODERATE		GOOD	MODERATE	POOR
GB109054049141 R Severn - Sundorne Bk to conf M Wenlock-Farley Bk	**MODERATE POTENTIAL**	GOOD	MODERATE			GOOD	BAD
GB109054049143 R Severn – M Wenlock-Farley BK to conf R Worfe	**MODERATE POTENTIAL**	MODERATE	MODERATE			GOOD	MODERATE
GB109054049145 R Severn - conf R Worfe to conf R Stour	**MODERATE POTENTIAL**	MODERATE	HIGH			GOOD	GOOD

GB109054049144 R Severn – conf R Stour to conf R Teme	**MODERATE POTENTIAL**	MODERATE	GOOD			MODERATE	MODERATE	
GB109054039760 R Severn - conf R Teme to conf R Avon	**MODERATE POTENTIAL**	MODERATE	HIGH			POOR		
GB109054044404 R Severn - conf R Avon to conf Upper Parting	**MODERATE POTENTIAL**	MODERATE	MODERATE			POOR		
GB109054032750 R Severn (E Channel) - Horsebere Bk to Severn Est	**MODERATE POTENTIAL**	MODERATE	GOOD			POOR		

Table 3 shows the WFD status for each of the water bodies involved in the Severn Drought Order. The majority of the waterbodies on the Severn, Vyrnwy and Clywedog have been designated as heavily modified water bodies due to the regulation of flows and therefore the 'one out, all out' principle is not used. No water body is considered to achive higher than moderate potential

The Severn is a large and deep river, where monitoring fish effectively by means of electric fishing for classification purposes is not possible. The fish data used for these waterbodies in the first RBMP was therefore not suitable to give a truly representative picture for the fish quality element. Further monitoring methods are being developed in order to improve this information in the future.

Physical Habitat
River habitat surveys (RHS) provide an assessment of the morphology of a 500m reach of river, recording both modifications and natural features, and giving an indication of habitat quality and diversity.

Hydromorphology forms part of the overall ecology of a water body by underpinning and supporting the biology. Most aquatic species have certain physical habitat requirements, in addition to those of water quality and hydrology.

RHS survey data can be summarised using two summary indices.
The habitat modification score (HM) is a scoring system used to assess the degree of modification associated with a river. The scores can then be used to place the water body in a habitat modification class. The HM score is independent of water body type and so can be used to describe artificial modification to physical structure across the board.

Table 4: Habitat Modification Scores

HMC	HMC description	HM score
1	Pristine/near-natural	0-16
2	Predominantly unmodified	17-199
3	Obviously modified	200-499
4	Significantly modified	500-1399
5	Severely modified	1400+

These classes differ from those describing ecological status under the WFD and also the category of 'heavily modified' which classifies an entire water body, and is derived from morphological and socio-economic criteria.

The habitat quality assessment (HQA) scoring system offers a broad measure of the diversity and 'naturalness' of the physical habitat structure of a site, including both the channel and river corridor. A survey will accumulate points under 9 different sub-score categories. These sub-scores are totalled to give the overall HQA Score.

HM and HQA indices are designed to give only a summary of the habitat over the 500m river length surveyed. For more targeted investigations (such as looking at siltation), using the raw data is recommended.

RHS surveys cover 500m lengths of river. Current work shows that this is likely to be representative of 1 km of river either side of the mid-point. For assessments at the water body scale, it is likely that a number of RHS surveys will be required to allow meaningful conclusions to be drawn.

River Habitat Surveys have been conducted throughout the Severn catchment, but for the purposes of this report only sites nearest the assessment points are included. Future monitoring should include RHS surveys that are centred on the individual macroinvertebrate sites.

Table 5: River Habitat Survey (RHS) scores

NGR of Site	River	Ecology Monitoring/ RSDO comparison sites	HMS Score	HMS Class	HQA
SN9280086100	CLYWEDOG	49774 Caravan Park SN94000 85700	10	1	54
SJ0430014400	VYRNWY	50350 Dolanog SJ06780 12860	0	1	53
SJ6790003400	SEVERN	52795 Coalport SJ 70200 02100	60	2	40
SJ6880002900	SEVERN	52795 Coalport SJ 70200 02100	40	2	37
SJ6910002800	SEVERN	52795 Coalport SJ 70200 02100	80	2	38
SO7892575192	SEVERN	52393 D/S Dowles Brook SO78000 76400	1560	5	34
SO8453127958	SEVERN	51327 Hawbridge SO84500 27720	474	3	31
SJ2330023400	TANAT	50766 LlanyblodwelSJ 24200 22900	90	2	45
SO6020068500	TEME	48210 Tenbury SO 59942 68511	45	2	44

The heavily Modified Scores (HMS) increase with distance downstream (Table 5). This is important for the ecology of the river as the more modified a river is the fewer habitats and refugia are available for macroinvertebrates and fish. The Habitat Quality Assessment (HQA) score provides evidence of this as it decreases as the river goes downstream.

Macrophytes

Macrophytes have traditionally been used to monitor the impacts of eutrophication in rivers. However like invertebrates they respond to a wide range of pressures. Different pressures can often have similar effects and it can therefore be difficult to apportion cause. Flows can have a significant impact on macrophyte communities within the reach of a river. The principal mode of impact is via physical stress caused by flows damaging the plants or causing uprooting. Some macrophyte types, such as marginal herbs and floating leaved plants, can only exist in areas of reduced flows, whereas submerged linear and fine leaved plants are morphologically adapted to thrive in areas of higher flows. If flows change then the plant community will often change in response. Where flows are reduced within a stretch of river it may cause plant taxa with a preference for high flows to either decrease in dominance or be lost altogether as more marginal taxa and broad leaf taxa are able to out-compete them and can expand into the middle of the river changing the balance in the plant communities. In lowland systems however, flow pressures can often be masked by nutrient pressures

River macrophyte nutrient index. The RMNI is designed to categorise a macrophyte community's preferences to nutrient levels. Scores range from 1 to 10 with scores of 1 representing plant communities with preference for very low levels of nutrients and 10 representing communities with a preference for very enriched conditions.

River macrophyte hydraulic index (RMHI). The RMHI describe a plant community's preferences for flow conditions on a scale of 1 to 10. Scores of 10 indicates a plant community has a preference for very slow or non existent flows, while scores of 1 are found in plant communities with a preference for very rapid powerful flows.

There is a close relationship between RMNI and RMHI as species of fertile environments tend to be associated with low energy systems. Impacts such as sedimentation, channel widening, flow abstraction and the introduction of physical modifications are all likely to result in a shift to an essentially lower energy depositional environment.

Number of aquatic plant functional groups (N FG). The N FG index is a richness or diversity index and describes the number of functional macrophyte groups existing within a surveyed plant community. There are 23 different functional groups defined. The higher the value, the more diverse and rich the plant community is considered to be;

Number of aquatic taxa (NTAXA). The NTAXA index is another richness index but simply describes the number of truly aquatic taxa. Higher values represent a more diverse and rich aquatic plant community.

Both the N FG and N TAXA indices are very useful indicators of habitat quality. High quality habitats with good flow regime, habitat heterogeneity, upstream connectivity and low sedimentation pressures will have higher values for both these indicesIn areas where channel modifications exist both these indices will often be reduced.

Very limited macrophyte monitoring has been undertaken on the Severn, Vyrnwy and Clywedog. Table 6 shows the results of the plant data available.

Table 6: Macrophyte Monitoring Results

WATERCOURSE	SITE_ID	SAMPLE_DATE	RMNI	RMHI	N_ATAXA	N_RFG	ALGAL	CLASS
SEVERN - LLANIDLOES FELINDRE BRIDGE	50744	05-Jul-06	4.15	5.08	5	4	0.05	High
SEVERN - LLANIDLOES FELINDRE BRIDGE	50744	15-Jul-08	4.3	5.12	8	5	0.05	High
SEVERN - DOLWEN	52148	04-Aug-04	5.33	5.83	13	6	1.75	High
SEVERN - CAERHOWEL	53127	17-Aug-04	7.28	7.21	6	6	0.5	Moderate
SEVERN - CAERHOWEL	53127	22-Aug-06	7.19	7.14	7	6	0.05	Moderate
SEVERN - PENTRE	155008	08-Sep-10	6.45	6.69	8	5	0.55	High
SEVERN -MONTFORD BRIDGE	50257	11-Aug-04	7.35	7.23	5	5	0.5	Moderate
SEVERN -MONTFORD BRIDGE	50257	26-Jun-06	7.54	7.23	3	3	7.5	Moderate
SEVERN - MONTFORD BRIDGE	50257	23-Aug-10	7.15	7.33	2	2	0	Moderate
SEVERN -ISLE OF BICTON	51052	02-Sep-04	7.54	7.65	6	5	0	Good
SEVERN - ENGLISH BRIDGE	155009	08-Sep-10	7.29	7.4	11	9	0.1	Good
SEVERN - CRESSAGE	52526	23-Aug-04	7.9	7.82	17	11	1.75	Good
SEVERN - CRESSAGE	52526	18-Jul-06	7.54	7.54	14	11	1.05	Good
SEVERN - AT APLEY FORGE	53779	18-Aug-04	7.54	7.29	9	6	0.6	Good
VRYNWY - DOLANOG	102683	29-Jun-04	4.34	5.13	14	4	1.75	High
VRYNWY - DOLANOG	102683	06-Sep-06	4.54	5.22	16	5	0.1	High
VRYNWY - PONTYSGAWRHYD	49740	21-Jul-04	5.87	6.3	17	10	0.1	High
VRYNWY - PONTYSGAWRHYD	49740	07-Sep-06	6.43	6.49	13	7	0.55	Good
VRYNWY - LLANYMYNECH	102681	02-Sep-04	6.97	7	10	6	0.05	Good
VRYNWY - LLANYMYNECH	102681	07-Sep-06	6.71	6.85	14	10	0.1	Good

Data only exists for the River Severn upstream of Bewdley and the Afon Vrynwy. No data is available for the lower reaches of the Severn as the heavily modified navigable stretches of the Severn are deemed unsuitable for accurately surveying any macrophyte community present.

In general there is an increase in both the RHMI and RNMI with distance downstream. In the headwaters, the macrophyte community is associated with faster and more powerful flows and lower nutrient status such and consists mainly of bryophytes (mosses and liverworts). The communities change as the sites move downstream to include a more marginal and submerged macrophytes (including Water Crowfoot, Water Milfoil and Starwort) and filamentous algae. The sites furthest downstream also include the presence of floating leaved plants (duckweeds). These communities indicate slower flows and a more nutrient enriched system.

Due to the lack of data it is not possible to determine whether periods of very low flow are having an effect on the macrophyte communities in the Severn, Clywedog and Vyrnwy. A specific baseline macrophyte monitoring programme would need to be designed and undertaken in order to determine these effects and whether the application of the drought order would have beneficial or detrimental effect on the ecology.

Invertebrates

The majority of the macroinvertebrate samples were collected using the standard Environment Agency three minute kick sample and 1 minute manual search method. The exceptions to this were the samples taken from the lower reaches of the Severn where it is not possible to collect samples in this way due to the depth of the water. In this case, a standard dredge sampling method was used. The samples were then analysed in the laboratory, macroinvertebrates identified and their abundance estimated. A number of different scoring methods were used to interpret the data.

Invertebrate taxa are able to tolerate different degrees of water quality. The **Biological Monitoring Working Party (BMWP)** score classifies families of invertebrates according to their tolerance of organic pollution. Using a scale from 1 to 10, invertebrates that are able to tolerate low oxygen levels associated with gross organic pollution, such as oligochaete worms, are given low BMWP scores, while invertebrates that require high water quality, such as stonefly larvae, are given high BMWP scores. A BMWP score for a standard stream invertebrate sample is calculated by adding together the individual BMWP scores of the taxa found. BMWP scores and the corresponding water quality can be compared between sites and scores can be compared over time to determine if the water quality has changed at a site.

The Average Score Per Taxon (ASPT) is derived by dividing the total BMWP score a sample by the number of taxa found. This gives a better reflection of water ‘quality’ because it is not influenced by the number of taxa recorded.

The **River InVertebrate Prediction and Classification System (RIVPACS)** programme predicts the probability of presence of taxa, based on a site’s physicochemical characteristics. A comparison of the observed taxa with those predicted can indicate changes in environmental quality. The system has been tested in a variety of studies to assess the effects upon the benthic communities of heavily abstracted watercourses.

The **Lotic-invertebrate Index for Flow Evaluation (LIFE)** method is primarily based on recognised flow associations of different macro-invertebrate taxa (species and families) and thus can measure the ecological effects of low flows. Flow categories are ascribed to families or species of invertebrate taxa, based on their sensitivity to and tolerance of low flows. These LIFE scores are cross-indexed with logarithmic abundance to give a flow score taxon (family or species group). A mean score is then calculated from each taxon list for each invertebrate sample. High LIFE scores indicate invertebrate assemblages that are sensitive to low flow, such as small, fast upland streams, while low LIFE scores indicate sites that are less sensitive to low flows such as wide deep rivers.

In order to determine if the invertebrate community at a particular site has been impacted by any periods of low flows, historic LIFE scores can be compared to flow data. However, there is usually a small time lag before the effects of the low flows are seen in invertebrates. Different flow parameters show greater correlation to LIFE scores than others. For example monthly flow figures or minimum monthly flow figures may show a greater correlation with LIFE than daily flows. This is because the impact of flow on different life stages of invertebrates will vary according to the invertebrate communities that the watercourse can support and the impact of flows will vary at different sites depending upon the structure of the site.

Historic LIFE scores can also be compared over time with each other to determine if artificial changes to the flow regime, such as augmentation in the catchment, have affected the invertebrate LIFE scores.

Predicted LIFE scores can also be calculated to determine if a site is stressed by flows. This is the LIFE score that would be expected at a site under pristine conditions, i.e. no water quality, habitat, or flow stresses. Expected LIFE (E) scores are calculated by generating a list of predicted invertebrates, using RIVPACS. Observed LIFE (O) scores are then divided by expected life scores to get a ratio (LIFE O:E).

Hydroecological Validation (HEV) uses ecological and hydrological data to help us assess the ecological response of a site to river flow (As per operational instruction 318_10 – Hydroecological validation using macroinvertebrate data). It compares expected and observed river ecology to see if there is a relationship between ecological condition and river flow. HEV can also be used to infer the effect of other pressures, such as water quality, sediment and morphology. This tool was specifically developed for unregulated rivers but has been used in this case to see how LIFE and the other variables change over time.

For this process RIVPACS is used. Some of the physical variables used to make RIVPACS predictions (width, depth, substrate type) can be modified by regulation. This may lead to an under prediction for the expected scores and thereby the O:E ratios may be higher than they should be.
In order to overcome this problem, the observed LIFE scores have also been compared to long term average and the lower quartiles for the site and displayed alongside hydrological data to see whether any declines in the LIFE scores appear to be related to river flow.

Increased siltation within a river reach is often associated with morphological change or a reduction in flows. However, it can also arise from sediment run off from poor land management. Siltation often reduces the quality of the habitat available, reducing interstitial spaces, oxygen availability, and light penetration. It can also have a physical impact, smothering macroinvertebrates and damaging sensitive gills. Macroinvertebrate communities impacted by siltation will often be missing the more sensitive taxa and can have reduced diversities, having one or two very dominant taxon.

The **Proportion of Sediment-sensitive Invertebrates (PSI)** index is a methodology used for assessing sediment pressures. PSI is a biotic index designed to describe an invertebrate community's sensitivity to sedimentation. The score decreases with increased impact of fine sediments covering the river bed (Table 2).

Table 2: Proportion of Sediment-sensitive Invertebrates (PSI) Biotic index

PSI score	River bed condition
81- 100	Minimally sedimented/unsedimented
61-80	Slightly sedimented
41-60	Moderately sedimented
21-40	Sedimented
0-20	Heavily sedimented

Limitations of the Ecological modelling

Limited data, inconsistent coverage of historical data and a lack of tools specifically designed for predicting the impact of low flows/drought on the ecology of regulated rivers made true assessment difficult.

The use of the DRIED UP (Distinquishing the Relative Importance of Environmental Data Underpinning flow Pressure) model was considered but excluded as not being suitable for use on regulated rivers such as the Severn.

A hydrological excel tool to assist in deriving flow statistics, which were then regressed against LIFE scores to test the strength of the correlation between LIFE scores and flows was used but then discounted as not providing any meaningful information in this case.

Therefore, the best available data was used and professional expertise was applied to the assessment process.

For the purposes of this report, the Severn (including its two main source tributaries, the Afon Clywedog and the Afon Vyrnwy) has been split into sections with seven assessment points. A macroinvertebrate sampling site with a robust historical dataset has been assigned to each of these sections. There was no macroinvertebrate data available for the Elmore assessment point, due to the methodology being unsuitable for this size of river and impacts of saline intrusion (freshwater invertebrates only). In addition to, two reference sites have also been included: the Afon Tanat (a tributary of the Vyrnwy) at Llanyblodwel and the River Teme (a tributary of the middle Severn) at Tenbury. Both reference sites are on rivers that are non regulated and give an indication of the reaction of macroinvertebrates to natural periods of lower flows in the Severn catchment.

Table 1: Severn Drought Order Invertebrate Assessment points

Assessment Point	**Watercourse**	**Invertebrate Site**	**Biosys ID**	**Grid reference**
Afon Clywedog, Bryntail	Clywedog	Caravan Park	49874	SN94000 85700
Afon Vyrnwy, Vyrnwy weir	Vyrnwy	Dolanog	50350	SJ06780 12860
River Severn, Buildwas	Severn	Coalport	52795	SJ 70200 02100
River Severn, Bewdley	Severn	D/S Dowles Brook	52393	SO78000 76400
River Severn, Saxons Loade	Severn	Upton on Severn	47463	SO85050 40890
River Severn, Hawbridge	Severn	Hawbridge	51327	SO84500 27720
River Severn, Lower Parting	n/a	n/a	n/a	n/a
Control site	Tanat	Llanyblodwel	50766	SJ 24200 22900
Control site	Teme	Tenbury	48210	SO 59942 68511

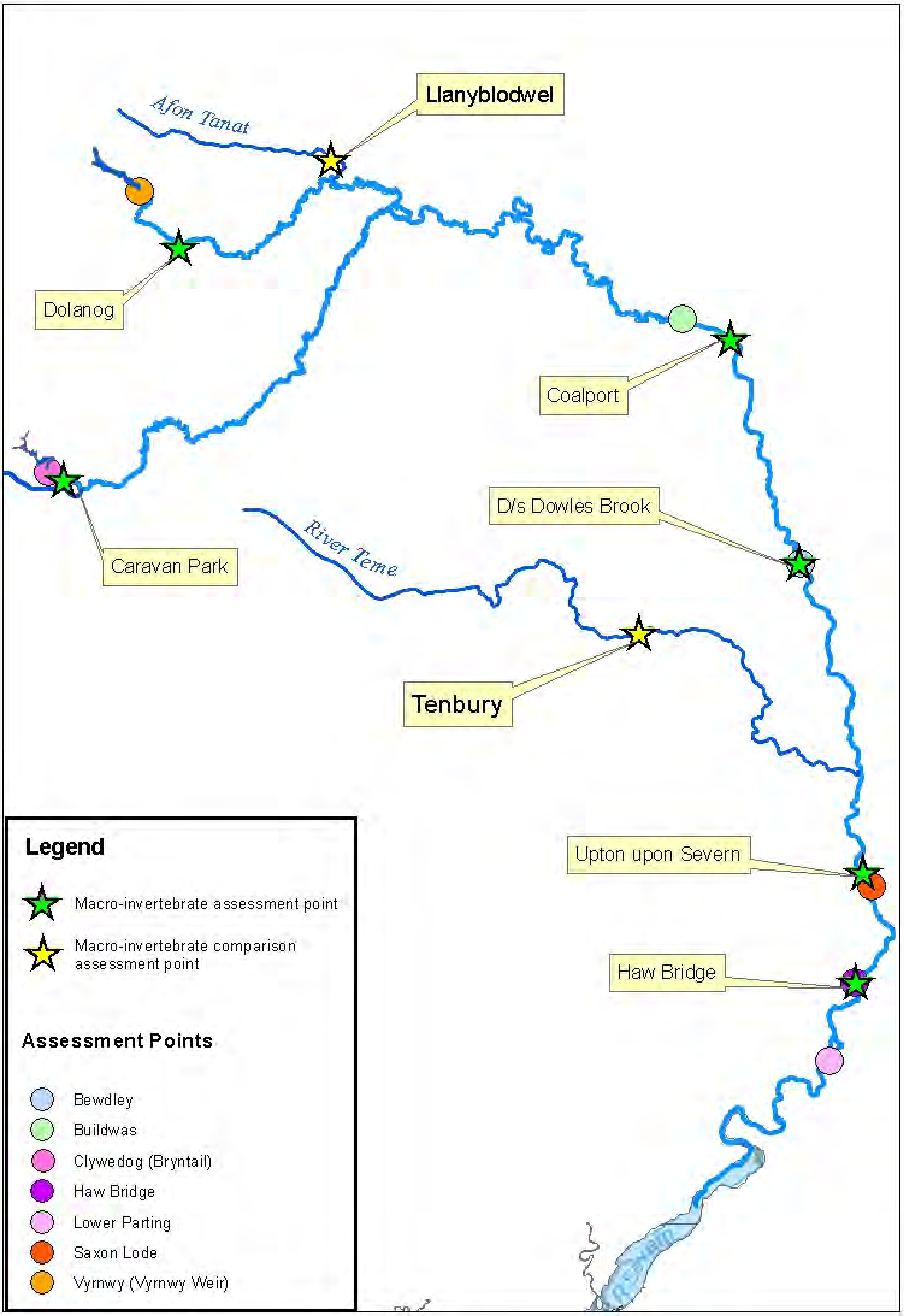


Figure 1 Map showing macroinvertebrate sampling sites used in this report

The LIFE index is a proven technique for assessing the impact of variable flows on benthic macroinvertebrate populations (Extence *et al* 1999). Summer flow variables are highlighted by Extence *et al*. (1999) as being a key factor in determining community structure in most chalk and limestone streams, whereas invertebrate communities in rivers draining impermeable catchments are much more influenced by short-term hydrological events. In addition, invertebrates in rivers with regulated or augmented flows tend to be most strongly affected by non-seasonal, inter-annual flow variation. As a result, the correlation of LIFE scores with flow can vary considerably between sites.

Figures O2a to O9b show the HEV plots and drought response plots for the six macroinvertebrate sites selected for this study and the two control sites. Generally historical macroinvertebrate data was available from the 1990's onwards.

Afon Clywedog – Park (Site ID 49874)
As part of the River Severn Regulation system, during periods of low flow releases are made from Clywedog reservoir in order to maintain flows at Bewdley. As a consequence flows increase at the Park site in times of regulation. The HEV LIFE plot for Clywedog, Park (Figure O2a) shows that generally after periods of regulation in the low flow years of 1989/90,1995/96, 2003, 2005, 2006 and 2010/11 the LIFE O:E does increase slightly in the autumn sample. The observed LIFE scores plotted in Figure O2a/b also follow the same pattern. The only exception to this is a decrease in LIFE and LIFE O:E in autumn 1996 just after the low flows encountered in 1996 and therefore an increase in regulation flow. Number of taxa (O:E) has traditionally been low at this site and is most likely to be due to the unstable nature and the compacted substrate of the Afon Clywedog because of releases from Clywedog reservoir. However there appears to have been a general increase in taxon richness over time with a corresponding decrease in ASPT. ASPT O:E is generally good and therefore water quality should not be an issue at this site. The observed PSI scores range between 69 and 90 and can therefore the site can be described as ranging from slightly silted to naturally unsilted. The lowest PSI O:E scores appear to occur in the spring preceding regulation, possibly indicating a build up of fine sediment before the increased flows of regulation remove the sediment from the system The autumn samples generally have a higher PSI O:E ratio than the ones taken in spring. There appears to have been a downward trend in both PSI O:E and observed PSI over time, suggesting a general increase in sediment at this site

Afon Vyrnwy - Dolanog
The lowest LIFE scores for the Vyrnwy at Dolanog (Figures O3a and O3b) occur in the autumns of 1995 and 2004. This may be reflecting the low flow years 1995/6 and 2003 but there is a lack of data collected for this site in the years proceeding these dates and this makes interpretation of the data unreliable. The lowest PSI score (58) also occurred in autumn 1996, suggesting a build up of fine sediment that may be a result of the low flows experienced during this time. The NTaxa O:E ratio is variable but the site, although very stable, can be difficult to sample especially in less than ideal conditions due to its substrate and fast flow.

River Severn - Coalport
This site can be difficult to sample, particularly during slightly higher flows and this has resulted in data gaps making interpretation difficult. The ASPT and N taxa plots (actual and O:E) (Figures O4a and O4b) indicate that there has been a general improvement in water quality since 2001.

There appears to be a delayed decline in observed LIFE scores and LIFE O:E following the low flows of 95/96 but lack of data during and immediately after these periods makes it difficult to draw any firm conclusions with regards to response to flow and the length of time taken for the macroinvertebrate community to recover. There also appears to be a decline following the low flows of 2010/11, followed by a recovery in LIFE by autumn 2012. The PSI scores are at their lowest when the LIFE reduces and follows the same pattern, indicating an increase in fine sediment build up as a consequence of the reduced flows.

River Severn – D/S Dowles Brook
For the purposes of long term monitoring invertebrates are usually sampled once in a season, but raw invertebrate data taken monthly from this site was found in report by Craig Goch Research Team, Severn Trent Water Authority covering the 1975 drought and subsequent recovery period . The data from this time was not sampled using the exact methods used today but it was felt that for the purposes of this report the data should not be excluded due the critical time period the data covered. Any data collected prior to 1995 was not subject to the same procedures and high analytical quality control standards that have been in place since but are thought to still be reliable and can be used to examine long term patterns. LIFE scores (O:E ratios and actual) were compared with flow data and are presented in Figures O5a and O5b. The lowest LIFE scores occur in the 1975 and 1989/90 drought period when flows were low, suggesting that the invertebrate fauna is responding to the low flows in these periods The LIFE scores begin to recover by the following summers of 1978 and 1991 respectively. This also corresponds with the lowest actual PSI values. There is also a dip in LIFE after the 1995/96 low flow period. There were no samples taken in the autumn 1996 or spring 1997, making the interpretation of this data difficult for this period, but LIFE scores had recovered by spring 1998. There was a decline in LIFE(both actual and O:E) autumn 2011 following the low flows in 2010/11. Unfortunately there are no samples in 2010 and high flows prevented the sample being taken in autumn 2012. The PSI results suggest that during periods of low flow there is an increase in fine sediment and the macroinvertebrate community is changing and responding to this.

The HEV LIFE plot from River Severn, d/s Dowles Brook (Figure O5) shows that this site appears responsive to changes in flow and that the invertebrate life has been impacted in the 1976/77, 1989/90, 1995/96 and more recently 2010/11 drought.

The lowest LIFE O:E scores do occur following the low flows in 1989/90. The low LIFE O:E scores in 1989/90 also have corresponding low PSI O:E scores.

River Severn - Upton on Severn
The LIFE and LIFE O:E scores (Figures O6a and O6b) do not appear to be corresponding to variations in flow. The poor PSI results are partly due in the highly modified nature of the site and fine sediment dropping out in the lower reaches of the Severn. However it may also be that the dredge method used to collect the invertebrate samples.

River Severn - Hawbridge
Similar conclusions can be made with regards to The Severn at Hawbridge. LIFE and LIFE O:E scores from this site (Figure O7a and O7b) appear not to be responding to changes in flow. The PSI results are suggesting fine sediment pressure. This would be expected for a highly modified site on the lower reaches of a large river

Afon Tanat - Llanyblodwel (Figures O8a and O8b) and the **River Teme –Tenbury (control sites)** (Figures O9a and O9b). Both sites appear to be responding to variation in flow but have not been stressed by lack of flow. The greatest impact on the macroinvertebrates appears to occur following a second year of low flows and the time taken to recover is lengthened. It would be expected that in the case of an area wide drought, these sites would respond and LIFE scores would reduce.

Historic Invertebrate Data
Historic invertebrate data for previous periods of low flow and proceeding recovery time were classified using the current techniques for WFD classification. The results are shown in Table 7.

Table 7: Historic Invertebrate WFD Classification Status

Site ID	Site Name	1975	1978	1989	1990	1991	1992	1995	1996	1997
49874	Clywedog - Caravan Park			Good	Moderate		Good	Good	High	Good
50350	Vrynwy - Dolanog							Good		
52795	Severn - Coalport							Good		
52393	Severn - D/S Dowles Brook	Moderate*	High*	Good	Good	Good	Good	Good		
47463	Severn – Upton on Severn							Poor	Moderate	
51327	Severn - Hawbridge							Bad	Bad	
50766	Tanat- Llanyblodwel			High	High	Good	High	High	High	
50350	Teme - Tenbury				High	Good	High	High		

* The 1975 and 1978 data from Severn - D/S Dowles Brook was not sampled using the WFD standard sampling technique but a 3 minute kick sample on the riffle was used and therefore it is considered consistent with the later methodology for the purposes of this report.

Samples from both spring and autumn are required in order to undertake a WFD classification. Unfortunately this data is not available for all sites and all years, hence the gaps in Table 7. The classification results indicate that although the invertebrate life was undoubtedly affected by the drought of 1975 the invertebrates had recovered by 1978. In the case of the 1989/90 drought, the WFD classification would have remained at good although again the invertebrate fauna were showing signs of stress and were affected by the low flows

General Impact of Low Flows
The general consequence of low flows is a reduction in the wetted width of the river, thereby reducing the availability of habitat for the invertebrates and the alteration of flow patterns and water velocity within the watercourse. The composition of the invertebrate assemblage alters, with the loss of invertebrates that require high velocity, high oxygen conditions and an increase in invertebrates that can tolerate these reduced flow conditions. As the flow declines further, stream margins become exposed and invertebrates that rely heavily on hydrological linkages to the

macrophytes at the edge of the channel for food, shelter and emergence are impacted as water recedes from these habitats. Even the taxa that live on the surface may become more prone to predation when the marginal vegetation is isolated from the stream/river edge.

The reduction in flow will often promote the settlement of fine sediment. Siltation stresses many aquatic insects by clogging their respiratory systems or smothering their food sources. This can slow post drought recovery in some watercourses. The low flows may also lead to a decrease in water quality due to the lack of dilution of effluents.

The most dramatic changes occur when flow ceases and pools form with possible decreases in dissolved oxygen and higher temperatures. Associated with this could be an increase in algal blooms, which can cause large fluctuations in dissolved oxygen as they produce oxygen in the day and then use it up overnight. Algal blooms can also block out light causing the death of submerged macrophytes and can smother the substrate, therefore reducing the interstitial oxygen. Many invertebrates rely on flow to provide feeding currents, enhance respiration, enable passive movement, import detritus or aerate the water through physical turbulence. These rheophilous groups will disappear as they are unlikely to find suitable refuges except in nearby flowing habitats within reach. The break in longitudinal connectivity also stops invertebrate drift preventing recolonisation in remnant flowing sections.

Recovery after a drought will depend on a number of variables including the drought length, the time of year when the drought occurred and the availability of recolonisers. Usually early colonists with short life cycles (e.g. chironomids and simuliids) are then joined by longer lived invertebrates (e.g. mayflies and caddisflies). Taxon richness then rises steadily as flows establish. However, previously common drought-intolerant taxa may be reduced and new habitat created for taxa that were rare before the drought.. The response of individual invertebrate species very much depends on their individual life cycles and environmental preferences. Ecological resilience to flow stress is greater in more natural channels, due to the greater habitat diversity and substrate stability that provide more refugia for the invertebrates at extreme high and low flows.

Actual Impacts of the 1975/76 drought

Research was undertaken by Craig Goch Research Team of Severn Trent Water Authority during and after the 1975/76 drought to determine the impact of the drought.

Afon Clywedog

Afon Clywedog has low density and diversity of invertebrate fauna. A small change in discharge when the river is at low flows may have a much greater ecological consequence than a large change at higher flows simply because the relative change in wetted area. Under normal circumstances many organisms are capable of moving down into interstitial spaces and remaining there for 6-8 weeks before recolonising the surface. In the Clywedog, the substrate is bedrock or heavily compacted and during the drought period of 1975/6 it was covered with silt from the scour valves.

Due to the increased use of the Clywedog for regulation in 1975 and 1976, the level of Llyn Clywedog was greatly reduced by the end of both summers. In order to conserve water and quicken refilling, outflows from Clywedog were greatly reduced (to 20mld)for considerable periods. This led to large areas of the river bed being left exposed as the water flowed along a narrow channel. The lowered water level in the lake and high winds in late summer resulted in greater silt erosion by the wave action from the exposed banks.

Compensation water was taken from the bottom in order to remove silt from the reservoir and this was deposited in the Afon Clywedog, exacerbating the ecological problems. From early 1975, flows were often higher and temperatures lower than normal during periods critical for the emergence, development and oviposition for many species of invertebrates e.g. *Serratella ignita* normally occur in large numbers over a short (3 month) period. It is present in very low numbers and is spread out over a 6 month period in the Afon Clywedog. This will result in a very sparse and sporadic emergence of adults and hence cause a lowered egg production for the following year. The effects of drought and spate will depend on the time of the occurrence in relation to an organism's life history – this is probably an important factor in the Afon Clywedog as the normal winter/summer flow regime is reversed.

Afon Vyrnwy

An investigation was undertaken between 1975 and 1978 order to determine the effect of proposed changes to the pattern of compensation releases from Lake Vyrnwy in order to achieve a more flexible approach to compensation flows and to balance differing interests of water supply, fisheries management and general ecology and minimising the frequency of spillage from the reservoir. These are the control rules that are still used today.

The Vyrnwy has two distinct reaches, the upper reach from the dam to the confluence with the Banwy, which is fast flowing with typical pool and riffle sequence; and the lower reach, that is deep and more slow flowing. The effects of changing the flow regime on the Vyrnwy and the likelihood that this would induce ecological change were dependent on the width, depth and flow at individual sites. The velocity over the bedrock was higher and less variable than over the stones. The most direct changes in flow in the Vyrnwy was to alter the wetted width of the river in the upper reach.

Quantitative samples were taken using Surber samples, but a direct comparison of the numbers of invertebrates collected can not be made with kick samples. The kick samples did not include the bedrock areas. Higher densities and more taxa were recorded from the stony substrate than from the bedrock (the bedrock contains pockets of sand and silt in the crevices and hollows particularly at times of low or stable flow). During the summer months, the bedrock was covered by epilithic and filamentous algae. Many of the invertebrate species that were found on the bedrock were algal feeders.

At Pont Robert, which was 5km downstream from the site at Dolanog, the whole of the river bed was covered at flows of 100mld. 2/3 of the bed is stones and boulders and 1/3 bedrock shelves. At times of low flow, <100 Ml/d, almost ½ of the wetted area was bedrock. At about 50 Ml/d, 1/3 of the bed was exposed During the summer of 1976, flows were generally very low and much of the stony substrate was dry. However during the monthly freshet, dry areas were rewetted and this instability is thought to have contributed to lower numbers found on the stones. The lowest number of animals was recorded during the summer and autumn of 1976.

At times of low rainfall when natural run off to the river is minimal, almost all the flow in the Vyrnwywas reservoir water. Under these conditions, the flow at Pont Robert falls well below the desirable 100 Ml/d, causing a drought reaction in the invertebrates as they move in to the smaller wetted areas. It is significant that the changes in flow resulted in fluctuations in the area of submerged gravels and stones, which are important habitats for the invertebrate fauna.

Severn - Bewdley
Invertebrate samples were taken to study the effect of a reduction in flow during the period of 1975/76 drought. During this period flow at Bewdley was maintained at 730 Ml/d but this presented some difficulties and the minimum flow was approximately 450 Ml/d.

Flow reductions due to abstractions occurred mainly during the night. This coincided with the period of greatest invertebrate activity, possibly leading to increased drift rates. The sampling site used for this study is the same site that is used today and is the riffle located downstream of the confluence with Dowles Brook. During low flows the area of the wetted riffle was reduced by up to 50% and confined to the eastern bank. The western edge of the river dried up completely and the central area became largely stagnant water 5-10cm deep. During 1977, the drying of the riffle and narrowing of the wetted area was further exacerbated by the building of a boulder dam about half a metre high above the riffle to increase the water depth in the upstream pool, probably for angling purposes.

In general the River Severn at Bewdley supported a rich and varied fauna and was characterised by the dominance of Crustacea, Ephemeroptera and Trichoptera. The drought conditions of 1976 and the artificial drought of 1977 had pronounced effects and the riffle fauna suffered from the low flows experienced. Crustacea, Trichoptera and Oligochaeta all declined in abundance whereas Chironomidae, Simuliidae and some Ephemeroptera increased in abundance.

Lower River Severn
During and immediately after the 1976 drought, there were some problems with water quality in the lower River Severn with an increase in nitrate and ammonia and a decrease in DO to 50-60%saturation. Increased use of Clywedog resulted in a noticeable reduction in turbidity and in the numbers of algal blooms. Dredge samples were taken from a boat. There was an exceptionally low abundance and species diversity of invertebrates, the lowest levels being recorded in autumn 1976. Low densities of invertebrates are thought to be mainly due to unsuitable substrate (ranges from thick glutinous mud to extremely dense clay which effectively forms a bedrock layer). The bedrock substrate would not provide a refuge from predators or adverse physical factors, while the large amount of shifting materials such as mud and leaves would contribute not only to a the lack of invertebrates but also prevent the establishment of plants and algae. It was noticeable that the substrate did not remain constant throughout the period of the study. Most of the invertebrates were found in piles of debris which offered more stability and protection than the natural substrates.

Assessment of Impact on the Current Environment: Severn Corridor Ecology

Limitations of the Ecological modelling

Limited data, inconsistent coverage of historical data and a lack of tools specifically designed for predicting the impact of low flows/drought on the ecology of regulated rivers made true assessment difficult.

The use of the DRIED UP (Distinquishing the Relative Importance of Environmental Data Underpinning flow Pressure) model was considered but excluded as not being suitable for use on regulated rivers such as the Severn.

A hydrological excel tool to assist in deriving flow statistics, which were then regressed against LIFE scores to test the strength of the correlation between LIFE scores and flows was used but then discounted as not providing any meaningful information in this case.

Therefore, the best available data was used and professional expertise was applied to the assessment process.

Discussion of possible impacts from the River Severn Drought Order in isolation

The main aim of this report is to separate the impacts of the River Severn drought order would have on the ecology of the River Severn as opposed to the ‘Do Nothing’ scenario of allowing the natural drought event to take its course, resulting in a potential complete loss of flows in the upper reaches of the Severn. The challenge is to try and differentiate and evaluate the pros and cons of applying the River Severn Drought Order, or leaving nature to run its course.

Macrophytes
Due to the lack of existing data it is not possible to accurately determine what extent periods of very low flow would impact on the macrophyte communities along the River Severn, Clywedog and Vyrnwy.

Diatoms
Diatoms are generally not considered to be appropriate for use in drought monitoring and assessment and therefore have not been specifically used in this case other than as part of the general WFD classification process.

Macroinvertebrates
This section will assess whether applying the Drought Order would have detrimental effect on the macroinvertebrate assemblages within the Severn, when compared to not applying the drought order. It must be remembered that any severe natural drought is likely to have a detrimental effect on the macroinvertebrate life within a river system. The exact response will depend on a number of variables and will differ according to the severity of the drought, the time of year and temperature i.e. there are likely to be more detrimental effects if the weather is hot.

Looking at the historical invertebrate data available it is possible to suggest what may happen to the invertebrate life under the different scenarios.

Bryntail AP(Site id 49874 Clywedog – Park)

Acute

Do nothing

Historic data suggests that this site does respond to changes in flow conditions and that LIFE scores will decline if the compensation flows are reduced. If the drought is allowed to follow the natural course of events, the compensation flows would fail in late September and for 35 days there would be flows of less than 10Ml/d. This failure is likely to have a detrimental effect on the invertebrate life in the Clywedog. The compensation flows are restored at the beginning of November in the model but flow variation does not happen until 306 days later when the reservoir refills while regulation is not required. Even with flows of 18.2 Ml/d for compensation, much of the river substrate will be exposed as the flow is reduced to a narrow channel (as recorded in 1977 at a site less than 1km upstream of the site) and therefore there will be continued longer term implications for the macroinvertebrate population. The amount of river bed exposed will be dependent on the site and the profile of the river bed at that point. The reaches closest to the dam will be the more adversely affected as there will be less run off from the reduced catchment size when it does eventually start to rain.

EA drought order

If the drought order is applied, there will be a reduction in flows from late August as opposed to late September but there is no complete failure of the compensation flows, therefore allowing flows to continue for a greater length of time. The macroinvertebrates will be compromised by the change in regime, but it will be to a lesser extent than if the compensation flows were allowed to fail by doing nothing and causing greater harm in the longer term. In this model, flow variation is lost for 224 days, an improvement of 82 days when compared to the do nothing scenario. The improvement in the flow regime will mean that the invertebrate population would be expected to recover more quickly. The flows in the river are still artificially elevated above what would naturally be present in a period of drought in a non regulated river and the system is likely to better off than many of the other watercourses in the locality.

Full in combination

Flows will be slightly higher than when applying the EA drought order alone and again there is no failure in the compensation flows. Flow variation is lost for a period of 221 days while the reservoir refills, giving an 85 day improvement from the do nothing model. Again the invertebrate life would be expected to be compromised but probably to a slightly lesser extent than the other options.

Chronic

Although there are still a number of issues to be resolved with regards to the accuracy of the modelling of the chronic flows, the general pattern is considered correct.

Do nothing

As discussed earlier, there would have been a dramatic decline in the invertebrate life following a failure in the compensation flows in the previous autumn in the acute scenario. In the chronic scenario where there is a long term drought, it is unlikely that the invertebrate life would have recovered from the previous years lack of flow particularly as the flow variation is lost until late may 1977. There would be another failure of compensation water in October 1977, which will cause a further impact on the already stressed invertebrate population. The length of time taken for the macroinvertebrate population to return to a pre drought/normal level would increase particularly as the amount of drift is restricted due to the dam, the low population densities within the Clywedog system and the nature of the substrate.

EA drought order
There would be an improvement to the situation as compared to the do nothing scenario as there would be no compensation flow failure and an improvement in the length of time without flow variation. This can only help to reduce the severity of the effects of the drought on the invertebrate population reduce the length of time that the macroinvertebrate community will take to recover from the drought after the flows have recovered.

Full in combination
Slight improvements are seen in the full in combination scenario, when flows are maintained at slightly lower level but for a longer period. Again the complete failure of compensation flow is avoided.

Vyrnwy Weir AP (Site ID 50350 , Afon Vyrnwy – Dolanog)

Acute
Do Nothing
This site appears to be responding to changes in flow and the declines in LIFE may be reflecting the low flow years 1995/6 and 2003 but there is a lack of data collected for this site in the years proceeding these dates and this makes interpretation of the data unreliable and estimating the recovery period difficult. The do nothing scenario does not cause a compensation flow failure but there are 174 days of no flow variation as the reservoir fills. The effects of changing the flow regime on the Vyrnwy and the likelihood that this would induce ecological change were dependant on the width, depth and flow at individual sites. Samples taken 5km downstream of the Dolanog site showed that flows fell well below the desirable 100mld, causing a drought reaction in the invertebrates as they move in to the smaller wetted areas. The changes in flow resulted in fluctuations in the area of submerged gravels and stones, which are important habitats for the invertebrate fauna. In order to determine the response of this site, future monitoring should include the use of cross sections of the river to look at the effect of the altering levels on wetted area and the exposure of substrate and sediments.

EA drought order
There are no improvements or deteriorations in flows when compared to the do nothing scenario.

Full in combination
The models show that there will be deterioration in the length of time (24 days longer) without flow variation. The greatest impacts will be seen closer to the dam as there less run off from the reduced catchment size when it does eventually start to rain.

Chronic
Do nothing
There appear to be 20 days of irregular failures of the compensation flows with a minimum of 17.46mld at the beginning of October 1977. The compensation failure, the extended period of reduced compensation flows (until April 1978) and lack of flow variation while the reservoir refills, will further exacerbate any detrimental response of the macroinvertebrate community following the previous years drought and extend

the period of recovery for the fauna to return to pre drought levels. The exact response will depend on the extent wetted area and the exposure of the substrate and sediments at specific sites.

EA Drought order
There will be a reduction in the number of days of irregular failures of the compensation flow predicted with the application of the drought order. This is an improvement on the 'do nothing' scenario, but there will still be an adverse effect on the macroinvertebrate life. The improvements can only help to reduce the severity of the effects of the drought on the invertebrate population reduce the length of time that the macroinvertebrate community will take to recover from the drought after the flows have recovered.

Full in combination
There is no failure of compensation flows but the extended period of reduced flows (until April 1978) and lack of flow variation while the reservoir refills will have a detrimental effect and increase the time taken for the macroinvetebrate community to recover, however this is an improvement on the do nothing and the EA drought order scenario as there is no compensation flow failure. The reaches closest to the dam will be the more adversely affected as there will be less run off from the reduced catchment size when it does eventually start to rain. The flows in the river are still artificially elevated above what would naturally be present in a period of drought in a non regulated river and the system is likely to better off than many of the other watercourses in the locality.

Buildwas AP (Site ID 52795, Severn – Coalport)

Acute

Do nothing
Historic data suggests that this site responds to flow and on occasions has suffered from flow stress. However, the nature of the site and the lack of data during and immediately after periods of low flow makes it difficult to draw any firm conclusions. The geomorphology of the River Severn as it flows through the Ironbridge Gorge may explain why this site may be more sensitive to changes in levels than other locations on the main Severn and has suffered from periods of flow stress in the past. When the flow is reduced through the rocky narrow channel, much of the riverbed will be left exposed. In order to determine the precise effect of reducing the flows within this short section of the Severn, cross sections and levels would need to be taken. Other sites within this stretch of river are likely to be slightly less sensitive to the reductions in flow.
The do nothing scenario will maintain the flow at 1100 Ml/d for nearly 2 months but then flow will be reduced to below 600mld at towards the end of October

EA drought order
The flows would drop by approximately 200Mld for August and September. Although the flows are lowered, they are still higher than what would naturally be present without the regulation. The EA drought order would provide a flow benefit for approx 20 days in the latter half of October.

Full in combination
Only slight improvements are seen in the full in combination scenario, when flows are maintained at slightly lower level but for a longer period but this is only a matter of a couple of days in early October.

Chronic

Do nothing

There is no significant flow failure but flows would be reduced to a lower level later in the season as the flows are not maintained by regulation. The invertebrate community in the Gorge has been shown to be stressed in periods of lower flows and therefore recovery time when flows do eventually improve is likely to be extended especially following a second year of low flows.

EA Drought Order

In this scenario there are no significant flow failures expected and there is a flow benefit in the latter part of autumn. Greater benefit is seen as regulation is continued, albeit at a lower level for a greater length of time in a critically flow stressed period.

Full in combination
Only slight improvements are seen in the full in combination scenario, when flows are maintained at slightly lower level but for a longer period but this is only a matter of days.

Bewdley AP (Site ID 52393, Severn - D/S Dowles Brook).

Acute
Do Nothing
There is a 20 day flow crash from mid October to beginning of November following the complete failure of compensation flows from Clywedog with a minimum flow of 336mld.

There was a pronounced deleterious effect on the invertebrate life in the latter part of 1975 and 1976. In 1975, the flow was maintained at the 730 Ml/d but this did present problems and the minimum flow was 450mld. This is 100Mld higher than predicted in the do nothing scenario. Observations made at the time likely to be exacerbated with even lower flows that are modelled in the do nothing scenario but the true extent of reduction can not be predicted accurately until cross sections of the river bed are taken and related to river levels. It is highly probable that the invertebrate life will be greater than has been seen before and the recovery time will be increased.

EA Drought Order.
If the drought order is applied and flows are maintained at 730Mld, there is no significant deterioration (within 10% of EFI) and flows are maintained at a higher level than if the natural course of events were allowed to continue, until it begins to rain at the beginning of November.

In the 1976 drought, the overall water quality at Bewdley was reported to have deteriorated during the summer months, especially in the periods of low flow. There has been a general upward trend in the ASPT at this site, indicating a general improvement in water quality at this site
In 1989, over the summer period to the end of September, Bewdley was maintained to 850Mld but there were a number of days when flows fell below this level with the lowest mean daily flow recorded at 706Mld. Flows also fell overnight to less than 650Mld on a number of occasions over a six hour period due to the overnight abstractions at Hampton Loade and Trimpley. A drought order was applied in late September 1989 and flows were maintained at 730Mld. There was a decline in the LIFE score during this period and it is probable that if the EA DO was applied to the modelled scenario, the macroinvertebrate population would be adversely affected. However, historically the invertebrate community does appear to recover relatively quickly after these events. This will be further aided by the improvements that have been seen in water quality since the mid 1970's and late 1980's.

Chronic

Do nothing

There is a flow crash in mid October with a flows falling significantly from the EFI (to the high risk band). The minimum flow is modelled to be 289Mld. This supports the conclusion of a significant flow impact and there is likely to be a severe detrimental impact on the invertebrate community.

During 1977, the drying of the riffle and narrowing of the wetted area was further exacerbated by the building of a boulder dam about half a metre high above the riffle to increase the water depth in the upstream pool. The effect of this was to mirror the drought of the previous year. This gives us an insight into the likely effect of a two year drought and the length of time taken for the invertebrates to recover. In this case life had recovered to pre drought conditions by spring 1978. However the modelled scenario flows are much lower than experienced in the actual drought of 1976 and therefore it must be concluded that there will be a much greater deterioration in the invertebrate community and the length of time taken to recover would be increased.

EA Drought order

Due to modelling issues it is difficult to assess the flow impacts with certainty. However it is expected that there would be no further adverse impacts, while more significant flow gains could be achieved if the drought continued for long enough.

Full in combination

Due to modelling issues it is difficult to assess the flow impacts with certainty. However it is expected that there would be no further adverse impacts, while more significant flow gains could be achieved if the drought continued for long enough

Saxons lode AP (Site ID 47463, River Severn – Upton on Severn)
Hawbridge/Deerhurst AP (Site ID 51327, River Severn – Hawbridge)

The invertebrate community appears not to be responding to variations in flow. The use of LIFE and PSI scores are unreliable as these indexes were not designed to be used with sampling technique used at these sites. An alternative method for monitoring the macroinvertebrates, such as airlifting needs to be trialled in the lower Severn. It has been suggested that the sparse and variable nature of the invertebrate community in these reaches is mainly due to the lack of suitable and stable habitat available in the lower reaches of the river, however until it can be monitored effectively across the whole width of the river, it is not possible to say for certain that this is the case.

It has not been possible to predict the impacts of the modelled scenarios on the invertebrate life in the lower part of the Severn. Future monitoring should include the use of cross sections of the river to look at the effect of the altering levels on wetted area and the exposure of substrate and sediments. This may help give further insight into predicting the response of the macroinvertebrate community.

ECOLOGY CONCLUSIONS

Any severe natural drought is likely to have a detrimental effect on the macroinvertebrate life within a river system. The exact response will depend on a number of variables and will differ according to the severity of the drought, the time of year and temperature i.e. it is likely to be more detrimental if the weather is hot. The response of individual invertebrate species very much depends on their individual life cycles and environmental preferences.
The biological data assessed within this report suggests that the upper and middle reaches of the River Severn invertebrate assemblages are responding to changes in flow. The sites have shown that flow sensitive ecology has been affected by low flows/drought events in the past. Reductions in LIFE scores in relation to the 1975/76, 1989/90 and1995/96 and 2010/11 droughts were detected. It is probable that in the scenarios given for the Severn Drought order and consequently the reduction in the amount of water that is being used for regulation, would have a negative impact on the macroinvertebrate community. Evidence from historical data suggests that the invertebrate life will recover relatively quickly. However it must be remembered the drought order is being used to prolong the length of time water is available for regulation of the River Severn. If the drought order was not applied i.e. the do nothing scenario, there would be a much greater deterioration in the invertebrate community and the length of time taken for the ecology to fully recover from the effects of a drought would be greatly increased.

Further work on the understanding of how flows impact the ecology of rivers and new tools will hopefully become available that will allow us to calculate the impact of modelled flows. Work is on- going in this area and it is hoped in future it will be possible to use a modelling approach on the regulated Severn.

Monitoring

Future Monitoring Requirements

To fully assess the impacts of the River Severn Drought Order, further regular invertebrate monitoring is required. This would ensure a complete set of baseline data is available at all flow conditions as a benchmark, against which to measure any impact on the macroinvertebrate community and then recovery time after a natural drought or Severn Drought Order event.

The sampling method used to the collect the invertebrate samples below Bewdley (i.e. Upton and Hawbridge) needs to be reassessed and the feasibility of monitoring the lower reaches of the freshwater section of the Severn needs to be investigated.

To gain baseline data it is proposed that the sites listed in Table 8 are monitored annually in spring and early autumn, with additional summer samples during natural drought events and Drought Order operation. All monitoring would be analysed to species level.

Table 8: Ecological Monitoring requirements

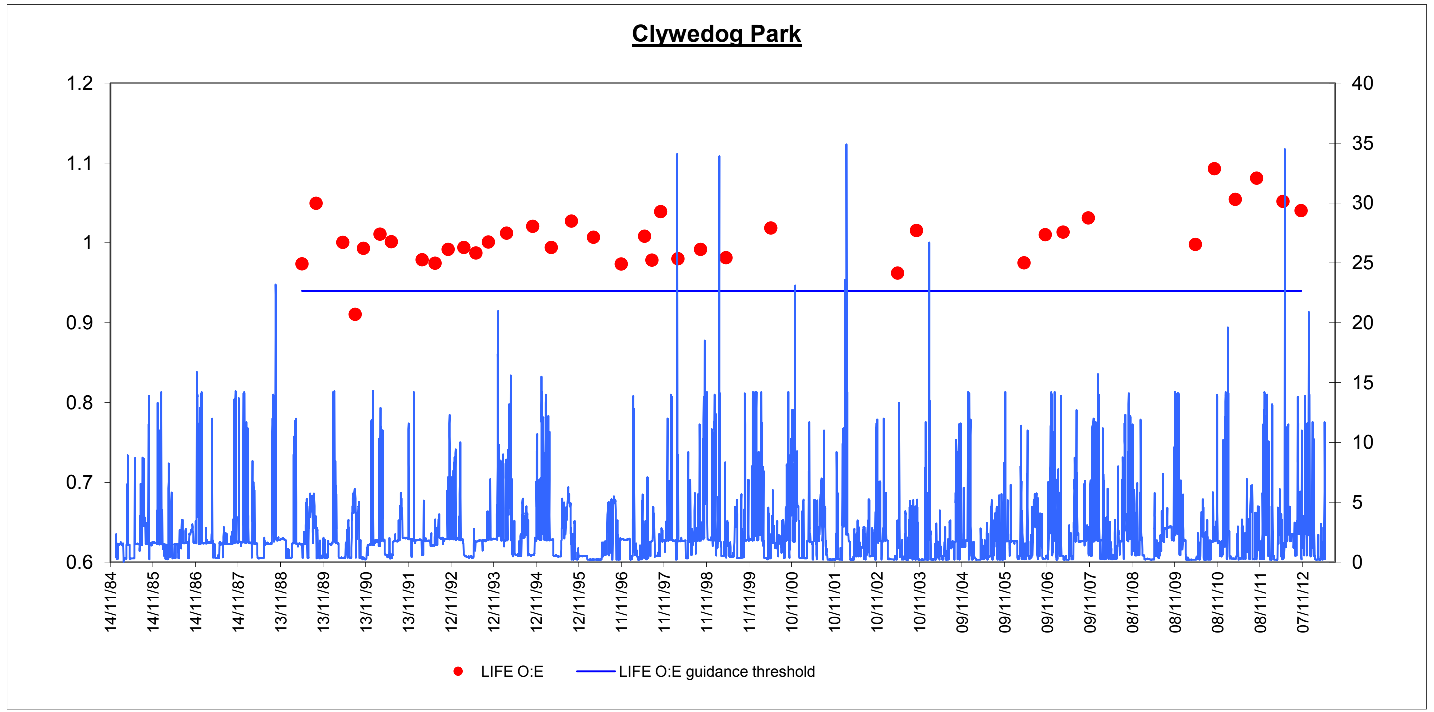
Watercourse	Site	Biosys ID	Grid reference
Clywedog	Caravan Park	49874	SN94000 85700
Vyrnwy	Dolanog	50350	SJ06780 12860
Severn	Dolwen	52148	SN 99700 85200
Severn	Isle of Bicton	51052	SJ 46773 16460
Severn	Cressage	52526	SJ 59380 04550
Severn	Buildwas	158364	SJ 64620 04425
Severn	Coalport	52795	SJ 70200 02100
Severn	d/s Dowles Brook	52393	SO78000 76400
Severn	Upton on Severn	47463	SO85050 40890
Severn	Hawbridge	51327	SO84500 27720
Tanat	Llanyblodwel	50766	SJ 24200 22900
Teme	Tenbury	48210	SO 59942 68511

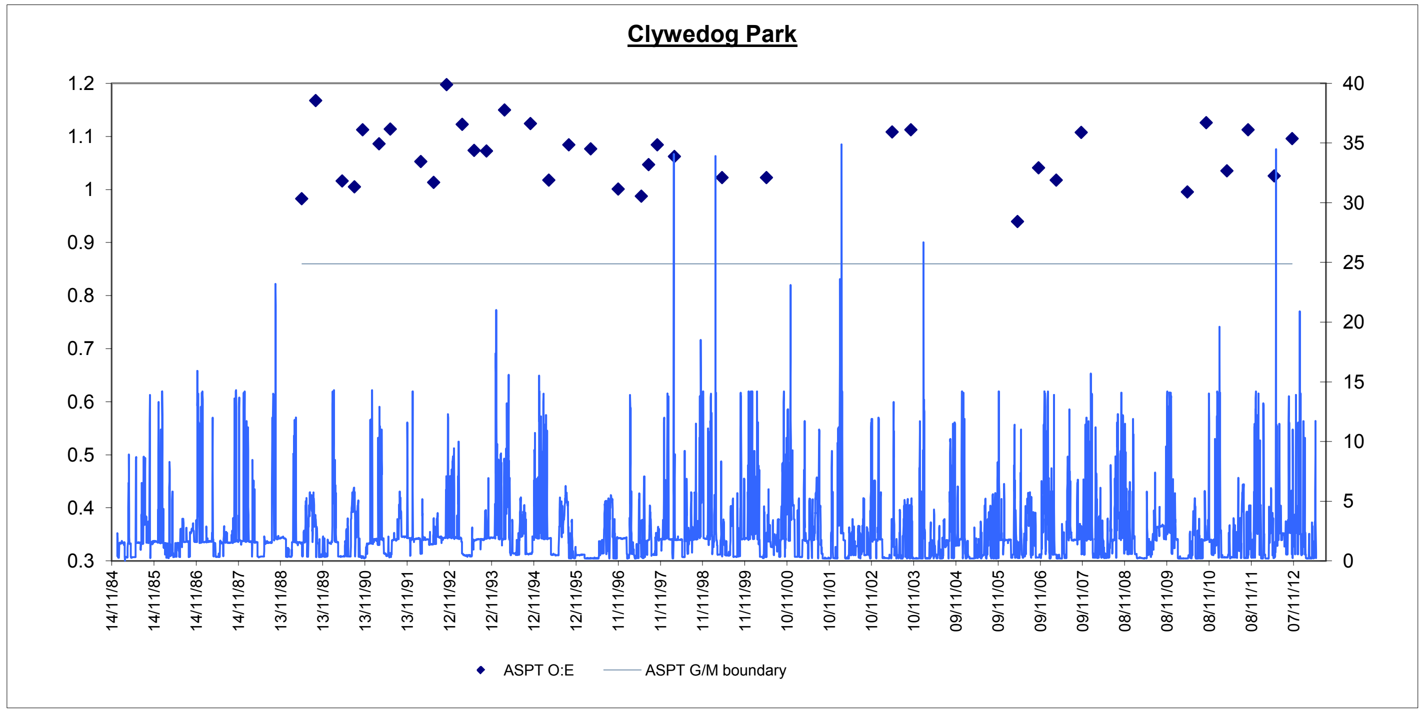
It is also proposed that a RHS survey is undertaken at each invertebrate site, as it is suggested that LIFE scores and LIFE flow relationships are influenced by physical habitat.

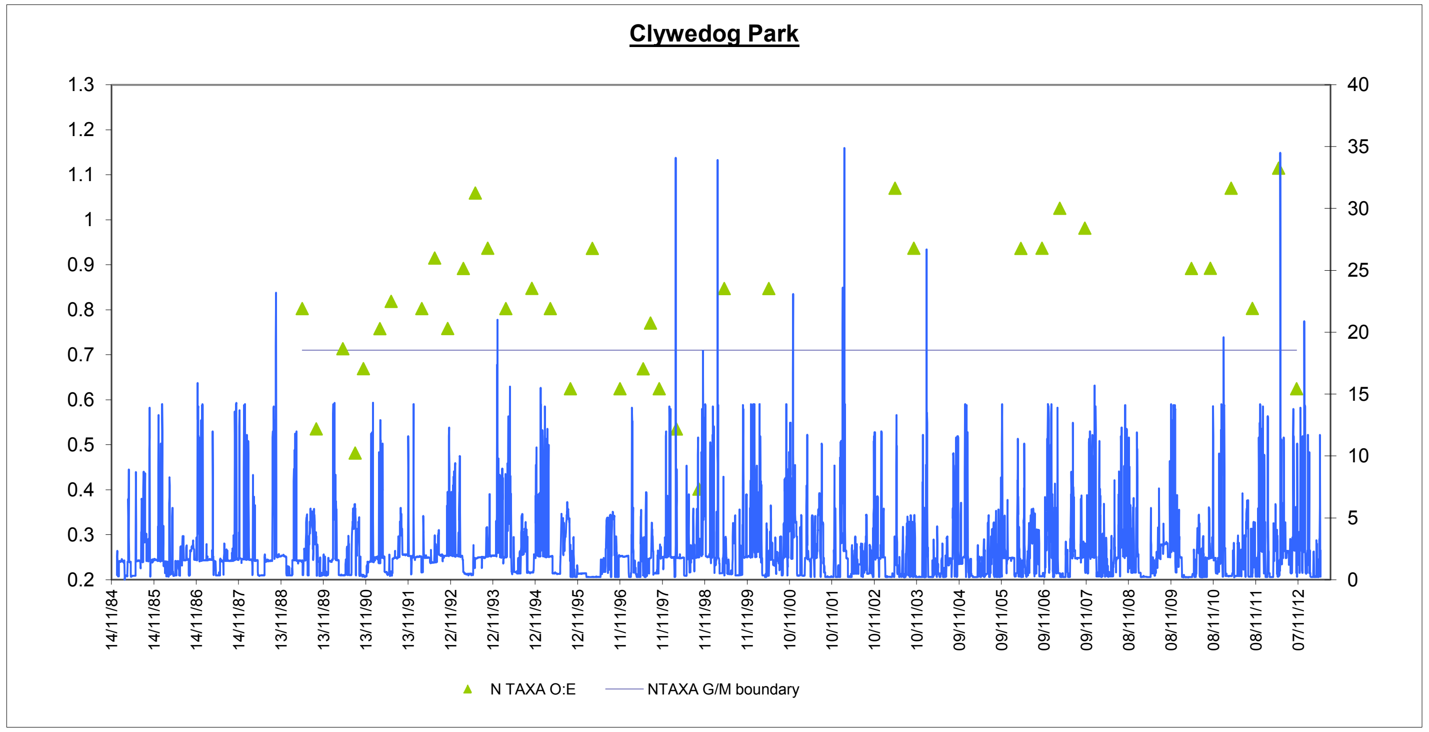
Appendix O.1

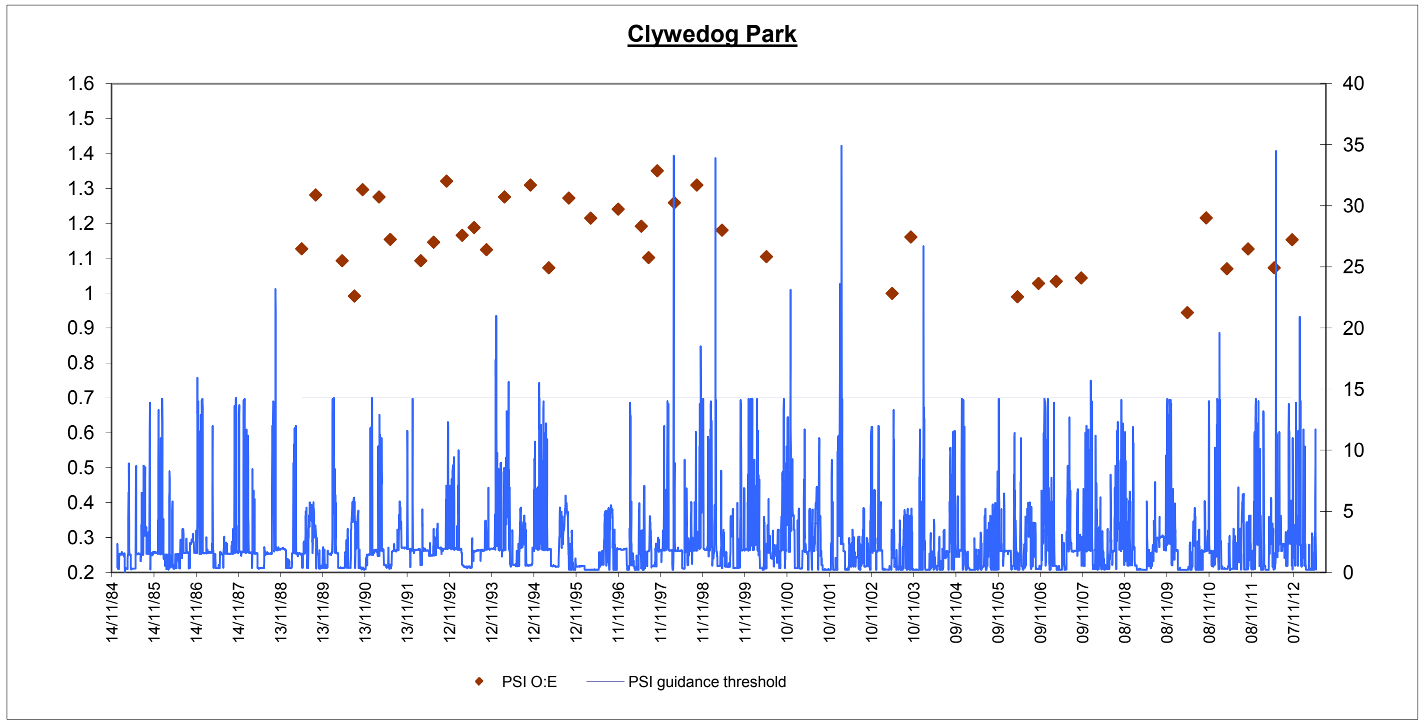
Macroinvertebrate HEV and drought response graphs

HEV plot at Clywedog, Caravan Park



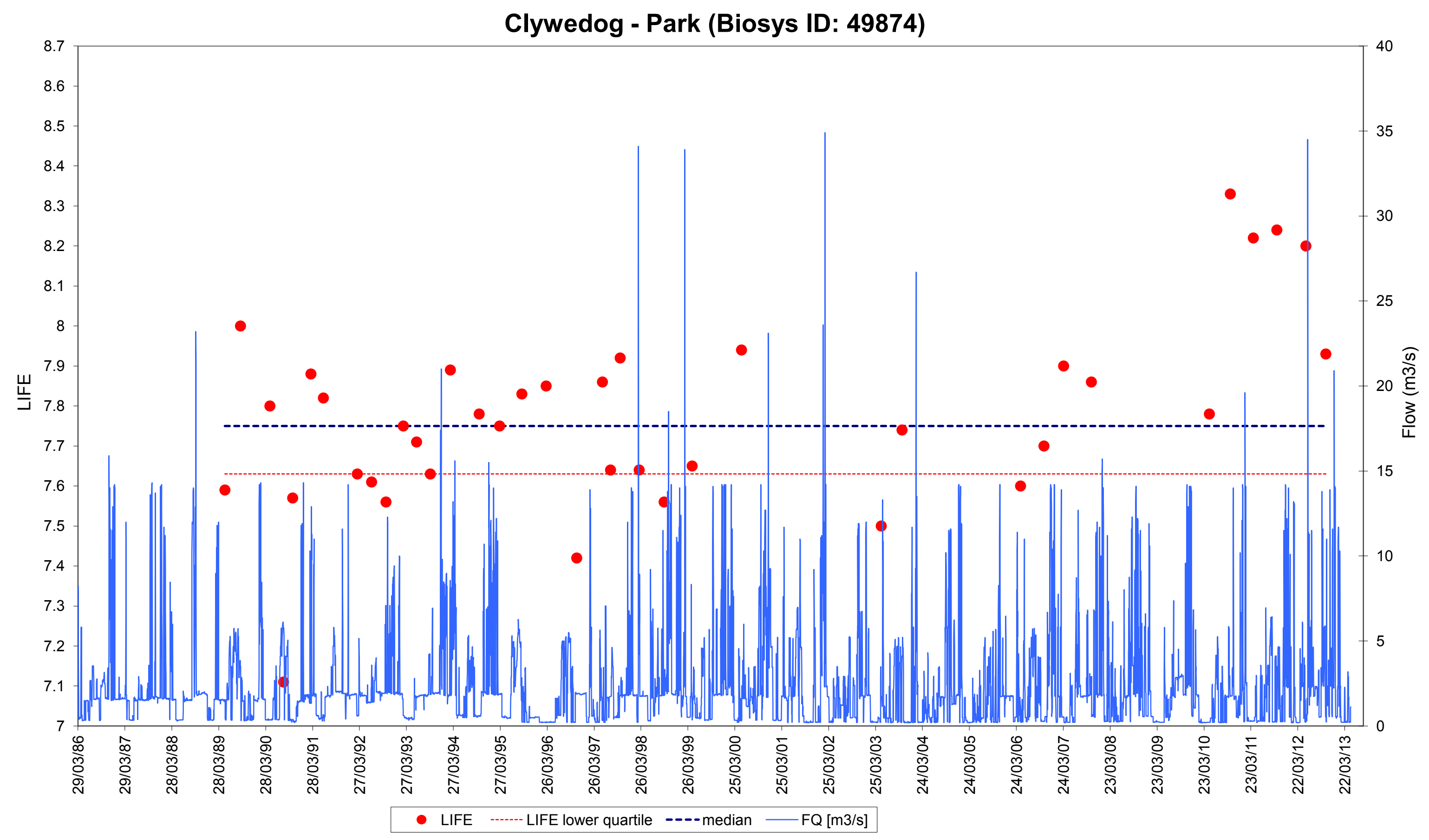


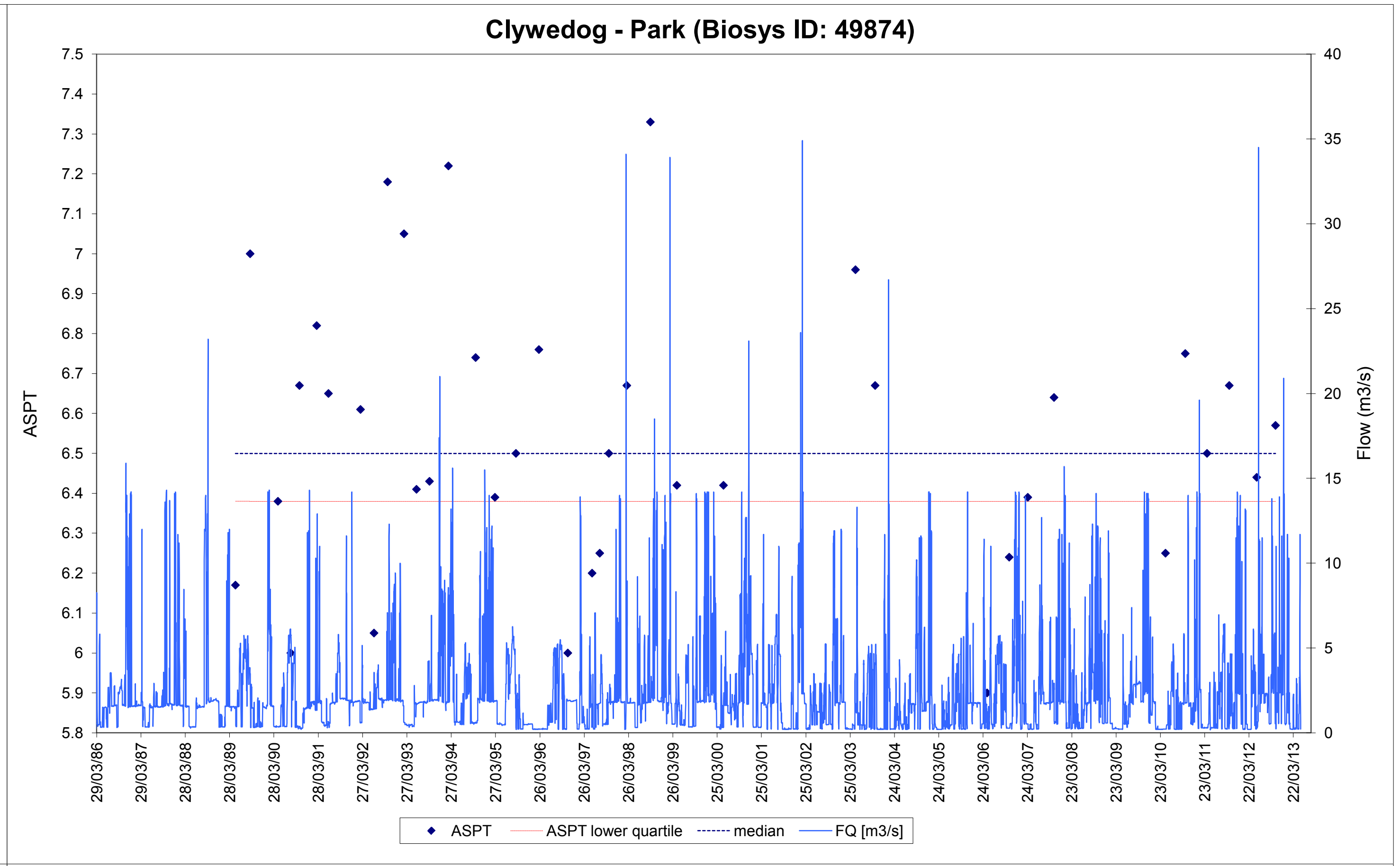


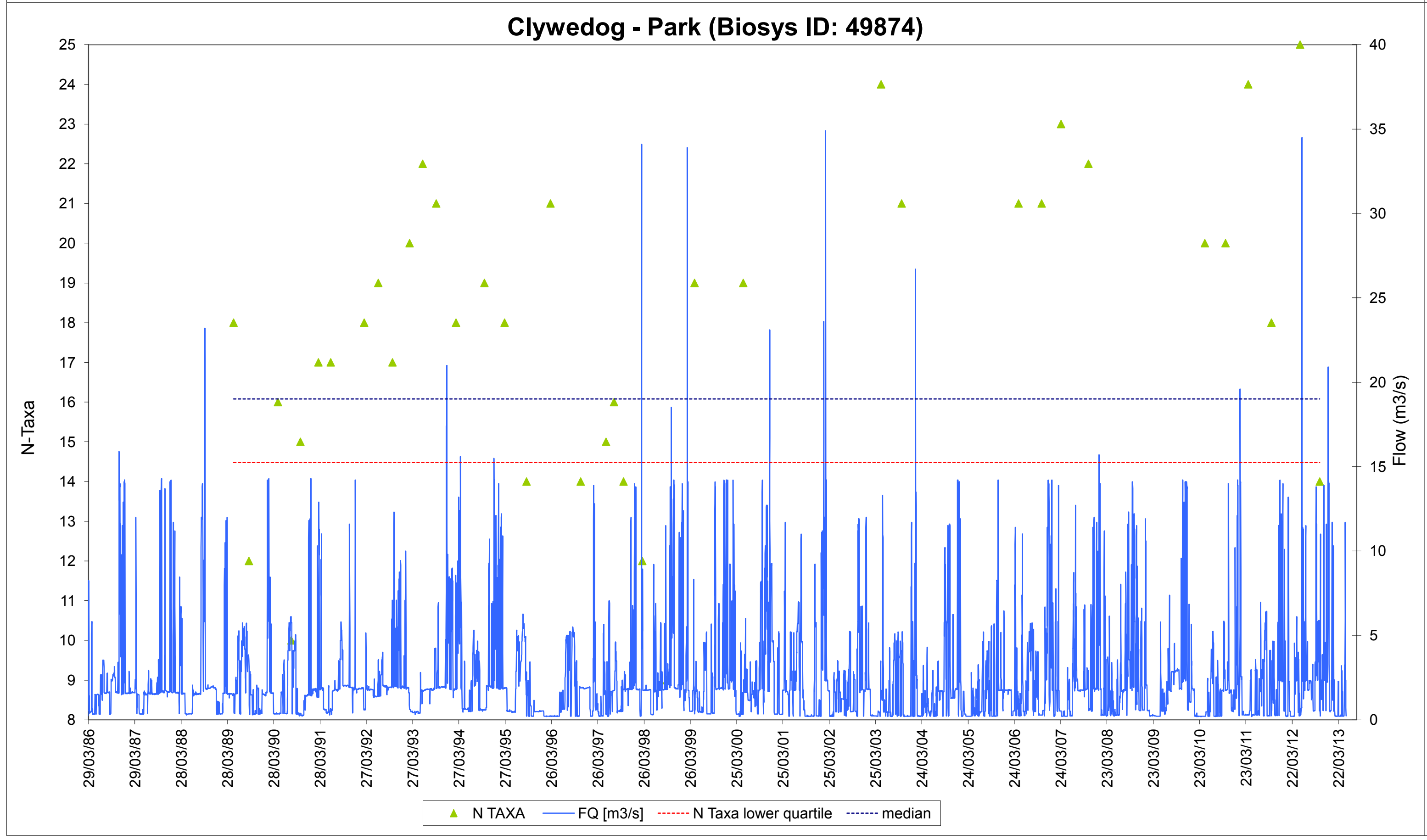


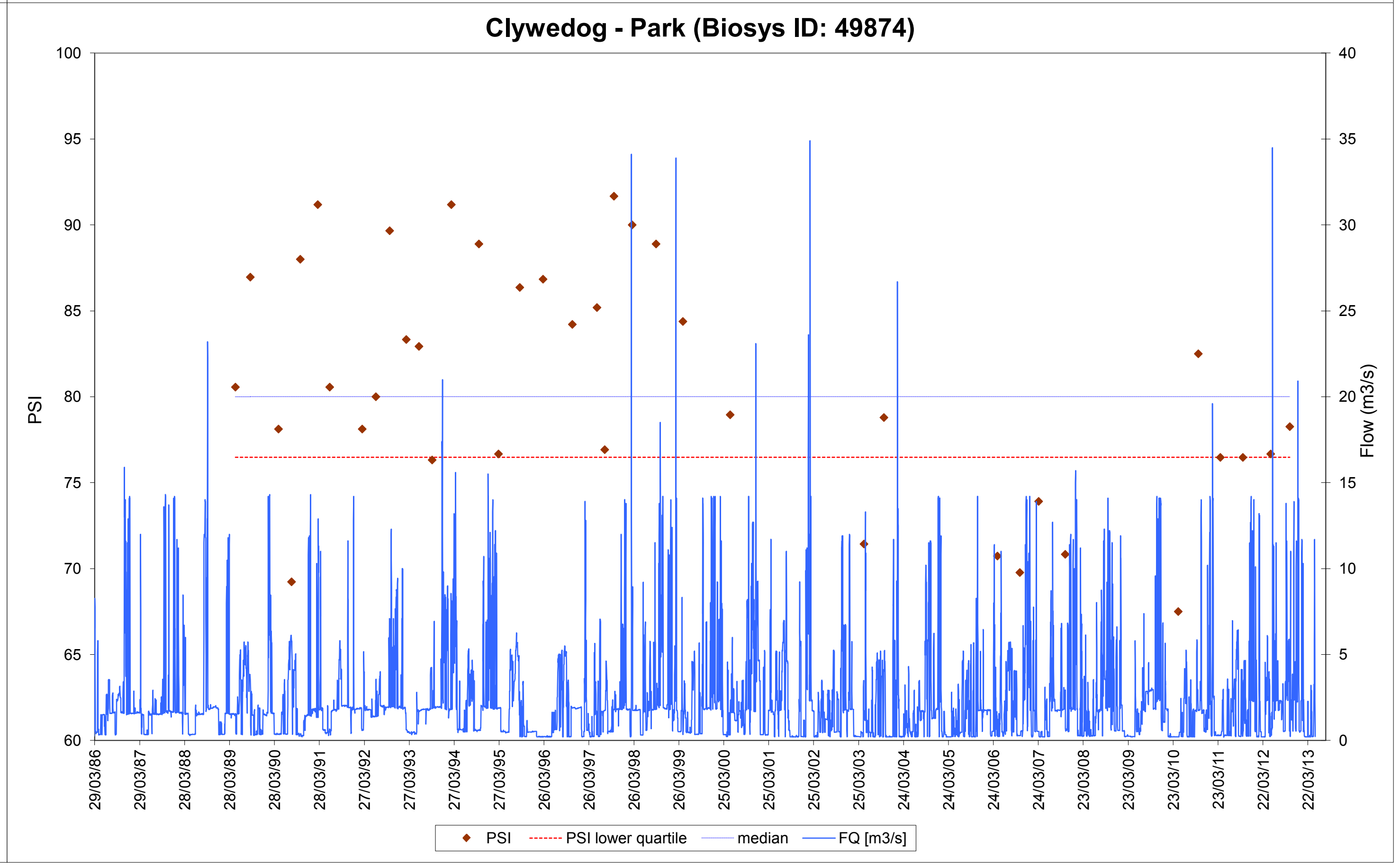
Drought response lta plot at Clywedog, Caravan Park

Clywedog - Park (Biosys ID: 49874)

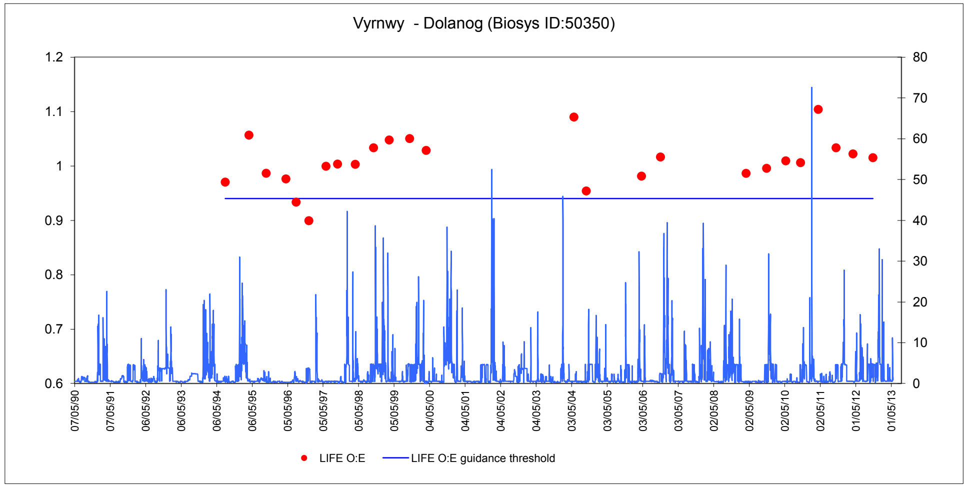


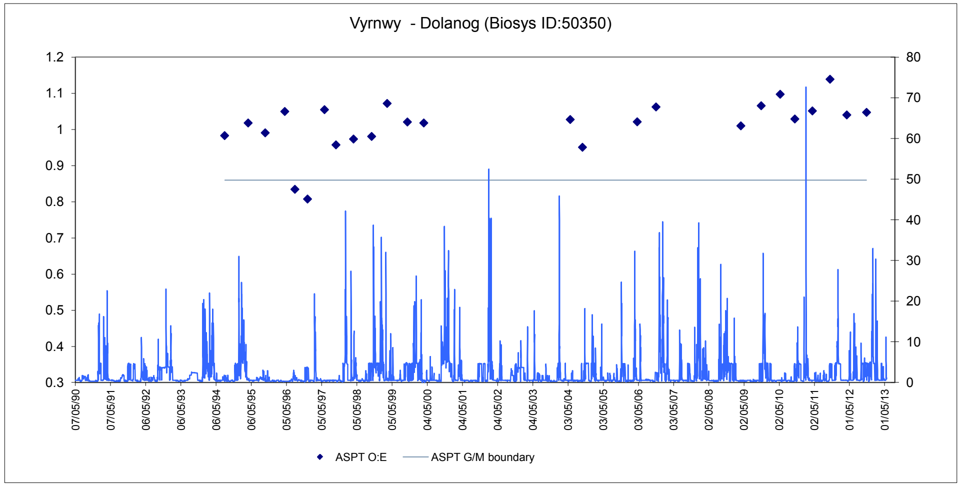


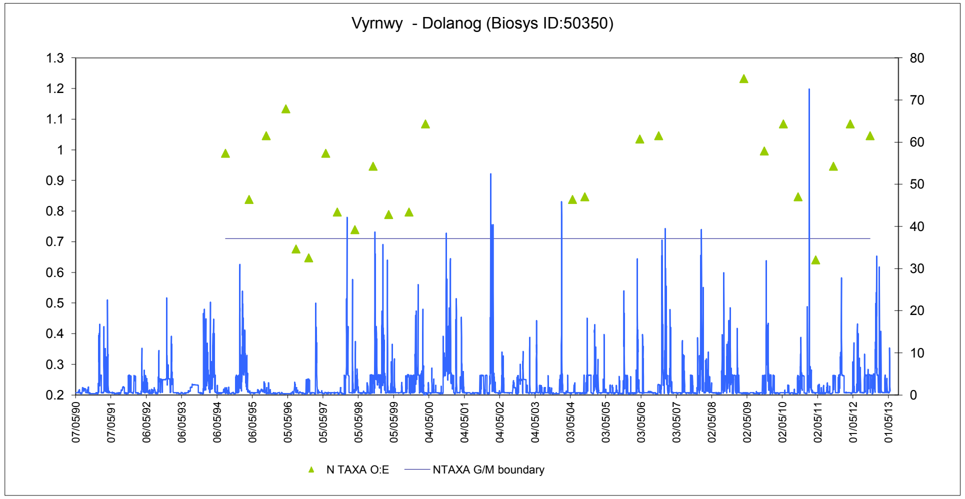


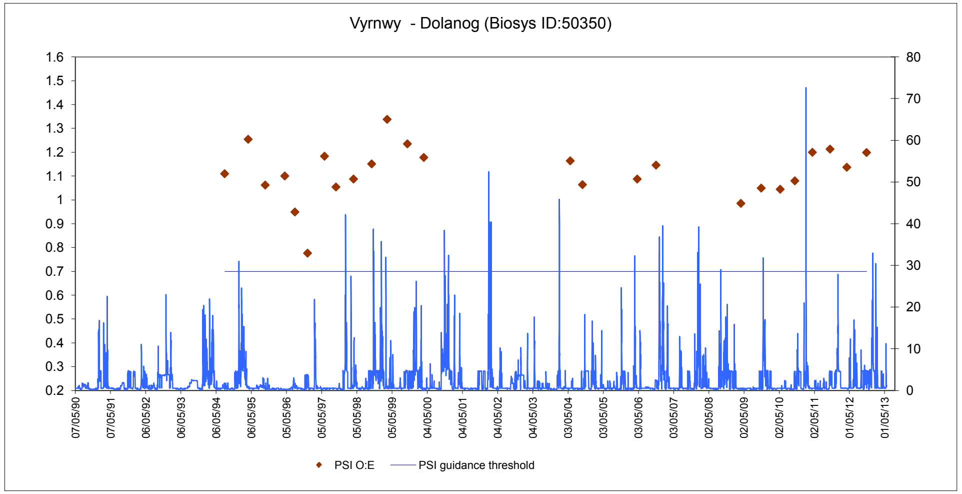


HEV plot at Vyrnwy, Dolanog



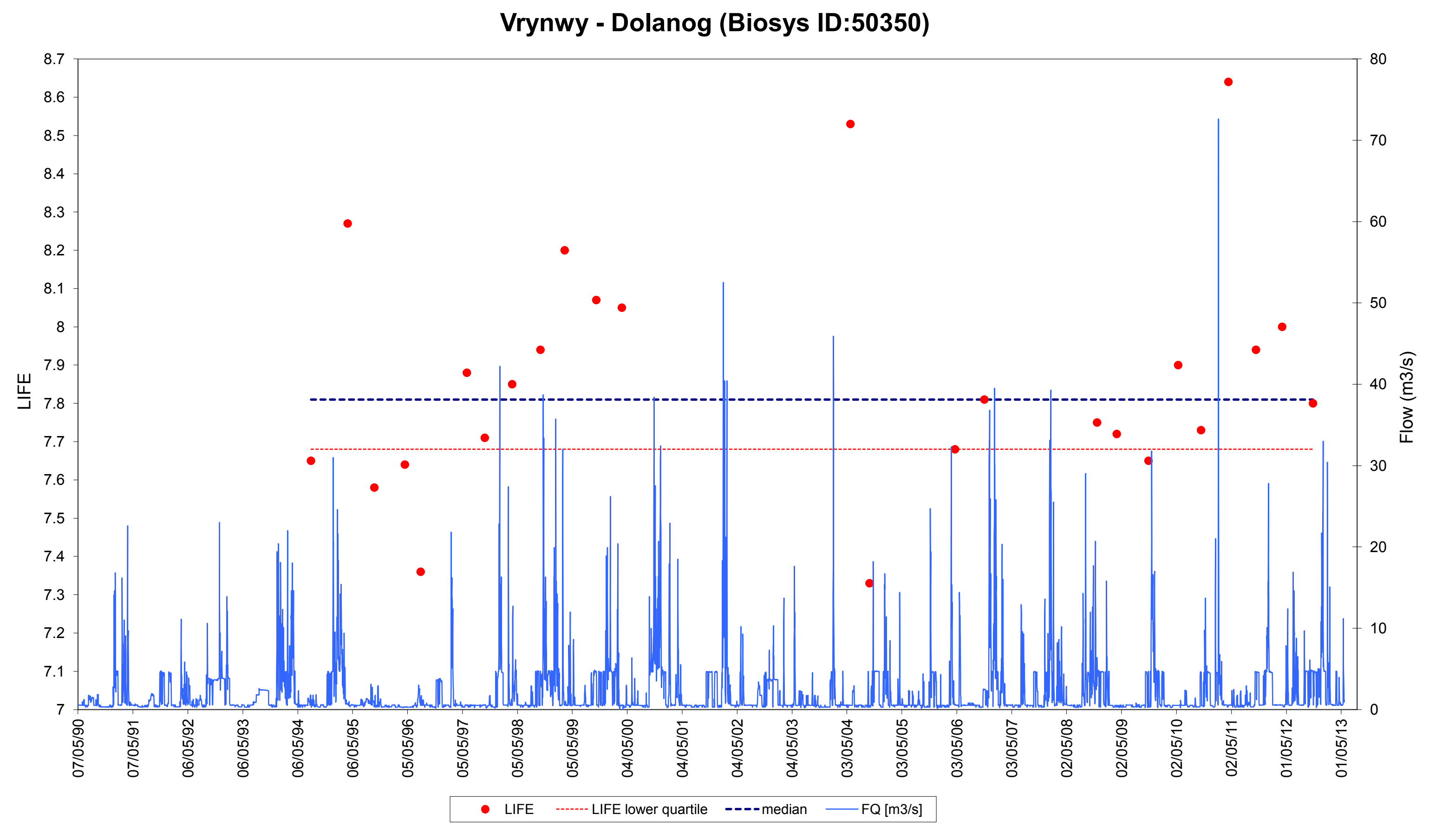


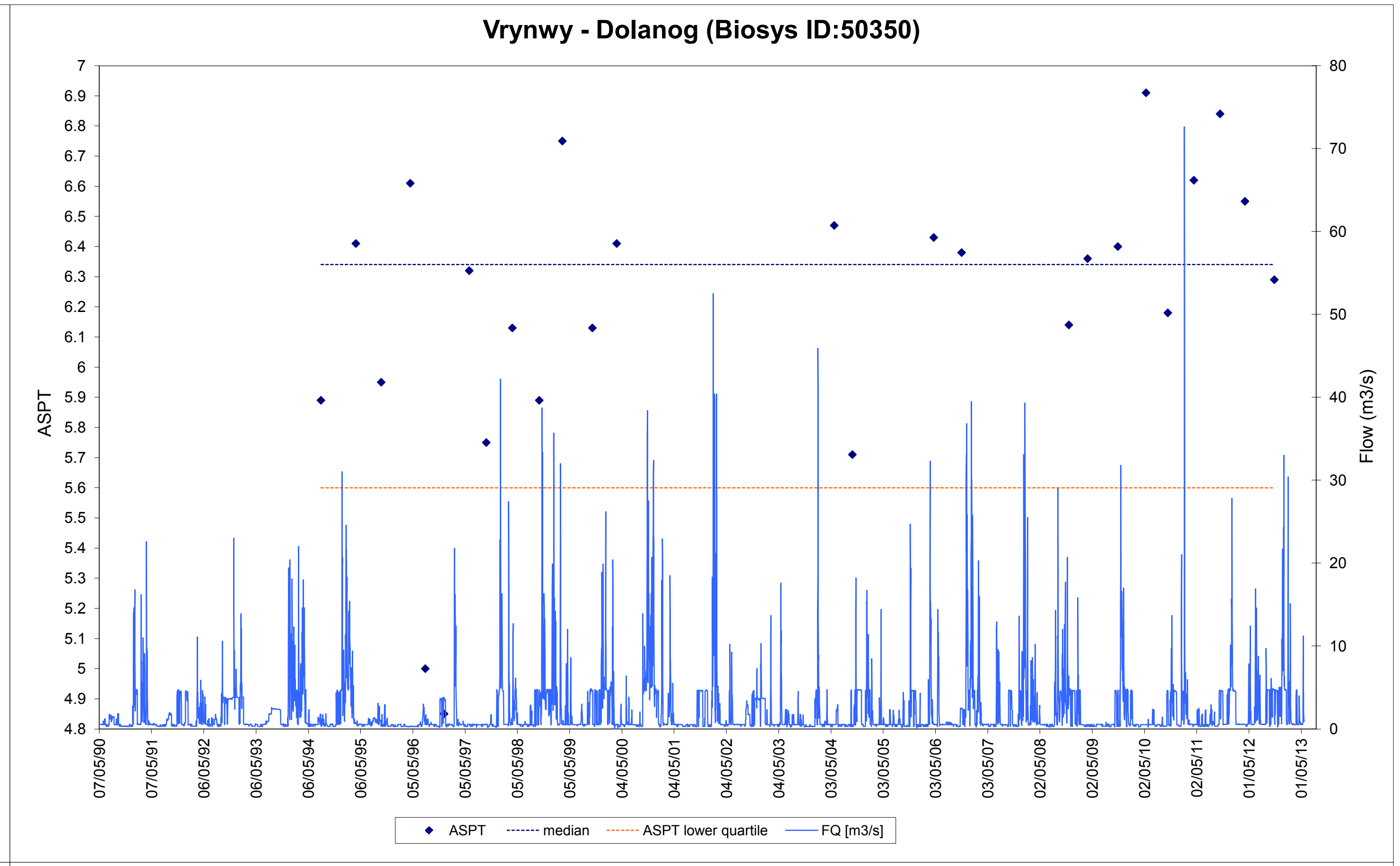


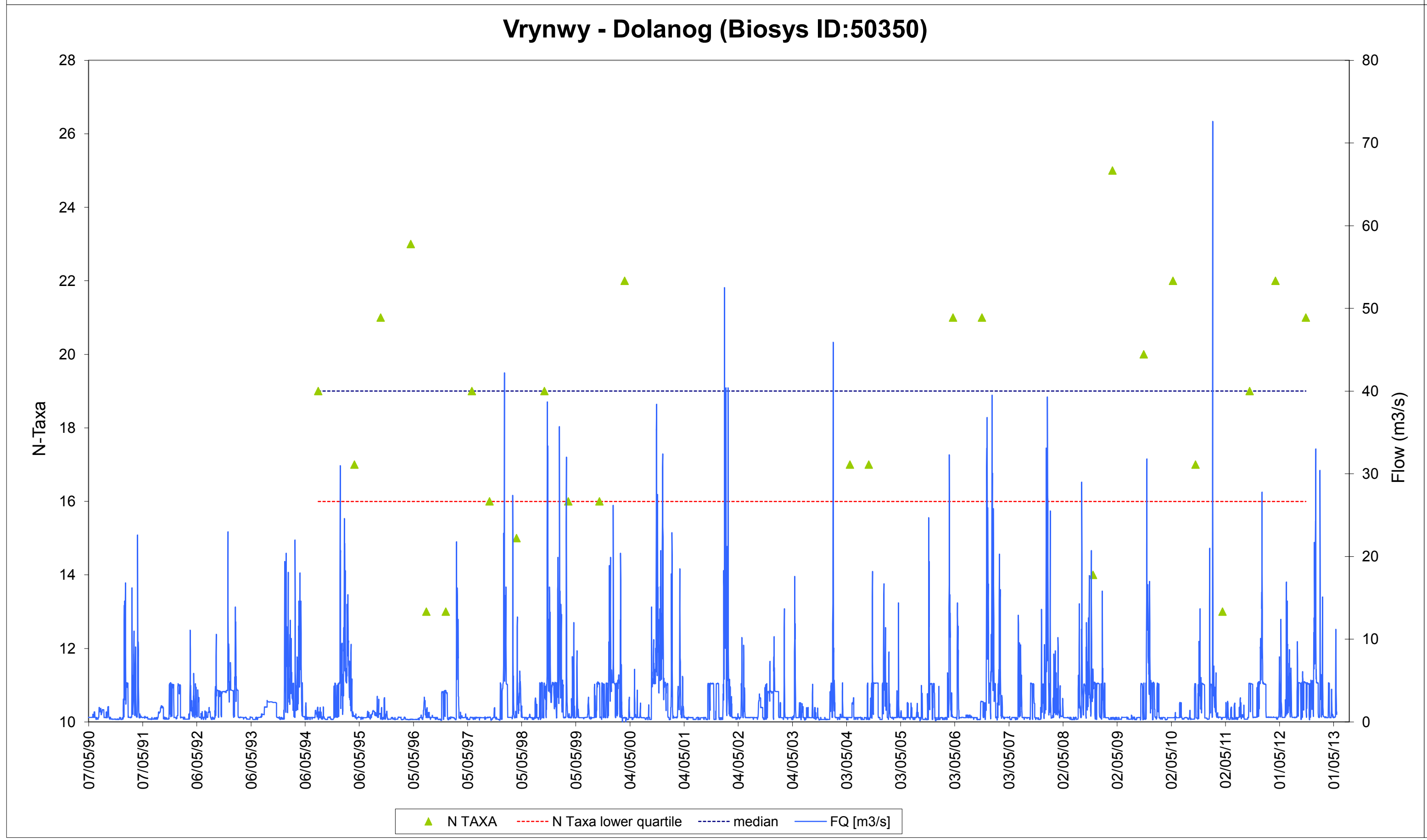


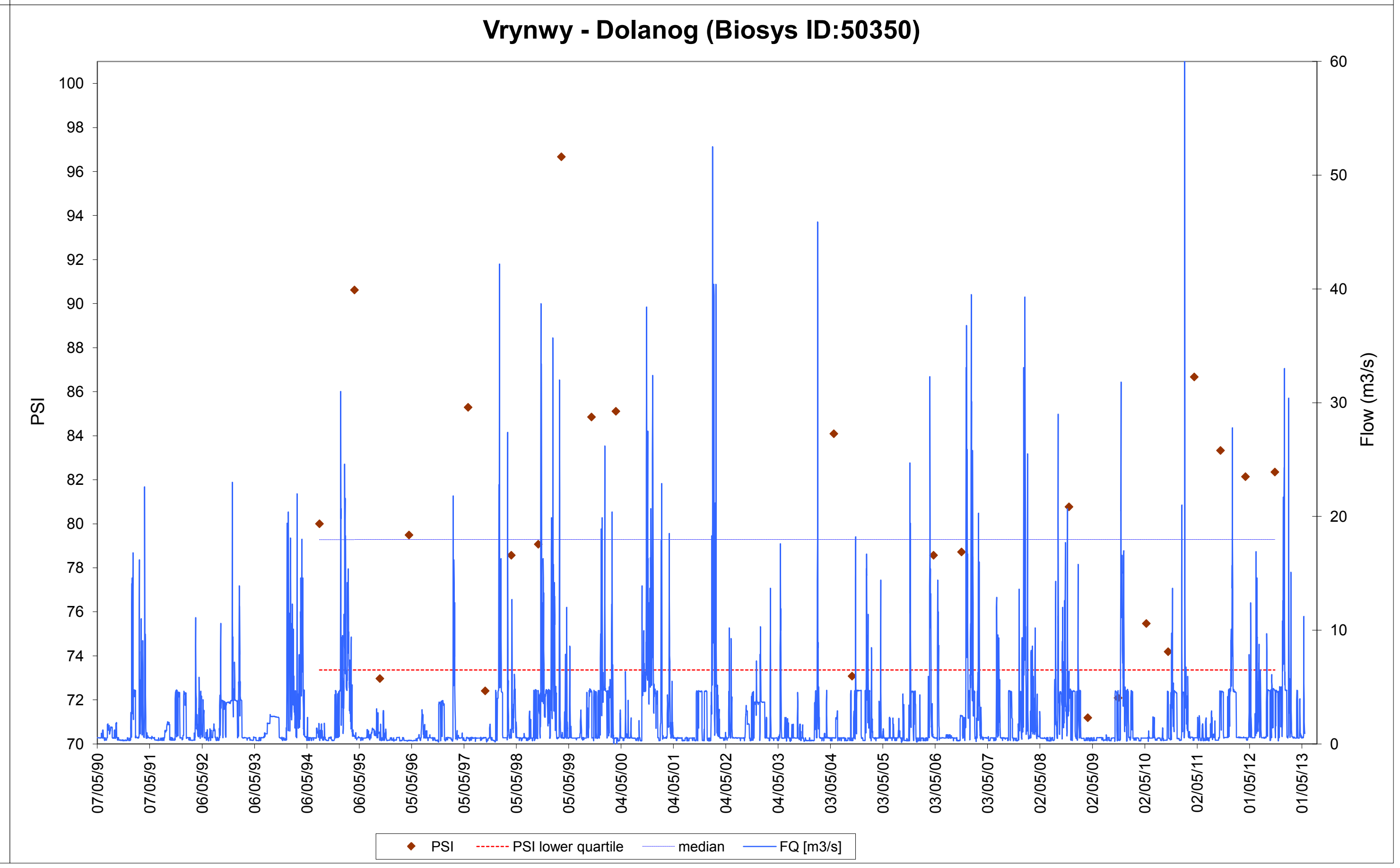
Drought response lta plot at Vyrnwy, Dolanog

Vrynwy - Dolanog (Biosys ID:50350)

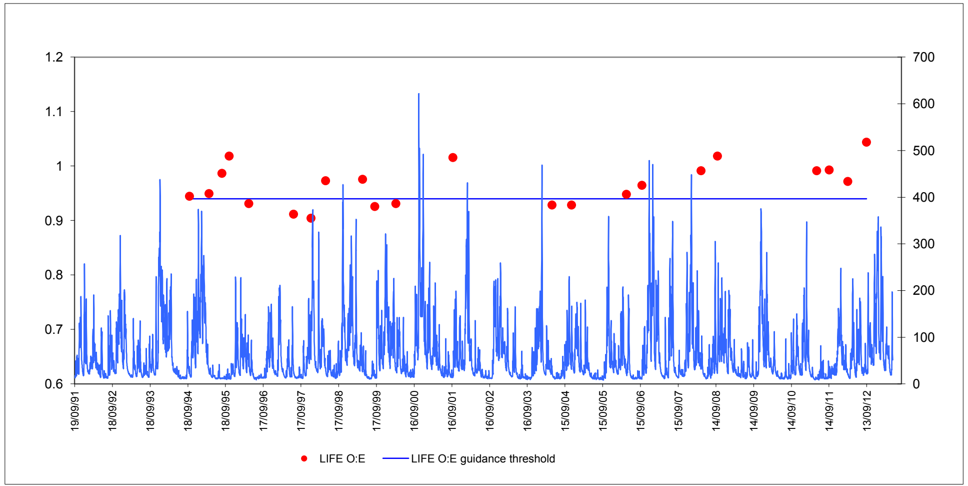


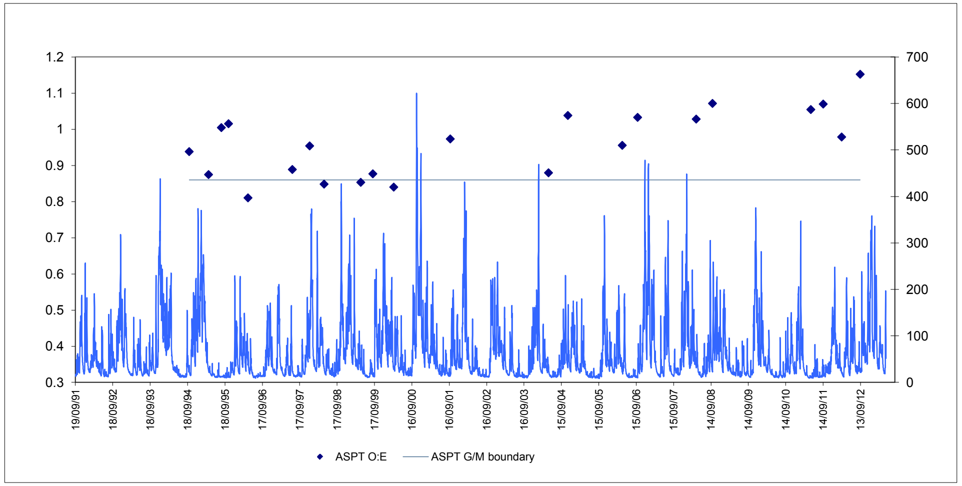


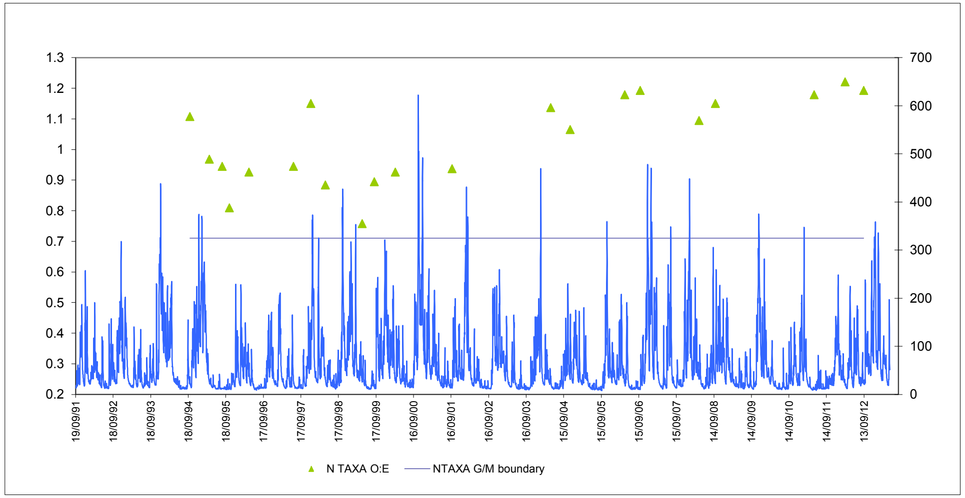


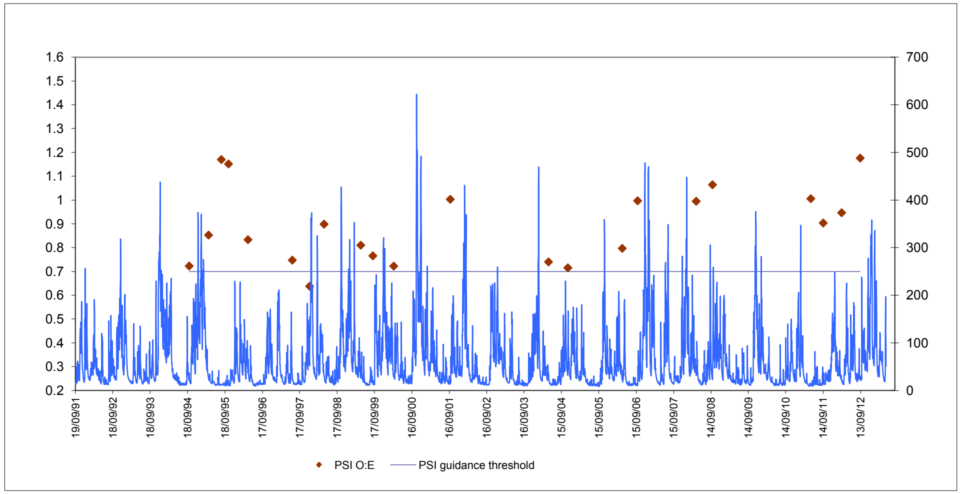


HEV plot at Buildwas, Coalport



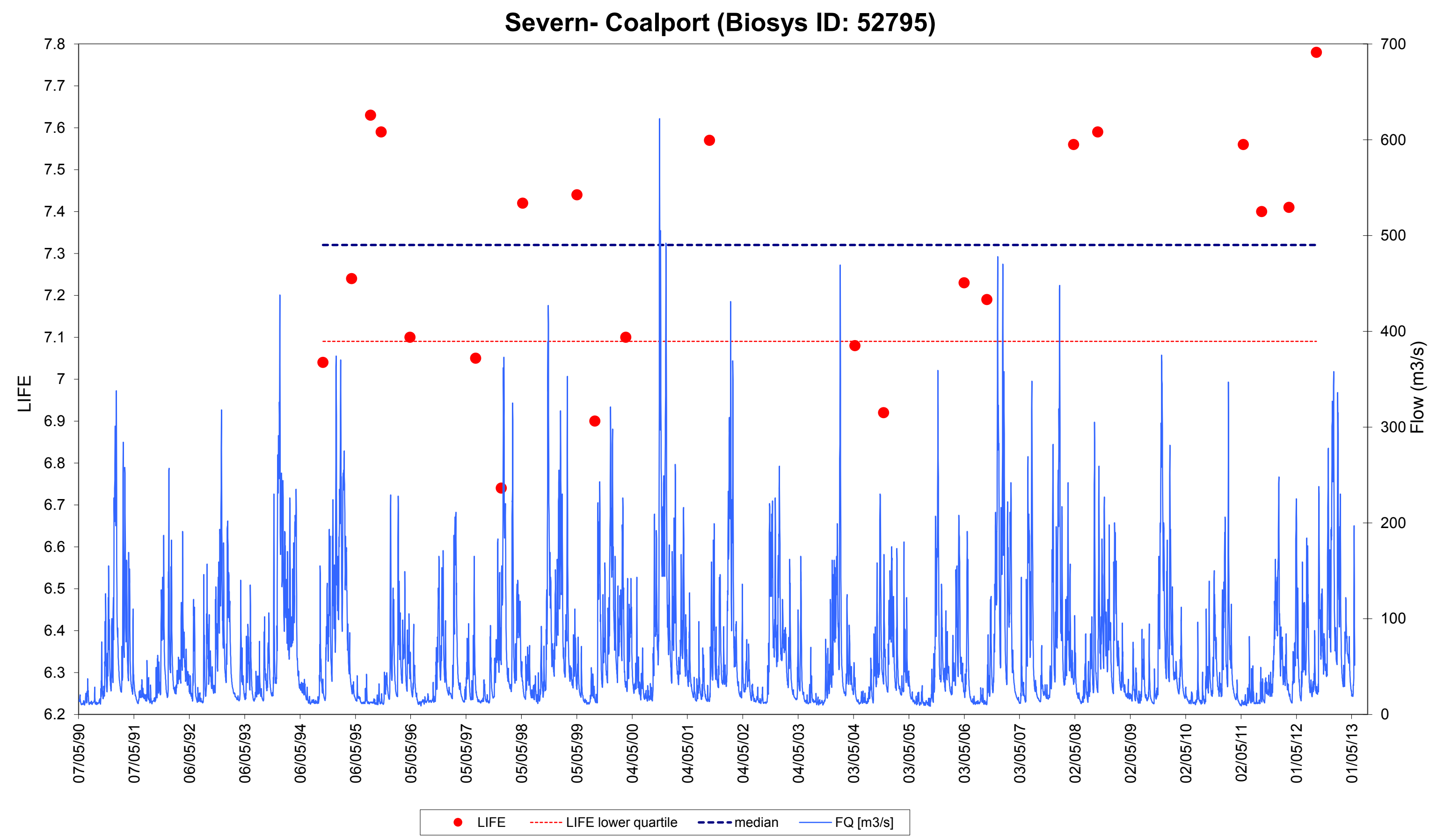


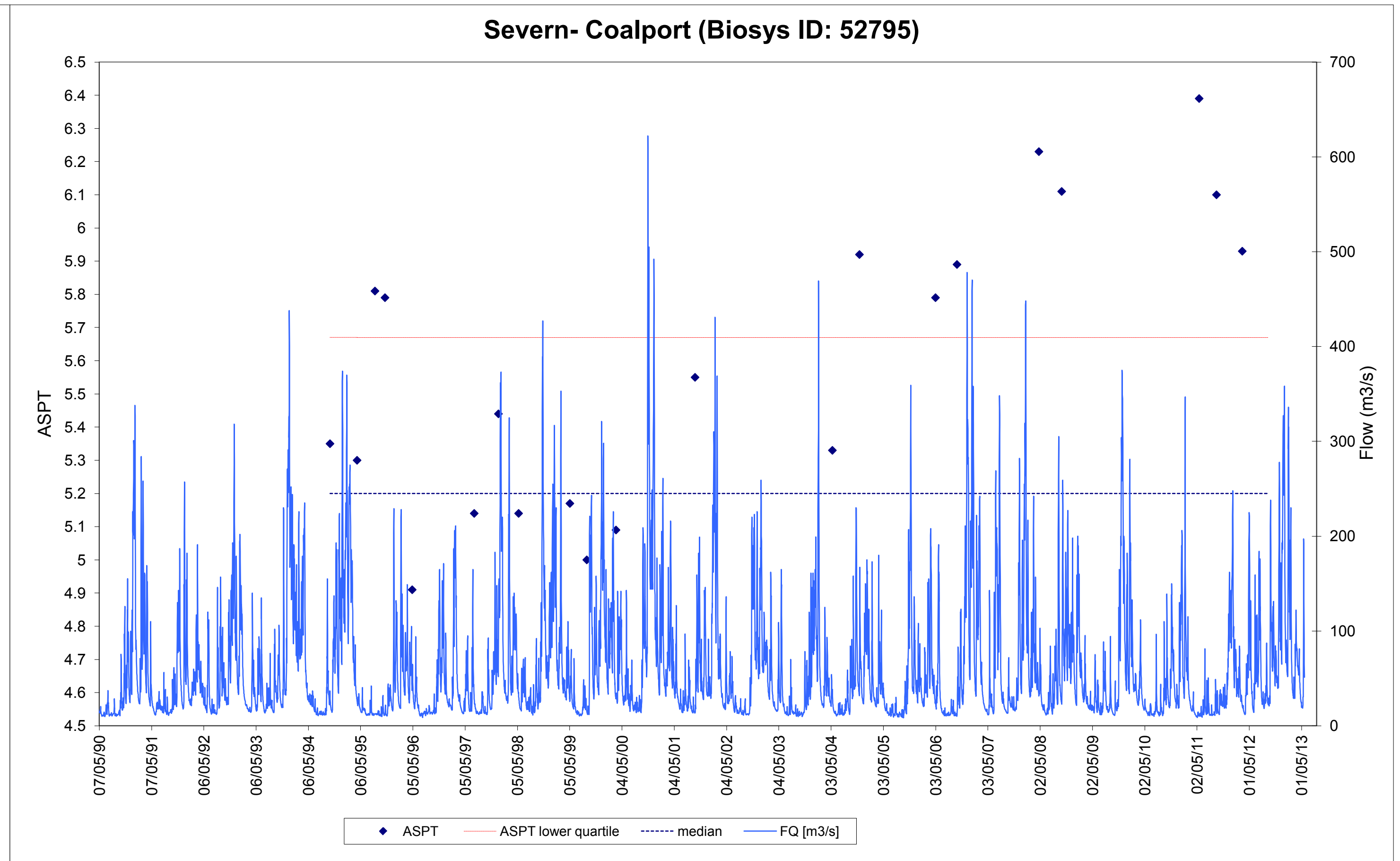


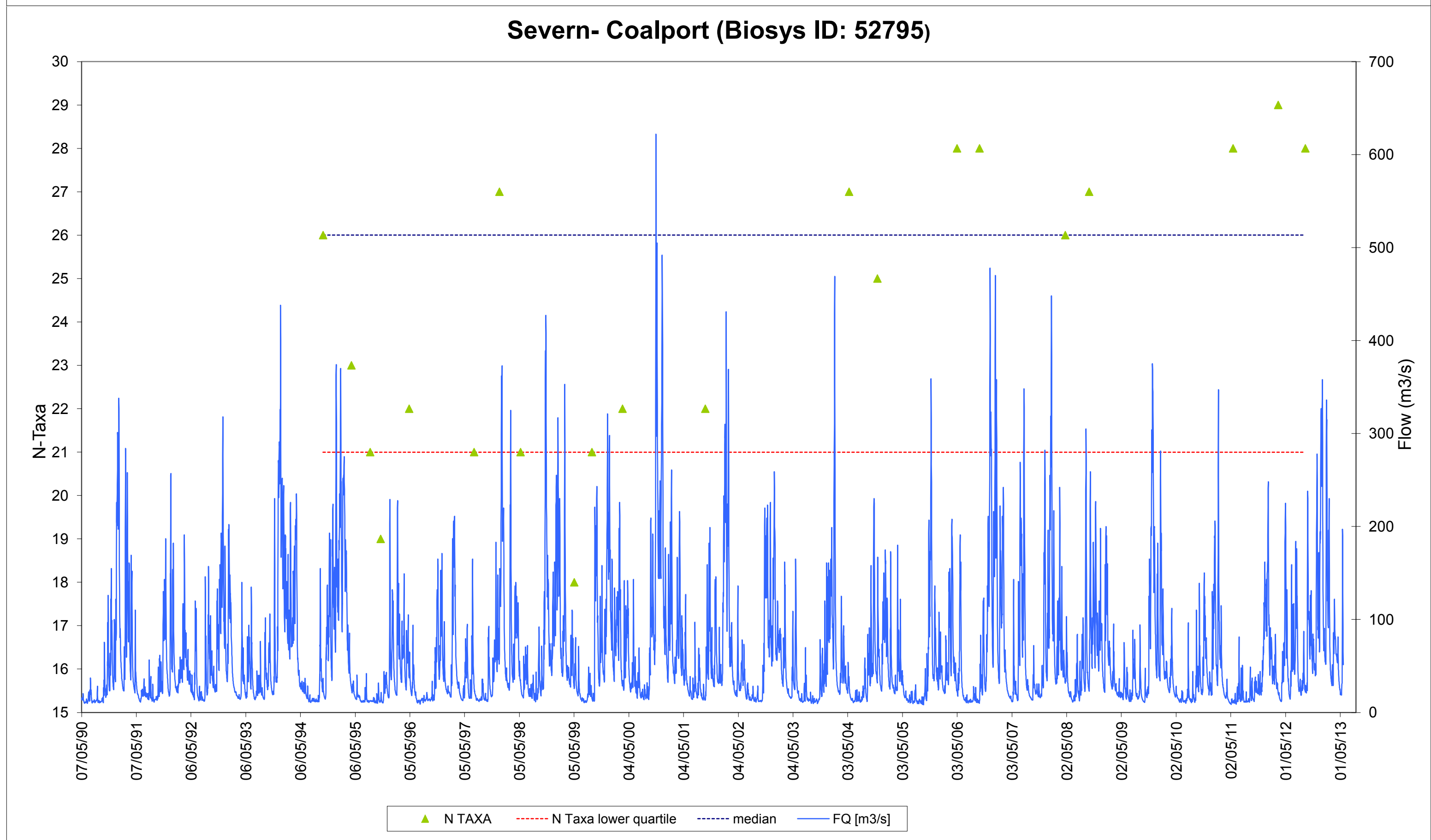


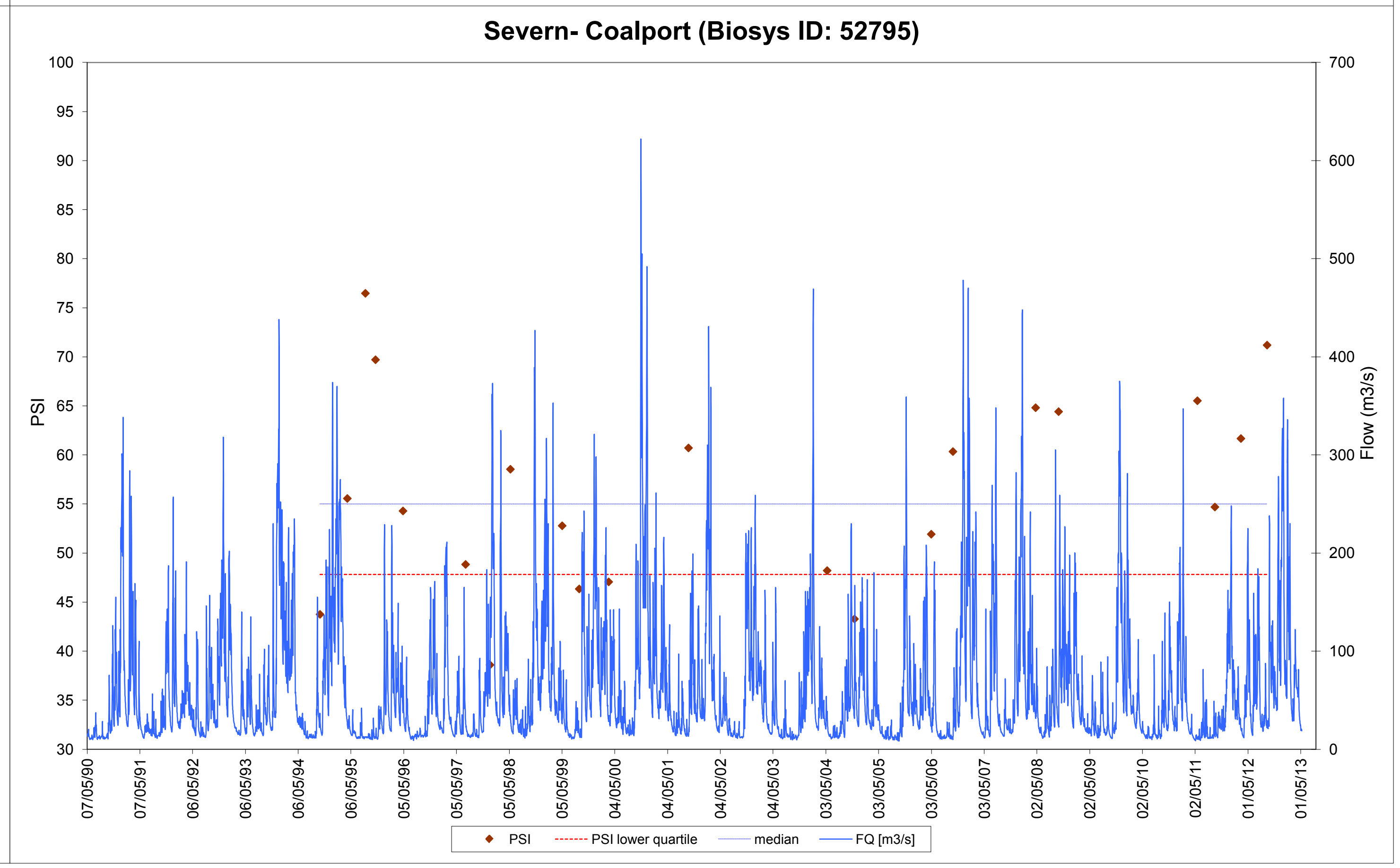
Drought response lta plot at Buildwas, Coalport

Severn- Coalport (Biosys ID: 52795)

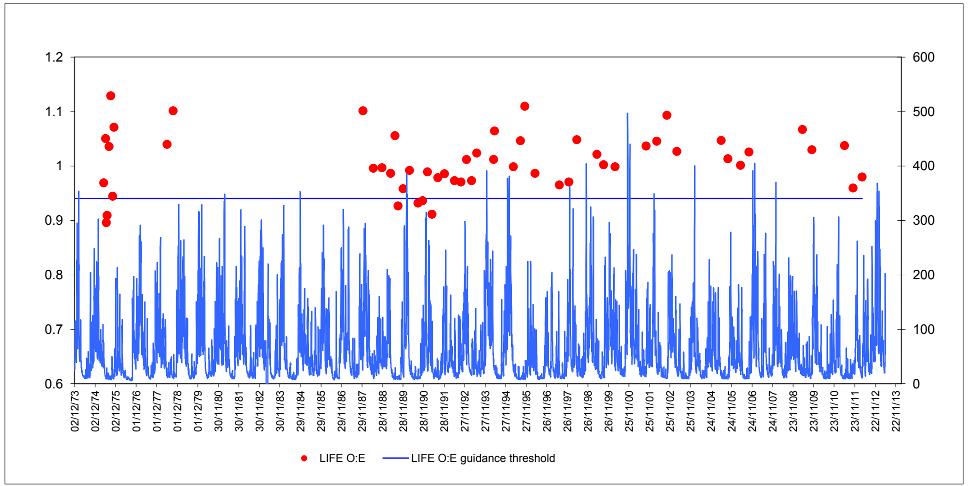


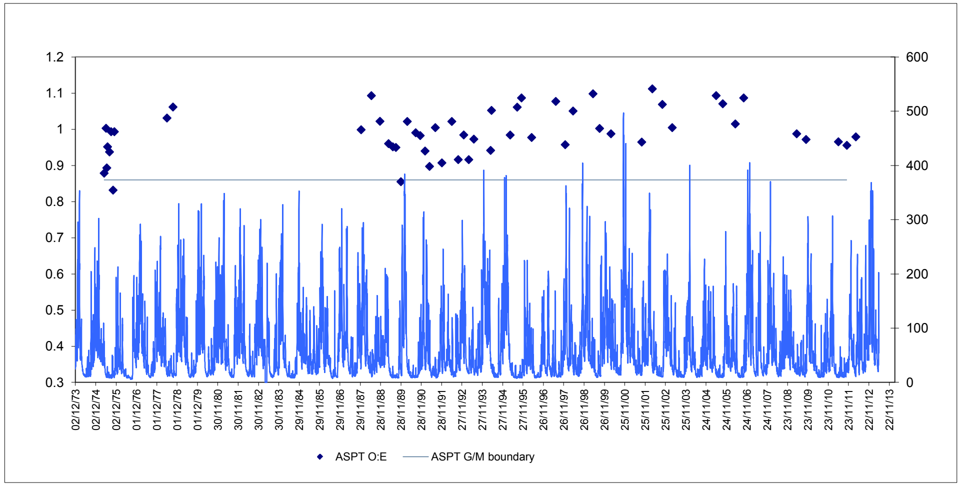


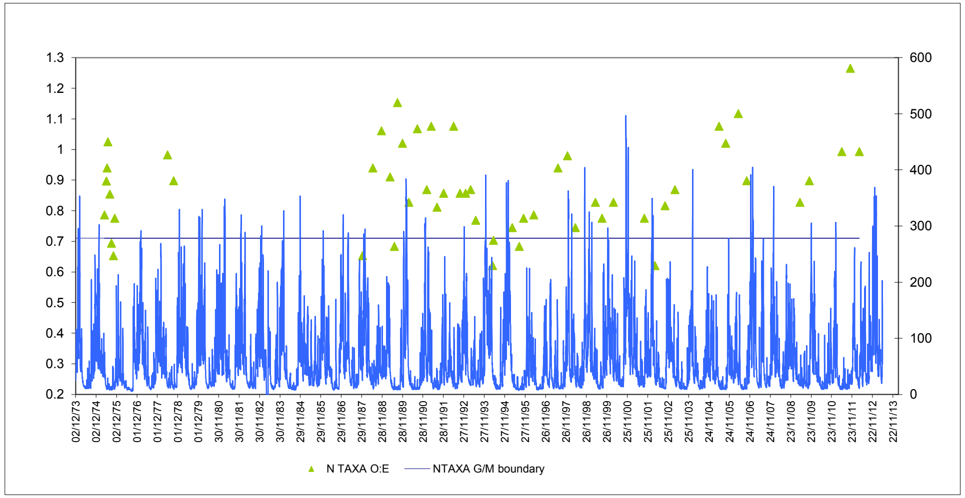


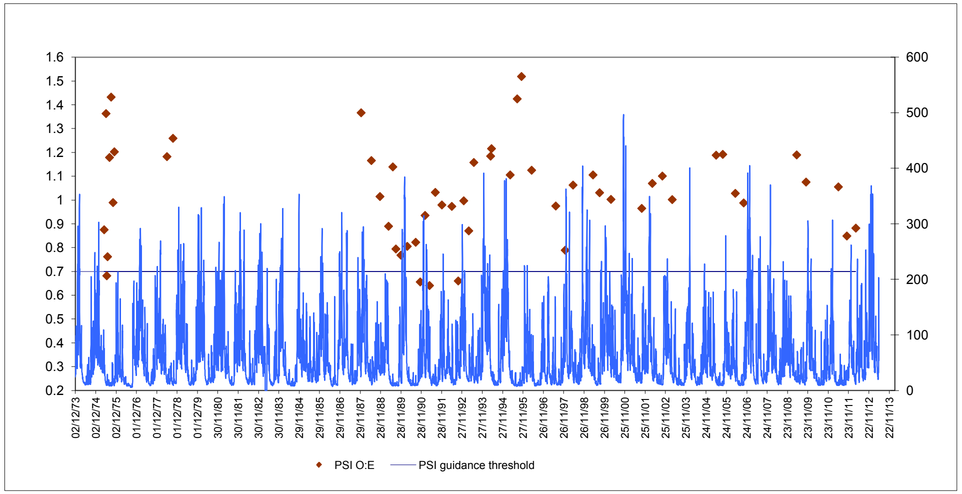


HEV plot at Bewdley, downstream Dowles Brook



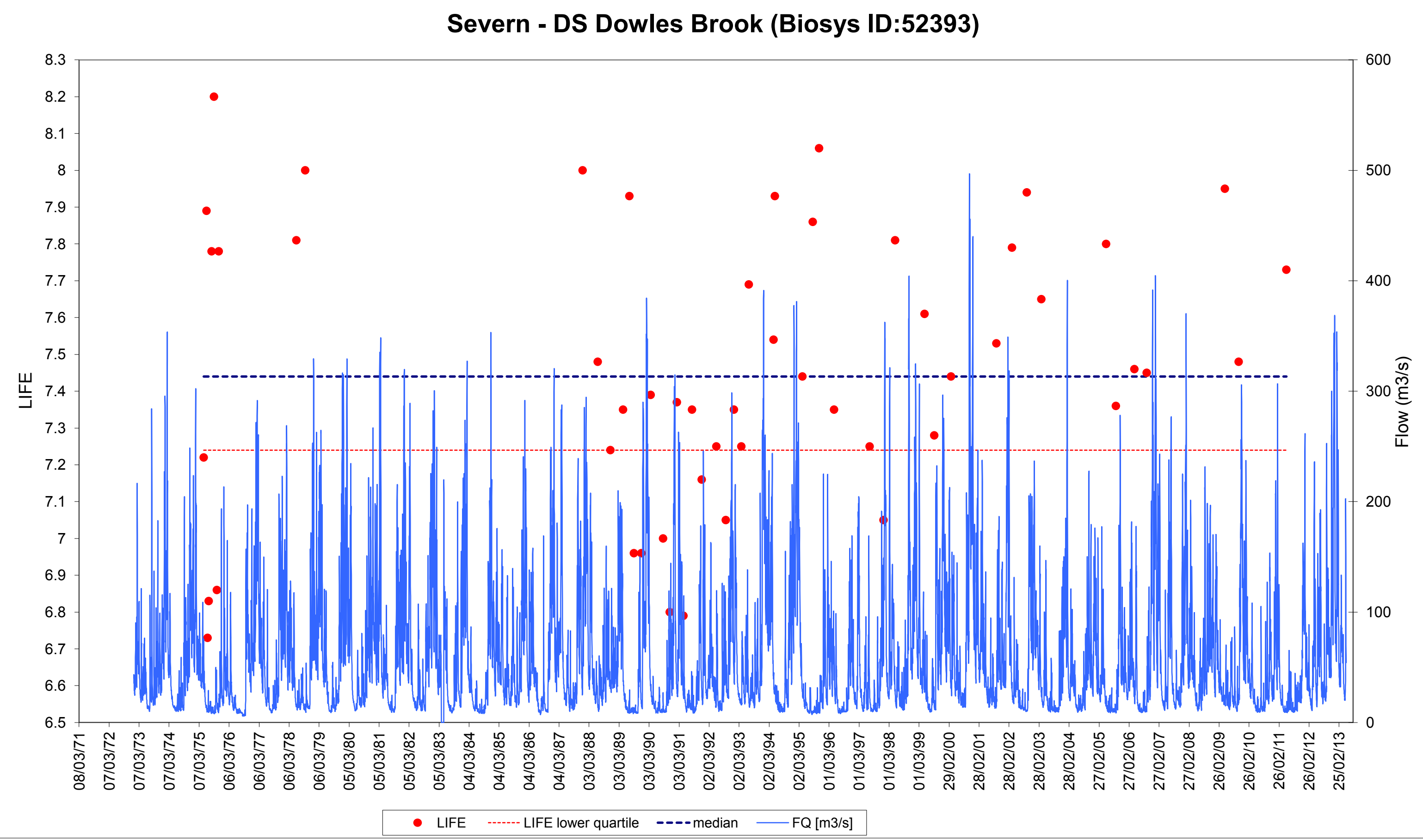


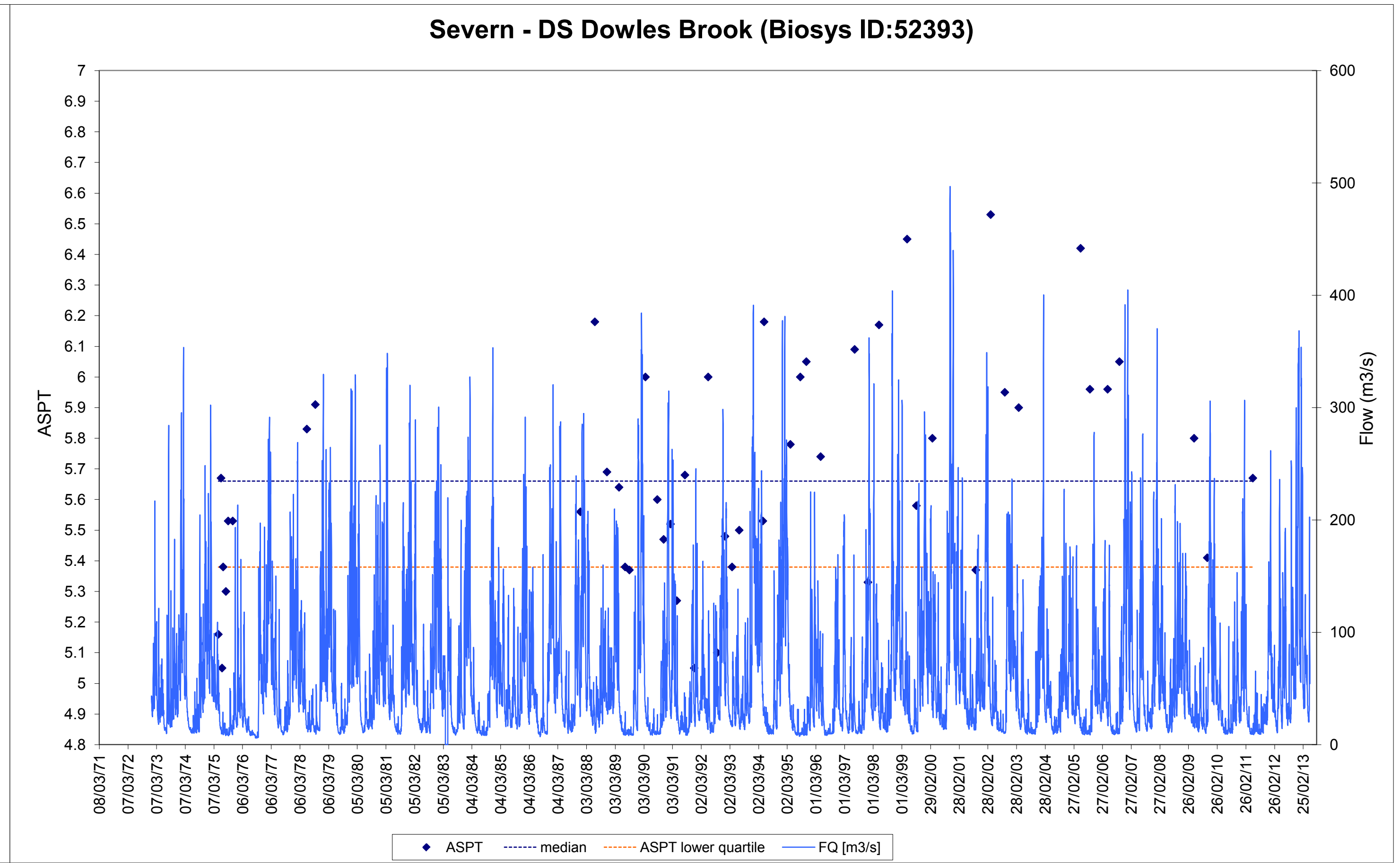


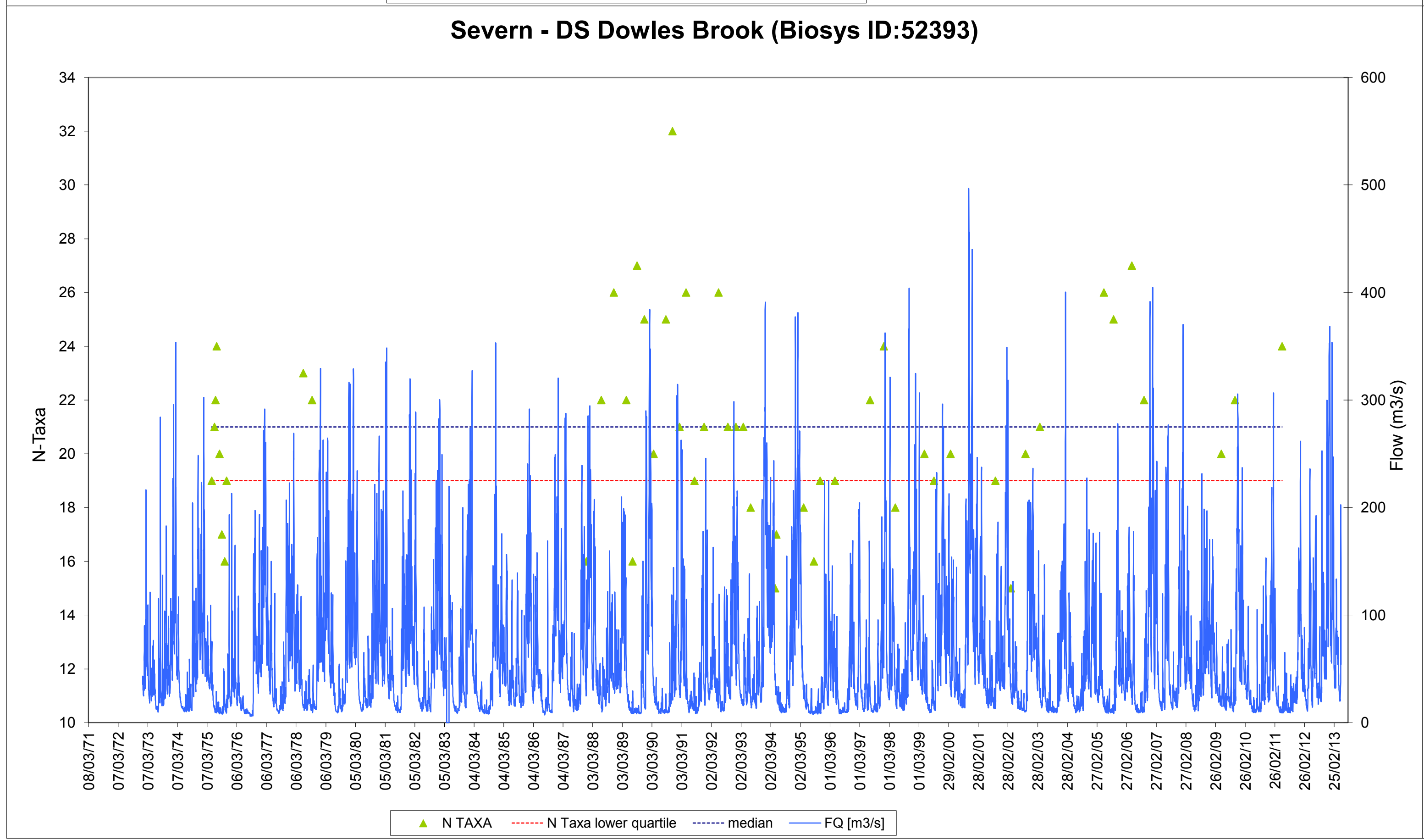


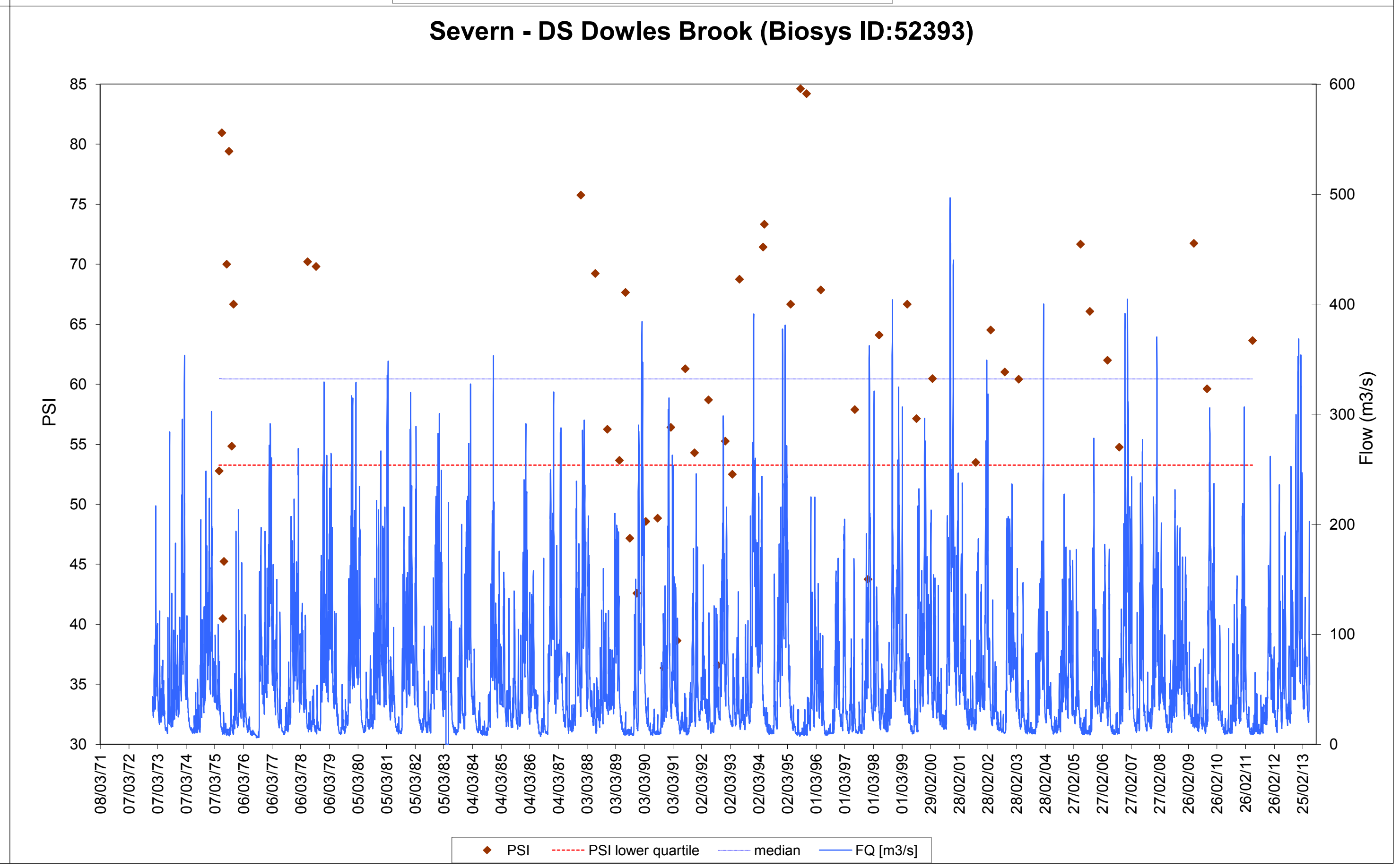
Drought response lta plot at Bewdley, downstream Dowles Brook

Severn - DS Dowles Brook (Biosys ID:52393)

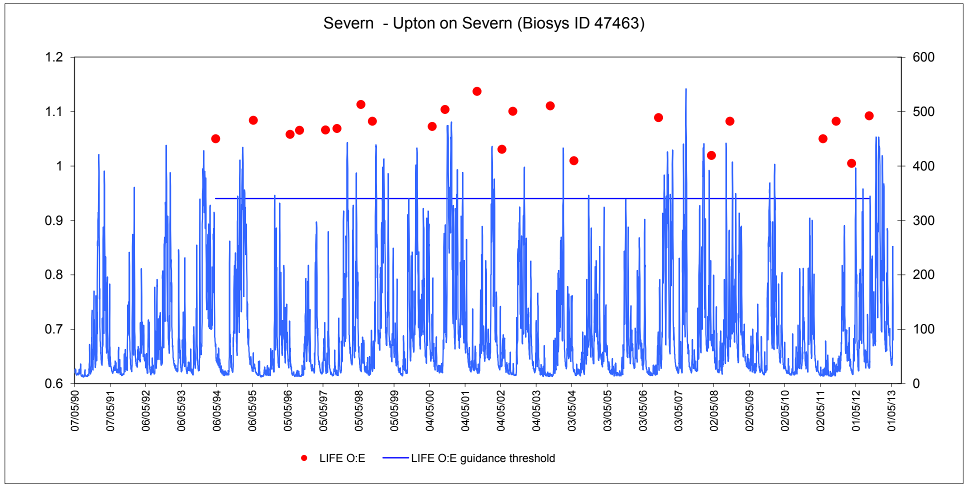


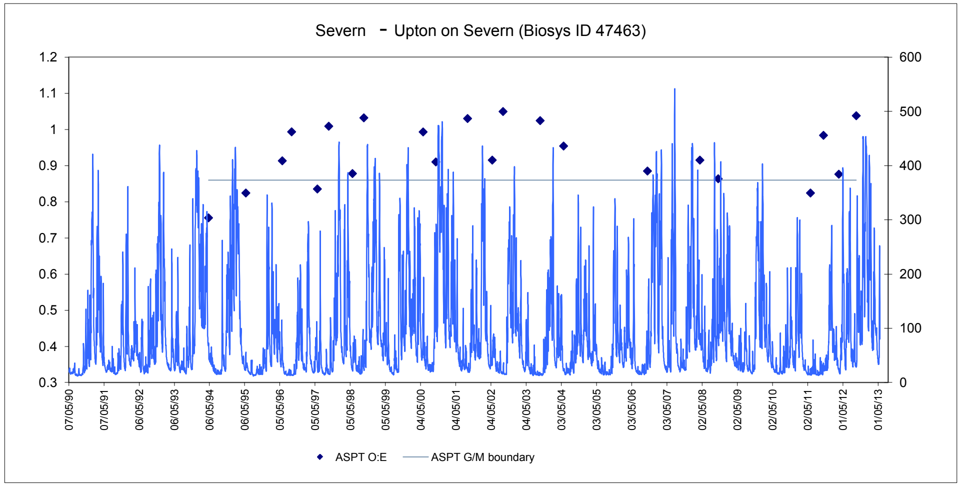


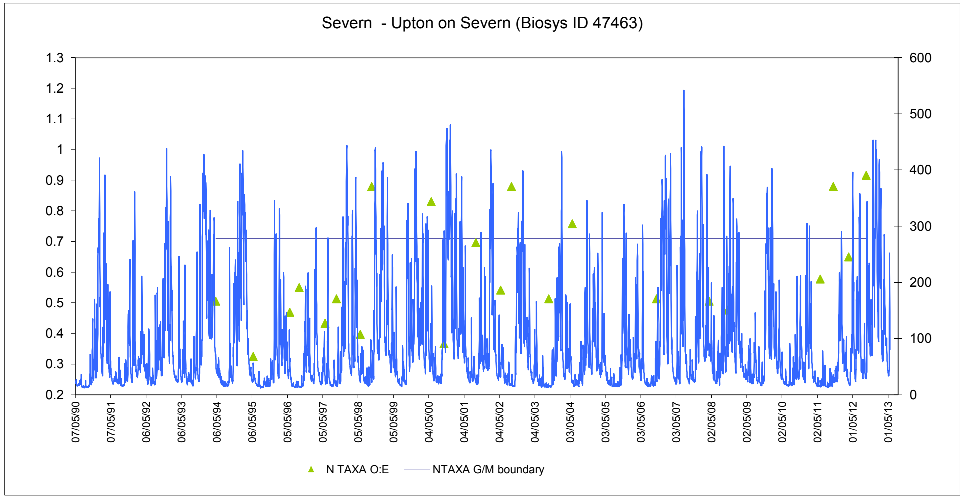


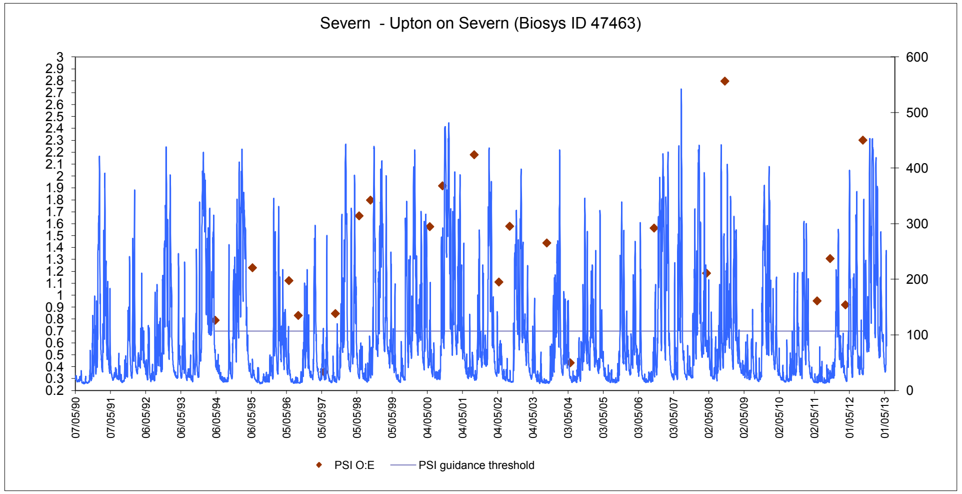


HEV plot at Saxons Lode, Upton on Severn



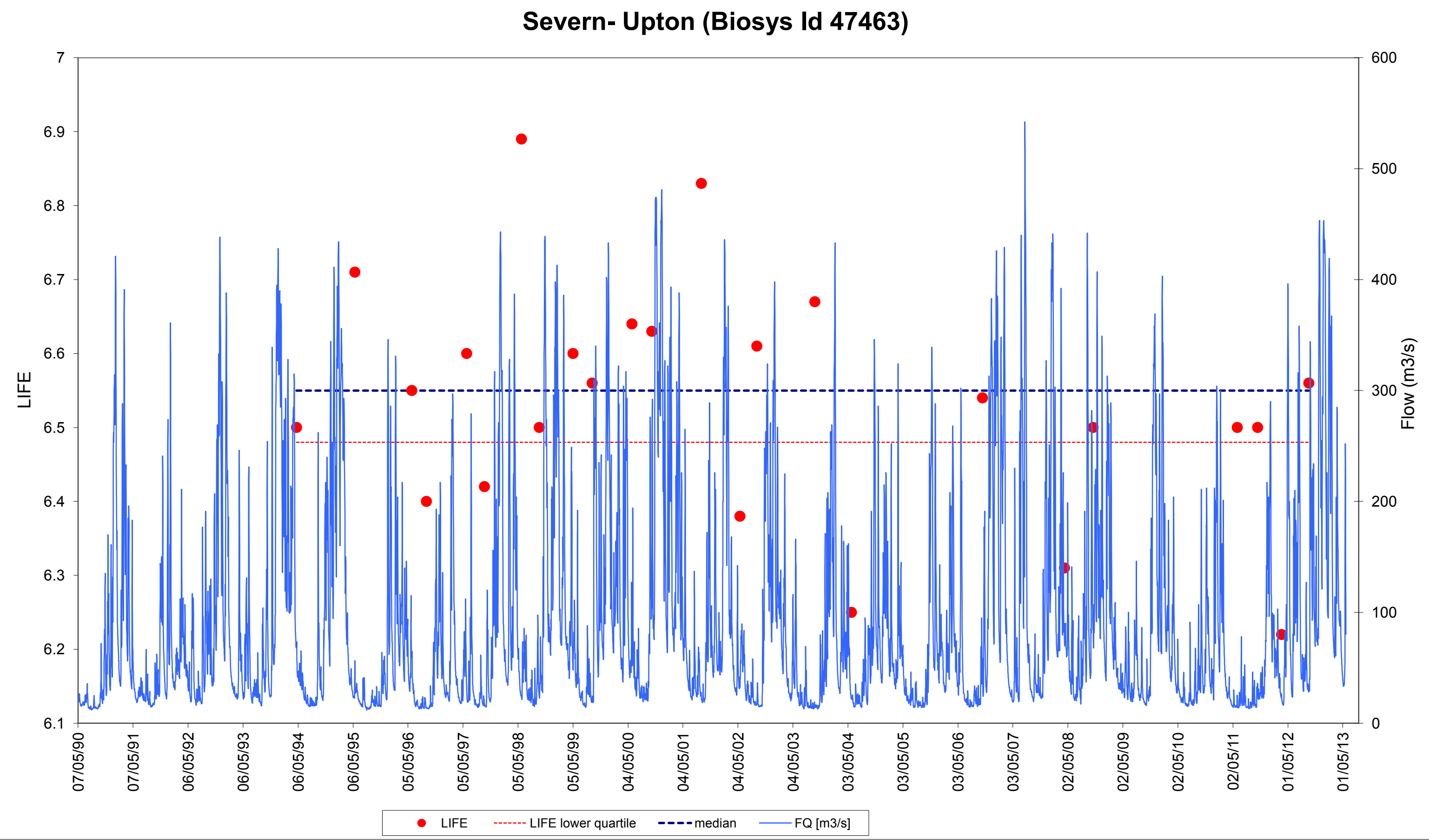


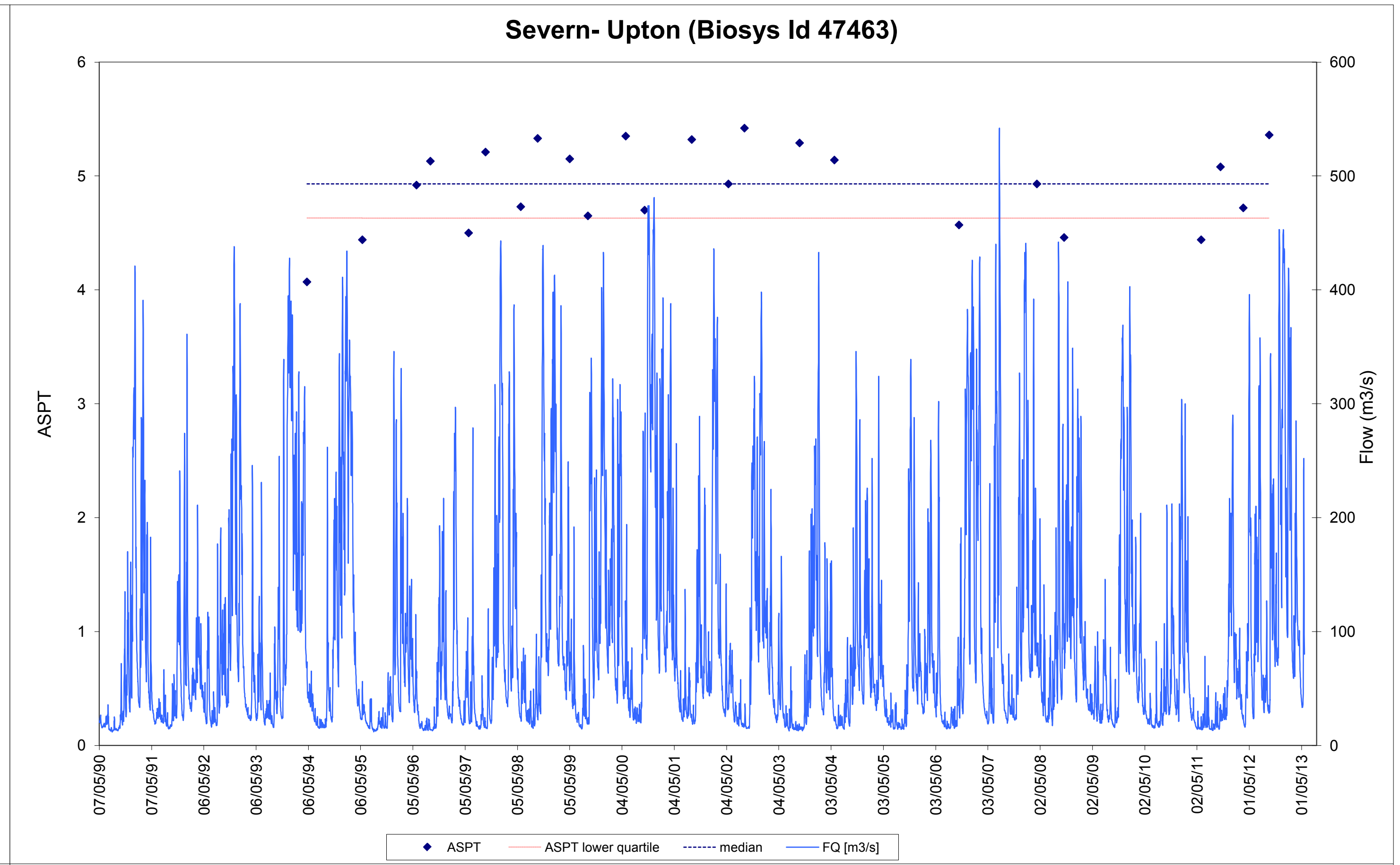


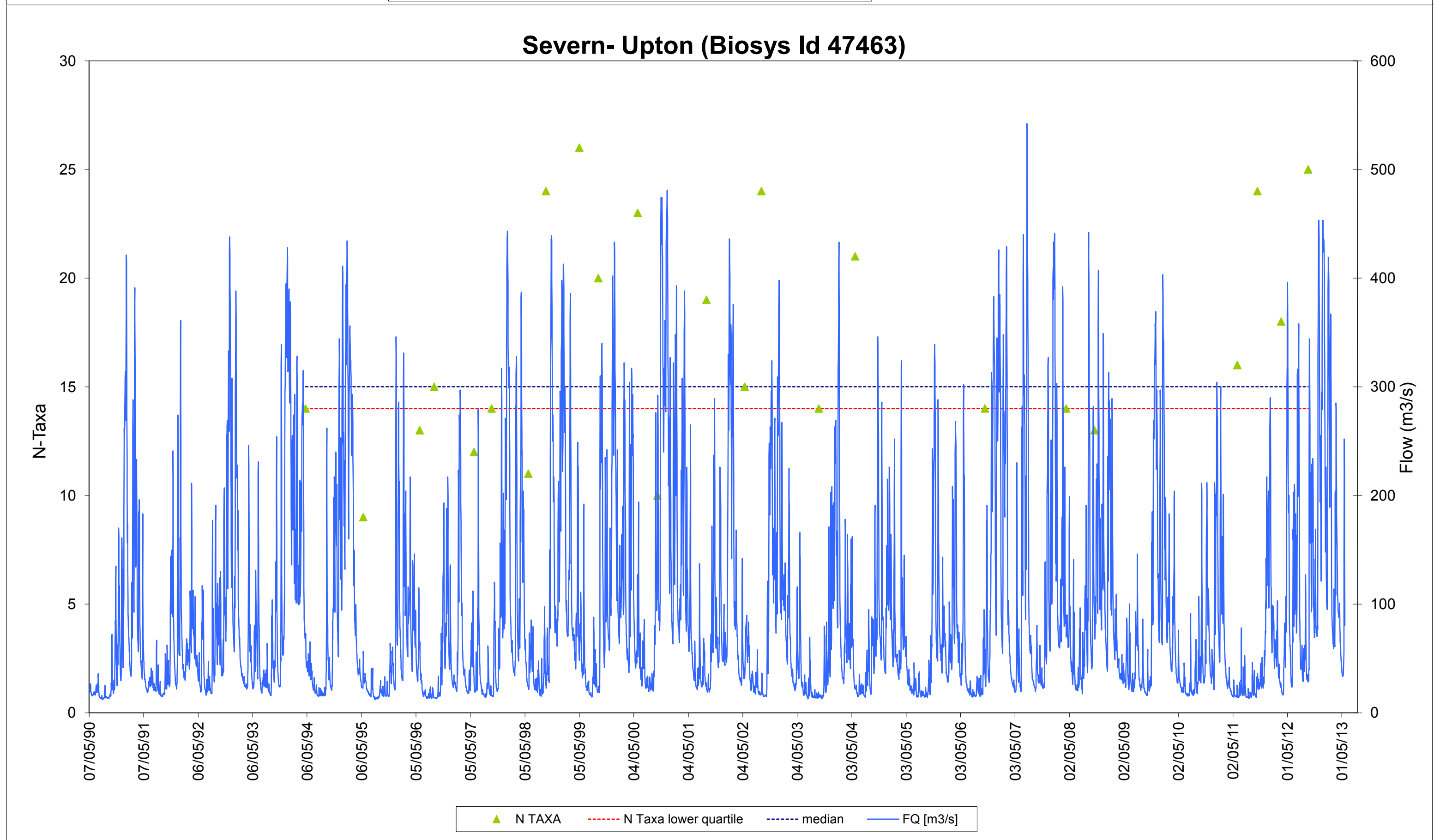


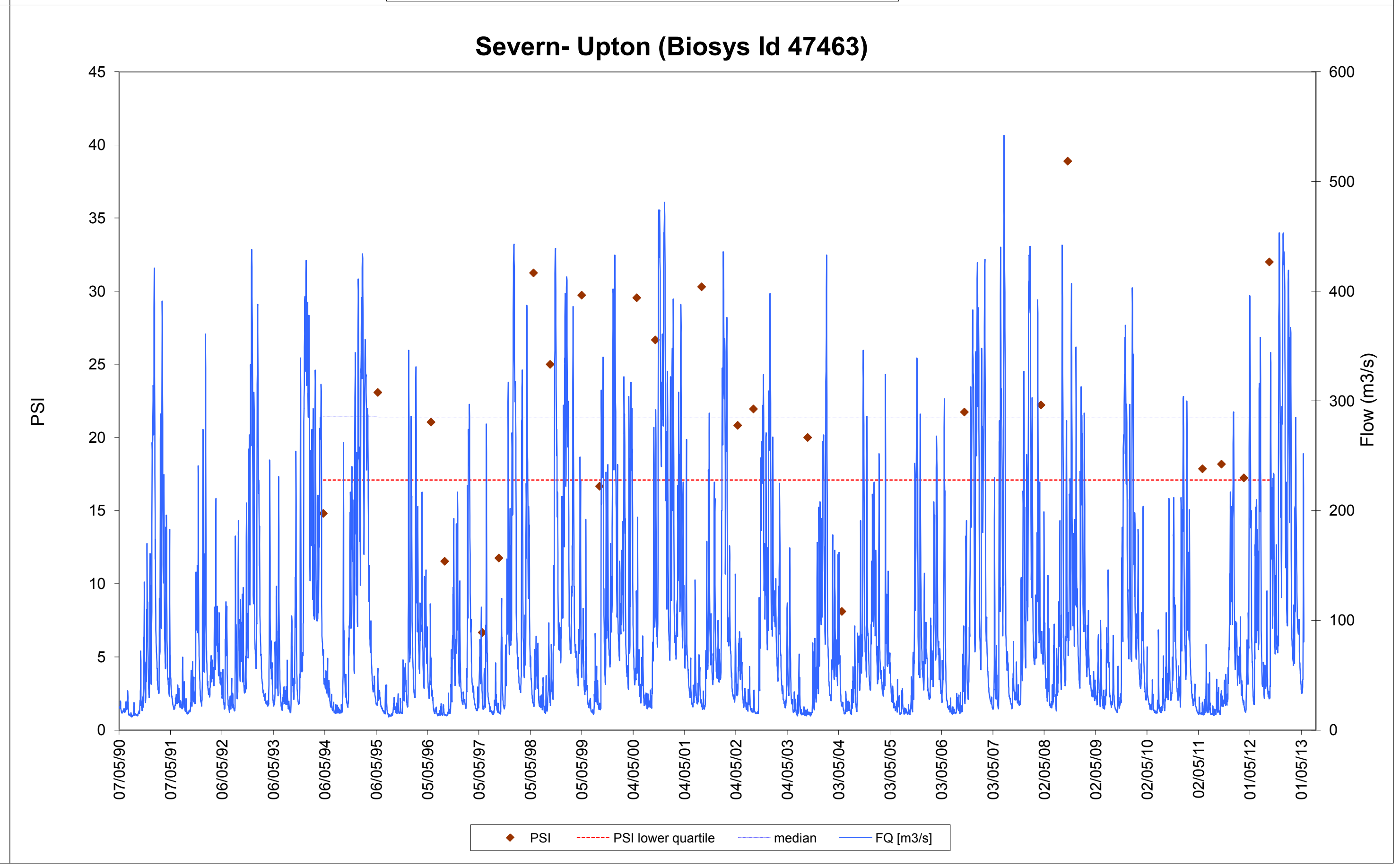
Drought response lta plot at Saxons Lode, Upton on Severn

Severn- Upton (Biosys Id 47463)

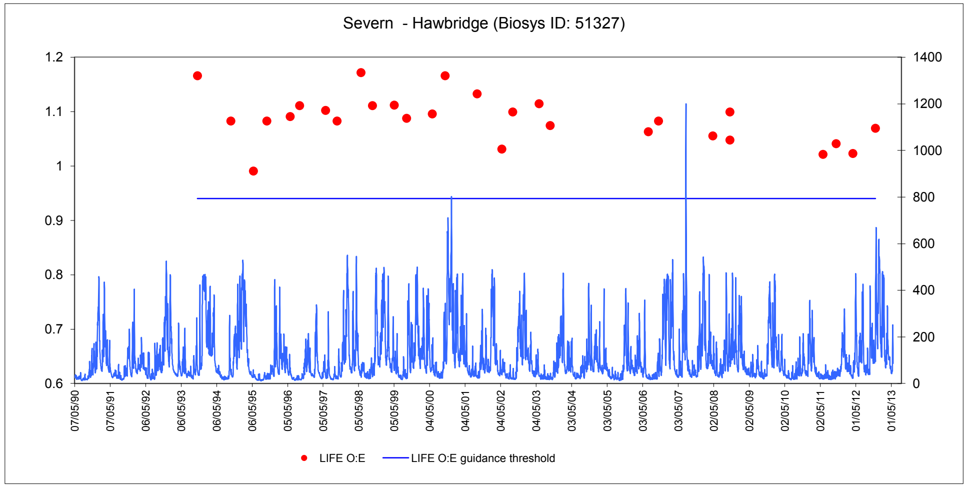


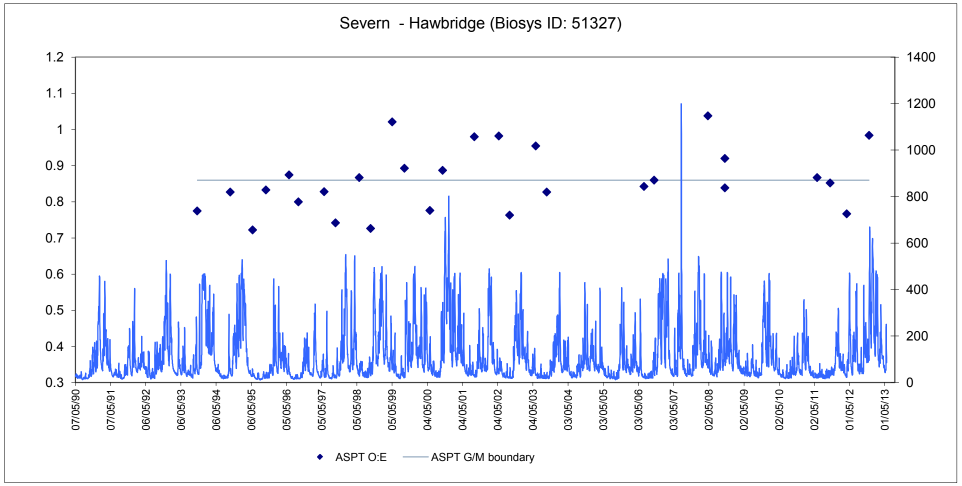


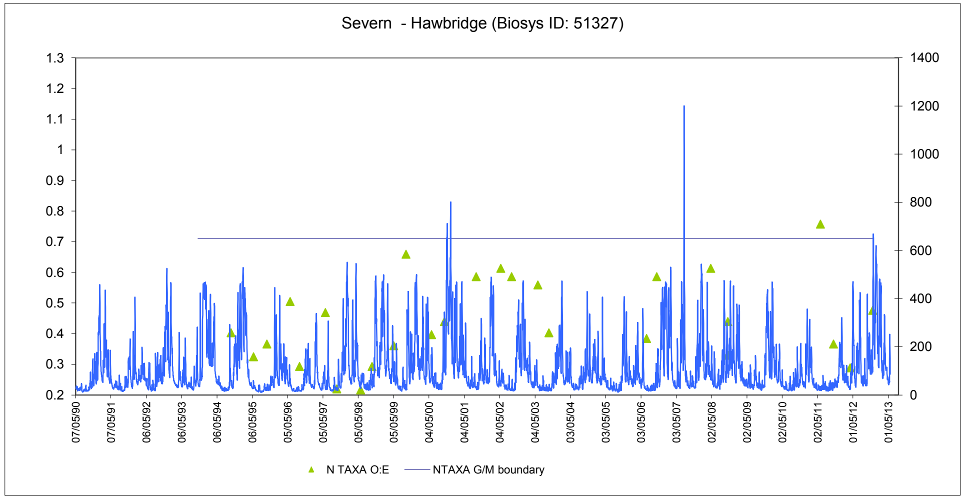


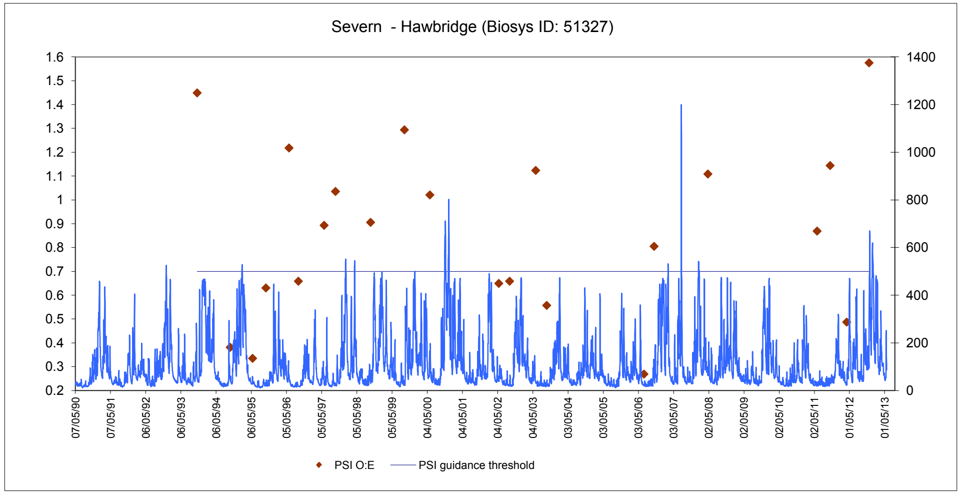


HEV plot at Deerhurst/Haw bridge, Hawbridge



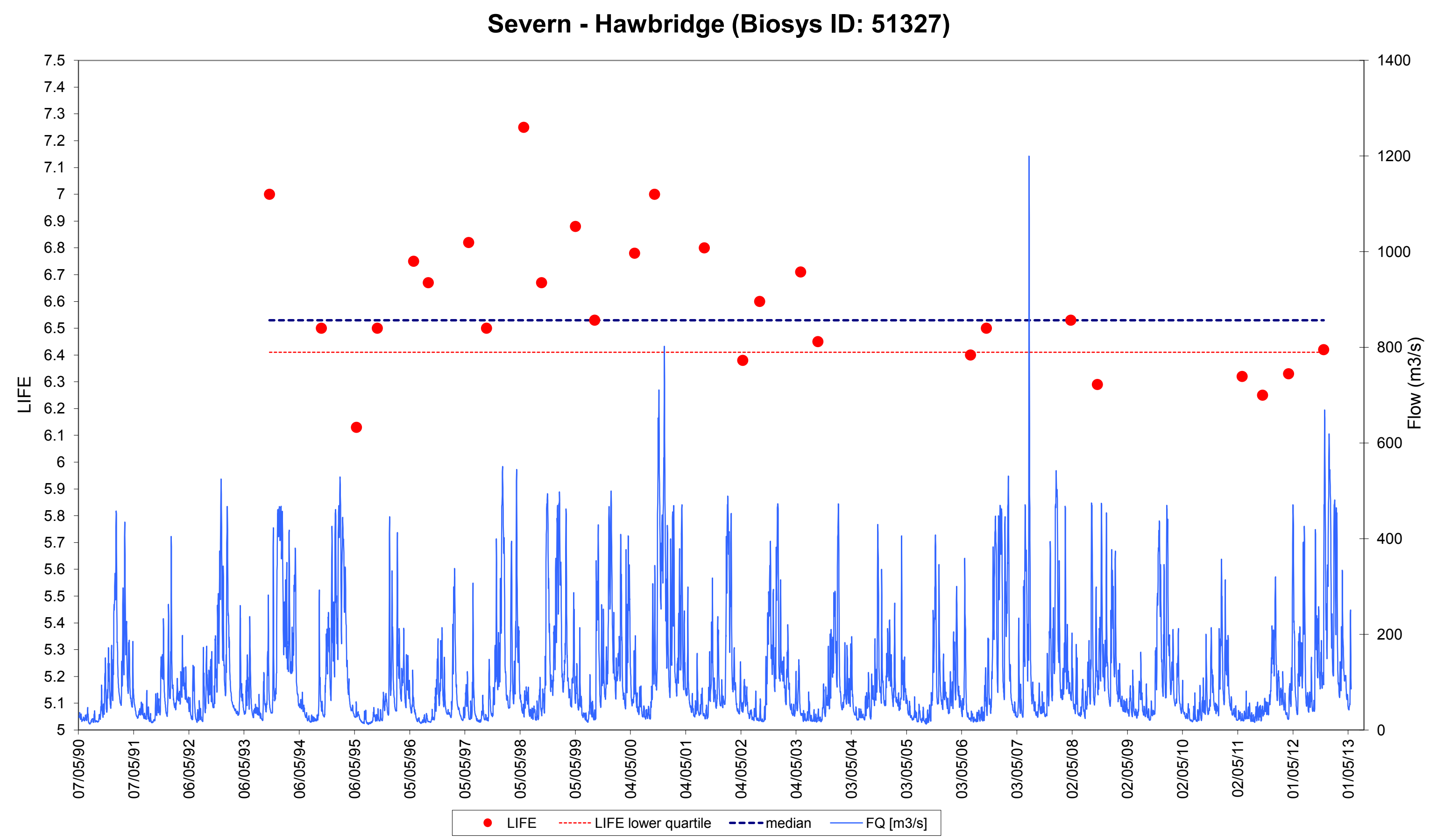


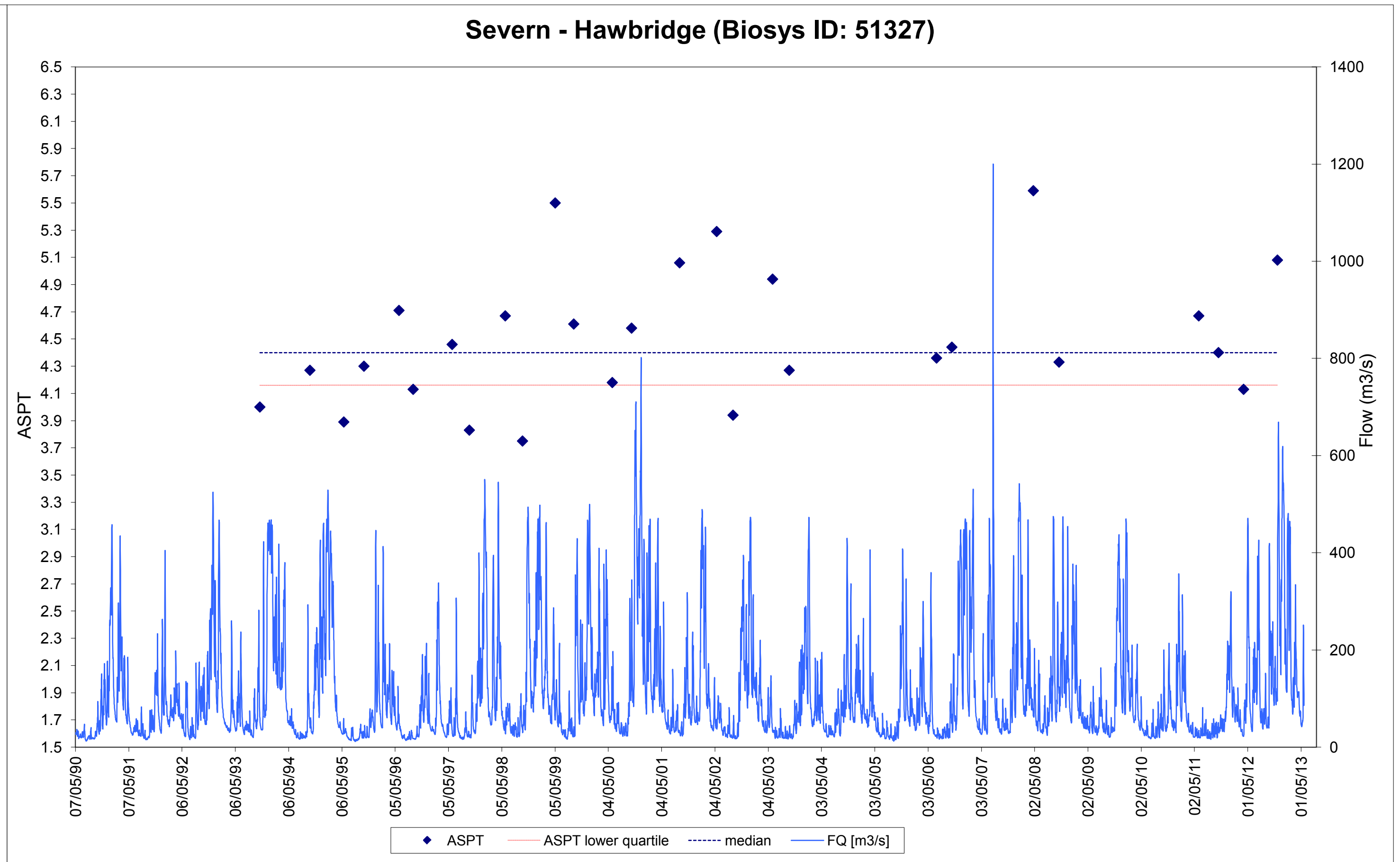


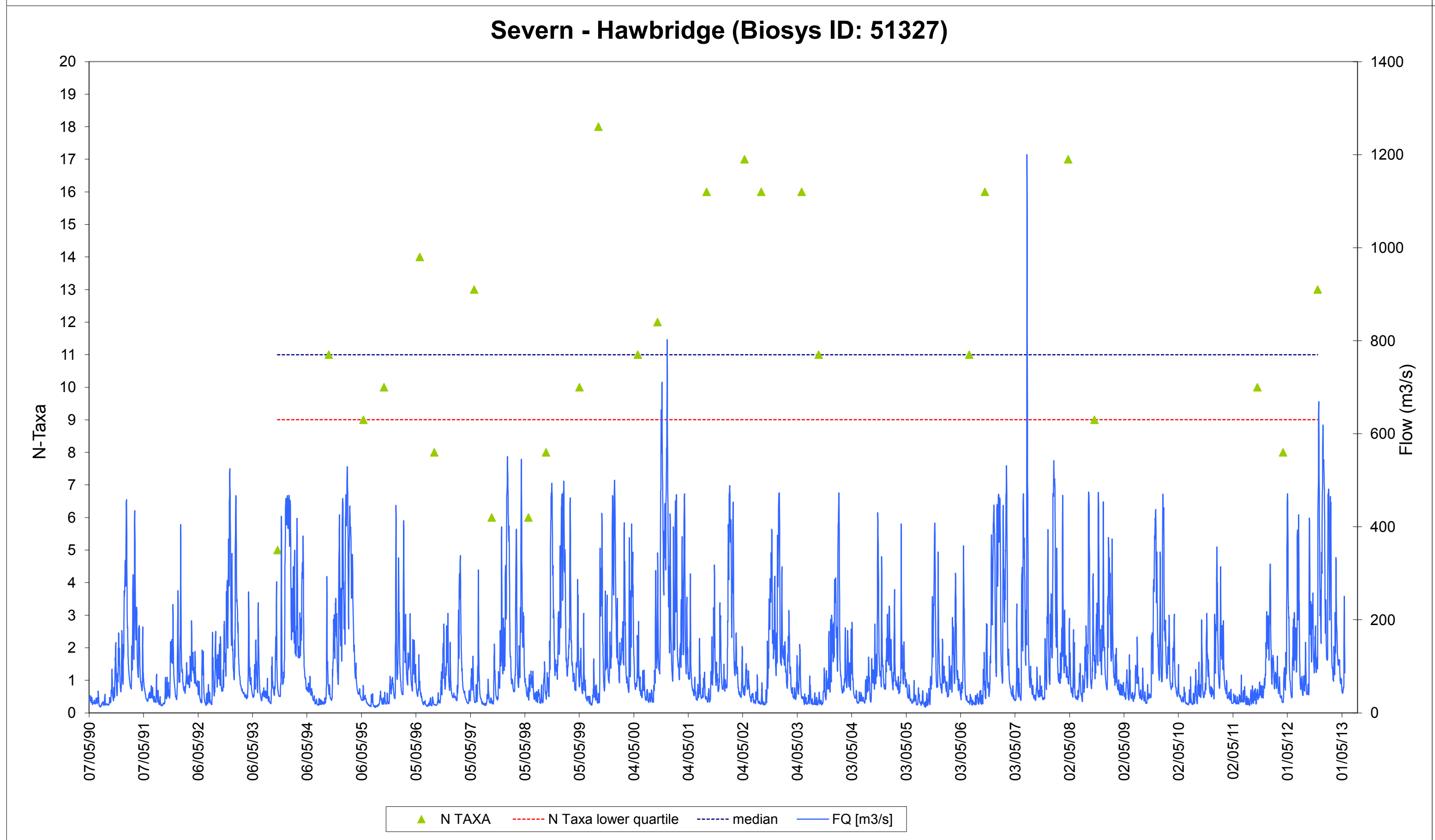


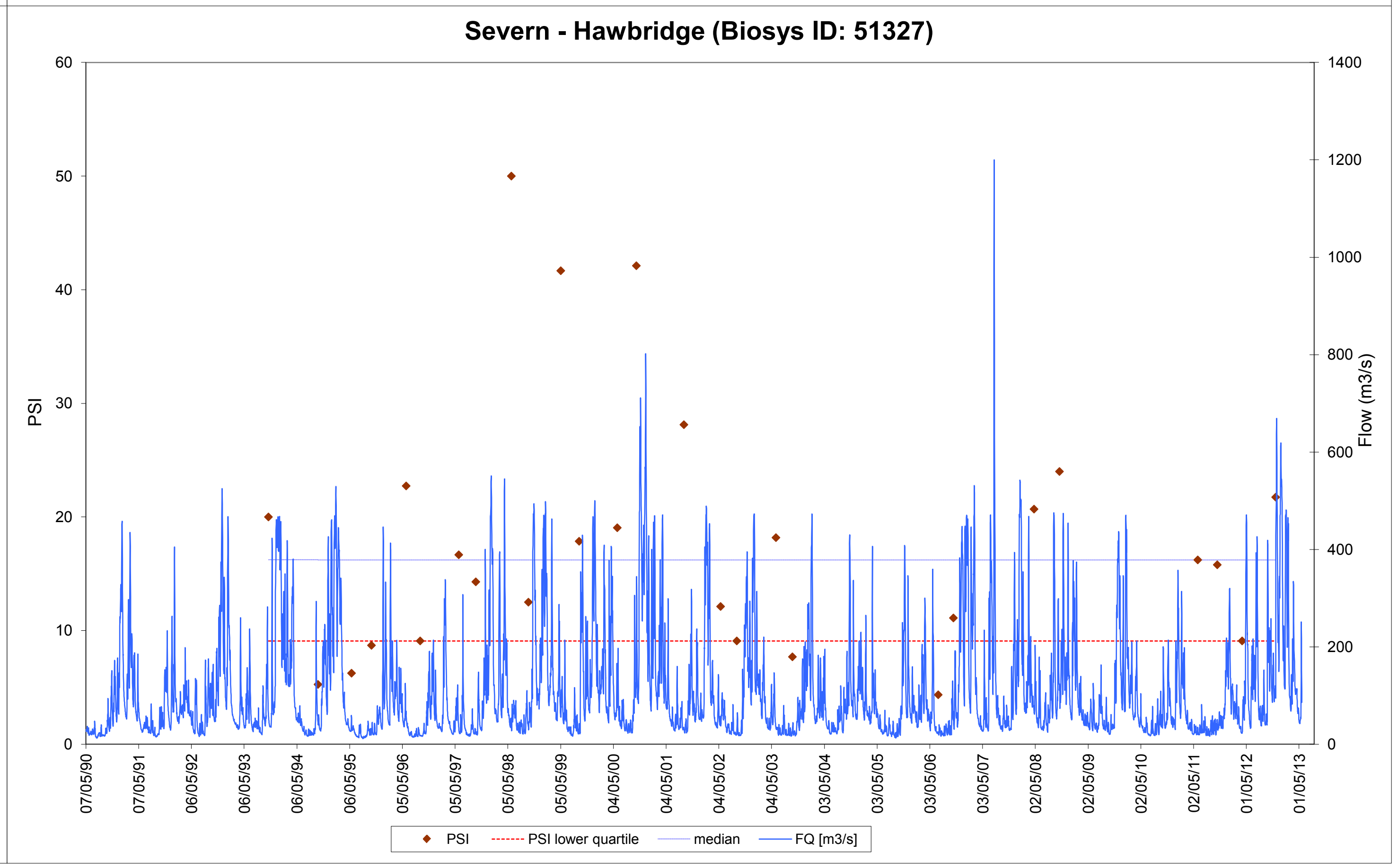
Drought response lta plot at Deerhurst/Haw bridge, Hawbridge

Severn - Hawbridge (Biosys ID: 51327)

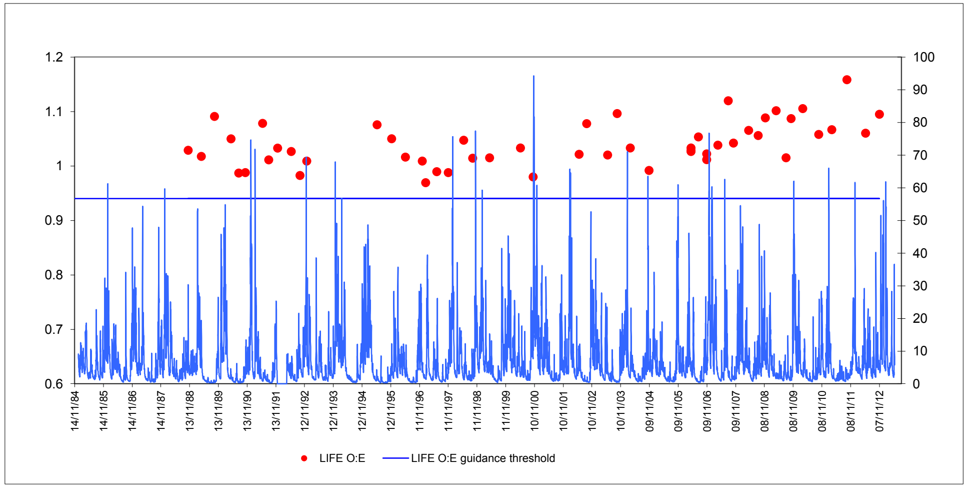


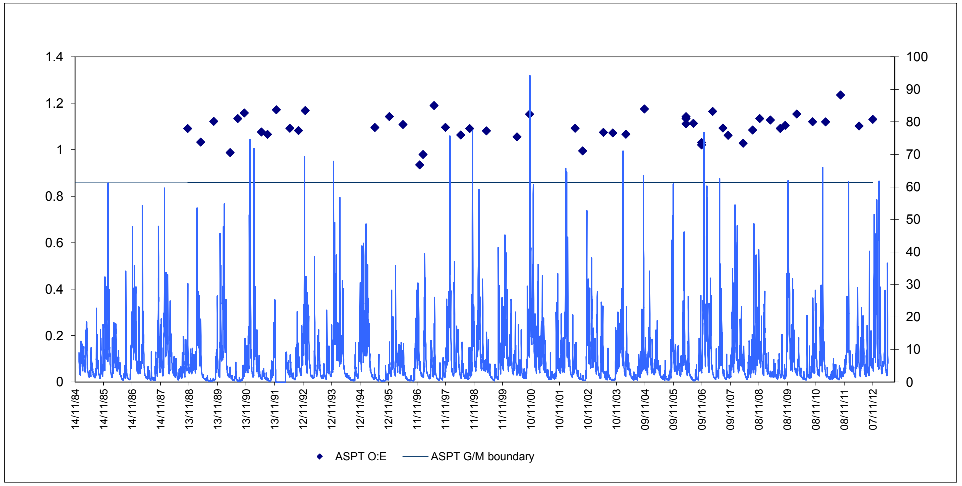


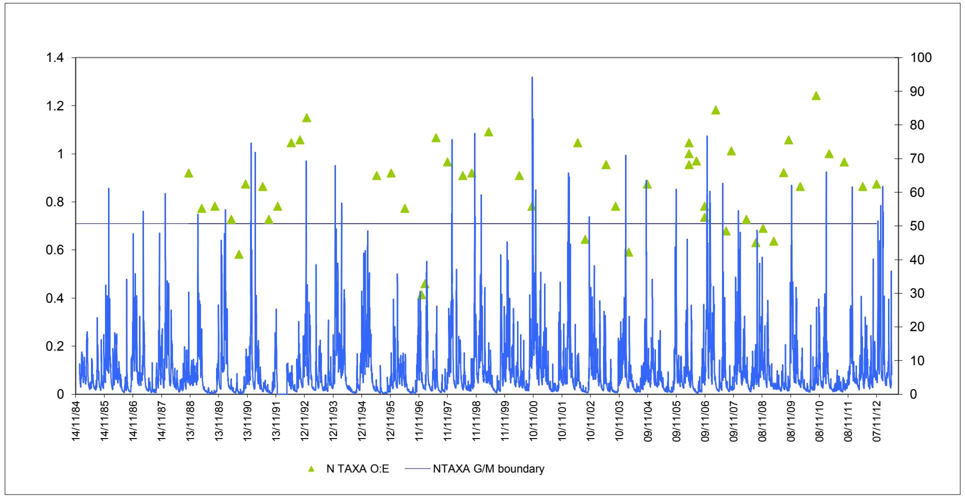


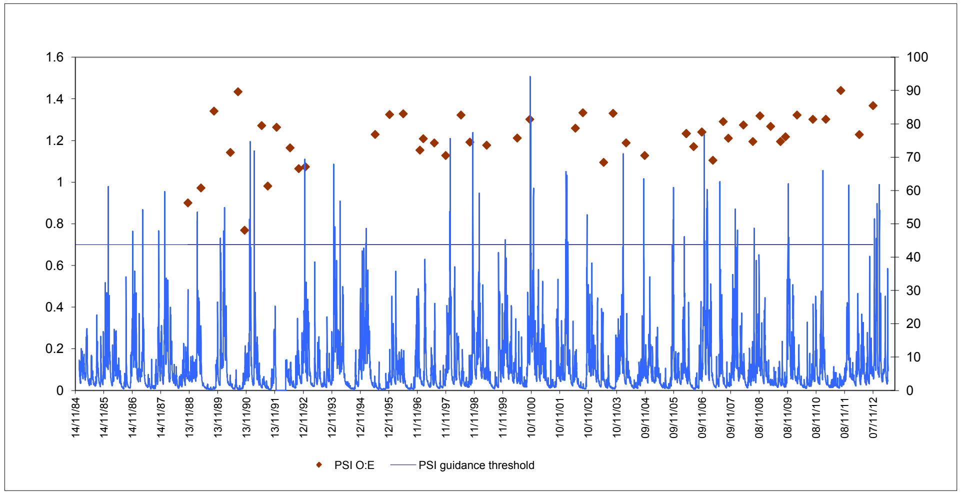


Control Point; HEV plot at Llanyblodwel on the River Tanat



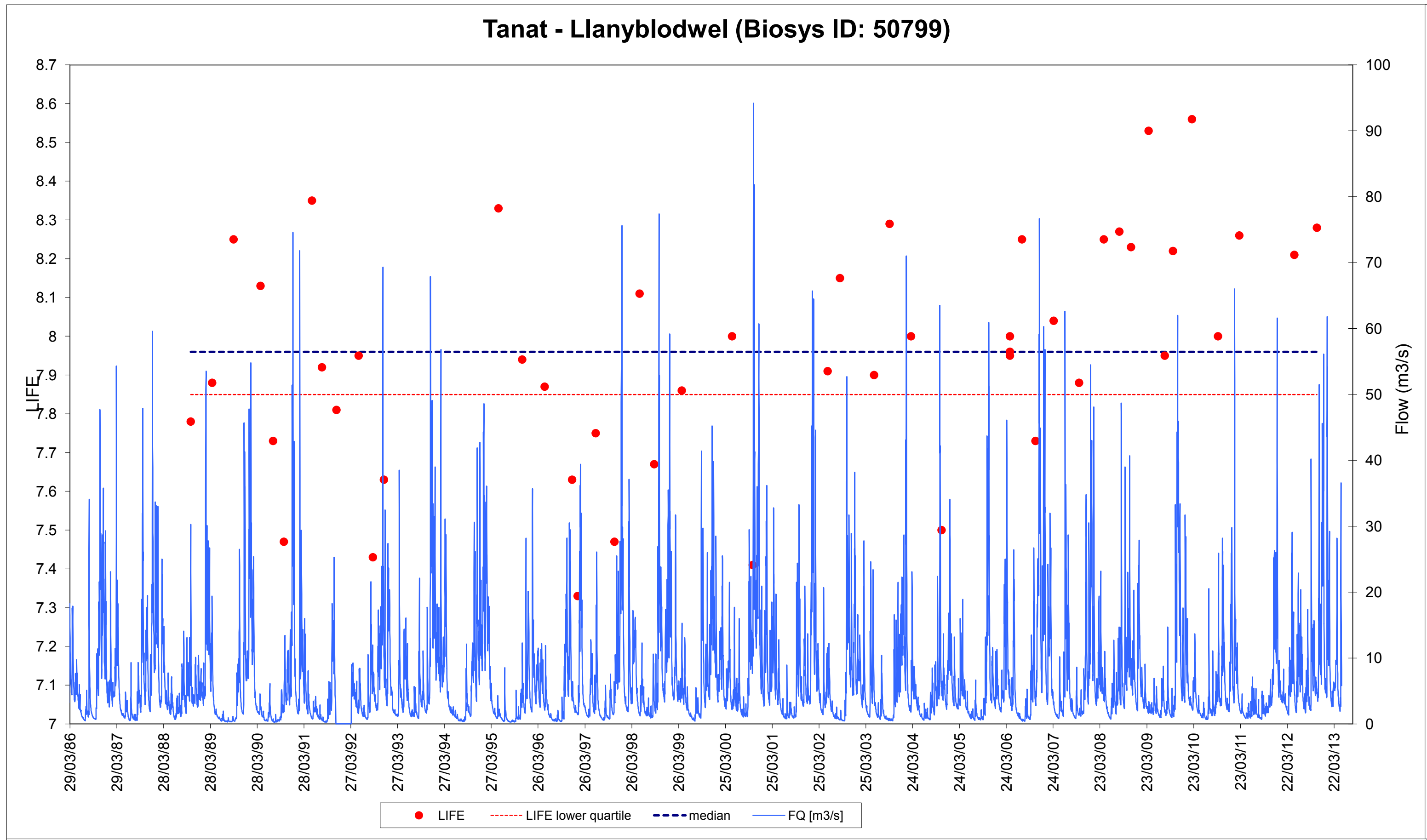


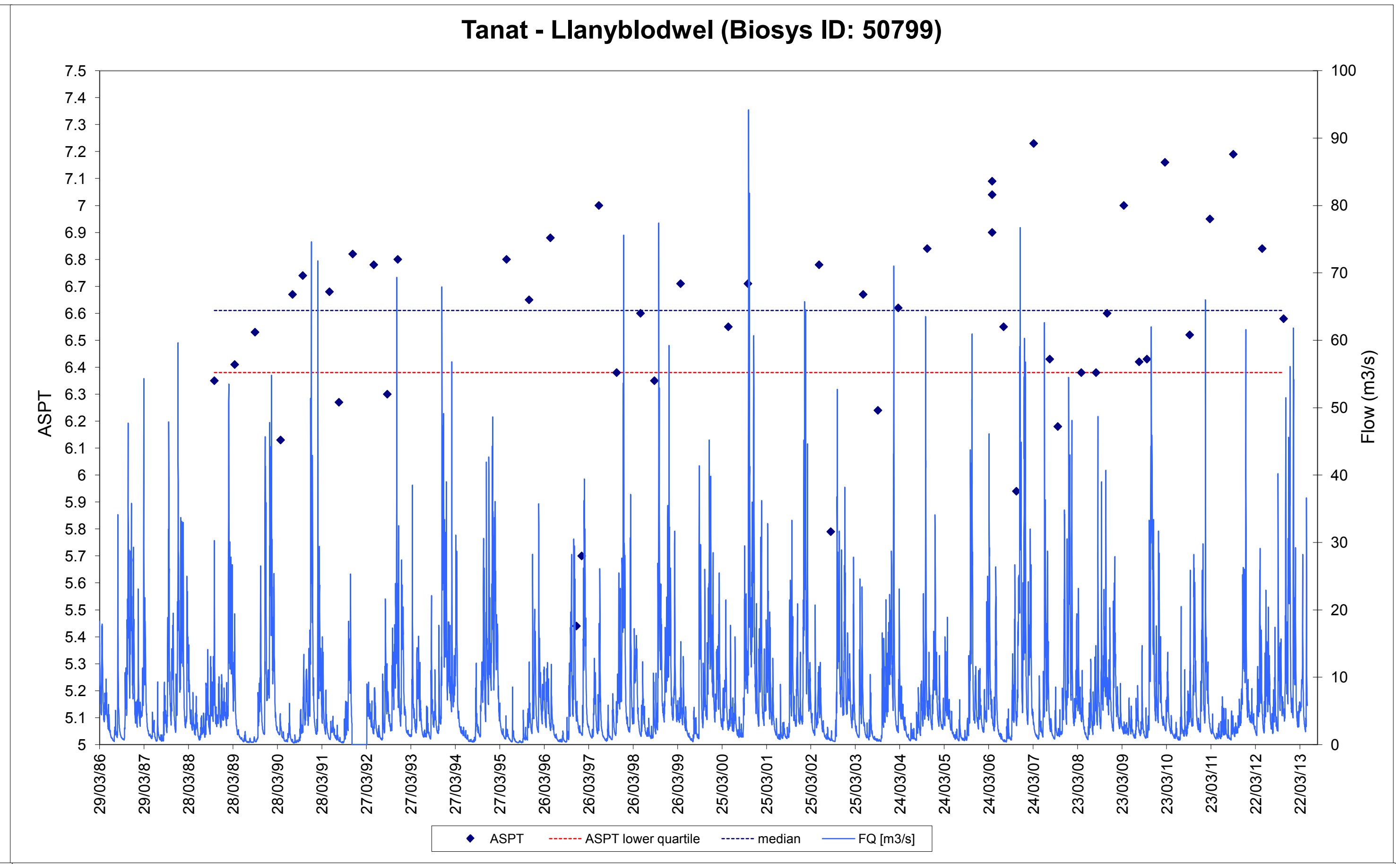


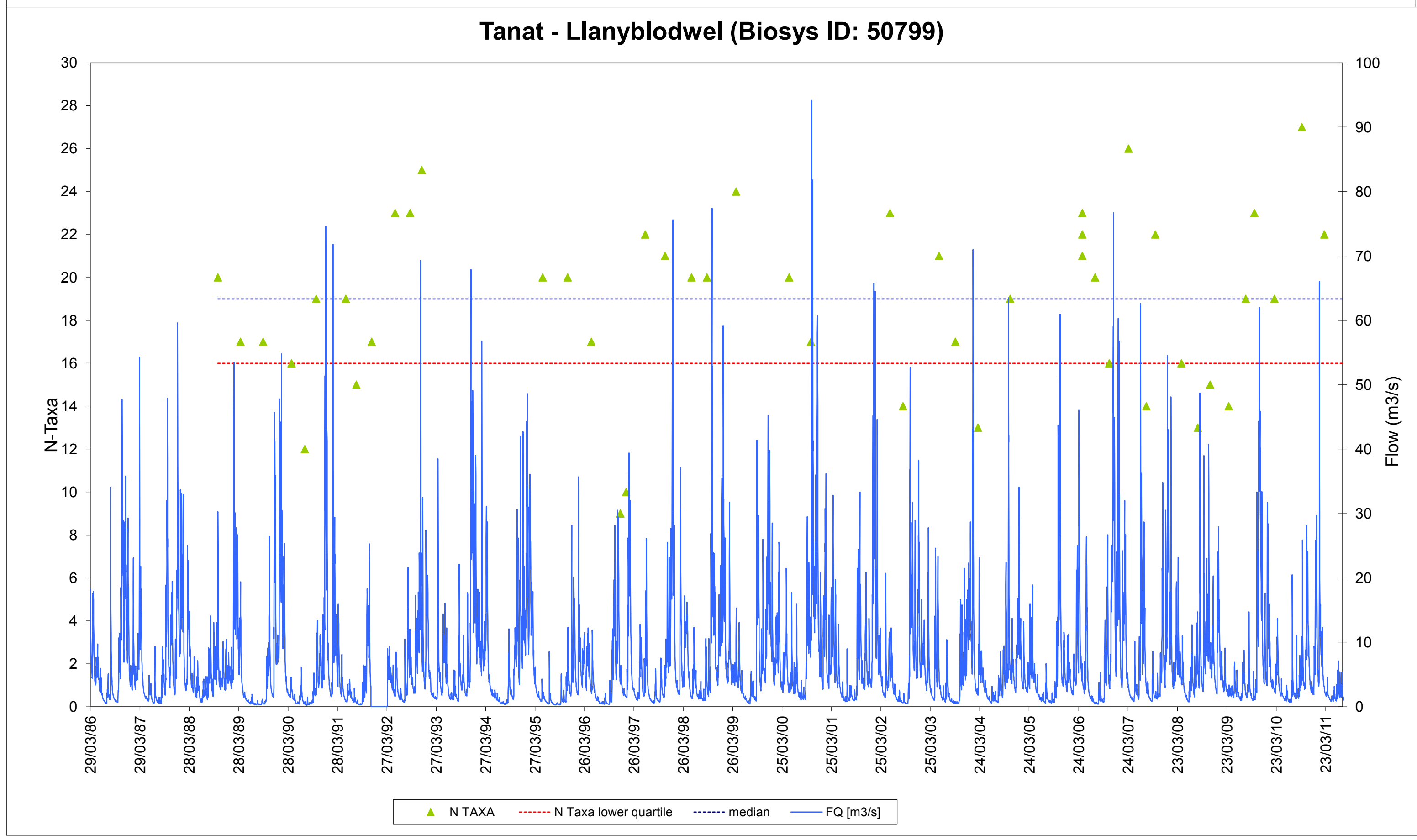


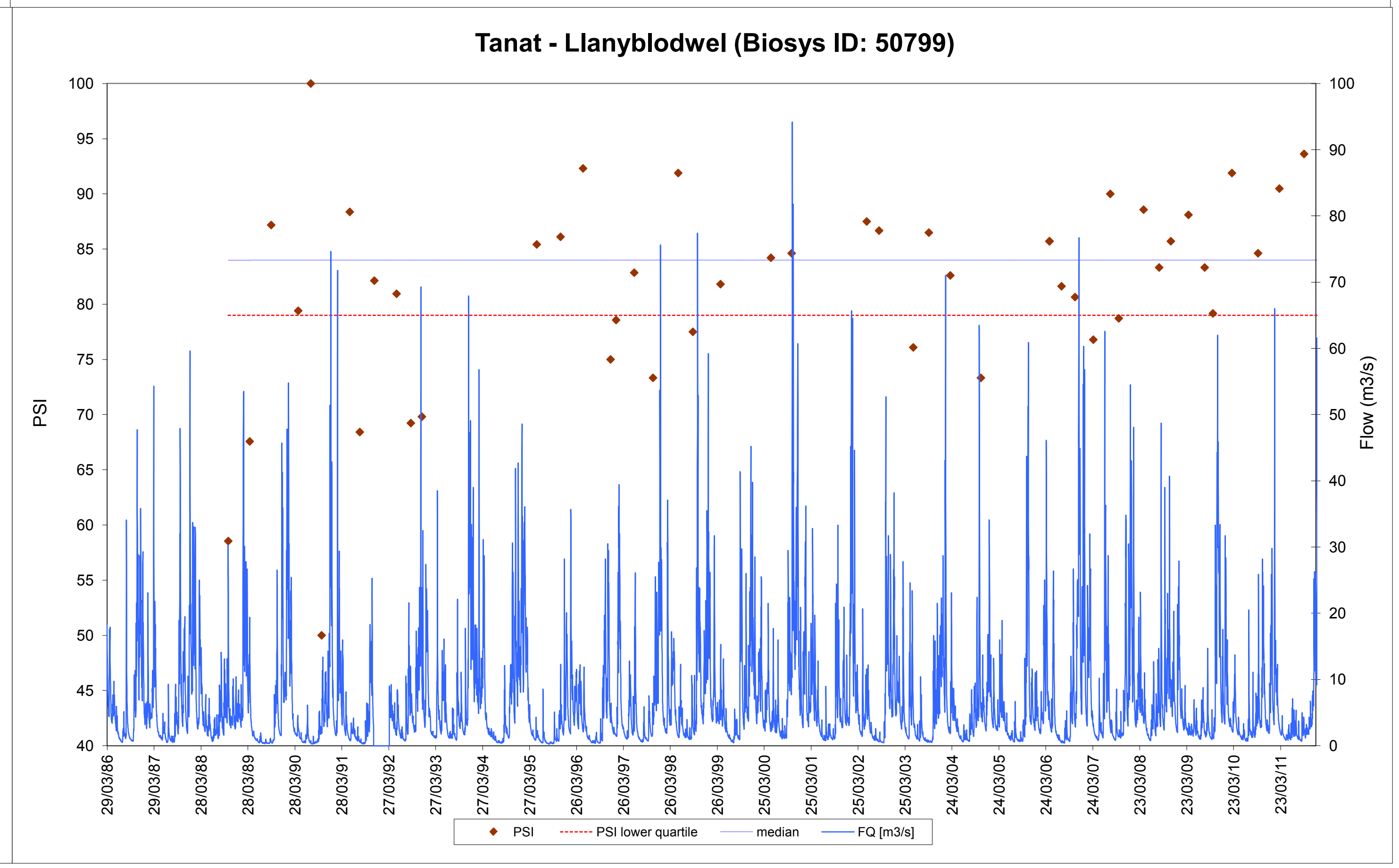
Control Point; Drought response Ita plot at Llanyblodwel on the River Tanat

Tanat - Llanyblodwel (Biosys ID: 50799)

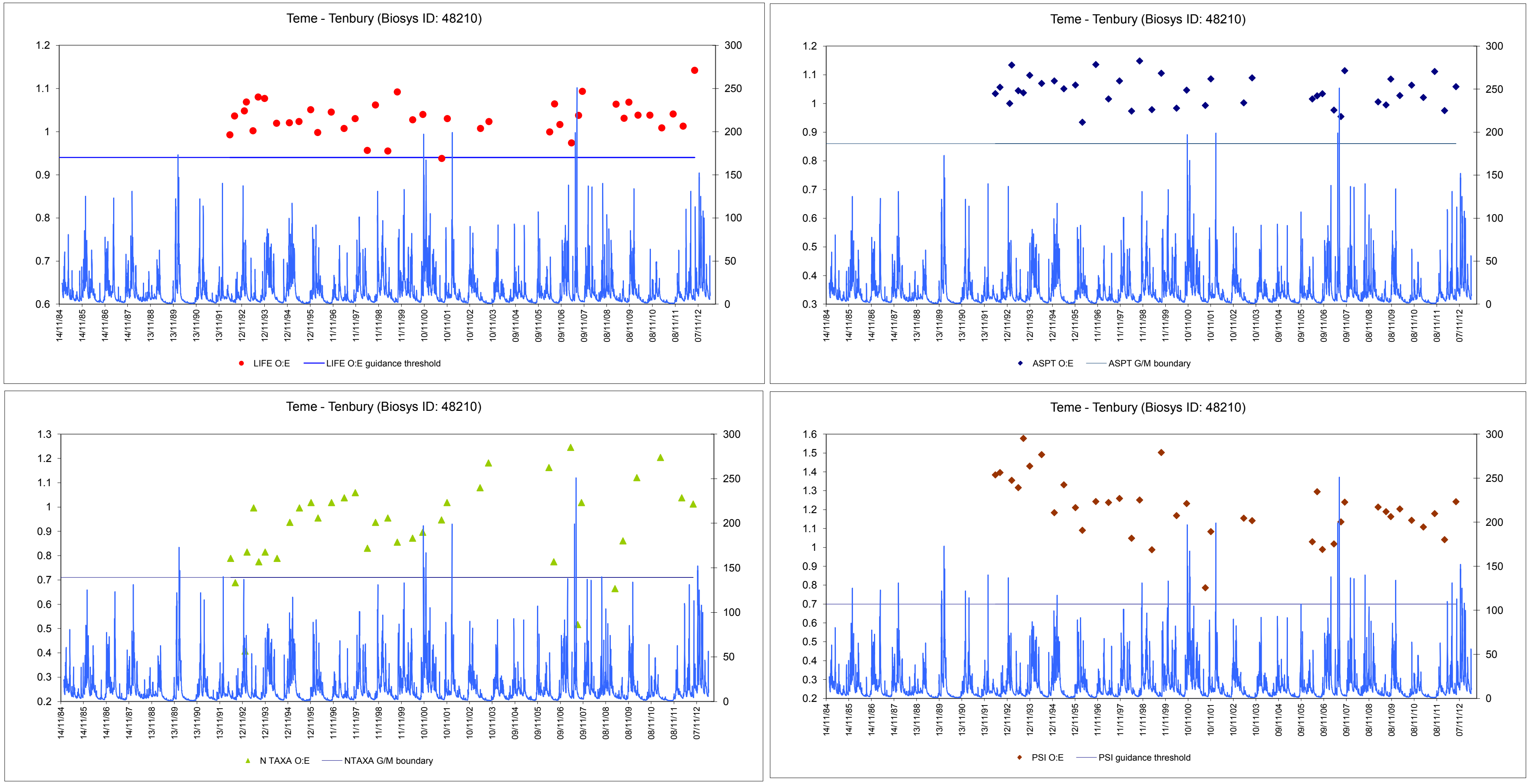






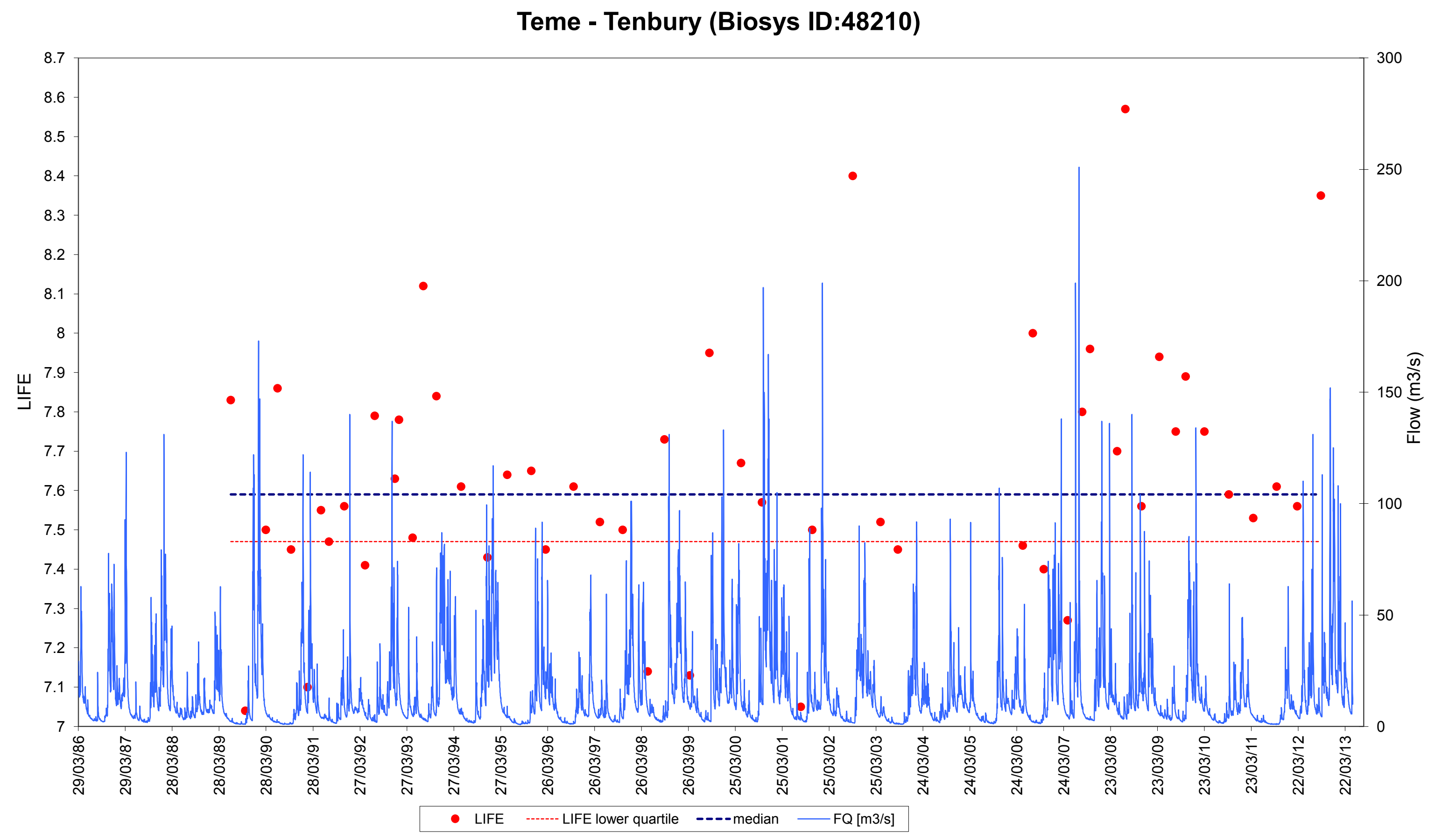


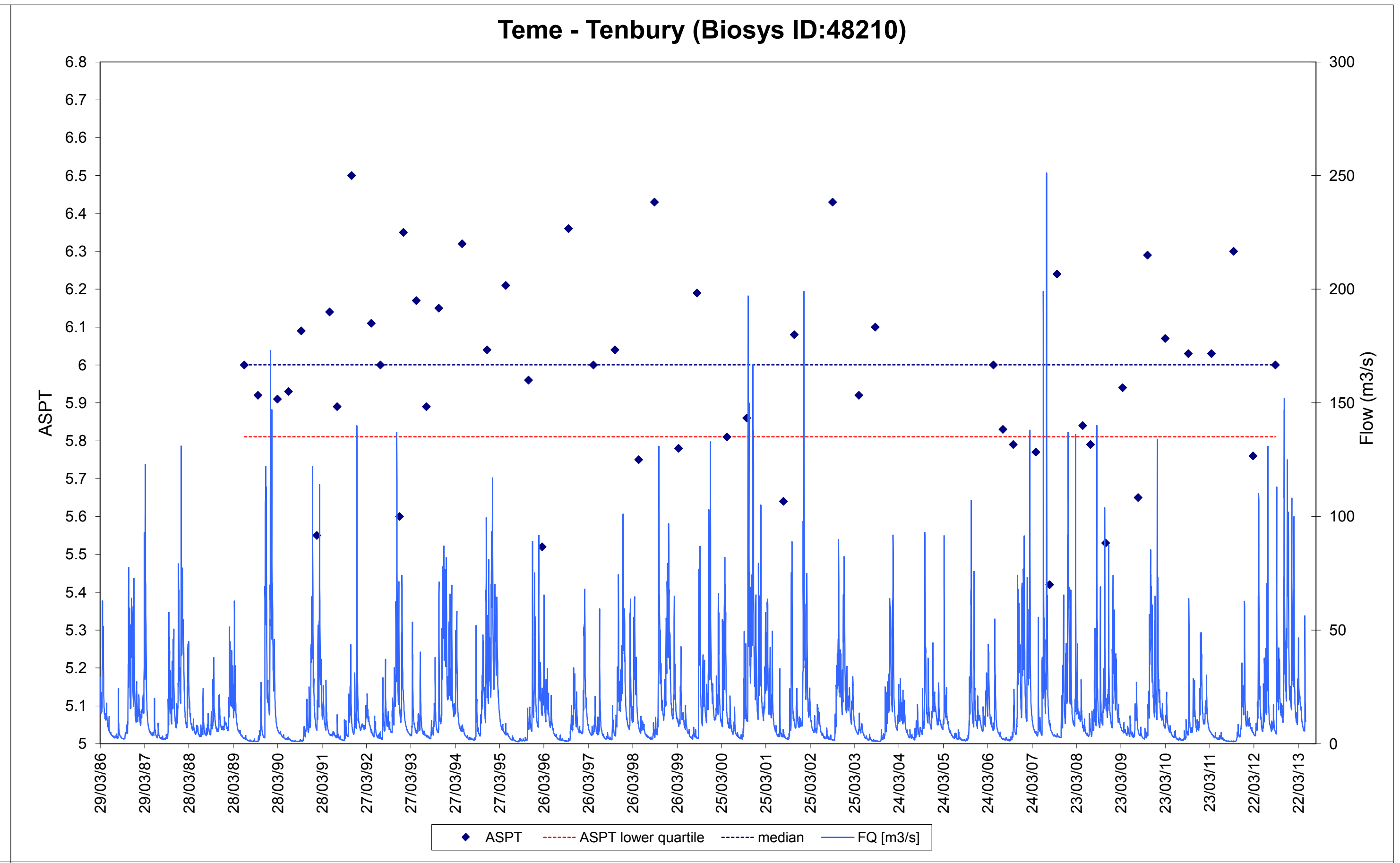
Control Point; HEV plot at Tenbury on the River Teme

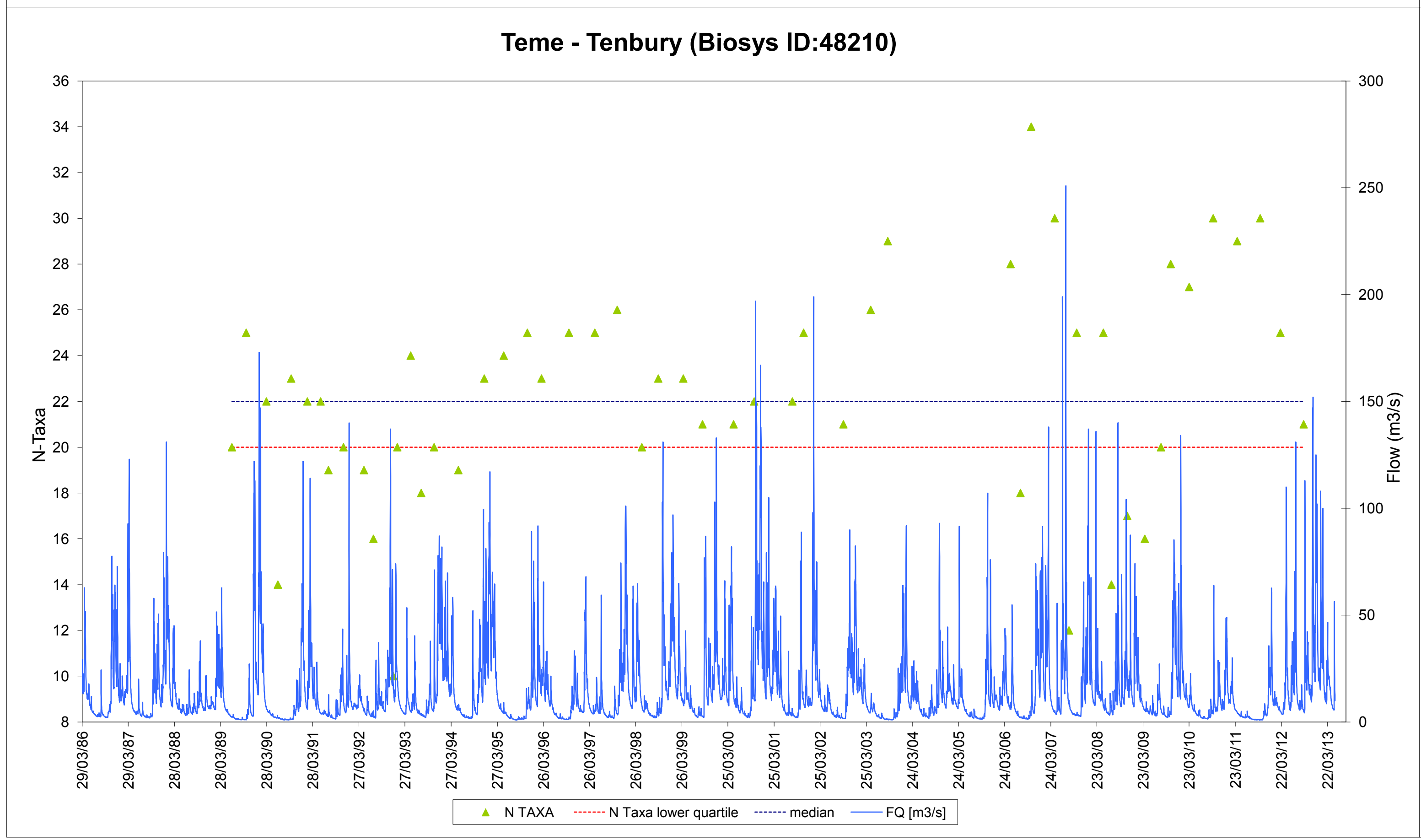


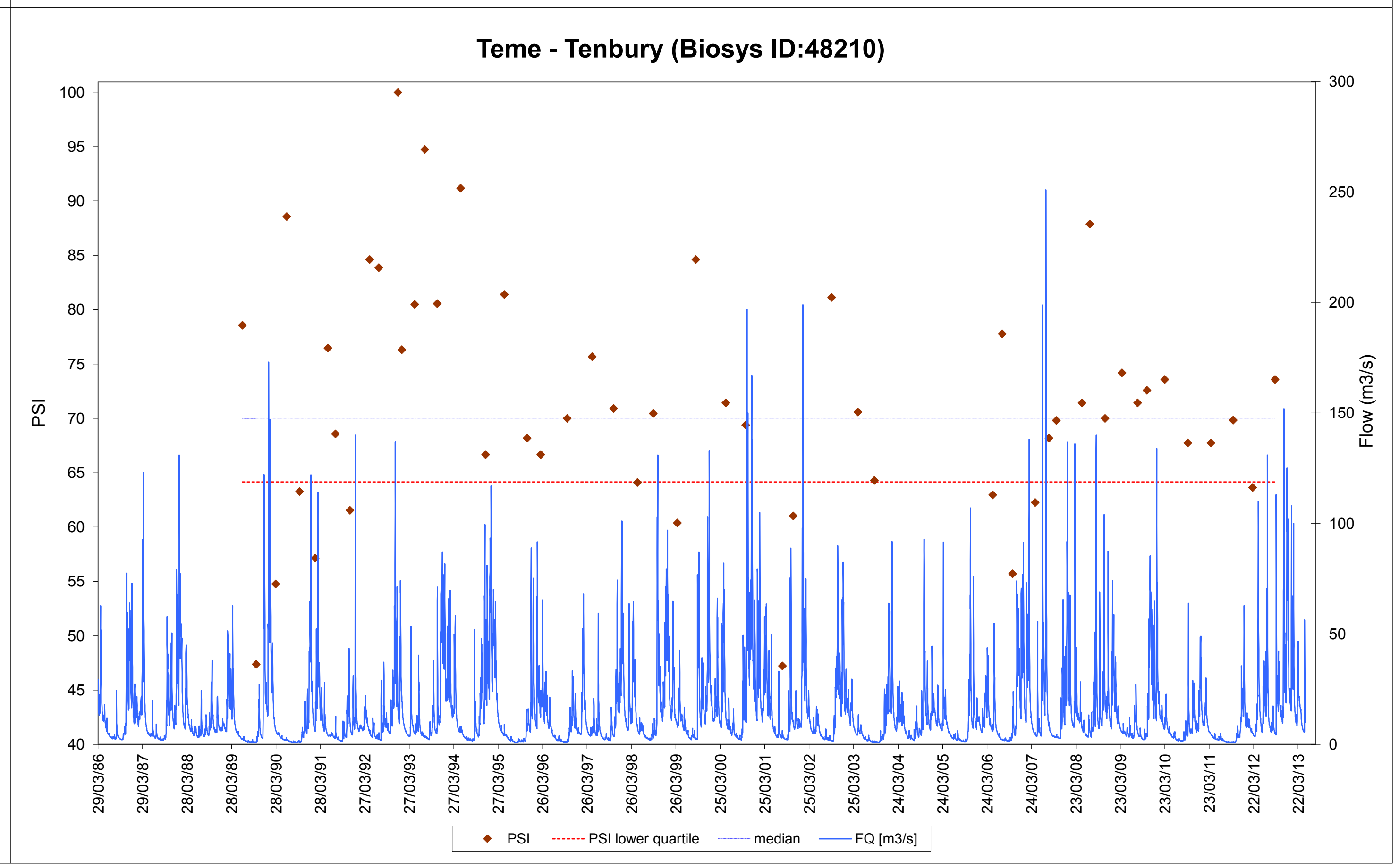
Control Point; Drought response lta plot at Tenbury on the River Teme

Teme - Tenbury (Biosys ID:48210)









Appendix P

Fish Technical report – River Severn Drought Order

FISH OF THE SEVERN CORRIDOR

Environment Agency
Martin Fenn
Analysis and Reporting

Fisheries data availability and Assessment

The River Severn supports a mixed coarse and Salmonid fishery. Important fish in this fishery include barbel (*Barbus barbus*), brown trout (*Salmo trutta morpha fario*), chub (*Leuciscus cephalus*), dace (*Leuciscus leuciscus*), perch (*Perca fluviatilis*), pike (*Esox lucius*) and roach (*Rutilus rutilus*). The Severn also has the following notable migratory species: Atlantic salmon (*Salmo salar*), sea trout (*Salmo trutta morpha trutta*) and European eel (*Anguila anguila*) and the Annex II species that the Severn Estuary has been given SAC status for Twaite shad (*Alosa fallax*), river lamprey (*Lampetra fluviatilis*) and sea lamprey (*Petromyzon marinus*). Fishing within the Severn is conducted for recreational and commercial purposes.

The main River Severn is a designated fishery under the EC directive on the quality of freshwaters needing protection or improvement in order to support fish life. The Salmonid fishery extends from the weir at Shrewsbury upstream, encompassing the Afon Vyrnwy. Below this the Severn is designated a cyprinid fishery (coarse fish) down to Saxons Loade near Tewkesbury.

The Environment Agency carries out routine surveys throughout the Severn catchment to evaluate the fish numbers and to determine whether or not populations are stable, improving or declining. The most widely used technique is electric fishing, but the effectiveness of this method generally reduces as the size of the river increases. Consequently the middle and lower reaches of the river present specific challenges when trying to assess the fish population present. Therefore other methodology is required. Mobile boat-based hydro-acoustic surveys have been used to survey these parts of the river, which provides a useful tool for estimating fish biomass and density. Surveys are conducted at night when coarse fish stop shoaling and are not hiding. The one downside of this method is it is unable to distinguish between species.

Rod catch data provides additional information on the fish stocks, with salmon and sea trout anglers obliged to submit records of catches made during a season. The Environment Agency also has a match catch database where data from fishing competitions provides information on the coarse fishery. However this is a voluntary scheme and it should be noted that all angling data are subject to bias in some form. Angling matches are judged on the biomass of fish caught, therefore anglers will fish selectively for those species that are most likely to be caught. This is likely to vary depending on the specific location on the river, the prevailing weather and the flow conditions being experienced at the time. Creel census data has also been collected which monitors catches by individual anglers at fishing hotspots along the River Severn. The primary purpose of the angler census is to collect data on species, sizes and rates of fish capture by anglers (primarily coarse anglers).

Migratory fish movements can be monitored by fish counters. Three different types of fish counter have been installed to monitor the upstream movements of Atlantic salmon at three locations within the River Severn catchment (see Figure 2). At Carreghofa on the Afon Tanat there is a resistivity counter that measures changes in conductivity within the water column and can tell whether movement of fish is upstream or downstream. Carreghofa weir is an impassable barrier to upstream salmon migration even at high flows so all fish moving upstream have to move through the fish pass and hence the counter. At Ashford on the River Teme there is a Vaki counter. This records fish movement through the counter as silhouettes through infra red beams (see figure 1). A debris screen has been added to reduce blockage of the pass. Salmon are able to jump Ashford weir during high flows.

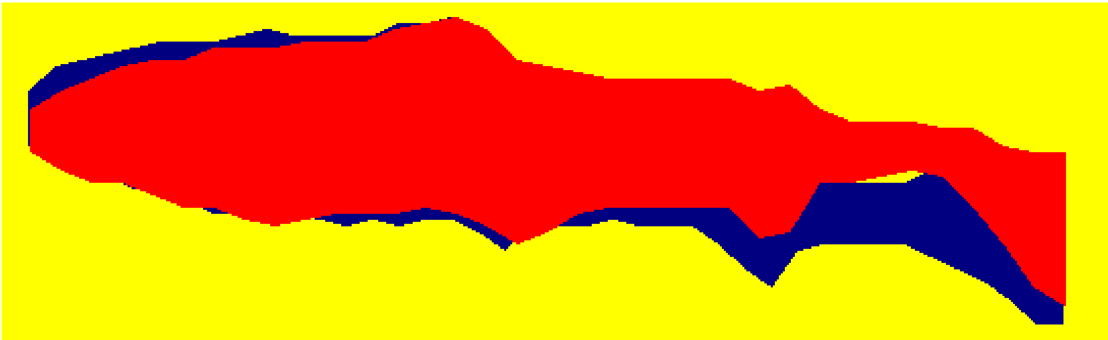


Figure 1: Salmon moving through Vaki counter at Ashford, River Teme

On the River Severn at Shrewsbury there has recently been installed a video camera system, which uses four cameras at the edge of the pass. Special motion detection software can be used to detect fish movement through the pass. These counters have shown that the salmon tend to move upstream through the fish passes as flows are starting to recede after high flows, especially in the autumn (Fenn, 2009). Therefore the use of the drought order is unlikely to have an impact on movement of fish through the fish passes.

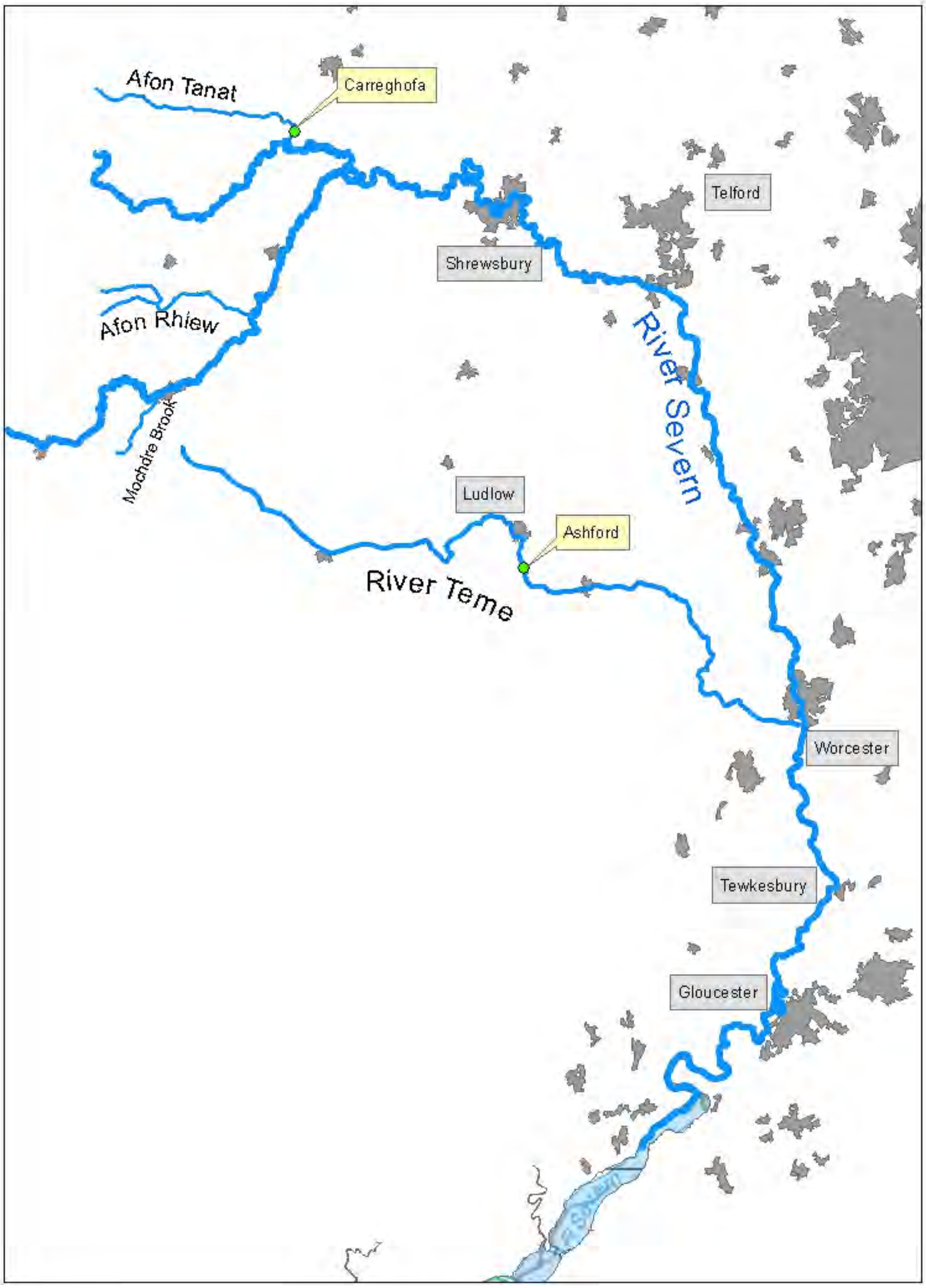


Figure 2: Map showing location of fish counters within Severn catchment

The Severn Estuary is an important fishery but is difficult to monitor. Fyke netting, seine netting and beam trawling are used to monitor fish populations as part of the TRac monitoring programme, but are only qualitative and not quantitative.

7.2 Fish Species Present

Before it is possible to make judgments on whether there is sufficient water for the fish in the River Severn it is imperative that the ecology of the fish is understood.

Resident (non-migratory) fish

The resident fish population of the River Severn is very diverse. Different sections of the river support different fish species. The upper section of the River Severn (above Welshpool) are the principal Salmonid (brown trout and grayling) spawning and nursery areas, although some spawning does take place in the middle reaches, in the shallow gravel areas downstream of Shrewsbury and between Bridgnorth and Kidderminster. Many of the tributaries also are utilised by salmonids for spawning e.g. River Teme. Brown trout will spawn around October (similar to the sea trout), while grayling spawn earlier from March to May. Both species lay their eggs in nests in gravels.

From Shrewsbury downstream coarse fish dominate with barbel being a very popular fish with anglers in the middle section of the Severn. These coarse fish tend to spawn in spring and summer when the water temperatures start to rise sometimes shoaling up in large groups.

Another fish found mainly in the upper sections of the River Severn is the bullhead (Cottus gobio), which is a BAP species. These are a bottom dwelling species that spawn between February and June. This species is impacted by low flows mainly due to deposition of fine sediment over their preferred hard substrate and so reducing available habitat.

Migratory fish

Atlantic salmon, sea trout, Twaite shad and both lamprey species are ‘anadromous’ which means they migrate up rivers from the sea to breed. While the European eel spends most of its life in freshwater and travels to the Sargasso Sea to spawn. Figure 3 shows movements of these fish through the year within the Severn catchment.

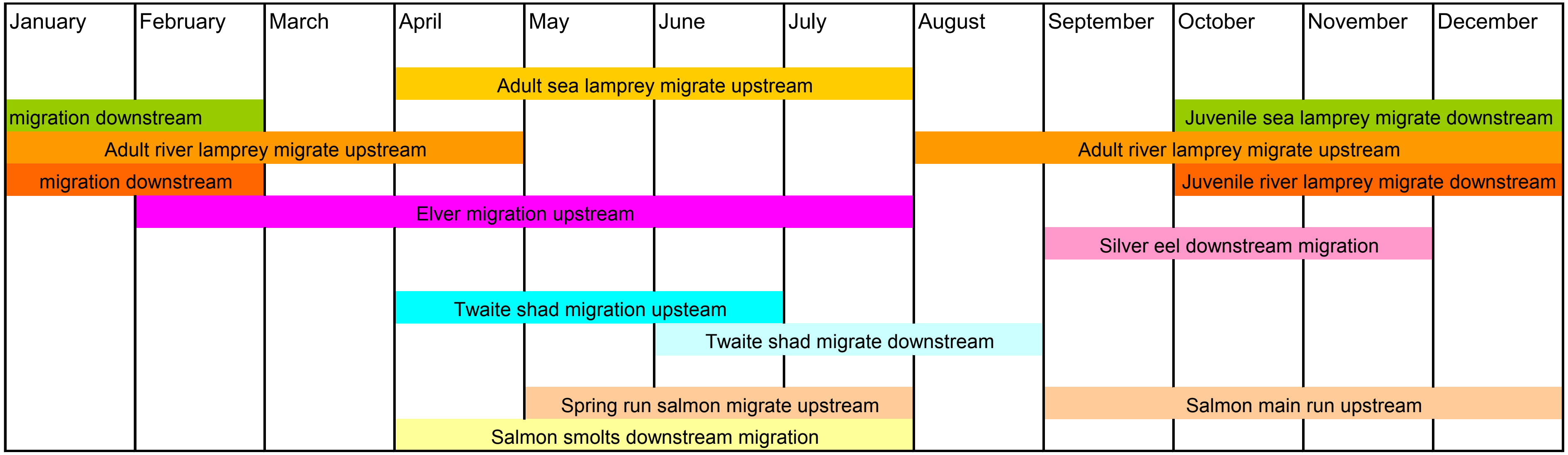


Figure 3: Graphical representation showing the movements of the migratory fish within the River Severn catchment

Annex II species

Shad

Historically both Twaite and allis shad spawned within the River Severn catchment. However, it is now generally accepted that the River Severn only sustains a reproductive population of Twaite shad not allis shad (Maitland & Hatton-Ellis, 2003). The Twaite shad generally migrate out of the estuary early in the year (April to June) to spawn in freshwater between mid May to mid July. The main trigger for movement upstream is thought to be water temperature (10.6 to 12.3^{o}c) and movement has been observed entering rivers between 05:00 and 20:00. The major obstruction for upstream migration for the Twaite shad is the weir at Diglis on the River Severn which prevents migration further upstream even in normal flow conditions. A multi-species fish pass has been added to the weir at Powick on the River Teme, which used to prevent further migration on a river the shad have been known to spawn on. Eggs are released into the water over gravel beds and hatch within 5 to 8 days (Maitland, 2004). Adult shad are repeat spawners and spent adult fish return to the estuary around June and July.

The juveniles require slow flowing nursery areas before they move down to the estuary (August and September). Juvenile Twaite shad tend to migrate down to the estuary earlier in the River Severn than in the River Wye and this is thought to be due to channelisation of the lower Severn, hence less useable habitat (Maitland & Hatton-Ellis, 2003).

<u>Lamprey</u>
River lamprey *Lampetra fluviatilis* and sea lamprey *Petromyzon marinus* are features for which the Severn Estuary is a SAC. The general lifecycle of lamprey involves the migration of adults upstream to reach spawning areas, normally stony or gravelly stretches of running water. Migration of sea lamprey is usually April to June, while river lamprey migrate upstream later in the year (August to December) and tend to migrate later during low flow autumns. Migrating adult lamprey (sea and river) have been shown to positively respond to pheromones released by ammocoetes within river systems. Hence allowing the adults to assess the suitability of rivers for spawning (Severn Tidal barrage scoping document, 2008). Sea lamprey often travel up the Severn as far as Shrewsbury and have been known to get to Newtown. They spawn in pairs or groups using features such as displaced stones, logs or clumps of vegetation to form crude nests, with adults dieing after spawning. After hatching, the young elongate larvae, known as ammocoetes which are only a few centimetres in length, swim or are washed downstream by the current to areas of sandy silt in still water where they burrow and spend the next few years in tunnels. After several years, the number of years varying with the species and habitat, the larvae metamorphose into the adult form.

<u>Notable species for SAC</u>

<u>Atlantic salmon</u>
The Atlantic salmon is a species of great importance for the River Severn. Although numbers have dropped through over exploitation, blockages to migration and pollution, in some areas populations are still good. Adult Atlantic salmon return to the River Severn throughout the year, but the two main runs of fish are the spring run and the autumn run. The spring run fish enter the Severn around May to July and stay in the river system until spawning in late autumn early winter. The River Severn has long been known for its spring run of large salmon. Once salmon have entered the estuary they do not eat and rely on fat reserves to survive until spawning. The autumn run fish start entering the Severn around late September until early December on the first high flows of the autumn but do not spawn until the first frosts of autumn. Salmon can migrate up the Severn to just above Llanidloes, which encompasses the regulated section of the River Severn. The cock fish generally get to the spawning grounds first where they will compete with other males for territories. Then the hens move in and excavate their redds (nests) in the gravels. When the redd is ready she will settle into it and start shedding her eggs. At this point the male moves in beside the female and then he fertilises the eggs as she ejects them. Straight after spawning is over the hen buries the eggs by shifting the stones from upstream back into the hollow. The majority of Atlantic salmon die after spawning with the males suffering the most fatalities due to the stresses involved, (normally fewer than ten percent of the adult salmon will survive). The eggs hatch, and the young salmon (initially referred to as fry, and later as parr) remain in fresh water for up to three years; they then enter the smolt stage and migrate downstream to begin the marine phase of their lifecycle. Most will remain in the North Atlantic for between one and three years before returning to freshwaters again to spawn.

A Salmon Action Plan has been produced for the River Severn back in 2003 and is in the process of being replaced by a Salmon and Sea Trout Strategy, which should be available in 2011.

<u>European eel</u>
The River Severn is an internationally renowned eel fishery (elvers) and has recently had an eel management plan published. The eel differs from the other migratory species found in the River Severn in the fact that it spawns out at sea and after one or more years the young elvers then migrate into freshwater. Large numbers of glass eels enter the Severn estuary between February and April and migration upstream in to the rivers occurs at night. All available evidence indicates that elvers and eels migrate upstream either without regard to river flow, or migrate to a greater extent at low flows than at high flows (Soloman and Beach 2004) and likely to be linked to water temperature. Two factors combine in the lower section of Severn to limit migration of elvers. Firstly the majority of the rivers entering the Severn have had flood defence works in the lower and tidal reaches including flood control tidal flaps and secondly the building of weirs. During the upstream migration small eels can climb vertical damp surfaces at times as long as there is sufficient grip, but this activity appears to be restricted to eels of less than 100mm. They then stay in freshwater as yellow eels for 8-18 years (Maitland, 2004) before they migrate back to the Sargasso Sea as silver eels usually from the beginning of September to the end of December. The larvae are then transported by oceanic currents back to Europe where they change into glass eels.

Eel populations throughout the United Kingdom are declining and further research is being undertaken to improve our understanding of the marine phase of their life cycle.

<u>Sea Trout</u>
The sea trout tend to migrate back in to the rivers after feeding in the sea for 12 to 14 months and start moving upstream to spawn around October time in gravels in rivers and streams generally in the lower Severn catchment, although occasionally anglers claim to have caught sea trout as far up as Shrewsbury. While sea trout do respond to increases in flow, they will move upstream without such a stimulus and are thought to require smaller discharges than salmon. Eggs hatch in approximately 150 days and the fry spend a year or more in the nursery streams before migrating back to sea.

Sea trout numbers in the Severn are low compared to the size of river, which could be due to distances needed to travel to reach spawning gravels.

Fisheries Current Environment

The present situation on the River Severn is quite complex and our understanding is impeded by the difficulty in monitoring such large rivers.

Creel census results from the summer of 2004 collected around Shrewsbury and Bridgnorth showed the majority of fishermen were catching chub and barbel. A similar theme can be seen in match catch returns and in winter time a move to roach and dace can be seen.

Long term catch return data for salmon over the period 1951 to 2012 are shown in Figures 4-6. . Putcher catches have dropped off significantly since the 1980's, however this could be more down to number of licences rather than salmon numbers. Similar trends can be seen for Lave net and Draft net catches. No specific trends can be seen linked to low flows.

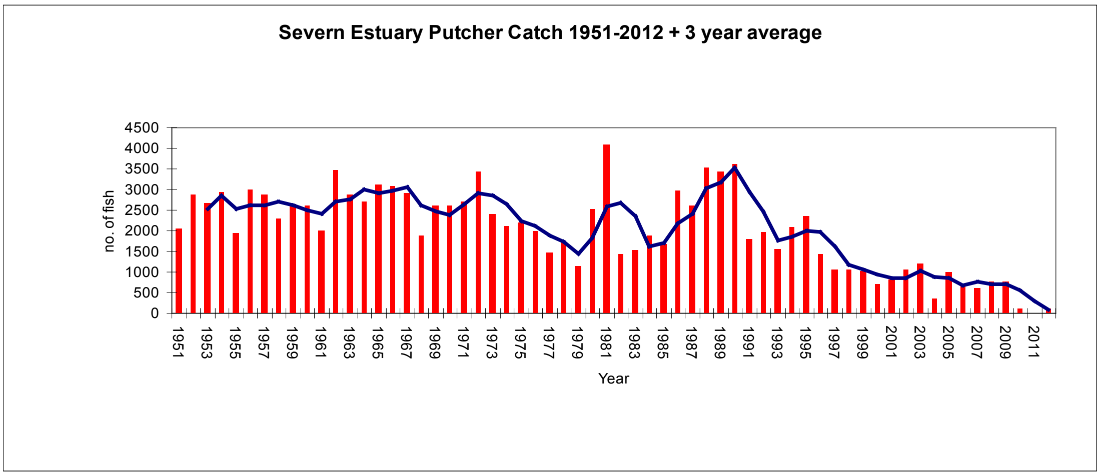


Figure 4: Severn Estuary putcher catch returns from 1951 to 2012

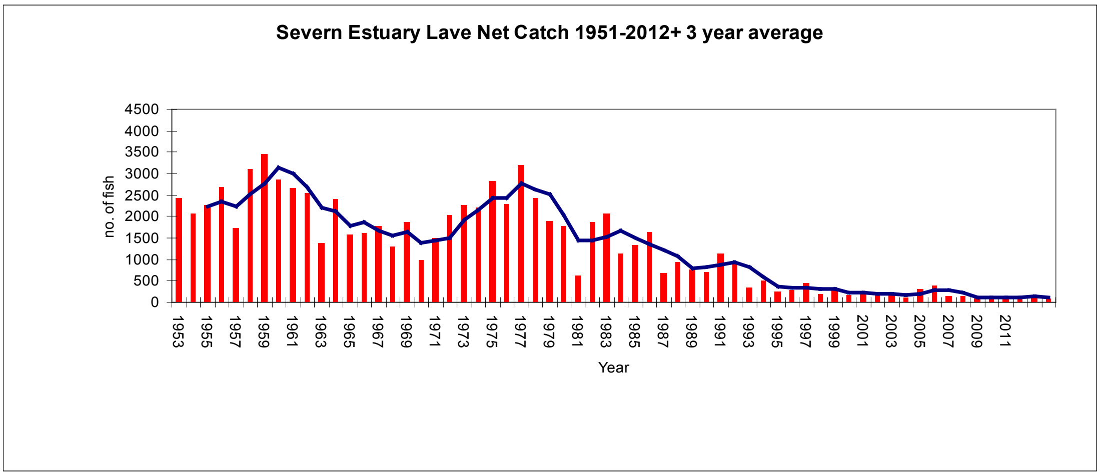


Figure 5: Severn Estuary lave net catch returns from 1951 to 2012

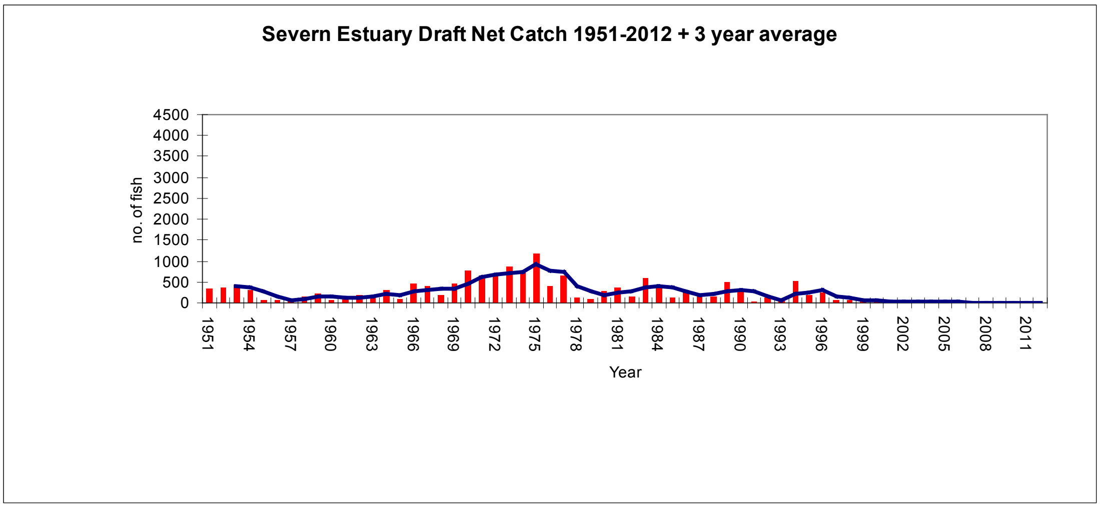


Figure 6: Severn Estuary drift net catch returns from 1951 to 2012

Rod catch data (Figure 7) for 1951 to 2012 has many fluctuations but the overall trend is downward. It is not unusual to see periods of population growth and decline, as recruitment and mortality rates are subject to many different impacts, e.g. disease, predation, commercial exploitation, prey availability and impact of flows. It is also possible that the decrease in rod caught salmon could be due to a downward trend in numbers of anglers and hours spent fishing.

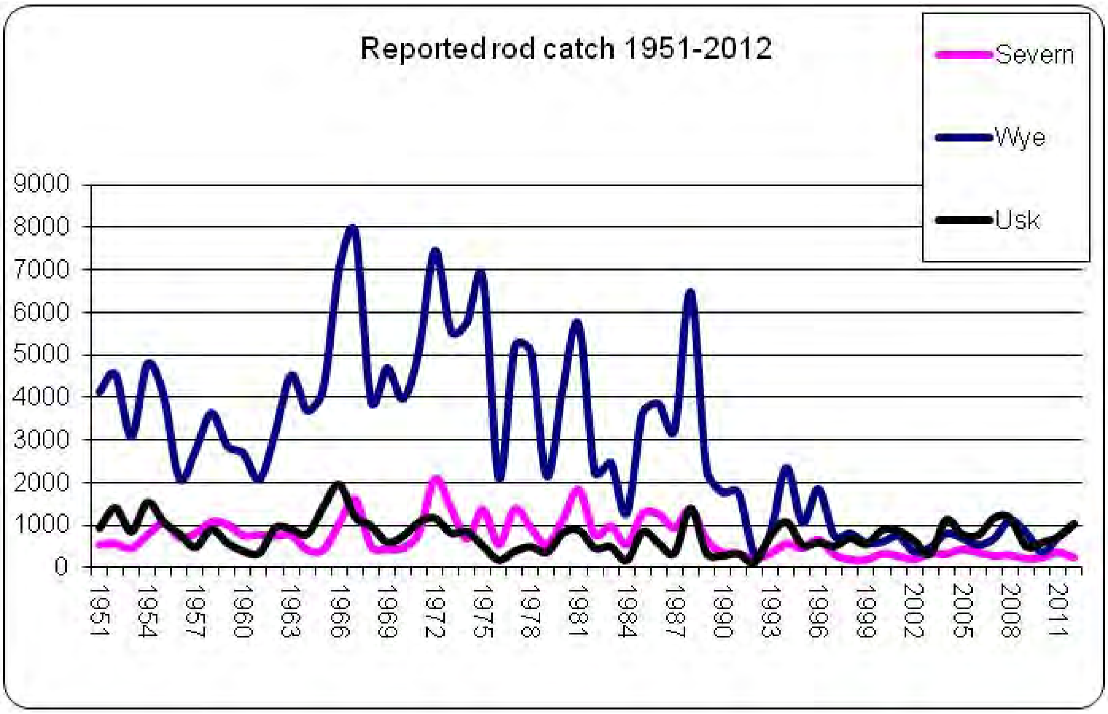


Figure 7: Annual rod catch data for salmon caught in the Severn, Wye and Usk (1951 to 2012)

The Salmon Action Plan (SAP) for the River Severn was published in 2003 and included a summary assessment of the status of salmon within the river, which concluded that the Severn had failed to achieve its conservation limit as measured by the relationship between rod catches and predicted egg deposition. Long term data is shown in Figure 8 with the Severn failing its target on seven occasions over the last ten year period (1999 – 2008). New estimates and conservation limits can be seen in Figure 9 for the River Severn. This was actually above the conservation limit in 2011, but results are variable.

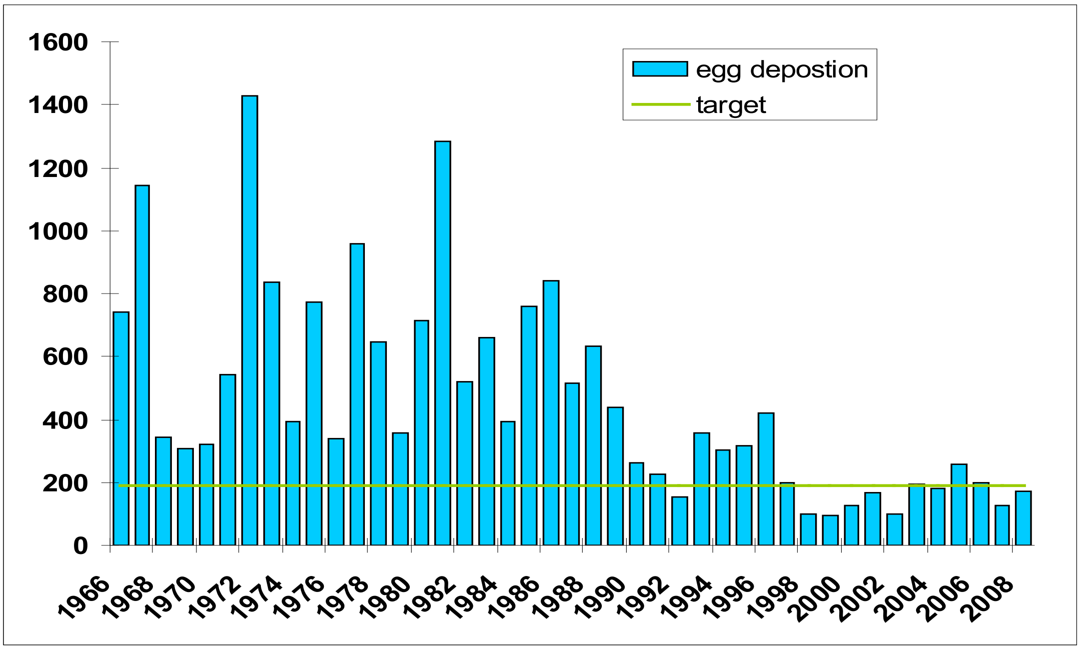


Figure 8: Calculated River Severn egg deposition rates with target limit.

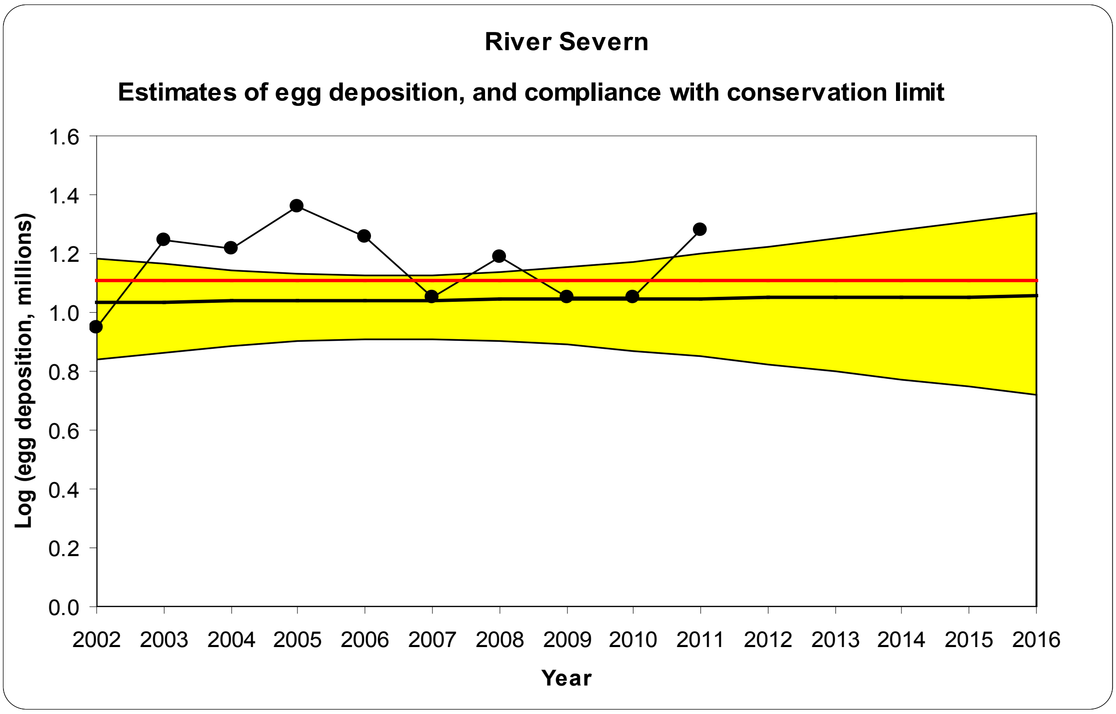


Figure 9: Estimates of egg deposition and compliance with conservation limit for River Severn

However, the SAP also reported that salmon redd counts for the River Severn and its tributaries remained high, with very high counts recorded in some tributaries. This would suggest that the egg deposition estimates based on rod catch data are probably under-estimating the actual level of spawning activity. Nevertheless, if it is assumed that fishing effort is relatively constant between years, so the trend in egg deposition rates shown in Figure 8 are likely to be valid, even though these can be subject to weather conditions, etc.

The best dataset available for 0+ salmon in the Severn catchment are on the Afon Tanat and Rhiew (Figures 10 and 11). Comparing these to egg deposition rates shows very little similarity. Variability in the numbers of juvenile salmon do not have a significant correlation with egg deposition rates for the Afon Tanat or Afon Rhiew. Through the monitoring period juvenile salmon numbers at Pedair-fford have generally declined. Glan Hafren has also seen a decrease over time. Llangynog numbers have gone up and down and Llangedwyn is a difficult site to fish to the point where the site has had to be changed and so results are variable. Sites on the Afon Rhiew appear to be more variable with no real trends to pick out. The reason for the low numbers of fish caught in 2007 was that sites were fished after high summer floods.

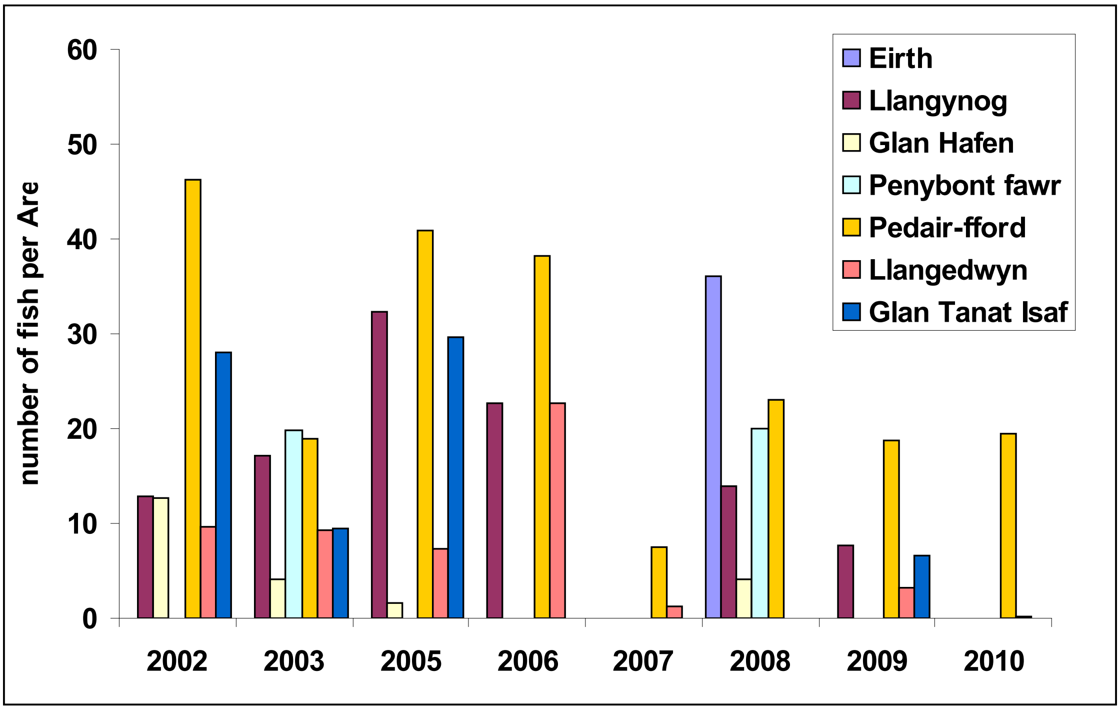


Figure 10: Numbers of 0+ salmon caught on electric fishing surveys on the Afon Tanat.
**2011/2012 data not included due to different methodology*

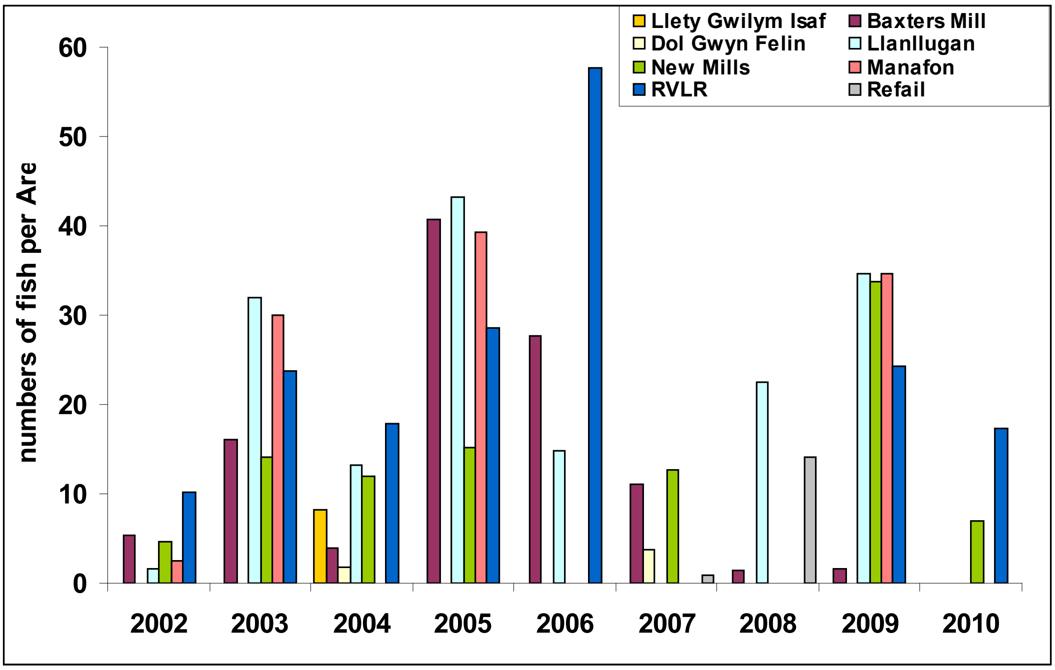


Figure 11: Numbers of 0+ salmon caught on electric fishing surveys on the Afon Rhiew
**2012 data not included due to different methodology*

Of the three fish counters running in the Severn catchment the only long term dataset available is that on the Afon Tanat at Carreghofa. Figure 12 shows salmon movements from 2003 to 2011 through the Carreghofa fish pass. Power failures in 2007 and 2008 caused a lower count but numbers were also considerably down in 2009 and 2010. The counter has shown a continued decrease in salmon numbers since 2006.

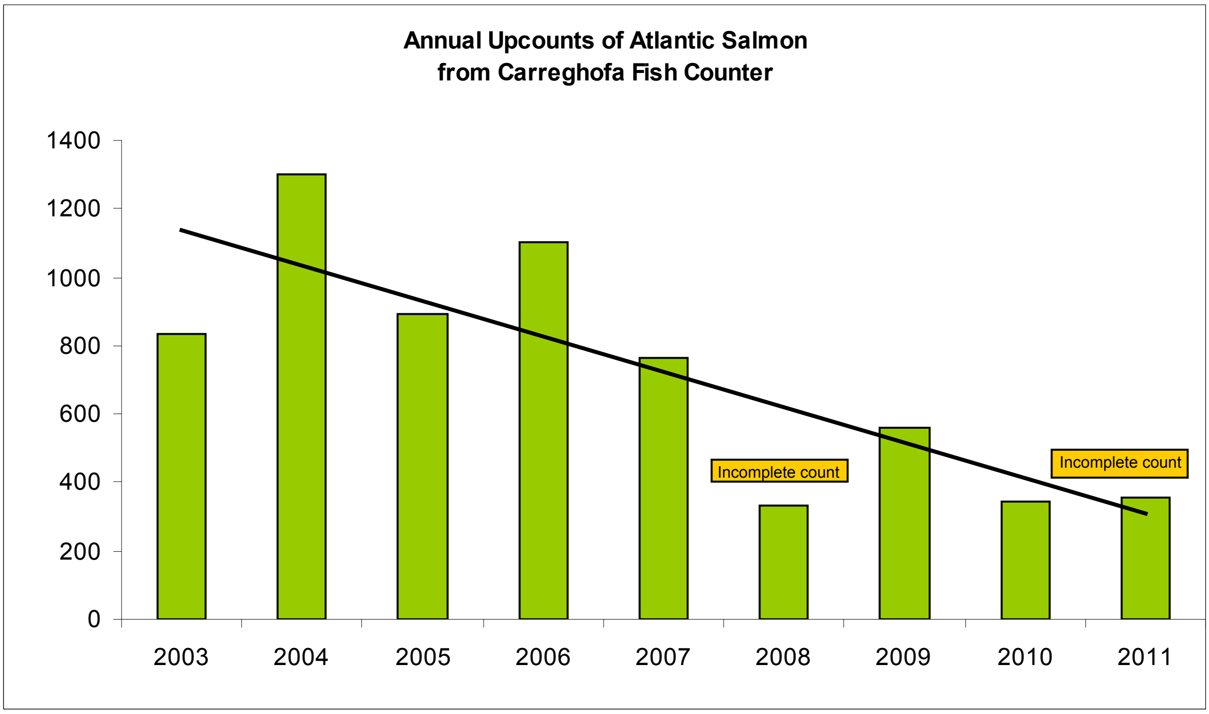


Figure 12: Annual salmon upcounts for Carreghofa, Afon Tanat 2003 to 2011

Figure 13 shows the main peaks of salmon movement through the counter in 2009 in relation to flow. It should be noted that flows during November 2009, peak movement period for salmon on the Afon Tanat, were exceedingly high possibly causing inefficiencies with the counter and possibly preventing salmon using the fish pass. Salmon have shown a preference of moving on the falling limb after high flows (see Figure 13) and as this was a sustained event salmon might have decided to spawn further down the catchment.

Figure 13: Salmon upcounts through the Carreghofa fish counter compared with mean daily flow (Ml/d) at Llanyblodwel (SJ 25230 22440)

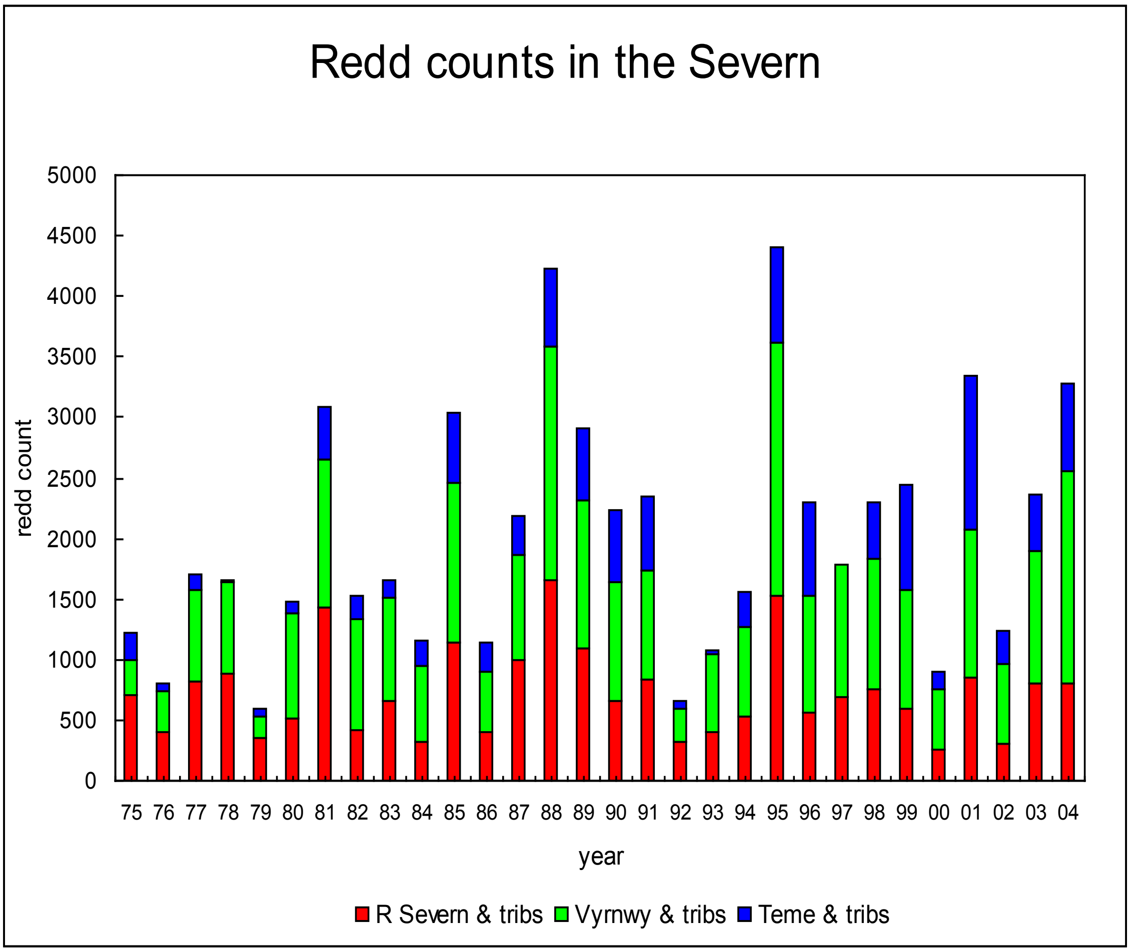


Figure 14: Salmon redds counted in Severn catchment from 1975 to 2004
**no redd count surveys conducted since 2004*

The counting of salmon redds (nests) has been carried out in the upper Severn since 1975 with results shown in Figure 14. This type of monitoring gives a good indicator of where the salmon are spawning within the river system but is not scientifically robust enough to be used by itself. High flows and water clarity can have a large impact on finding the redds and so numbers are not always reliable. For example high flows in autumn 2000 would have made redd counting very difficult, which could be the reason for the low count.

In Figure 15 redd counts for the main River Severn upstream of Newtown, the Afon Vyrnwy and the tributaries Afon Tanat and Rhiew are shown with wet and dry years highlighted. None of the waterbodies show a link between redd counts and wet and dry years.

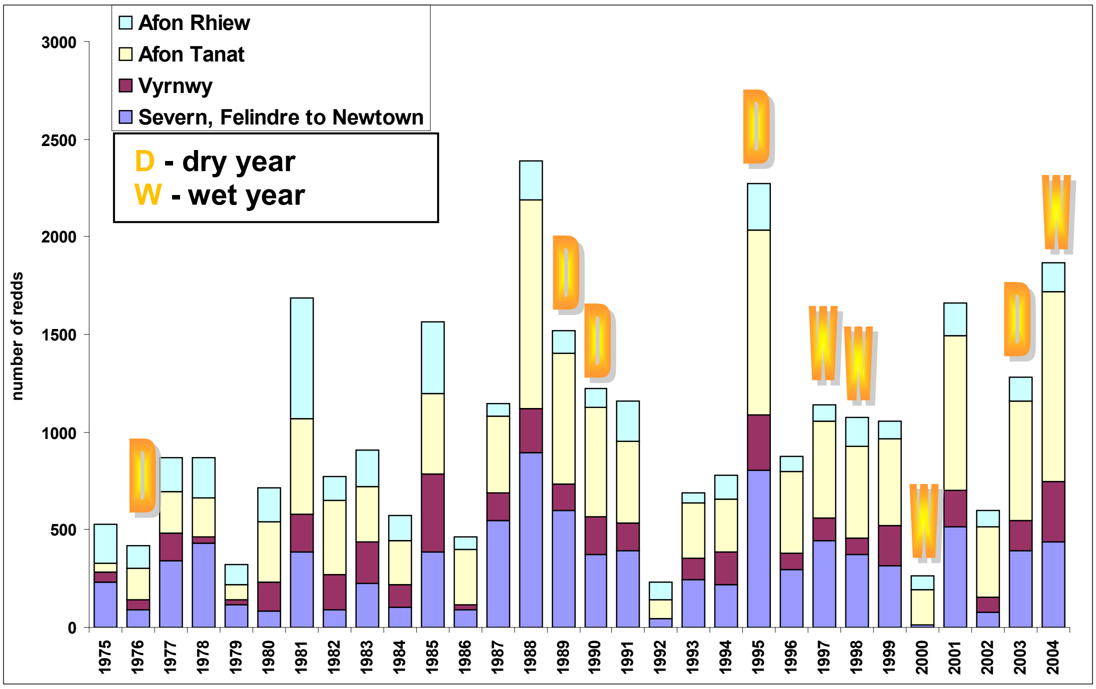


Figure 15: Redd counts for main River Severn, Afon Tanat, River Vyrnwy and Afon Rhiew.

Historically a number of sites have been electric fished on the main River Severn as far down as Worcester (see Figure 16). These have been done mainly for two reasons:

- Principal Salmonid – assessing the success of salmon spawning in the main River Severn (discussed earlier)
- Principal coarse – assessing the coarse fish population where angling interest is highest

These surveys have initially been used for Water Framework Directive (WFD) classification, but unfortunately do not adhere to the monitoring methodology requirements (full width surveys with stop nets). Sites downstream of Newtown cannot be fished quantitatively due to width, depth and velocity of the river. Therefore results can vary considerably and are not reliable in assessing populations and hence electric fishing in the main River Severn has ceased. Work is ongoing on how to classify this watercourse for WFD using fish as a quality parameter.

Results from these surveys can be used to give an idea of the spread and dominance of certain fish species within the River Severn. For example the principal Salmonid surveys have proved that salmon do use the main River Severn for spawning as far down as Bewdley.

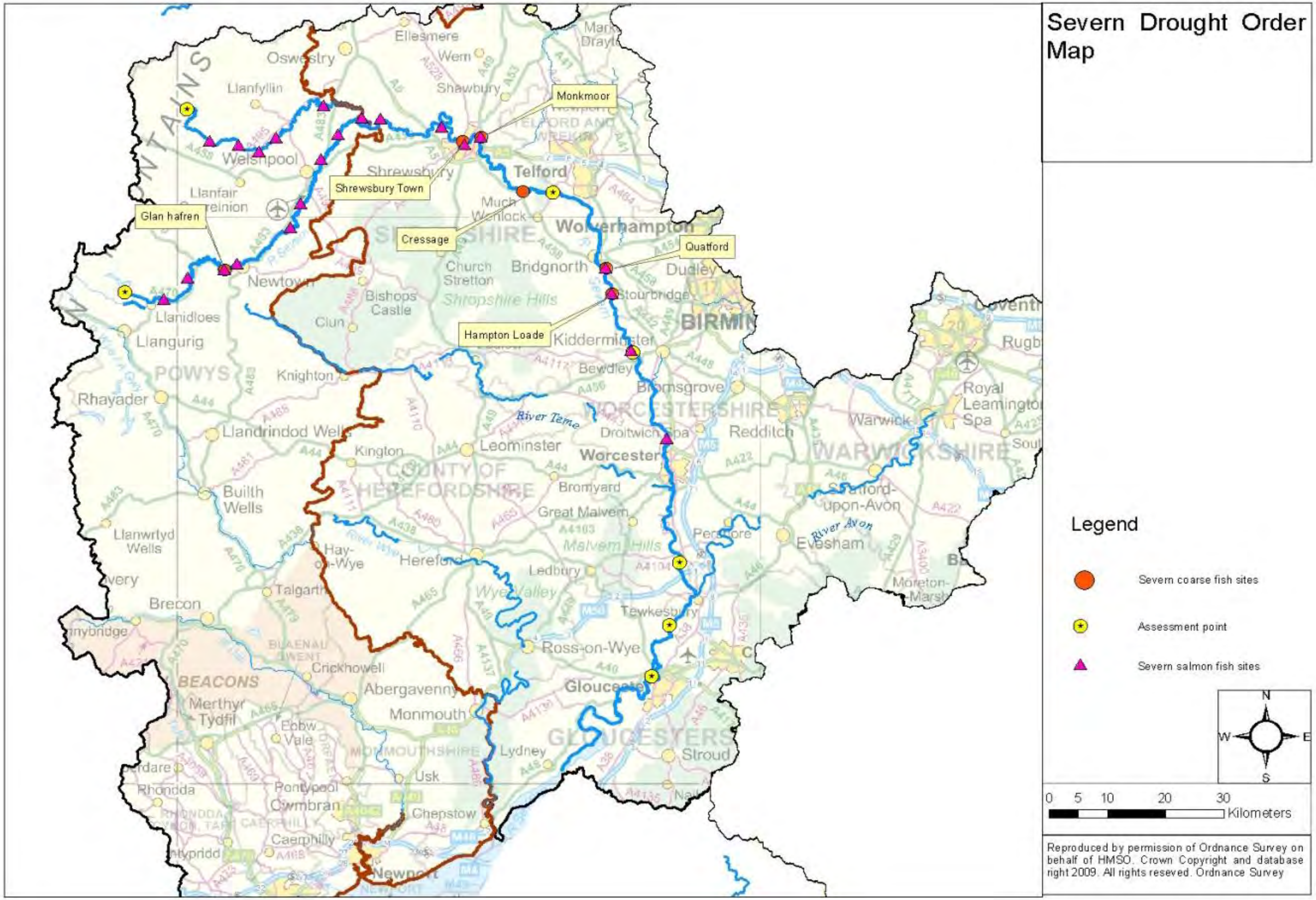


Figure 16: Map of electric fishing sites on the River Severn

Electric fishing results for the principal coarse fish sites are shown in Figures 17 to 22 (no data has been presented for Glanhafren as it was only fished once in 1992). As can be seen the River Severn is home to a diverse fish population, although numbers caught are generally quite low (believed to be due to inefficiencies in electric fishing deep wide rivers). At Shrewsbury Town gudgeon, roach and dace dominate, although gudgeon numbers vary considerably. At the River Severn, Cressage it is generally bleak and roach that are caught in the largest numbers. Weights have been calculated for Cressage to show that although bleak and roach dominate numerically they are not necessarily a large proportion of the biomass. In 2008 just two barbel were caught, but these easily outweighed the bleak and roach on this survey. Further down the River Severn it is a combination of roach, gudgeon and bleak dominating (numerically) at the other sites.

Temporal changes are not so obvious. Hampton Loade has the best coverage of surveys over the last 20 years with 6 surveys stretching from 1992 to 2009. Roach numbers rise and fall through this time period, but do not appear to coincide with dry or wet years. In 2009 all five sites were surveyed with bleak and roach dominating at all the sites except Cressage where nothing was caught in large numbers.

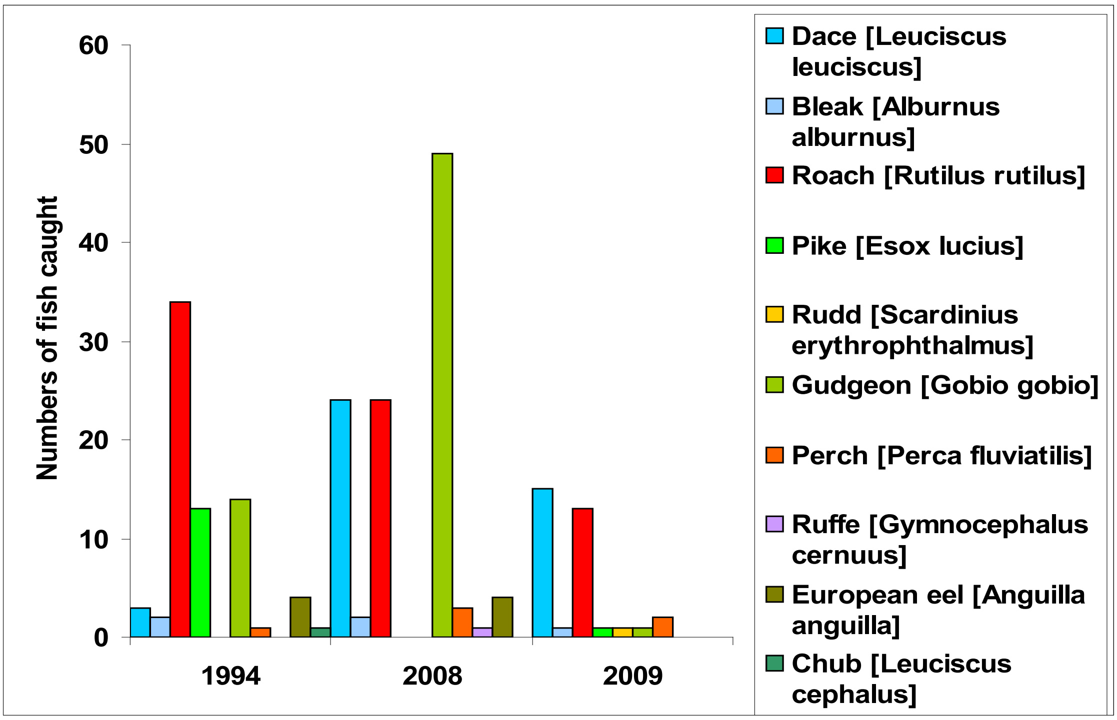


Figure 17: Numbers of fish caught at Shrewsbury Town, River Severn
**no electric fishing surveys since 2009, boom boat electric fishing to be trailed in May 2013.*

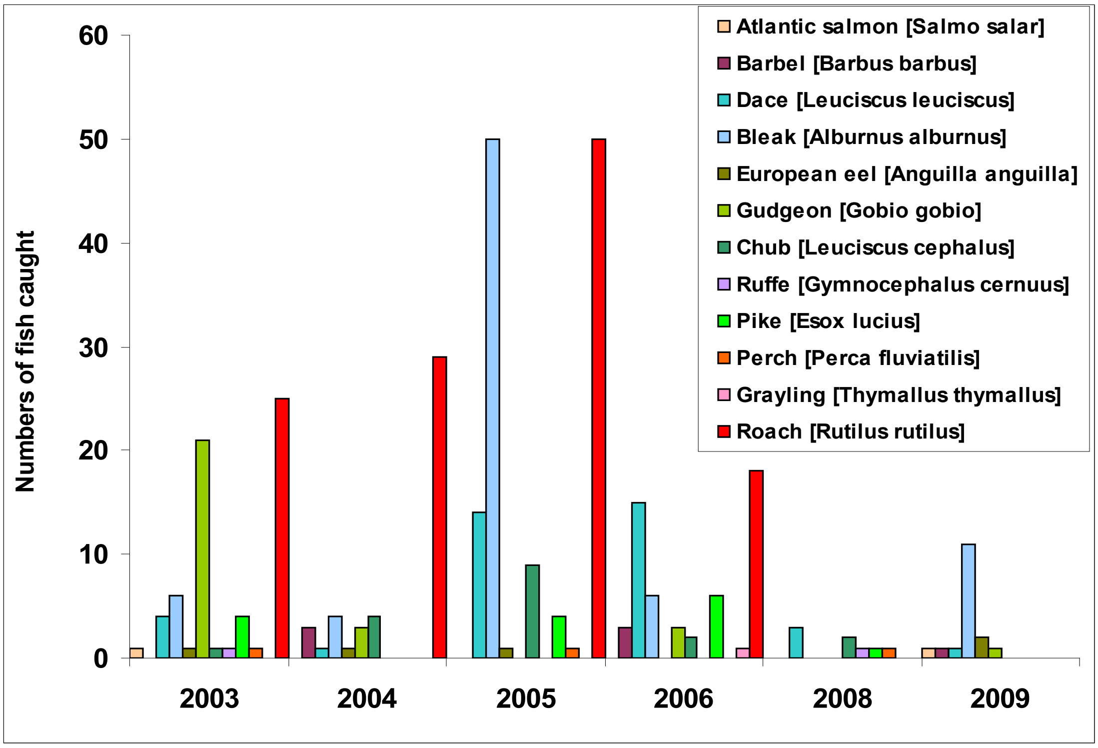


Figure 18: Numbers of fish caught at Monkmoor, River Severn
**no electric fishing surveys since 2009, boom boat electric fishing to be trailed in May 2013.*

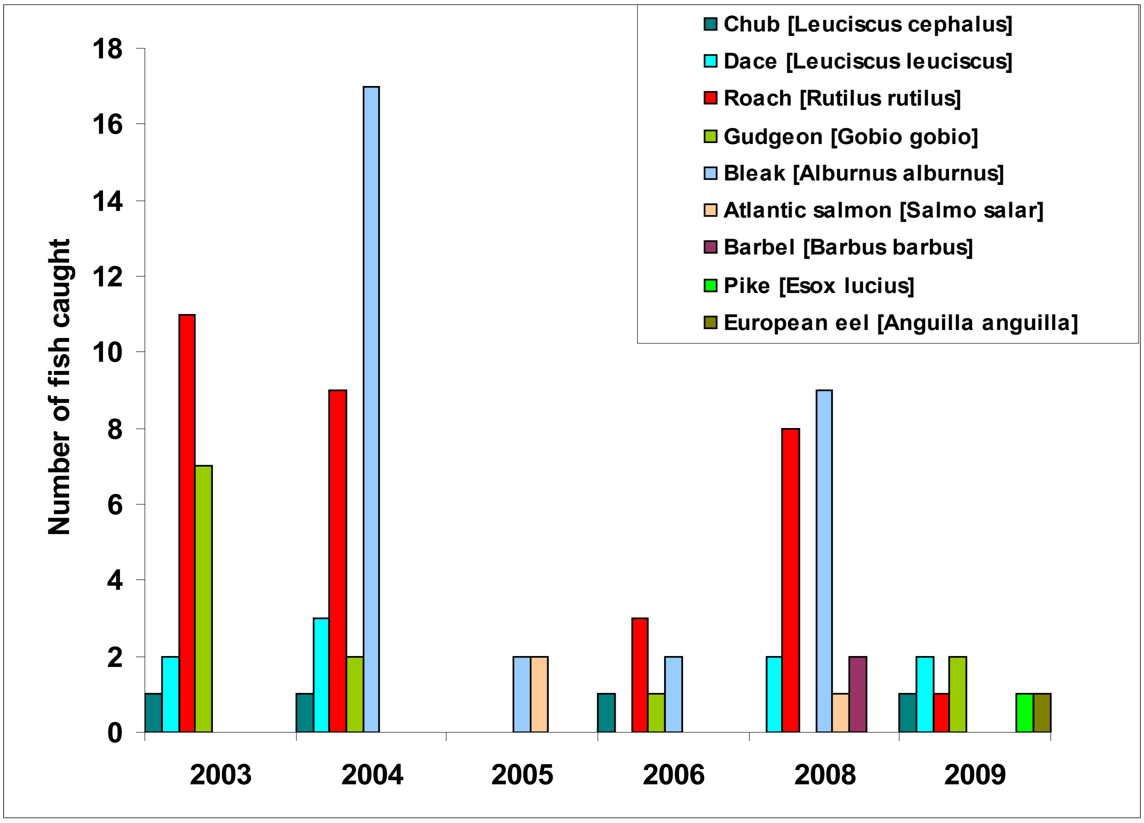


Figure 19: Numbers of fish caught at Cressage, River Severn
**no electric fishing surveys since 2009, boom boat electric fishing to be trailed in May 2013.*

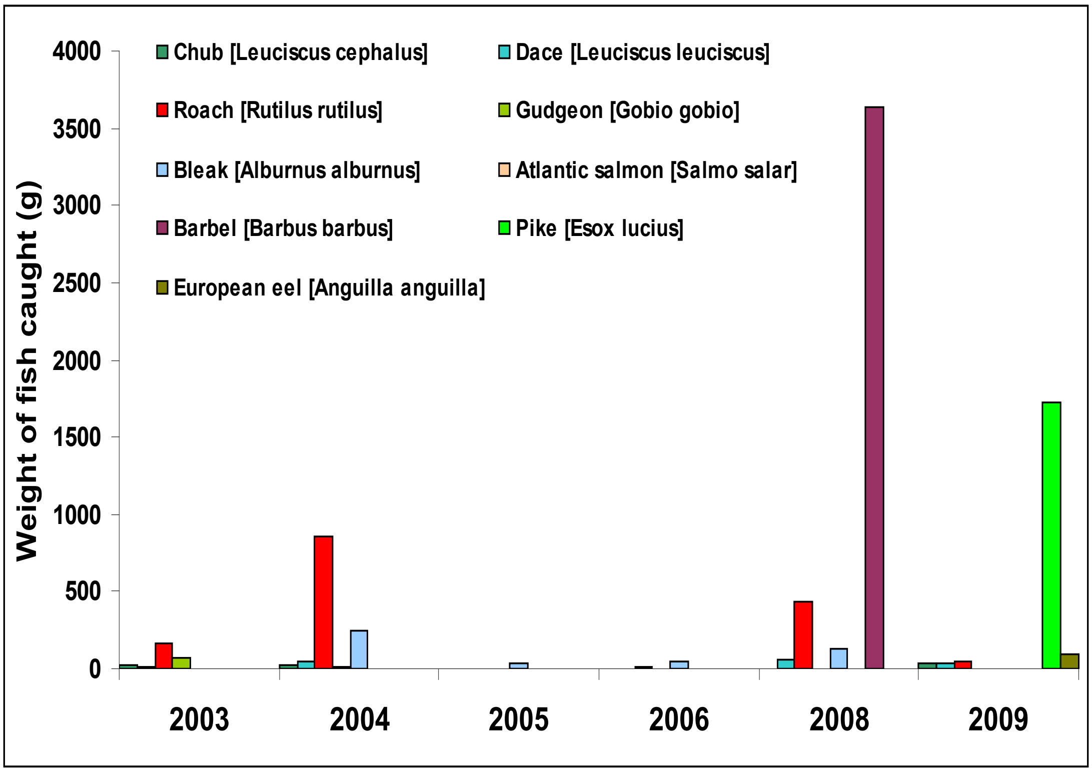


Figure 20: Weight of fish caught at Cressage, River Severn
**no electric fishing surveys since 2009, boom boat electric fishing to be trailed in May 2013.*

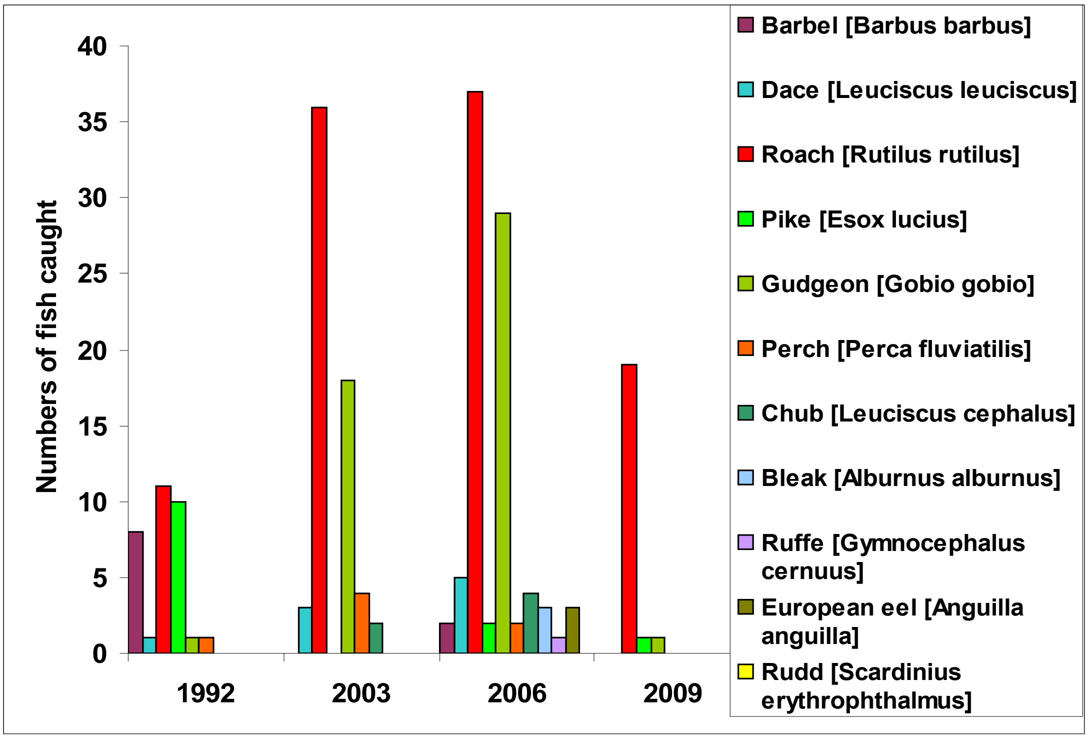


Figure 21: Number of fish caught at Quatford, River Severn
**no electric fishing surveys since 2009, boom boat electric fishing to be trailed in May 2013.*

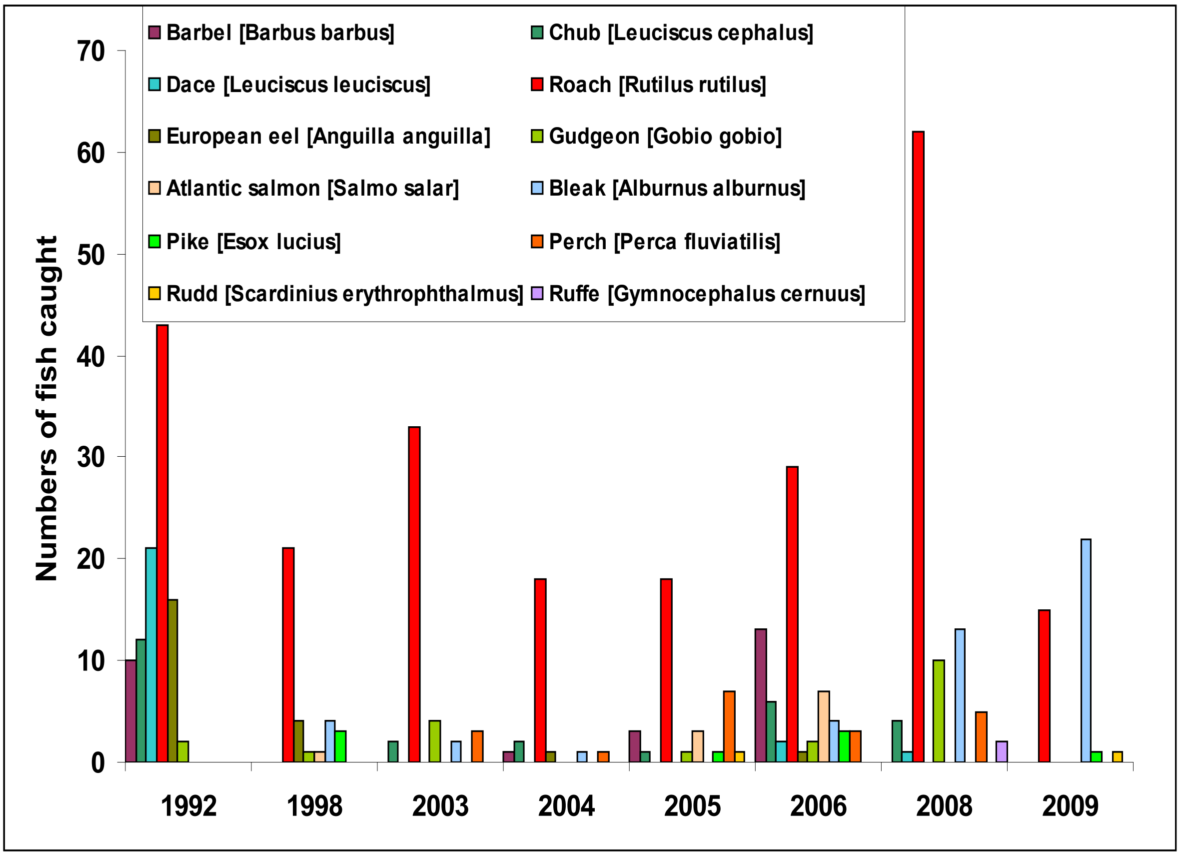


Figure 22: Number of fish caught at Hampton Loade, River Severn
**no electric fishing surveys since 2009, boom boat electric fishing to be trailed in May 2013.*

Boat based hydro-acoustic surveys have been carried out on the middle and lower sections of the River Severn as part of the strategic fisheries monitoring programme. Figures 23 and 24 show examples of results from 2008 surveys.

Figure 23: Densities of fish on Holt to Lincomb section of River Severn

Generally the hydroacoustic results have shown that fish densities along the river often have a clumped distribution. It has been noted on surveys that fish were often found in higher densities at the bottom of weirs as can be seen at Lincomb weir in Figure 23.

Figure 24: Densities of fish on Upton to Upper Lode section of River Severn

Hydroacoustic data from a number of rivers throughout the country are shown in Figure 25. These results suggest that the River Severn has low fish densities compared to other rivers sampled nationally.

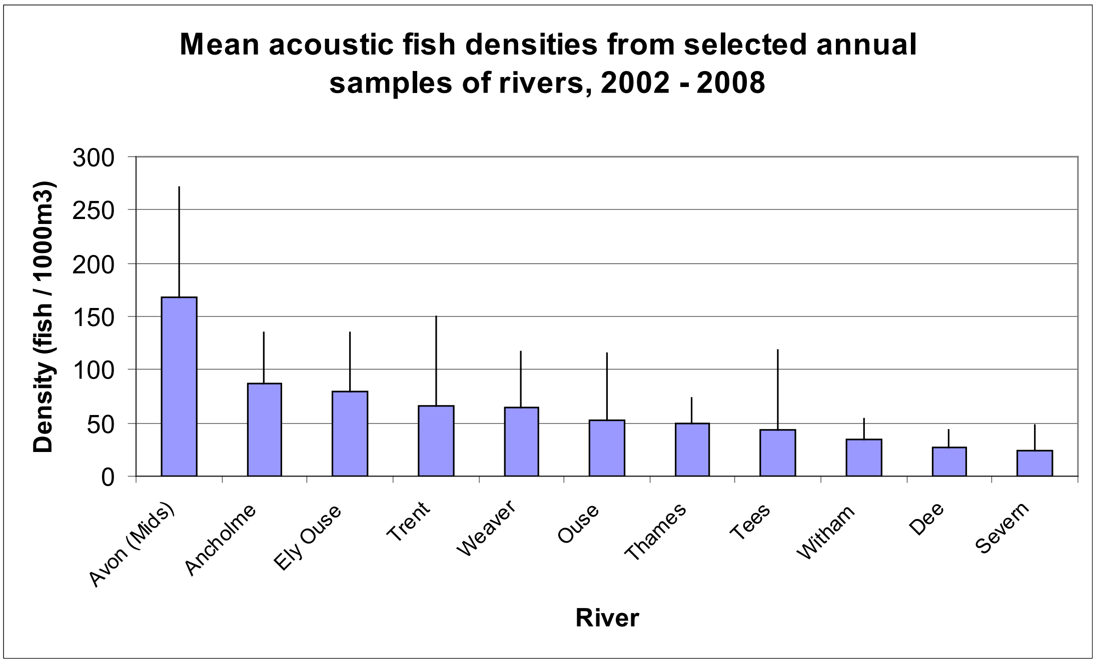


Figure 25: Mean fish densities from hydroacoustic data collected between 2002 and 2008

Some angling clubs have match catch data going back further than our monitoring results. For example the Leighton Anglers (close to Buildwas) have provided match catch data from 1964 showing weight of fish caught (Figure 26). As can be seen since the early 1970's barbel have been the main fish that anglers have caught in competitions. This is not surprising due to anglers targeting species like barbel to maximise their match weight. Up to 2003 weights of fish caught have stayed relatively constant or even improved. In the drought period of 1975/6 numbers of barbel caught were lower, while chub increased. However, this is not repeated in 1989 or 1995.

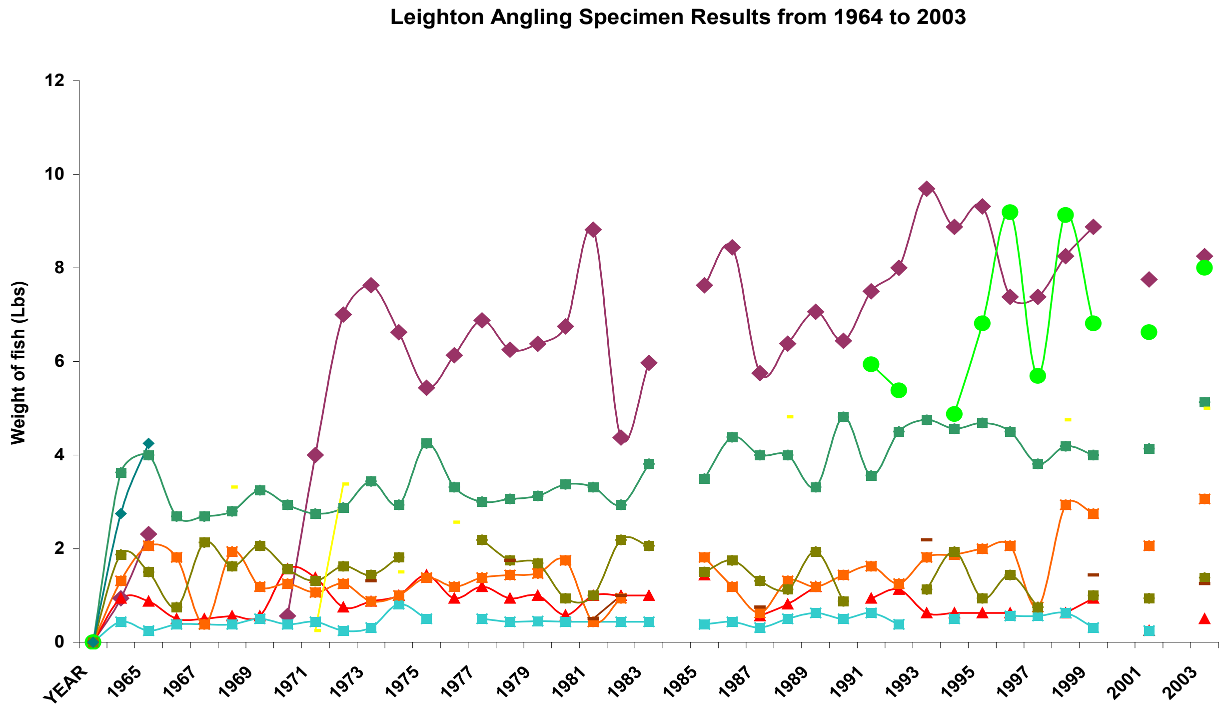


Figure 26 Match catch data from Leighton Anglers 1964 to 2003
**no new data available from Leighton anglers (other angling clubs data available for future work).*

More recent data has been supplied showing total weight caught and number of anglers per match for the period 2007 to 2010 (Figure 27). It is suspected that the 2007 summer floods have had an impact on the numbers of fish caught. The loss of juvenile fish swept out in the flood will have caused a weak year class, but these fish would not have been targeted by anglers until a few years later (e.g. 2010). For example in 2007 6.73 kg of fish were caught per angler, while in 2010 it was only 3.9 kg per angler.

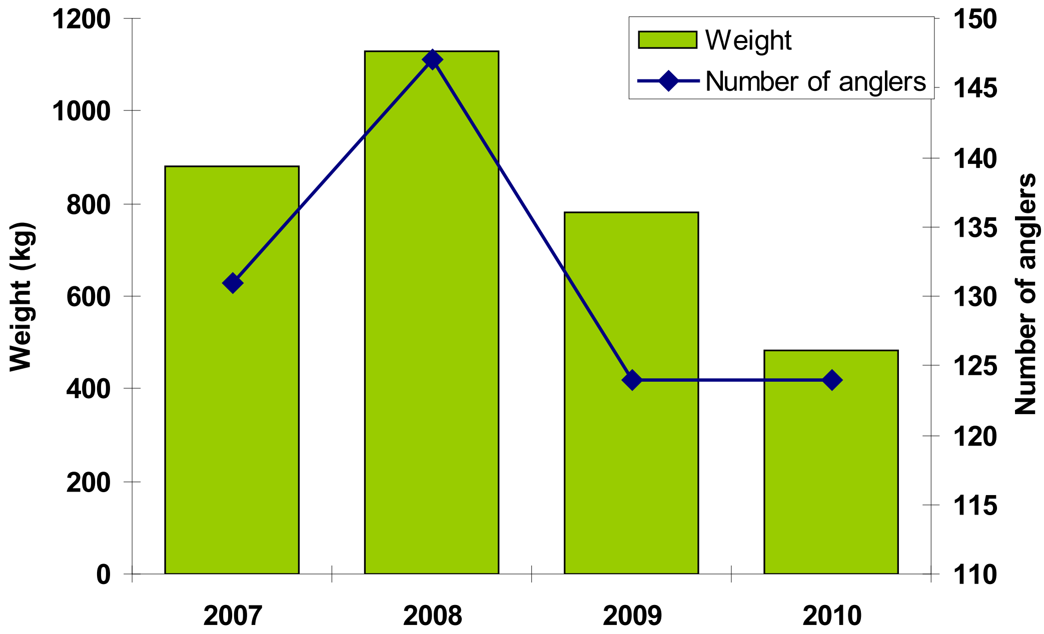


Figure 27: Leighton Anglers match catch data for 2007 to 2010
**no new data available from Leighton anglers.*

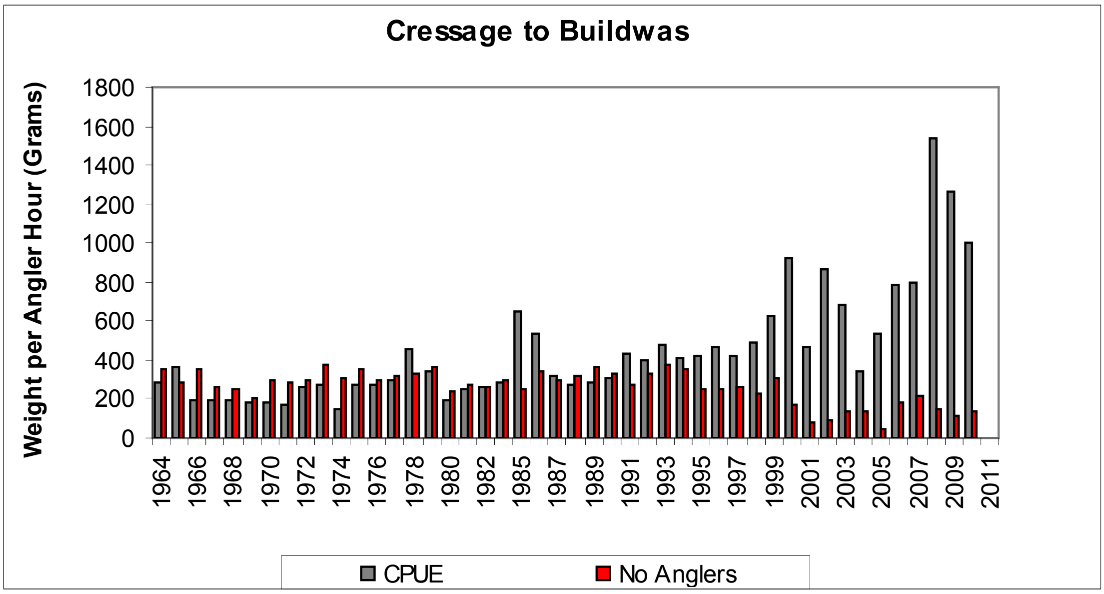


Figure 28: Catch Per Unit Effort (CPUE) and numbers of anglers for Leighton Anglers match catch data

7.4 Assessment of Impact on the Current Environment from the Severn Drought Order and In combination

The main aim of this report is to assess the impacts of the River Severn drought order on the fish within the River Severn catchment, in comparison to the ‘do nothing’ approach.

From monitoring results within the River Severn and its tributaries there is little evidence on which to assess the impact of normal dry and wet periods on fish populations. A Drought Order was put in place on the River Severn in the droughts of 1976 and 1989. Reports from these periods suggest that generally the dry summers were good for coarse fish on the Severn and bad for salmonids and where serious problems were experienced they were either in the sub-catchments or estuary and so beyond any influence of regulation (NRA,1990 and Severn Trent Water,1977).

For the migratory fish the first question has to be whether having a flow less than 850 Ml/d at Bewdley will reduce the distance up the river they can access. Figure 29 shows some of the main obstacles to fish migration on the main River Severn, Vyrnwy and Clywedog. The Atlantic salmon and sea trout will require freshets to cause upstream migration so those ‘spring’ run salmon might not be able to access as far up the catchment although the likelihood of a drought order being used before the end of July is unlikely. These fish then stay within the river until the first frosts of autumn before they spawn. This means they are susceptible to low flows during the summer as they stay in pools and can become trapped. Solomon and Sambrook (2004) concluded that low flows during the summer caused fish to remain in the tidal water and then not make it into the river, which could possibly be linked to high temperatures and low dissolved oxygen. However, the main run of salmon in the Severn catchment are in the autumn. These fish would be waiting until higher flows later in the year and so might be at risk to low flows in the estuary, especially at times of spring tides. Redd counts within the Upper Severn area suggest that in 1995 low flows did not have a detrimental impact on salmon creating redds in fact this was the best count on record, although conversely 1975 and 1976 were lower counts. As stated earlier weather and river conditions will impact surveys for redds potentially giving a biased count

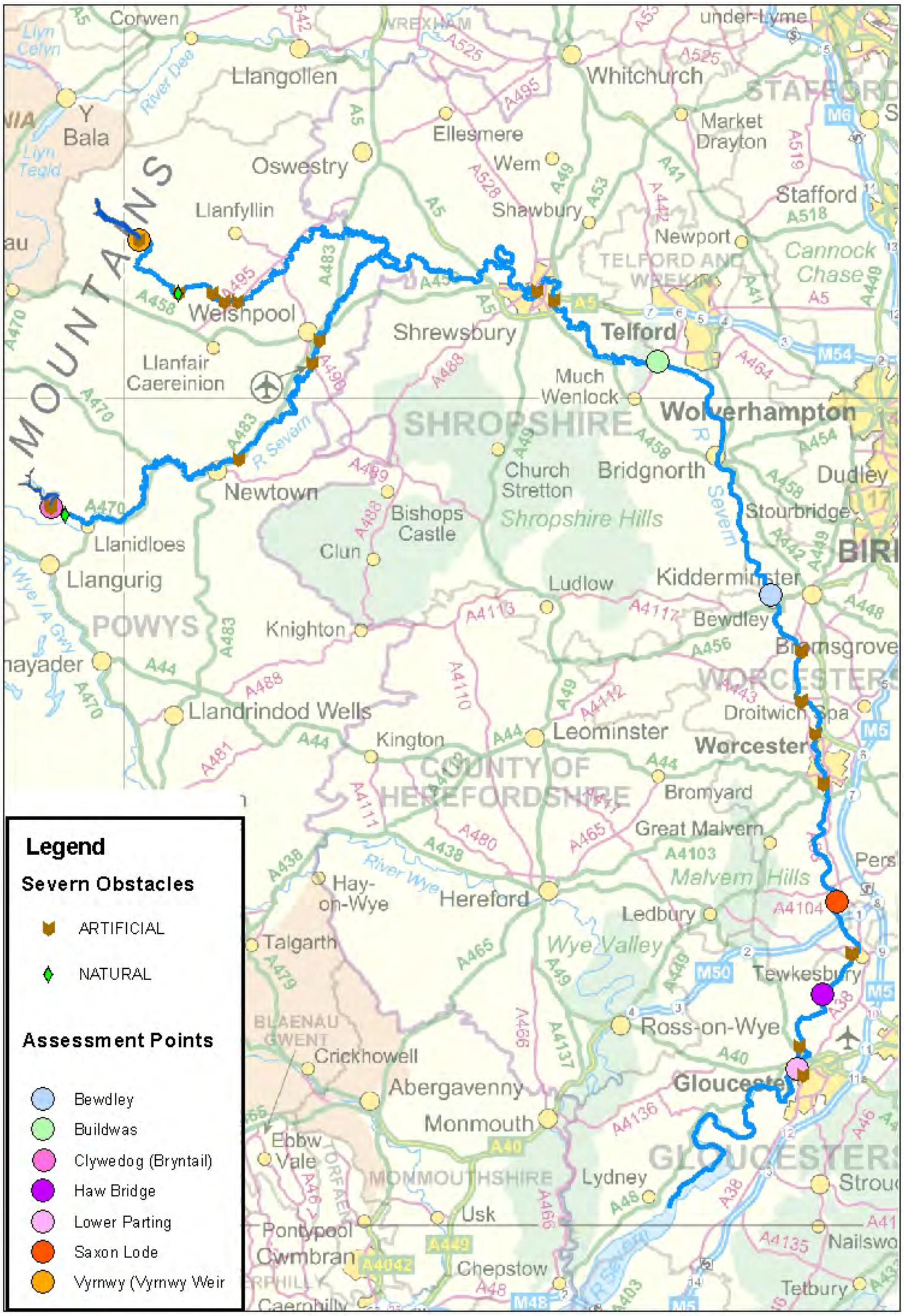


Figure 29: Map showing barriers to fish migration on the River Severn, Vyrnwy and Clywedog

The fish counter on the Afon Tanat gives a good count of salmon using the Afon Tanat catchment as it is on a weir that would be impassable for salmon if not for the fish pass and is not far from its confluence with the River Vyrnwy. This has shown that the autumn run salmon will wait until flows increase in the winter to travel upstream. While dry years have not shown there to be an impact on autumn run salmon the spring runs are generally lower. Flows on the Afon Tanat are not impacted by regulation, but salmon reaching the Tanat have to travel up the River Severn and Vyrnwy. It is a similar story on the River Teme, which has some key habitats for salmon but flows are not impacted by regulation. It is likely that both the Tanat and Teme would be impacted far greater by a drought than the River Severn as flows would not be supplemented.

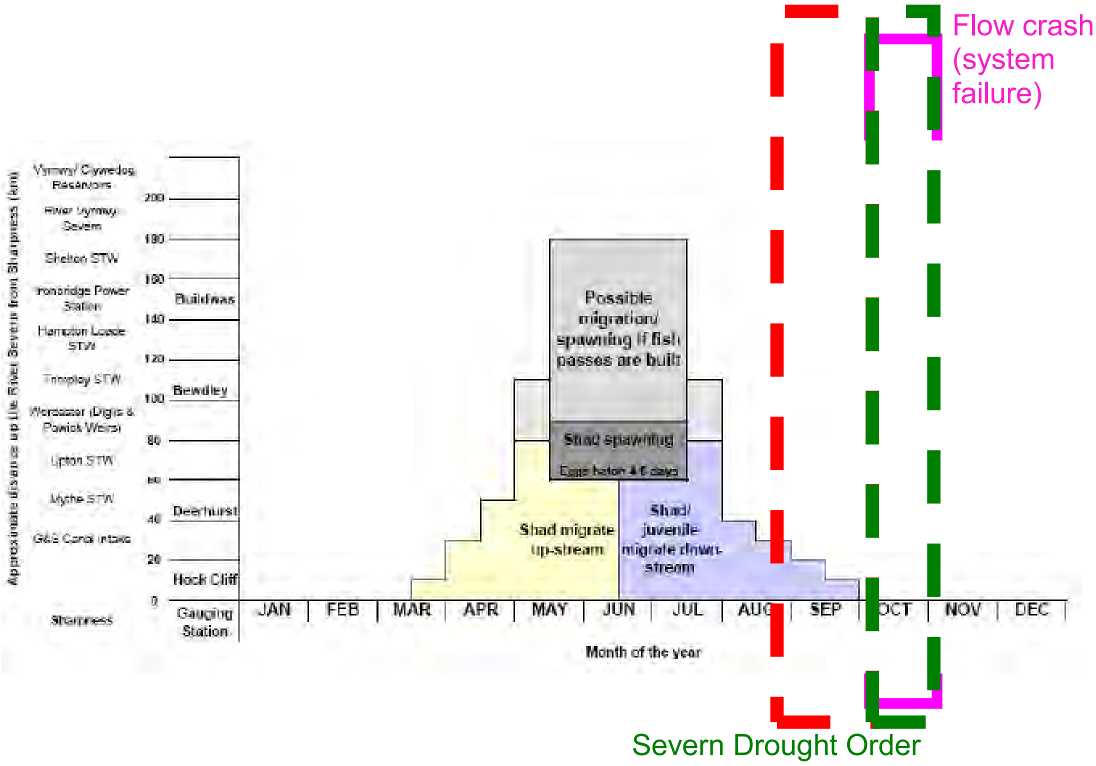


Figure 30: Twaite shad movements within the Severn catchment (red hatched box is section where flows lower with Severn Drought Order and green hatched box flow better, pink hatching where flow crashes in do nothing approach)

Previous studies (Severn Estuary SPA & SAC Review of Consents Stage 3) have shown it unlikely that low flows would have an impact on Twaite shad and sea lamprey migration (see Figure 30). In fact Twaite shad on the River Severn had a very successful year in 1975, which was accredited to lower flow and higher water temperatures increasing the growth and survival of the juveniles before moving down to the estuary (Maitland, 2003). The lowest flows that have been measured and appear to be suitable for Twaite shad at Saxons Loade have been summarised in Table 1 (taken from Review of Consents). There is a proviso that these were seen as ‘acceptable’ flows where the shad year class did not appear to be affected

Table 1 Acceptable low flows for Twaite shad at Saxons Loade

	cumecs	Ml/d
May	16.5	1426
June	12.2	1054
July	12.2	1054
Aug	9.8	847
Sept	12.2	1054
Oct	12.2	1054

However, it could have a limited impact on river lamprey migration, although peak migration upstream is generally October to March when flows are higher (see Figure 31). It is not envisaged that the Elvers (young of European eels) migration would be impacted hugely by these low flows for they migrate upstream early in the year. Elvers migrating upstream later in the year would have difficulty with some obstructions.

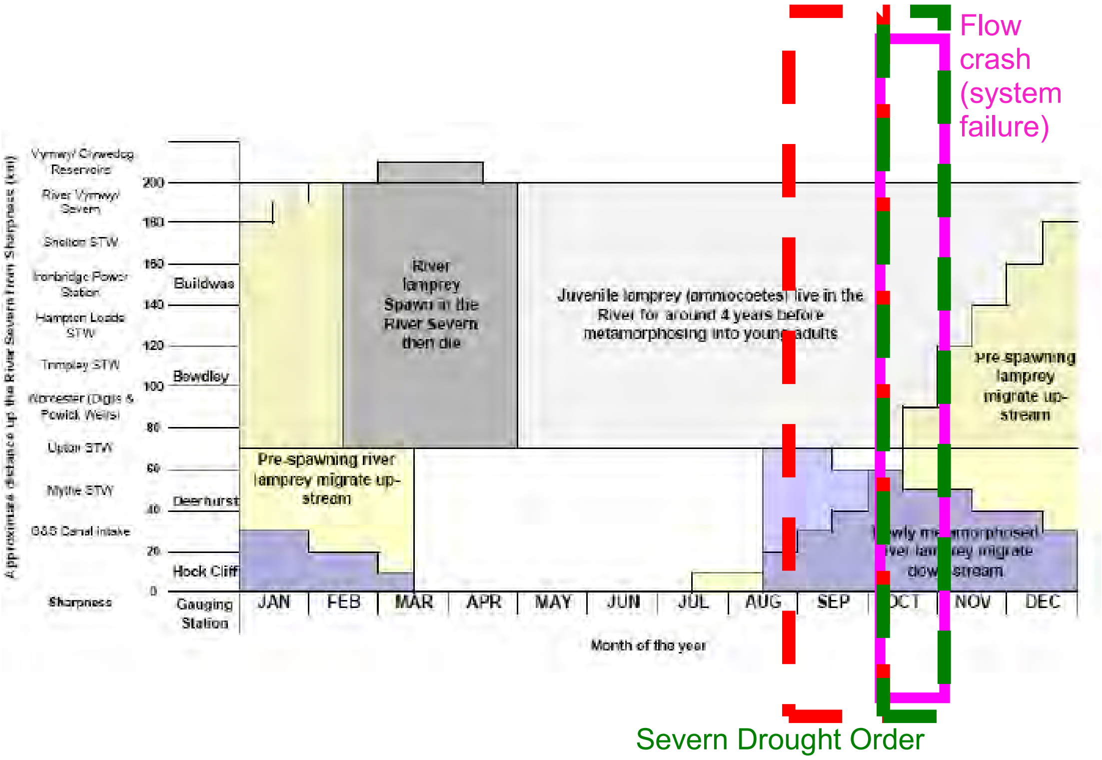


Figure 31: River lamprey movements within the Severn catchment (red hatched box is section where flows lower with Severn Drought Order and green hatched box flow better, pink hatching where flow crashes in do nothing approach)

As far as the resident species are concerned barriers to movement caused by low flows will cause a reduction in spawning and feeding areas they will be able to utilise. The movement of coarse fish is sometimes overlooked but they can move long distances without obstructions. The main obstacles to movement would be the weirs along the River Severn (often barriers in normal flows) and very shallow riffles exposed in low flows, which increase in frequency higher up the catchment.

Low flows can cause a decrease in water quality due to lack of dilution of effluents, with possible decreases in dissolved oxygen and higher temperatures. This is remediated slightly by the fact that sewage treatment works are believed to work more efficiently in warm temperatures. Each species has different tolerances to drops in water quality with salmonids, especially juveniles, the most susceptible (see Table 2). To coincide with this the higher the water temperature the more toxic certain compounds such as ammonia become to fish. It has been reported that oxygen sags in the upper estuary have been linked to several episodes of fish mortality. The majority of reported fish killed have been salmon, but mortalities of Twaite shad and lamprey have also been reported (Hutchinson and Wade, 1992). These oxygen sags are linked to spring-neap tidal cycles. Fish within the upper section of the Severn Estuary will have to deal with these water quality issues and lower flows will lead to increased saline intrusion on spring tides.

Table 2 Tolerances of certain fish to dissolved oxygen levels and temperature

	Dissolved Oxygen	Temperature (^{o}C)
Salmonids	40 - >100%	1 to 20
Roach	20 - >100%	1 to 25
Carp	10 - >100%	1 to 28

Associated with a drought is an increase in algal blooms. These can cause large fluctuations in dissolved oxygen as they produce oxygen during day time and then use it up during night time. This can cause fish kills and quite often during hydroacoustic surveys on the middle section of the River Severn fish densities are higher at the base of weirs where the water has become oxygenated. During 2011 reports came in from lock keepers on the River Severn that algae was building up during low flows. In the upper reaches gravels can become smothered by filamentous algae leading to reduced water percolation through redds and potentially impacting macro-invertebrates which are the main food source of juvenile salmonids. The use of a drought order is unlikely to enhance algal growth during natural low flow conditions.

Another associated problem with low flows is they will cause a decrease in the wetted area available to fish. This then leads to trapped fish and also reduces the availability of cover from predators. Many anglers perceive predation to be one of the greatest problems for fish stocks in the River Severn and the increases in numbers of cormorants and goosander have been mainly blamed for this. The decreased wetted perimeter also increases competition for food and spawning areas. Spawning areas become limited and if water levels drop suddenly this can impact fish that have spawned in late spring and early summer leaving eggs out of the water e.g. roach spawn on aquatic macrophytes in late spring which makes them prone to water level fluctuations. However, this is unlikely to occur in sections of the River Severn where coarse fish are known to spawn. Under low flow conditions Atlantic salmon parr can exhibit a preference for shallow riffles rather than migrating to pools (Armstrong, Braithwaite and Fox, 1995). This is thought to be due to brown trout being more common in pools (competition) and that salmon in pools are more vulnerable to predation.

Indirectly coarse fish will be impacted in rivers that receive large volumes of groundwater as part of the river regulation system (River Tern and River

Perry). The groundwater will be a lot cooler than river water and therefore will be detrimental to spawning and juvenile fish growth for coarse fish. However, in the main River Severn coarse fish may well have a good year during drought conditions as water temperatures will be higher meaning earlier spawning and faster growing juveniles.

Assessment of Impact from the River Severn Drought Order

Flows have been modelled for each assessment point for an acute (one year) and chronic (two years) drought scenario based on the 1976 drought. Hydrographs have been produced to show differences between various management options:

- Do nothing
- EA Drought Order only
- Water companies drought order only
- In combination (EA and water companies drought orders)

Each assessment point will be looked at separately with respect to the expected impact the different flow regimes would have on the fish population. Regarding fish populations and impacts the EA drought order only and in combination are so similar they will be assessed as one. It must be noted that this is only a modelled scenario and timings of low flows in real life would most likely differ and hence cause different problems.

Acute Scenario

Clywedog

This section is likely to be impacted by the introduction of the Drought Order as it relies heavily on flow from Clywedog Reservoir. Previous studies (Cowx and Gould, 1989) have shown that large releases from the reservoir have left the Afon Clywedog with an impoverished Salmonid population. When the drought order is first introduced a decrease in flow occurs as releases from Clywedog decrease. It is envisaged that this is a high proportion of the total flow of this section especially in the Afon Clywedog, as there is virtually no groundwater to add to surface water flows. The fish population is Salmonid which require high dissolved oxygen (especially juveniles). If water levels drop very rapidly (if dead water reached) this could leave fish stranded on riffles or in pools that might dry up leaving them vulnerable to predation and decreasing dissolved oxygen. The acute scenario shows that while flows do drop off sharply initially with the drought order they then keep some flow within this section and at least dead water at Clywedog is not reached. Without the drought order dead water is reached at Clywedog and this could have a large detrimental impact on the fish population. This occurs for 35 days in the do nothing management option, which would have large repercussions on the fish population. Back in the 1990's the Environment Agency requested a PHABSIM for the upper River Severn. This involved habitat assessment for Atlantic salmon under different flow conditions in the upper Severn based on flows at Dolwen (SN 996 581). It was concluded that not letting flow drop below 70Ml/d at Dolwen would be beneficial for adult spawning (141.4% in Wetted Usable Area) and juvenile (16.4% WUA) salmonids. In the acute scenario the do nothing approach causes the flow to fall below 70Ml/d for 397 days (1975-79), while the EA Drought Order and full in combination cause the flow to fall below 70Ml/d for 305 and 295 days respectively (23% and 26% change). This can be seen to be a significant improvement for salmon at Dolwen.

Vyrnwy

The majority of the Afon Vyrnwy is dominated by salmonids, with increasing coarse fish numbers near its confluence with the River Severn. The flow graphs for the Vyrnwy assessment point show that having a drought order in place would have a negligible difference to flows in the acute scenario. Even in the do nothing approach the flow never crashes, just that there is very little flow variation over the winter (November to April). This might limit the migration of Atlantic salmon to the top of the Vyrnwy; however a barrier at Dolanog (13kms downstream reservoir) prevents salmon progressing to the reservoir even in high flows.

Buildwas

This section of the River Severn is dominated by coarse fish, but is still used by migratory Atlantic salmon, eels and lamprey. The acute scenario shows negligible differences between having the drought order or not and in the flow duration curves all management options are above the EFI (Environmental Flow Indicator) line used within the water resources national CAMS process. The Ironbridge Gorge would be an area of concern as the river changes character considerably as it changes from a slow meandering river (Buildwas) to a more enclosed riffle/run system as it passes through the gorge. Here it would be expected that the available habitat for fish would reduce. Cross sectional information of the wetted perimeter would be required to assess the impact on this section.

Bewdley

The Severn at Bewdley again is a coarse fish dominated system and is in the vicinity of some large scale abstractions for public water supply. There are still a number of important riffles in this section of the River Severn, which are used by salmonids for spawning. The acute drought scenario shows flows reduce to an average 368Ml/d for 22 days (from 12th October), which is below the High Risk EFI line (i.e. >30% lower than EFI), for the do nothing approach. For the drought order (and in combination) the flows reduce slightly later and does not drop to such a low level showing some form of mitigating effect from these management options.

This is where the first navigation weirs start impacting the nature of the River Severn. Salmon below weirs that can not get through the rudimentary fish passes would be prone to predation and angling pressure. In 2011 with low flows in the main Severn through the summer the main catch of salmon was below Diglis weir on the River Severn. This gives evidence that salmon were unable to pass through Diglis weir fish pass.

Saxons Lode

The river is now becoming increasingly engineered and less like a natural watercourse. In the acute drought scenarios a slight difference is seen through September where flows are slightly higher with do nothing than with the drought order. With the drought order (and in combination) flows would be around the ‘acceptable’ level for shad at Saxons Loade for August flows (847Ml/d), but lower than September (1054Ml/d). It is unlikely that the flow with the drought order in September (around 800Ml/d) would have a negative impact on shad. However, the crash in flow in October is worse with no drought order and could impact any shad that have not migrated down to the estuary. The drought order (and in combination) management options drop below the High Risk EFI line for longer than the do nothing approach in the flow duration curves, but this is a broad environmental indicator, while knowing more about the ecology of the shad it is more likely to be beneficial to the juvenile fish to have low flows in this section of the River Severn at this time. Research by Aprahamian & Aprahamian (2003) looking at year class strength of Twaite shad within the River Severn found flows from June to August to be inversely correlated to year class strength with no significant correlation to flows in May, September and October. It is also anticipated that the coarse fish fry within this section would also benefit from enhanced growth due to the low flows especially as water quality has been shown not to deteriorate.

Haw Bridge/Deerhurst

In the do nothing management option at Haw Bridge/Deerhurst the flow crashes on the 13th October for 19 days and drops below the High Risk EFI (average flow 608Ml/d), while the drought order and in combination tend to be around the Medium Risk EFI. However, the do nothing approach has higher flows than the drought order and in combination for around 45 days, average flows of 1100Ml/d and 1000Ml/d respectively. The flow crashes should not be at a critical time for most fish species in this section as water quality is not thought to deteriorate enough to impact coarse fish species and salmonids will mainly be waiting in deeper water or the estuary for the autumn rains before migrating up the river.

Lower Parting

This section is very different as it is within the tidal range of the estuary. Any high tides combined with the low flows of a drought could have a very negative impact on the fish population. This will be due to saline intrusion and increased suspended solids causing low dissolved oxygen levels. All management options within the acute drought are equally susceptible to high tides suggesting that the effect of drought on dissolved oxygen is unavoidable. Work completed by Hutchinson and Wade (1992) recommended that a flow of 1800Ml/d at Haw Bridge would be required to maintain dissolved oxygen levels above 3mg/l (critical concentration for survival of migratory salmon), prevent suspended solid concentrations of greater than 6000mg/l and prevent saline intrusion for 94% of predicted tides. During the acute drought model this flow is not attained for 19% of the year. This suggests potential for fish kills (mainly salmon). However, water quality within the estuary has been improved dramatically since this study. Timings of high tides and low flows would be critical on the magnitude of this problem. As regards the timings of flow declines in the do nothing management option the crash in October could be the most detrimental to salmon and river lamprey waiting to migrate upstream and any shad that are still in the upper estuary. Any high tides within this time period could cause large fish losses and the Severn estuary usually has a spring tide once every two weeks.

2011 was a very dry year with low flows on the River Severn through the summer, however no dead salmon were recorded by the Severn netsmen. At present it is not certain where within the estuary salmon wait as monitoring movements is very problematical, but they tend to respond rapidly to increases in flow in lower Severn.

Chronic

Clywedog

Flows over the winter months between first and second year would be lower (as reservoir filling up) and this could limit the dispersal of salmon spawning in the upper Severn as insufficient flows to stimulate movement up the catchment. It is anticipated this would be worse in the do nothing management option.

In the second year of the chronic drought scenario the do nothing approach has an extensive period of flow failure (again), which would cause substantial fish kills. This would be the second consecutive year and so would create long term issues for the fish community and lengthen the recovery time considerably. Both the drought order and in combination prevent total flow failure, which would be beneficial.

At Dolwen the flow falls below 70Ml/d (1975-79) for 469 days, while the EA Drought Order and full in combination cause the flow to fall below 70Ml/d for 413 and 389 respectively. Although this is a less significant difference than in the acute scenario, the difference is still greater than 10% and so can be assumed to be beneficial for salmon.

Vyrnwy

In the do nothing management option again low flows during the winter months while the reservoir fills up will limit the dispersal of salmon spawning. Also in the second year near the end of the drought there are 20 days of irregular flows which could impact the fish population. Not only could the change in flow be an issue so could the fluctuating temperatures (reservoir water generally colder). Salmonids will benefit from the cooler water, but at the detriment to the coarse fish in the lower Vyrnwy.

Buildwas

Even in a chronic drought Buildwas flows stay above the EFI for all three management options. As with the acute scenario it would be anticipated that the available habitat for fish within the gorge would reduce. Cross sectional information of the wetted perimeter would be required to assess the impact on this section.

Bewdley

In the do nothing management option the flow crashes below the High Risk EFI for 24 days from 10th October to a minimum level of 289Ml/d, which has not been seen in recent history. This would cause large problems for riffle sections that would dry out, with juvenile salmonids being impacted most.
Salmon below the navigation weirs that can not get through the rudimentary fish passes would be prone to predation and angling pressure, which could be worse with the drought order and full in combination lowering flows to 750Ml/d from July onwards.

Saxons Lode

For short periods with no drought order the flows will be reduced substantially within this section (average flow of 428Ml/d for 22 days from 10th October). No information is available on the impacts this could have on the fish population, but low flows in 1976 and 1989 did not cause significant fish kills.

This section is important for migratory fish such as shad and eel and the low flows in the chronic scenario might actually be beneficial to the juvenile shad (Aprahamian & Aprahamian, 2003).

Hawbridge/Deerhurst

It is anticipated that the impacts within this section are most likely to be the same as at Saxons Loade. The only exception being that on very high spring tides when freshwater flows are so low in October (with the do nothing management option) a certain amount of saline intrusion might occur which could impact dissolved oxygen levels.

Lower Parting

The flow crash in October with the do nothing option could cause serious problems for fish in the upper estuary, especially migratory salmon waiting for the autumn high flows. Any spring tides at this time would cause serious problems with average freshwater flow of only 350Ml/d modelled.

Fish kills within the upper estuary were largest in the late 1980's, early 1990's and mainly in June and July. Again if the drought order and full in combination comes on too early this could cause freshwater flows entering the estuary to be too low to prevent saline intrusion and dissolved oxygen sags. Although water quality has been improved sediment oxygen demand can still cause significant dissolved oxygen sags and could lead to deaths of fish (especially salmonids) within the upper estuary.

Conclusions

The closest events in recent history to these scenarios were the droughts of 1976 and 1989. Conclusions from these events on fisheries were that most impact from regulation was found in the upper Severn and that even when higher flow levels in early June were adhered to it had little positive impact on the lower river and estuary. Serious problems were encountered in the sub catchments and the estuary rather than the main River Severn, where flows were kept higher by regulation releases. These releases would have been beneficial for the salmonids within the upper Severn and scale readings from fish caught during 1989 electric fishing surveys gave the general impression that the summer had been beneficial for coarse fish.

Twaite shad

Research by Aprahamian & Aprahamian (2003) showed that both 1976 and 1989 were good spawning years on the River Severn for Twaite shad. Therefore a drought of similar magnitude and of similar timings would not be expected to be detrimental to Twaite shad; in fact it might lead to a good spawning year. The main concern would be for those shad that are still within the upper estuary in the late autumn with the do nothing scenario. With freshwater flows so low saline intrusion and sediment oxygen demand could cause distress, especially if we have hot weather in early October as was the case in 2011. Lower flows earlier in the summer due to a drought order might limit upstream migration of adult shad. Water temperature was positively correlated and flow negatively correlated to year class strength for shad (Aprahamian and Aprahamian 2001). Multiple regression analysis indicated that water temperature was the only significant variable for year class strength.

Lamprey
It has been concluded that both sea and river lamprey would not be impacted significantly through the various management option. River lamprey migration might be slightly delayed, but they have such a long season for migration (over winter) it is unlikely to be too detrimental.

Atlantic salmon
The impact on salmon is not so straight forward. Fish kills in the upper estuary were a problem in the 1976 and 1989 droughts for adult salmon waiting to migrate. Water quality has improved significantly since those events, but the large flow crashes of the do nothing scenarios would cause serious issues, especially if linked to a spring tide.

The juvenile salmon parr would also be impacted in the upper Severn when the flow crashes in the do nothing scenario. Regulation releases will be generally beneficial to salmonids (cooler water) and so keeping releases going for longer with the drought order and full in combination would be beneficial. Cowx, et al. (1984) reviewed the impacts of the drought of 1976 on an un-regulated river in upland Wales and discovered that the only measurable impact on the fish population was the loss of the 1976 year class of young salmon.

European eel
Although the drought might impact the movement of elvers upstream it is not thought that any of the management options would be significantly different to have a demonstrable impact on the eel population.

Sea trout
The sea trout population in the Severn is not as well understood. It is unlikely that many sea trout use the main river for spawning and so it will be adult sea trout in the upper estuary waiting to migrate upstream that would be impacted. Juvenile sea trout tend to be in the smaller streams and not the main River Severn and therefore not impacted by river regulation on the Severn.

In the event of an acute and especially a chronic drought the fish population of the River Severn would be significantly impacted. These impacts would be envisaged to be worst at the top of the catchment where salmonids dominate and at the very bottom in the estuary. Although a better understanding of the impacts on the upper estuary are required. Previous low flow investigations have shown that low flows increase mortality especially in 0+ salmon, trout and grayling (Riley, et al 2009) and that maintenance of a river flow over a longer period is beneficial to the fish population. With the drought order in place river levels do not drop to the catastrophic levels of the ‘do nothing’ approach in the upper reaches. Hence the drought order is beneficial to the fish population in the upper River Severn. Further downstream the beneficial impact of the drought order diminishes for the Severn, especially in the acute scenario.

It is important to note that low flows with both the acute and chronic drought scenarios are still higher with river regulation than they would be naturally at Bewdley.

Summary impacts

Table 3 Impacts of drought order on acute and chronic drought scenarios

			Do nothing		**Severn Drought Order**		**Full in combination**	
Assessment Point	**Fish population**	***Current Fish WFD classification***	**Acute scenario effect**	**Chronic scenario effect**	**Acute scenario effect**	**Chronic scenario effect**	**Acute scenario effect**	**Chronic scenario effect**
Clywedog	Salmonid	*GOOD*	Moderate	Major	Minor	Moderate	Minor	Moderate
Vyrnwy	Salmonid	*GOOD*	Minor	Minor	Minor	Minor	Minor	Minor
Buildwas	Coarse (migration corridor)	*POOR*	No impact	No impact	No impact	No impact	No impact	No impact
Bewdley	Coarse (migration corridor)	*MODERATE*	Moderate	Moderate	Minor	Minor	Minor	Minor
Saxons Loade	Coarse (migration corridor)	*MODERATE*	Minor	Minor	Minor	Minor	Minor	Minor
Haw Bridge	Coarse (migration corridor)	-	Minor	Moderate (depends on tides)	Minor	Minor	Minor	Minor
Lower Partington	Coarse (migration corridor)	-	Moderate	Major	Moderate	Moderate	Moderate	Moderate

Mitigation Options

Possible mitigation ideas;

- Improve fish passes on the navigation weirs lower down the Severn. The Canals and Rivers trust have already started looking at hydropower on these weirs, which would require improving fish passes.
- More elver passes within lower Severn
- Using the 70Ml/d at Dolwen to protect top section
- Further development of SGS
- Research other sources of water to supplement flows or public water supplies in exceptionally dry years
- Regulate to Deerhurst to better protect the estuary

Future Monitoring

1) Lamprey surveys following guidance from Harvey & Cowx (2003), which involves electric fishing for ammocoetes and using fish counters (where feasible) to sample adult migration upstream .
2) If improved fish passes implemented on navigation weirs a fish counter on the lowest fish pass would be desirable.
3) Need some specific shad monitoring as recommended by Hillman, Cowx & Harvey (2003):
    - Juvenile density (represented by catch per unit effort, CPUE). Micromesh seine netting is the most appropriate sampling method to assess juvenile shad in the lower river/upper estuary
    - Adult run size. Fish counters should be used to monitor the time and approximate size of adult spawning migration.
4) Assessment points further up the corridor are required
5) Need to look at how flows change river levels and then how this impacts wetted perimeter at selected sites down the corridor. A number of cross sections throughout the river corridor.
6) Need better understanding of salmon movements in the estuary
7) Expect most impacts on Salmonid sites, hence best to set up monitoring for these:
    - Electric fishing on Severn (above Dolwen), Clywedog and Vyrnwy (quantitative). Also timed surveys on riffles further down the Severn to estimate juvenile salmon distribution
    - Habscore all quantitative sites on a 1 in 6 year programme
    - Use fish counter data from Shrewsbury to assess annual salmon migration (and other fish movements)
    - Fry sampling on main River Severn (netting) to assess coarse fish population

Appendix Q

Water Quality Improvements at Netheridge

Brief Note on Changes in the Ammonia, BOD and COD Levels discharged by Gloucester (Netheridge) STW from 1974 to Present

Environment Agency
Peter Jonas
Technical Specialist Tidal Waters
6th March 2012.

The oxygen demand on the receiving waters of the Severn Estuary due to the discharge from Gloucester (Netheridge) STW is characterised by the levels of ammonia, biochemical oxygen demand (BOD) and Chemical Oxygen Demand (COD) in the final effluent. This brief note assesses the changes which have occurred in the levels of these determinands in the final effluent from Gloucester (Netheridge) STW from 1974.

The earliest monitoring data for Gloucester (Netheridge) STW is in January 1974. There was apparently no consent for the STW until 1992, although it is assumed that there was a Deemed Consent issued under COPA. It would be useful to check what Deemed Consent was in force prior to 1992.

Prior to 1992, the only treatment given to the discharge was apparently primary settlement. In 1992, the consent had limits for BOD and Suspended Solids (SS): these were 95%iles of 120 mg/l BOD and 180 mg/l SS. In 1993, these limits were tightened to 60 mg/l BOD and 90 mg/l SS. These limits indicate that some secondary treatment was in place. However, the limits only applied to a maximum flow of 20,000 m^3/d, so that not all the normal flows arriving at the STW were being treated.

In 1996, the limits for BOD and SS were tightened further, and a limit was also put on the discharge for Ammonia. The 95%ile values were 25 mg/l BOD, 45 mg/l SS, and 15 mg/l Ammonia. These 95%ile limits have remained in force since 1996, although there have been some minor changes to the maximum values allowed in the consent. The discharge from 1996 has therefore received secondary treatment, and this treatment has been applied to all normal flows arriving at the STW. The consented Dry Weather Flow since 1996 has been 42,800 m^3/d, with a maximum flow of 105,000 m^3/d.

It is apparent that the major change in treatment level at Gloucester (Netheridge) STW was in 1995 to 1996, although some improvements were made in the period 1992 to 1995. These changes are evidenced by the changes in concentrations of Ammonia, BOD,and Chemical Oxygen Demand (COD) in the final effluent over the period 1974 to 2000, as shown in Figures 1 to 3. It should be noted that the change in concentrations which are apparent in 1992 relate to the difference between the settled final effluent and the treated final effluent, although until 1996 not all the flows received the higher level of treatment.

The mean concentrations of ammonia, BOD, and COD for the 3 different final effluent streams are summarised in Table 1 below.

Table 1

	Settled Final Effluent	Treated Final Effluent	Secondary Treated Effluent	Secondary Treated Effluent
Mean Values	**1974 to 1995**	**1992 to 1995**	**1995 to 2000**	**2004 to 2007**
Ammonia as N mg/l	42.77	25.32	0.39	0.75
BOD mg/l	326.21	20.49	3.62	2.47
COD as O2 mg/l	594.90	131.89	62.20	

These mean values indicate that the overall reductions in Ammonia and BOD are about 100 fold between the settled final effluent and the secondary treated effluent, and about 10 fold for COD.

Based on these changes in concentrations, it is clear that there have been significant reductions in the oxygen demand on the receiving waters of the Severn Estuary arising from the discharge of effluent from Gloucester (Netheridge) STW since the last major drought in 1976. In any future drought, the impact of the discharge from Gloucester (Netheridge) STW will therefore be considerably less than it was in 1976, notwithstanding that there has been some increase in effluent flows over the same period.

Figure 1

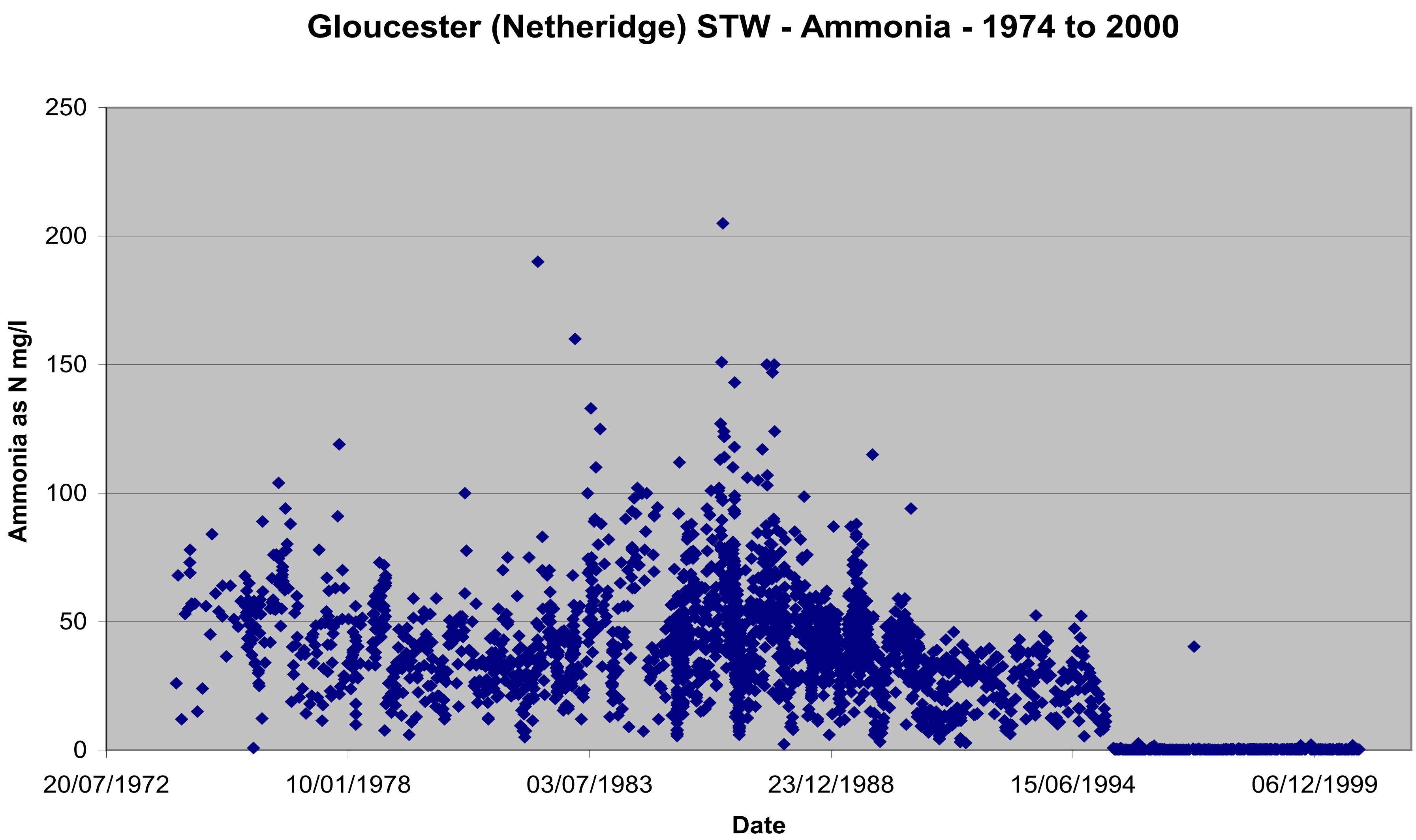

Gloucester (Netheridge) STW - Ammonia - 1974 to 2000
250
200
150
100
50
0
Ammonia as N mg/l
20/07/1972
10/01/1978
03/07/1983
23/12/1988
15/06/1994
06/12/1999
Date

Figure 2

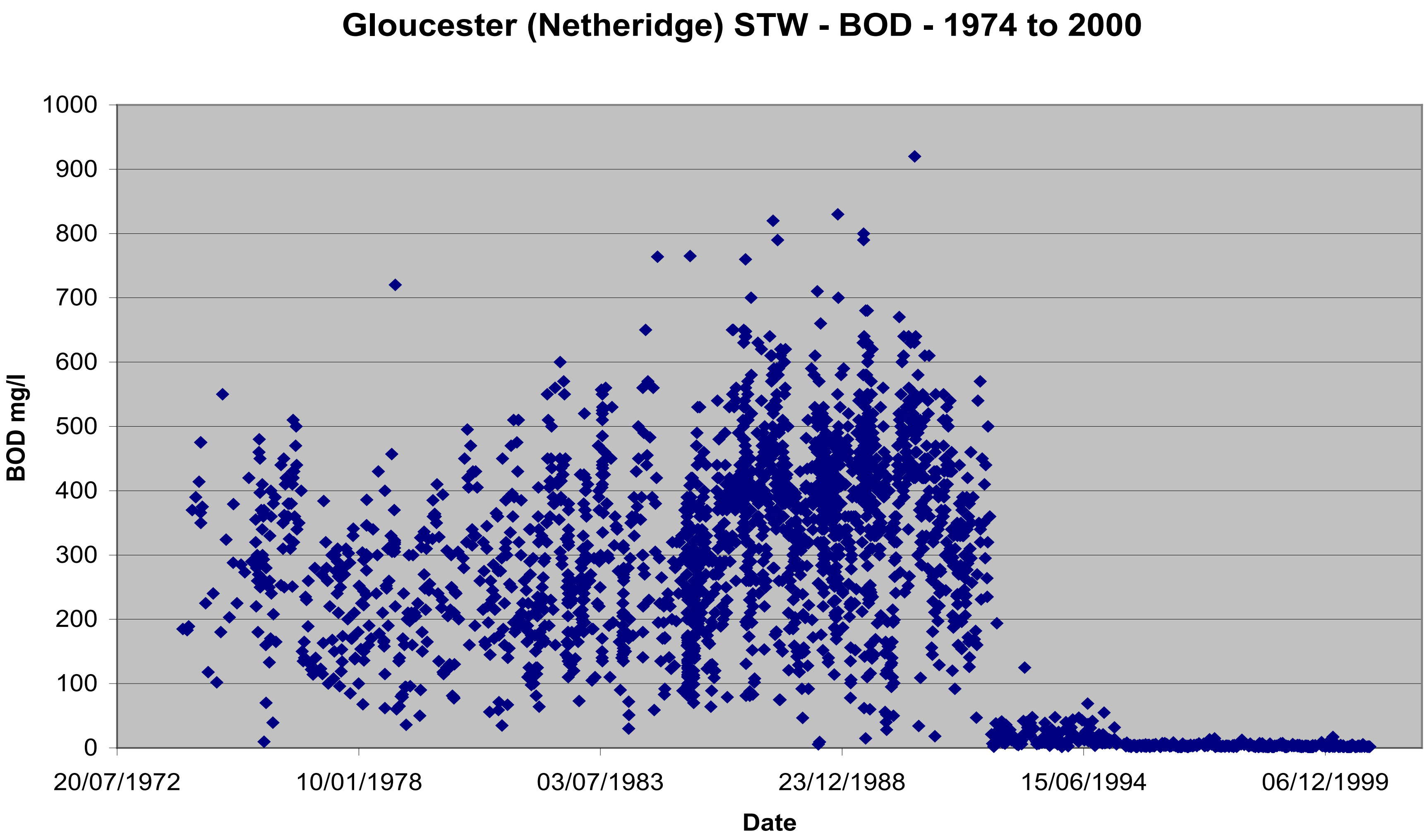
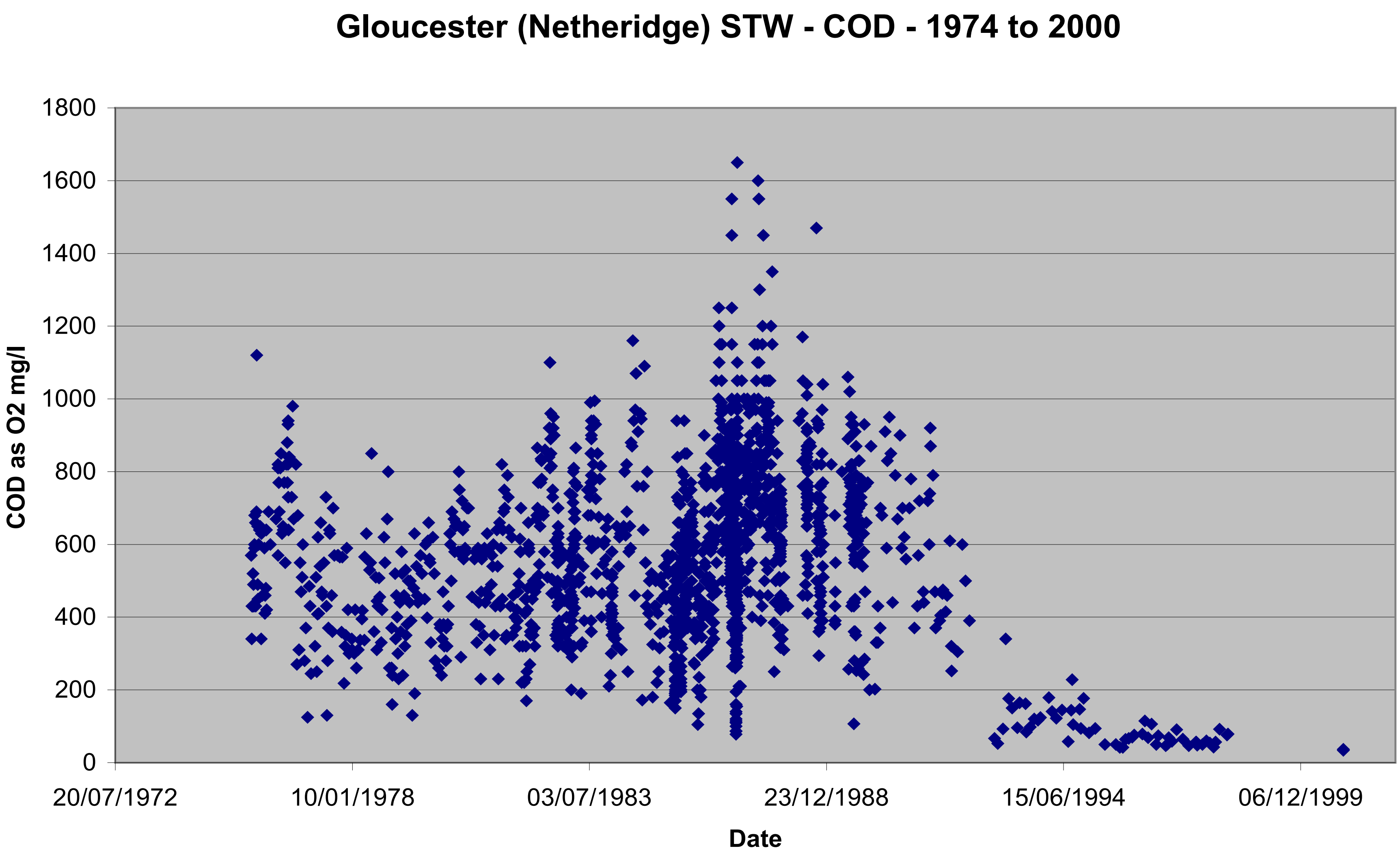

Gloucester (Netheridge) STW - BOD - 1974 to 2000
BOD mg/l
1000
900
800
700
600
500
400
300
200
100
0
20/07/1972
10/01/1978
03/07/1983
23/12/1988
15/06/1994
06/12/1999
Date

Figure 3


Gloucester (Netheridge) STW - COD - 1974 to 2000
COD as O2 mg/l
1800
1600
1400
1200
1000
800
600
400
200
0
20/07/1972
10/01/1978
03/07/1983
23/12/1988
15/06/1994
06/12/1999
Date

Appendix R

Water Quality Assessment of the Upper Severn Estuary (RoC)

Water Quality Assessment of the Upper Severn Estuary Related to Performance at Gloucester Netheridge STW

Environment Agency
Damon Llewellyn

The Upper Severn Estuary has historically suffered with significant sags in the dissolved oxygen concentrations. These sags have been most noticeable in the stretch of water downstream of the discharge of treated sewage from Gloucester Netheridge STW although, there are several explanations as to why they occur.

The historic discharge from Netheridge STW, especially large quantities of untreated sewage during storm events, has offered one explanation although an alternative train of thought suggests that the impact of salinity and suspended solids may be responsible. The latter theory suggests that the area of maximum turbidity (and greatest suspended solid concentrations), often related to the fresh-salt water interface, can be associated with the location of the oxygen sag. Consequently, the degree of the oxygen sag is directly linked to the amount of freshwater entering the estuary with a greater flow restricting the area of maximum turbidity to the wider parts of the channel where the biochemcal oxygen demand is less concentrated.

Netheridge is the main sewage treatment facility serving the population of Gloucester, a current population equivalent of nearly 145,000, and has a consented flow of 42.8 Ml/d. The treatment on site was improved during the AMP2 investment period with an improved quality and tightened discharge consent coming into effect on 1st January 1996. Further consent revisions have since followed.

This tightening of BOD and suspended solids limits is demonstrated by the data displayed in Figure 1 and Table 1 below with BOD concentrations noticeably improving from February 2000:

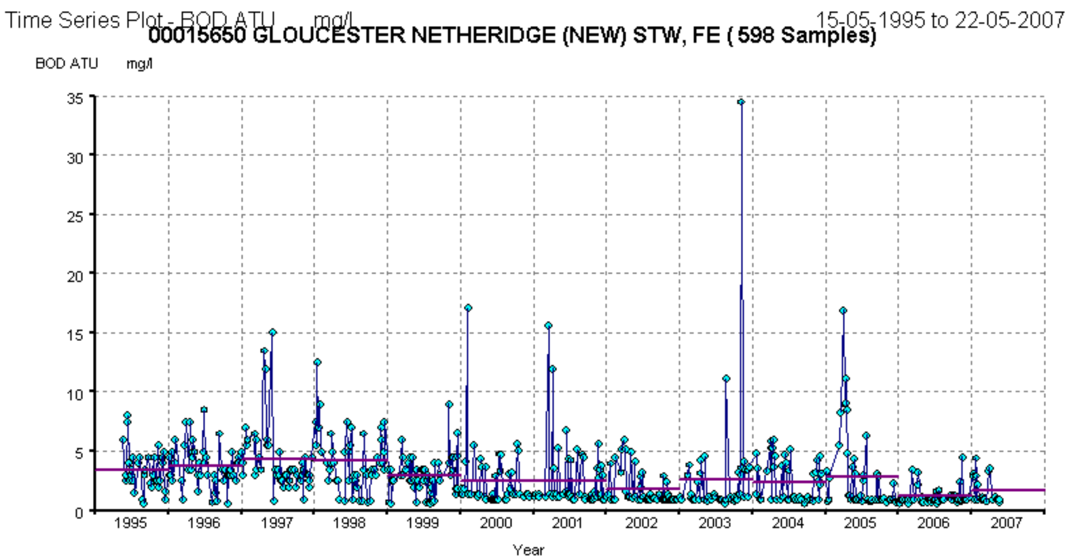


Figure 1 – Gloucester Netheridge STW – BOD discharge data 1995 to 2007

Cusum Stats - BOD ATU mg/l 15-05-1995 to 22-05-2007

00015650 GLOUCESTER NETHERIDGE (NEW) STW, FE (598 Samples)

	Start Date	End Date	N	Mean	Std Dev	SDD	Significance
1	15-05-1995	07-02-2000	234	3.73	2.346	1.888	
							0.1%
2	08-02-2000	28-10-2003	180	2.07	2.008	1.976	
							0.1%
3	04-11-2003	27-05-2005	74	3.60	4.613	4.144	
							0.1%
4	01-06-2005	22-05-2007	97	1.35	1.017	0.930	

Table 1 – Gloucester Netheridge STW – Changes in Final Effluent BOD Concentrations – 1995 to 2007

Unfortunately, these major improvements show no major corresponding reduction in BOD concentration within the Severn Estuary immediately downstream of the discharge point. This is probably a consequence of the estuarial nature of the receiving watercourse and the naturally turbid conditions associated with such watercourses. What is evident, however, is an increase in the lower range of dissolved oxygen concentrations (Figures 2 and 3):

00015203 R SEVERN (TIDAL) LOWER REA (136 Sa
Restricted (O Diss %sat %)

Number of Observations (LT)	64
Date Range	17-01-1995 to 06-01-2000
Minimum	49.00
Mean	89.63
Maximum	127.00
Standard deviation	14.539
SDD	11.464
Non-Parametric estimate (Weibull) of:	
5 Percentile	56.25
10 Percentile	64.50
20 Percentile	81.00
Median	92.00
80 Percentile	100.00
90 Percentile	103.00
95 Percentile	111.25

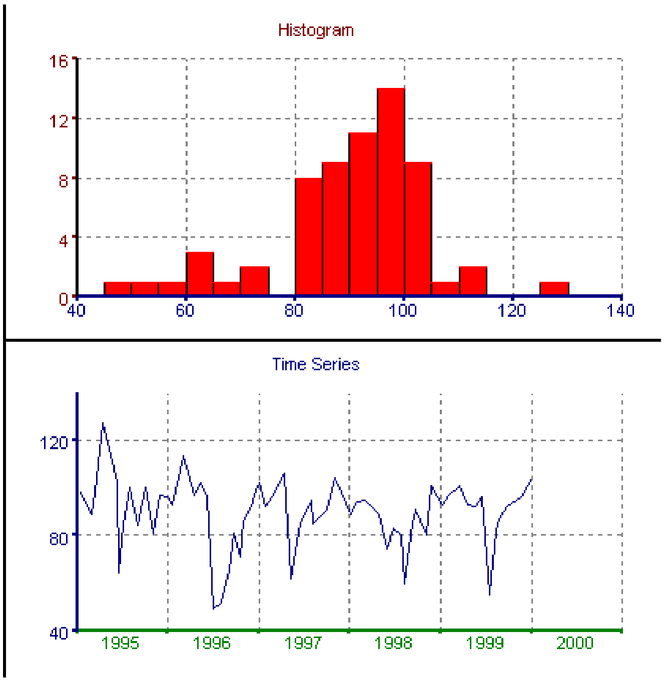


Figure 2 – Dissolved Oxygen distribution data for Severn Estuary at Lower Rea, downstream Gloucester Netheridge STW – January 1995 to January 2000

In practice, this improvement could be linked to the reduced BOD and solids concentrations being discharged from the sewage treatment works although, it must also be considered that a range of possible explanations exist.

00015203 R SEVERN (TIDAL) LOWER REA (136 Sa
Restricted (O Diss %sat %)

Number of Observations (LT)	67
Date Range	08-02-2000 to 11-08-2006
Minimum	55.00
Mean	89.40
Maximum	138.00
Standard deviation	14.639
SDD	12.104
Non-Parametric estimate (Weibull) of:	
5 Percentile	64.40
10 Percentile	69.80
20 Percentile	78.60
Median	91.00
80 Percentile	99.40
90 Percentile	105.00
95 Percentile	113.40

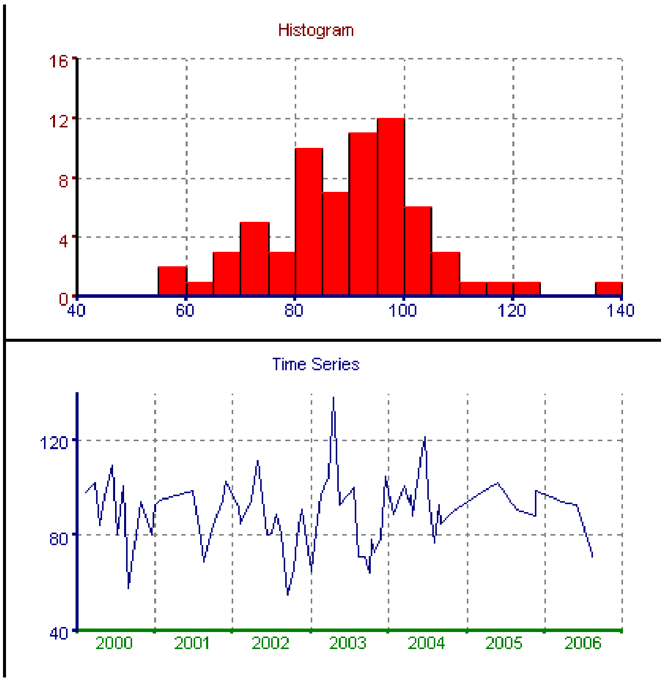


Figure 3 – Dissolved Oxygen distribution data for Severn Estuary at Lower Rea, downstream Gloucester Netheridge STW – January 2000 to August 2006

The estuarial effect is further demonstrated by the fact that the collected data shows little deterioration in water quality across the point of discharge from Gloucester Netheridge STW, both before and after the AMP investment. All of the sanitary determinands demonstrate similar concentrations at both Upper and Lower Rea on the Severn Estuary, a situation which would be regarded as unlikely should the discharge be made to an inland watercourse with predominantly downstream flow as opposed to the tidal flow experienced at Gloucester.

As monthly collected data, the frequency is prohibitive when it comes to assessing the impact of improvements in the treatment of storm sewage at the discharge.

Appendix S

Recommended Monitoring Programme

Introduction

The jointly produced 'Drought permits and drought orders' guidance identifies the need for a robust monitoring programme to support any drought order application. The monitoring programme ensures evidence will be collected to identify and enable the mitigation of drought impacts.

The recommended monitoring programme only contains sites specific to assessing the River Severn Drought Order, however the EA (and other bodies/organisations) have an extensive monitoring network, in addition to the sites listed, and all available data would be used during a real event. For example, WFD monitoring data and reports, Severn Estuary monitoring (6 yearly Habitat's Directive programme) programme etc.

Data monitoring limitations

Due to the significant size of the River Severn catchment, and area of potential impact from the River Severn Drought Order, it is challenging to design a specific monitoring programme that is not too large to be feasible, or too sparse to be useful. The proposed monitoring programme represents a range of monitoring at the key assessment locations (conditions will vary locally between these targeted sites), however the programme application may need to be flexible and discussions will need to be held between the in-combination organisations.

Due to the large area and tidal variations within the Severn Estuary, monitoring baseline conditions in the Estuary is very challenging. For example, surveying fish at specific locations only provides a snap shot picture of what species were caught on that day according to the environmental conditions at that time. Various fish species may avoid the monitoring nets, or simply be located elsewhere within the Severn Estuary and therefore be excluded.

Various Severn Estuary monitoring options and techniques were considered for this project. For transitional fish, the conclusion is to increase the frequency of baseline monitoring over the next 5 years, at 3 existing locations, to help understand more about transitional fish behaviour within the Severn Estuary, and how they may be impacted by low flows/drought. Macrophyte surveys were considered inappropriate for the Estuary due to the absence of significant vegetation. Diatom surveys were also considered for the Upper Estuary (already conducted in the middle and lower section), however due to the dynamic nature of the system along this section the results are unlikely to be conclusive or helpful in understanding the ecosystems response to low flows/drought. Invertebrate surveys were also considered unfeasible for the lower Severn, some deep water surveys have been proposed and will be trialled at Haw Bridge, but the size and dynamic nature of the upper Severn Estuary make it unlikely results would be conclusive for this project.

RSDO Monitoring programme

All **'baseline'** monitoring specific to the River Severn Drought Order is required to collect a benchmark of the aquatic environment and ecology in the River Severn over a normal range of flow conditions. This data can then be used alongside low flow/drought evidence to determine the impact of natural drought, any additional impacts from operating the River Severn Drought Order, and help assess what the minimum flow requirements are for the River Severn. The baseline monitoring will be included in the Environment Agency's annual work programme, highlighting the River Severn Drought Order as a key driver[1].

The **'low flow'** specific monitoring is required to collect data for naturally developing drought conditions prior to a River Severn Drought Order application, building a representative benchmark for comparison. The data will inform decisions on when an application may be required and provide evidence to help separate natural drought impacts from those caused solely by the River Severn Drought Order (or in combination). The low flow specific monitoring will be included within the Midlands Drought Plan, linked to appropriate triggers.

The **'Severn Drought Order'** monitoring will be triggered by the activation of the River Severn Drought Order conditions. The data collected will allow the state of the environment to be regularly monitored and compared against both the baseline and low flow data, to help assess the true impacts from the drought orders operation. Monitoring can also be used to help target any mitigation options available at the time. The Severn Drought Order specific monitoring will be identified in the Midlands Drought Plan.

'Post low flow/natural drought and/or Severn Drought Order' specific monitoring is required to monitor the recovery time following both a natural low flow/drought event, and the use of the River Severn Drought Order. Monitoring after a natural event will provide the baseline evidence crucial for then comparing data from a Severn Drought Order operational event against, distinguishing between what would have occurred even if the drought order were not operated and helping to isolate the drought order specific impacts which then need managing appropriately. Both sets of monitoring will also provide evidence on the long term implications of drought events. The Post low flow/natural drought and/or Severn Drought Order specific monitoring will also be identified in the Midlands Drought Plan.

All the proposed River Severn Drought Order monitoring sites and requirements are listed in Table 1, starting in the upper most catchment and working downstream towards the Severn Estuary. It is recommended that gap analysis and collaborative work be carried out with in-combination organisations, and the Environmental Report be updated periodically to ensure it is kept up to date. The monitoring programme should retain a degree of flexibility to cope with the dynamic nature of droughts, additional routine or one-off monitoring could be warranted according to each event.

1 Drivers describe the justification for monitoring and support the financial investment.

<u>Table1: River Severn Drought Order Monitoring Sites</u> (last updated: December 2013)

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
1	Bryntail (2109)	SN 9134 8679	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
2	Caravan Park (49774)	SN 940 857	Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis. Level data into nearest gauging station.
			Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology – RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
3	Afon Clywedog, Below Dieldre Brook	SN9447285487	Electric fishing	1 every 3 years	Baseline frequency	Baseline frequency	Year after the event	Should **not** increase during low flows to avoid further stress to fish.
4	River Severn at Llanidloes Felindre bridge (00074380)	SN 94397 83902	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
5	Dolwen (2118)	SN 9897 8520	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
6	Dolwen (52148)	SN 997 852	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
7	River Severn at Dolwen (00072250)	SN 99704 85184	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
8	River Severn - Caersws (00070450)	SO 03190 91711	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
9	River Severn foot bridge back lane cp nton (00067800)	SO 10518 91644	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
10	River Severn at cil gwran bridge Aberbechan (00065870)	SO 14445 93515	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
11	River Severn, Abermule	SO1580095000	Electric fishing	1 every 3 years	Baseline frequency	Baseline frequency	Year after the event	Should **not** increase during low flows to avoid further stress to fish.
12	River Severn at Caerhowel bridge (00064480)	SO 19685 98132	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
13	Vyrnwy Weir (2003)	SJ 0188 1904	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
14	Dolanog (50350)	SJ 067 128	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year – summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
15	Afon Vyrnwy, New Bridge	SJ 14200 11500	Electric fishing	1 every 3 years	Baseline frequency	Baseline frequency	Year after the event	Should **not** increase during low flows to avoid further stress to fish.
16	Llanyblodwel (50766) (R. Tanat)	SJ 24200 22900	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	Control (reference) site: To calculate area, wetted width and perimeter for habitat impact analysis.
17	Llanymynech (2028)	SJ 2529 1963	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
18	River Severn at Llandrinio (00060200)	SJ 29795 16898	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
19	Montford (2005)	SJ 4119 1446	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
20	River Severn at Montford Bridge (00056710)	SJ 43192 15316	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
21	Isle of Bicton (51052)	SJ 46773 16460	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
22	Isle of Bicton (51052)	SJ 46773 16460	Ecology – macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
23	River Severn Shelton intake (00055140)	SJ 46850 13605	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
24	Shrewsbury Showground	SJ4876913212	Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
25	River Severn at Atcham (00052182)	SJ 540550 9299	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
26	Cressage (ecology 52526, WQ 00049650)	SJ 59380 04550	Ecology – Invertebrate (52526)	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
			Water Quality (00049650)	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
27	Buildwas (2134)	SJ 6455 0440	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
28	Buildwas (158364)	SJ 64620 04425	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
29	Coalport (52795)	SJ 702 021	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
30	River Severn at Coalport (00045702)	SJ 701900 2060	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
31	Bridgnorth Town	SO7191392968	Fry sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme
32	River Severn at Apley Forge (00044720)	SO 70686 98298	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
33	D/S Dowles Brook (52393)	SO 780 764	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	May need to investigate a new site but would still sample in parallel with d/s Dowles Brook to ensure sites are comparable
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
34	Bewdley (2001)	SO 7823 7616	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
35	River Severn at Bewdley (00038360)	SO 78707 75407	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
36	Holt Fleet (ds bridge)	SO8269363338	Fry sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
37	River Severn at holt fleet meadows, Holt Fleet (00034302)	SO 82454 63350	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
38	River Severn – D/S bevere weir (mid) (00032360)	SO 83566 59116	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
39	River Severn - Worcester bridge (00030850)	SO 84663 54769	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
40	River Severn - rear of oil depot bath rd Worcester (00030090)	SO 85101 52319	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
41	Tenbury (48210) (R. Teme)	SO 59942 68511	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	
			Ecology - macrophyte	1/year - summer	Baseline frequency	Baseline frequency	Baseline frequency	Awaiting further guidance from WRTS that may alter this part of the programme
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Awaiting further guidance from WRTS that may alter the frequency of the sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	Control (reference) site: To calculate area, wetted width and perimeter for habitat impact analysis.
42	River Teme at Powick (13598380) (R. Teme)	SO 836 525	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
43	River Severn (upper) Kempsey (mid) (00029500)	SO 84685 49500	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
44	Upton on Severn (47463)	SO 850 408	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	Trial the use of airlift method for deep water sampling and compare with dredge sampling method
			Ecology – diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Will need to use artificial substrate for diatom sampling
			Ecology – RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
			Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
45	River Severn - Upton on Severn (00027540)	SO 85178 40790	Water Quality	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
46	Saxon's Lode (2032)	SO 8634 3904	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
47	River Severn (upper) Tewkesbury (00026230)	SO 88870 33719	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
48	River Avon at Tewkesbury (04767100) (R. Avon)	SO 893 332	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
49	Deerhurst (2606)	SO 8679 3010	Hydrology - Flow & stage	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Low flow calibration critical
50	Haw Bridge	SO8524028146	Fry Sampling, netting	Annually	Baseline frequency	Baseline frequency	Baseline frequency	Already in our monitoring programme

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
51	Hawbridge (51327)	SO 845 277	Ecology - Invertebrate	3/year – Spring, summer & Autumn	Baseline frequency	Monthly	Baseline frequency	Trial the use of airlift method for deep water sampling and compare with dredge sampling method
			Ecology - diatom	2/year - Spring & Autumn	1 extra summer	Monthly	Baseline frequency	Will need to use artificial substrate for diatom sampling
			Ecology - RHS	1 every 6 years	Baseline frequency	Baseline frequency	Baseline frequency	
			Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.
52	River Severn (lower) Ashleworth (00024062)	SO 81930 25040	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
53	West channel, River Severn	SO816196	Hydrology - Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
54	East channel, River Severn	SO 825 191	Hydrology - Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
55	D/S G&S abstraction	SO 824 183	Hydrology - Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
56	River Severn (lower) Severn rd foot bridge (00021202)	SO 82283 18228	Water Quality	Monthly	Baseline frequency	Fortnightly	Baseline frequency	Monitor for BOD, Ammonia, Phosphate, Nitrate & dissolved Oxygen.
57	Epney D/S	SO 760 110	Hydrology - Flow & stage	3/year	See Drought Plan triggers	Weekly	Revert to baseline	Spot Flow Gauging (no flow gauge present).
58	D/S Epney	SO 760 110	Cross section & inundation surveys	1 every 5 years	Baseline frequency	1 additional for calibration	Baseline frequency	To calculate area, wetted width and perimeter for habitat impact analysis.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
Severn Estuary Monitoring [*1]								
59	Cott Point	SO 80330 18051	Transitional Fish *(with supporting WQ samples)*	4/year – Every other month from May to November inclusive (5 years)	Baseline frequency	Baseline frequency	Baseline frequency	Fyke Net. Currently sample twice a year (spring and autumn). See justification in footnote *2 under table. Supporting WQ needed; Temp, DO (% & mg/l) & salinity.
60	Water End	SO 75608 14407	Transitional Fish *(with supporting WQ samples)*	4/year – Every other month from May to November inclusive (5 years)	Baseline frequency	Baseline frequency	Baseline frequency	Fyke Net. We at present sample twice a year (spring and autumn). See justification in footnote *[2] under table. Supporting WQ needed; Temp, DO (% & mg/l) and salinity.
61	Arlingham Passage	SO 69370 11428	Transitional Fish *(with supporting WQ samples)*	4/year – Every other month from May to November inclusive (5 years)	Baseline frequency	Baseline frequency	Baseline frequency	Fyke Net. We at present sample twice a year (spring and autumn). See justification in footnote *[2] under table. Supporting WQ needed; Temp, DO (% & mg/l) and salinity.

	Site Name	NGR	Type	Baseline Frequency	Low Flow/ natural drought Frequency	River Severn Drought Order event Frequency	Post low flow/ natural drought and/or Severn Drought Order Frequency	Further details/ Comments
62	Severn (North bank)	SO 72051 08065	Fucoid Extent	Continuous	Baseline frequency	Baseline frequency	Baseline frequency	Continuous salinity tag deployment
63	Gatcombe	SO 68260 05210	Water column	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Phytoplankton, Chlorophyl, Salinity, Temperature, DO, Secchi, Light.
64	Bollow Point (Bullo Pill)	SO 75130 13870	Water column	Monthly	Baseline frequency	Baseline frequency	Baseline frequency	Phytoplankton, Chlorophyl, Salinity, Temperature, DO, Secchi, Light
65	*Oldbury Power station successor*	*ST 60772 94200*	*Fish assemblage surveys*	*Monthly*	*Baseline frequency*	*Baseline frequency*	*Baseline frequency*	*Old power station is being decommissioned, monitoring no longer possible. However, a new power station is being commissioned and as part of the EIA a stipulation for monitoring of fish could be made*

[1] Reference will be made to useful baseline data collected for other purposes, e.g. the 6 yearly European site reporting programme, carried out by NRW, NE EA and others, WFD baseline data and reporting etc.

[2] Further monitoring at three points in the Lower Tidal Severn is required. The main period of concern in the estuary is perceived to be May to November. Monitoring in the estuary has to be undertaken at neap tides due to the large changes in the Severn estuary and so is difficult to schedule in. It is thought that monitoring every other month through the critical period gives a better understanding and hopefully a baseline of 5 years should give us a spread of different hydrological years.

It is suggested that the above recommendations be discussed and updated as required in consultation with STWL, SSW, The Canal and River Trust, Natural England and Natural Resources Wales.

Appendix T

List of all Technical Report Recommendations

Hydrology Technical Report recommendations

- Update the River Severn Estuary residual flow study (written in 1992) work to establish the current freshwater inflow targets, based on the existing abstractions and water quality conditions.
- Develop a flow 'prediction' model or improve existing models capability, to cater for the needs of Drought Order and Permit investigations.
- Integrate water quality and water resource flow models to ensure continuity in drought/low flow testing.
- Develop hydro-ecological 'prediction' tools capable of assessing the regulation experienced along the River Severn.
- Investigate whether an inundation model, similar to flood risk mapping but for low flows, can be developed (particularly in the high risk area's such as the Lower River Severn) to help visualise and quantify the environmental impacts.
- Explore how well non-water company abstraction is represented and how easily it can be manipulated inside Aquator.
- Incorporate the Shropshire Groundwater Scheme Drought Order operation in modelling work, including the application of the East Shropshire Permo-Triassic Sandstone Groundwater Model to provide a tool with which to predict environmental impacts within the operational footprint of the SGS.
- Need to improve the Gloucester and Sharpness canal abstraction and conceptualisation inside the Severn Drought Order modelling.
    - Enter a specific drought related abstraction profile for the canal, replacing the current monthly average used.
    - Check how the tributaries CAM and Frome are represented in Aquator – if directly to the River Severn then it might be more appropriate to represent 'Total abstraction' for the canal (i.e. including Cam and Frome) to remove from the River Severn. However, both tributaries maybe further downstream than flow models can work therefore not necessary.
- Investigate how the Gloucester and Sharpness canal abstraction is represented inside Severn Corridor CAMS and the WRGIS tool to ensure the maximum worse case abstraction volume is included.
- Investigate how the Gloucester and Sharpness canal abstraction is represented inside Low Flows Enterprise, and whether the channel split can be built into the model.
- Get reservoir storage levels prior to 1990 onto WISKI to capture important historic droughts. It's unclear who would have these potentially hard copy records.
- The Canal and River Trust (was British Waterways) do not currently measure all of their abstraction (losses mainly) and submit returns data annually – investigate whether abstraction returns could be requested more frequently during Severn Regulation operation, in line with other Act of Parliament partners. Or as a minimum through potential/drought critical periods. The aim would be to better conceptualise flows into the Severn Estuary and aid efficient operation of Severn Regulation.

- Explore whether the Canals and Rivers Trust could bring the Gloucester and Sharpness canal operations in line with the Montgomery canal. This would involve setting out agreed abstraction reductions and operations to cater specifically for high regulation demand and drought conditions.
- Consider additional assessment points upstream of Buildwas e.g. Dolwen, Abermule, Llanymynech, Montford.
- If the frequency of RSDO operation increased or a greater need arose, consider cost effective development of new sources for Severn Regulation.

Aquator Water Resource modelling

- Drought permit VBA code should be added to the new STWL Severn & Wye model upon its release. The new model is expected to contain improvements in water routing and resource zone characterisation.
- Mott MacDonald and STWL are currently working on a project to improve the original HYSIM Aquator background flows using new rainfall data and a longer calibration period. The impact on the current project results is expected to be restricted due to the data processing to create the acute and chronic scenarios.

Future modelling should be based on the new Severn & Wye model and background data sets. In addition the current project methodology should be repeated using the new model and background flows in order to confirm our results. Any significant variation between new and old models should be investigated.

- Separating the discharge values from the natural background flow for higher modelling accuracy.
- Reviewing how the regulation system is represented and isolating the River Severn Drought Order as a separate demand saving option for better modelling capability.
- The Severn & Wye model was originally created for STWL. Abstractions by SSW, and DCWW are included in the model, but their supply networks have been dramatically simplified. With the permission from both water companies and access to the necessary data the Environment Agency could improve the Severn & Wye characterisation. Commercial confidentiality must be a key priority in any such improvement.
- Extension of the model further downstream of lower parting (R. Severn) & Redbrook (R. Wye).
- Additional demand saving levels could be added to the model (Section 2.10 Limitations).
- New additional climate change scenarios should be conducted based on UKCP09 flow predictions. This could adopt the EA's methodology used by water companies in their 'Water Resources Management Plans'.

Water Quality Modelling

- Monitoring to improve calibration would entail a better understanding of the inputs to the model in terms of polluting load. I am not sure the calibration could be improved through additional WQ modelling. It is almost a case of having to walk the river/desktop study with EOs to ID polluting loads for inclusion in the model. The model could also better represent all abstractions in order to improve flow calibration further.

- Low flow WQ monitoring could be useful in validating the output from drought modelling in SIMCAT although would not be used in the build/running of the model unless it was possible to build a specific SDO/drought SIMCAT model...

With regards to the improved representation of drought conditions, SIMCAT would need to be fundamentally changed to be able to better represent the intricate operation of the major abstractions in terms of hands of flows and drought orders. In most cases, the model is already built based on measured abstracted flows although the representation of this data could probably be improved.

In short, it is not felt that SIMCAT is the best modelling tool for the job given the limitations discussed. In order to fully understand and better replicate the impacts of drought flows, a specifically developed water resource model capable of accurately representing current and drought conditions would be the recommended way forward. Perhaps a water quality function could be incorporated within AQUATOR?

All SIMCAT models are initially calibrated for flow followed by a water quality calibration exercise based upon the accurate representation of the flow characteristics. Any work beyond this point tends to be in the form of 'what-if' scenarios. In other words, what will happen to the quality if we halve the flow?

Providing the initial calibration is as accurate as possible, any change in the model with regards to flow should give a suitably accurate prediction of the impact on quality. What is lacking in SIMCAT is the functionality to represent the complicated flow controls in the River Severn. If this could be rectified in SIMCAT (or any other model for that matter, then an accurate water quality prediction in drought conditions should be possible.

In an ideal modelling world, a tool capable of predicting both temporal and spatial changes in water quality and flow would be available with the capability to represent any number of different flow situations. Providing it was then fully calibrated in terms of water quality in 'normal' conditions, reactive predictions in water quality at any location or time could be possible.

Ecology Technical Report Recommendations

- The sampling method used to the collect the invertebrate samples below Bewdley (i.e. Upton and Hawbridge) needs to be reassessed
- The feasibility of monitoring the lower reaches of the freshwater section of the Severn needs to be investigated further.
- Develop the DRIED UP model for use with regulated rivers such as the Severn.

- Future monitoring should include cross sections of the river at specific sites with reference to flows/levels in order to predict the effect of the altering flows on the wetted area and the exposure of substrate and sediments at those sites.
- During drought events, a series of photographs should be taken at regular time intervals at the strategic sites throughout the Severn corridor and then related to the actual river level/flow data.
- The development of a low flow forecasting model would then be a next logical step.

Fish Technical Report Recommendations

- Fish pass potential should be incorporated/considered where ever possible along the main River Severn, e.g;
    - A refurbishment project at Diglis weir, to incorporate an appropriate fish pass.
    - A fish counter down at Upper Loade/Deerhurst would give a better understanding of salmon migration and could be used to produce a statistical model to assess impact of changes in flows.
- Need better understanding of salmon movements in the estuary, suggestions;
    - Radio tracking migratory fish within different sections of the estuary would be very difficult but give a better understanding of movements within the estuary and could be used in conjunction with fish counter data in production of statistical model
- Lamprey surveys following guidance from Harvey & Cowx (2003), which involves electric fishing for ammocoetes and using fish counters (where feasible) to sample adult migration upstream .
- If improved fish passes implemented on navigation weirs a fish counter on the lowest fish pass would be desirable.
- Need some specific shad monitoring as recommended by Hillman, Cowx & Harvey (2003):
    - Juvenile density (represented by catch per unit effort, CPUE). Micromesh seine netting is the most appropriate sampling method to assess juvenile shad in the lower river/upper estuary
    - Adult run size. Fish counters should be used to monitor the time and approximate size of adult spawning migration.
- Expect most impacts on Salmonid sites, hence best to set up monitoring for these:
    - Electric fishing on Severn (above Dolwen), Clywedog and Vyrnwy (quantitative). Also timed surveys on riffles further down the Severn to estimate juvenile salmon distribution
    - Habscore all quantitative sites at an appropriate frequency
    - Use fish counter data from Shrewsbury to assess annual salmon migration (and other fish movements)
    - Fry sampling on main River Severn (netting) to assess coarse fish population

Severn Estuary Water Quality Technical Report Recommendations

- further investigation needs to be carried on the operation and its effects of the Sharpness-Gloucester Canal abstraction on river flows in the East and West Channels.
- Data on conductivity (salinity) and turbidity (suspended solids) from monitoring being undertaken by The Canals and Rivers trust or the Port of Gloucester needs to be obtained, and the work of Hutcherson and Wade (1992) reviewed.
- Time Series data and vertical profiles on the levels of Dissolved Oxygen at various locations in the Tidal River Severn during low river flows is needed to assess the impact of the current discharge from Gloucester (Netheridge) STW.
- The recent bathymetric study of the upper reaches of the Severn Estuary by Gloucester Harbour Trustees should be obtained, if it has not been already. The data from this study would provide information on the nature of the low water channel from Gloucester down to the SAC, as well as allow a re-assessment of the tidal volumes.
- The benthic ecology of the Tidal River Severn and the upper part of the SAC needs to be assessed in detail, using available information. If necessary, this information could be supplemented by some survey transects looking at seasonal variations in the upper Estuary, which would provide some data on the response of the benthic ecology to changes in river flows.
- In the long-term, a numerical model of the upper reaches of the Severn Estuary, looking at saline intrusion and the up-estuary transport of suspended sediments could be developed, to allow actual flow and tidal conditions to be modelled.

Appendix U

Additional Fisheries Information: Severn Estuary HRA

Additional Fisheries information: Severn Estuary HRA

Environment Agency
Martin Fenn

Introduction

The Severn Estuary is one of Europe's most important estuarine nursery areas for fish, even with the issues caused by its unique character. The level of primary production in the Severn Estuary is severely impacted by poor light penetration due to high sediment loads. These turbid waters limit the production of both phytoplankton and attached algae (potential food source). Added to this the high bed shear stresses and instability of the estuary bed has a major impact on the sub tidal invertebrates (another potential food source). However, in areas where the substrate is more stable populations of invertebrates flourish ensuring an important food source for the fish of the estuary.

The Severn Estuary is important for its migratory fish, which assisted in its designation as a SAC. The Annex II species found within the estuary include twaite shad (Alosa fallax), river lamprey (Lampetra fluviatilis) and sea lamprey (Petromyzon marinus). The Severn also has the following notable migratory species: Atlantic salmon (Salmo salar), sea trout (Salmo trutta morpha trutta) and European eel (Anguilla anguilla).

Also the large fish assemblage within the estuary is one of the important features in the designation of the estuary as a RAMSAR site.

Figure 1. Map of Severn Estuary SAC with power station sampling points

Available Data

Due to the enormous size of the Severn Estuary monitoring of the fish population is extremely difficult. The best fish data collected to date has been from the power station intakes at Oldbury (ST 60633 94448) and Hinkley Point (ST 21155 46107) Power Stations. Individuals become entrained on the cooling water-intake screens used at power stations these are washed off into metal cages and can then be counted. Obviously this form of monitoring has an element of bias as only fish swimming near location of intakes are entrained and pelagic species have a better chance of avoiding the intake. Also juvenile fish are generally slower and weaker swimmers so more likely to be entrained. However, this long term data set (especially at Hinkley Point) is invaluable as an estimate of the fish community of the Severn Estuary.

Another source of information is from the Severn netsmen. These fishermen use traditional methods almost unique to the River Severn to catch Atlantic salmon. The Environment Agency also has a Transitional fish sampling programme for the Severn Estuary mainly using fyke and seine netting.

Table 1. Environment Agency tidal lower Severn and upper estuary transitional monitoring sites

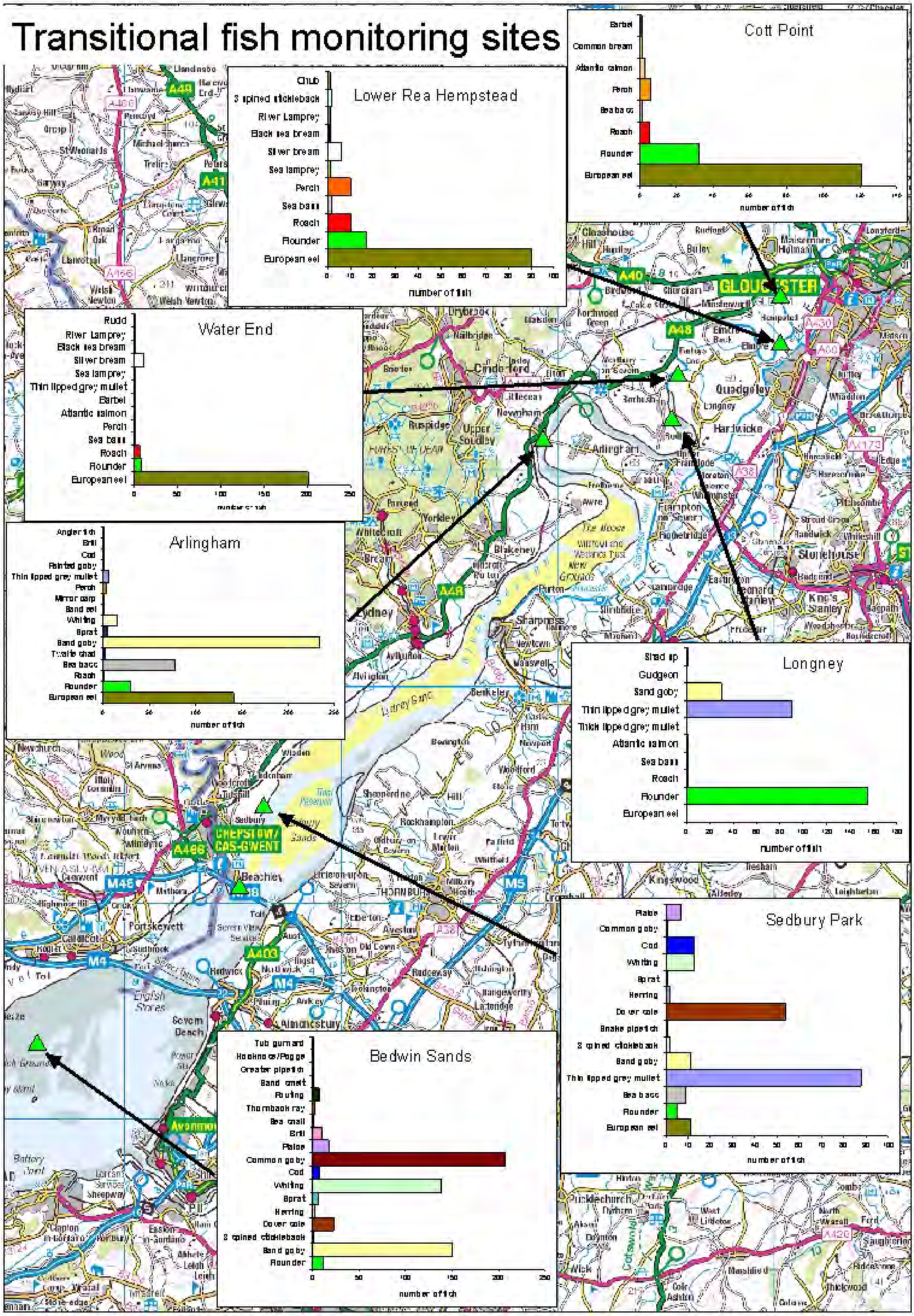
Site Name	Method	NGR	First Surveyed
Bedwin Sands	Otter Trawl	ST4602383542	2007
Sedbury Park	Seine Net	ST5650994499	2008
Arlingham Passage	Fyke Net	SO6937011428	2007
Longney	Seine Net	SO7536212378	2008
Lower Rea Hempstead	Fyke Net	SO8033315876	2008
Water End	Fyke Net	SO7560814407	2008
Cott Point	Fyke Net	SO8033018051	2008

There has been limited success in radio tracking fish within the Severn Estuary due to the difficulty in catching large enough numbers.

There is unfortunately no fish counter on the lower River Severn either to assess movement of migratory fish.

More research papers and Government documents have been produced recently due to the interest in harnessing the tidal power of the estuary for electricity generation. This has increased understanding of this system and provided access to more information.

Figure 2. Map showing locations and numbers of fish caught at transitional monitoring sites within the Lower Tidal Severn and upper estuary (EA)



Fish Population Present

A list of fish species recorded in Bridgewater Bay are displayed in Table 2. This shows the wide diversity of fish present in the estuary with their corresponding functional group:

- Marine Migrant – species where adults live and breed in marine environments, with juveniles frequently found in estuaries in large numbers. Juveniles can be opportunistic (i.e. can find suitable conditions within or outside estuaries), or dependant (i.e. require estuarine types of habitat).
- Marine Straggler – generally marine species abundant in the marine environment but occurring infrequently in the Severn Estuary
- Estuarine Species – species that typically occur and breed in estuaries
- Freshwater Straggler – species that typically occur and breed in freshwater but are found in low numbers in the Severn Estuary
- Anadromous – species that migrate from the sea into freshwater to breed
- Catadromous – species migrating from freshwater into the sea to breed

The majority of the fish species in this list are highly mobile and will move up and down the estuary with changing tides and seasons. Results from Oldbury (Table 3) show that the main fish caught at this point of the estuary over a long period tend to be sprat, whiting, sand goby and bass. Variations overtime have been noted for certain species by Hendersen and Bird (2010) with some changes related to recent warming (water temperature) and the North Atlantic Oscillation. Species such as the European eel have seen a national decline caused possibly by excessive fishing for elvers, freshwater habitat degradation, barriers to migration and the introduction of parasite Anguillicola crassus from Asia (Hendersen, Seaby and Somes, 2007). What is interesting is that at Oldbury the European eel was still ranked 9th in the 1972 to 1977 and the 2006 to 2011 catches. This could suggest that numbers in this part of the estuary have not seen as marked a decline. However, reports by Hendersen, et al. (2007) have highlighted major concerns with falling eel numbers at Hinkley Point.

Table 2. List of species recorded within from Hinkley Point and functional group

(taken from Severn Tidal Barrage Scoping Topic Paper, 2008)

Species	Functional Group	Species	Functional Group
Anchovy *Engraulis encrasicolus*	MARINE STRAGGLER	Norway pout Trisopterus esmarkii	MARINE STRAGGLER
Angler fish *Lophius piscatorius*	MARINE STRAGGLER	Painted goby Pomatoschistus pictus	MARINE STRAGGLER
Ballan wrasse *Labrus bergylta*	MARINE STRAGGLER	Pearlsides Maurolicus muelleri	MARINE STRAGGLER
Bass *Dicentrarchus labrax*	MARINE MIGRANTS	Perch Perca fluviatilis	FRESHWATER STRAGGLER
Black goby *Gobius niger*	ESTUARINE SPECIES	Pilchard Sardina pilchardus	MARINE STRAGGLER
Black sea bream *Spondyliosoma cantharus*	MARINE MIGRANTS	Piper Trigla lyra	MARINE STRAGGLER
Blonde ray *Raja brachyura*	MARINE STRAGGLER	Plaice Pleuronectes platessa	MARINE MIGRANTS
Blue whiting *Micromesistius poutassou*	MARINE STRAGGLER	Pollack Pollachius pollachius	MARINE MIGRANTS
Brill *Scophthalmus rhombus*	MARINE STRAGGLER	Poor cod Trisopterus minutus	MARINE MIGRANTS
Cod *Gadus morhua*	MARINE MIGRANTS	Pout Trisopterus luscus	MARINE MIGRANTS
Common goby *Pomatoschistus microps*	ESTUARINE SPECIES	Raitt's sandeel Ammodytes marinus	MARINE STRAGGLER
Common sand eel *Ammodytes tobianus*	MARINE STRAGGLER	Red mullet Mullus surmuletus	MARINE STRAGGLER
Common sea snail *Liparis liparis*	MARINE MIGRANTS	River lamprey Lampetra fluviatalis	ANADROMOUS
Conger eel *Conger conger*	MARINE STRAGGLER	Rock cook Centrolabrus exoletus	MARINE STRAGGLER
Corkwing wrasse *Crenilabrus melops*	MARINE STRAGGLER	Rock goby Gobius paganellus	MARINE STRAGGLER
Crystal goby *Crystallogobius linearis*	MARINE STRAGGLER	Saithe Pollachius virens	MARINE STRAGGLER
Cuckoo wrasse *Labrus mixtus*	MARINE STRAGGLER	Salmon Salmo salar	ANADROMOUS
Dab *Limanda limanda*	MARINE STRAGGLER	Sand goby Pomatoschistus minutus	ESTUARINE SPECIES
Dover sole *Solea solea*	MARINE MIGRANTS	Sand smelt Atherina boyeri	ESTUARINE SPECIES
Dragonet *Callionymus lyra*	MARINE STRAGGLER	Scaldfish Arnoglossus laterna	MARINE STRAGGLER
Eel *Anguilla anguilla*	CATADROMOUS	Sea lamprey Petromyzon marinus	ANADROMOUS
Fifteen-spined stickleback *Spinachia spinachia*	MARINE STRAGGLER	Small eyed ray Raja microocellata	MARINE STRAGGLER

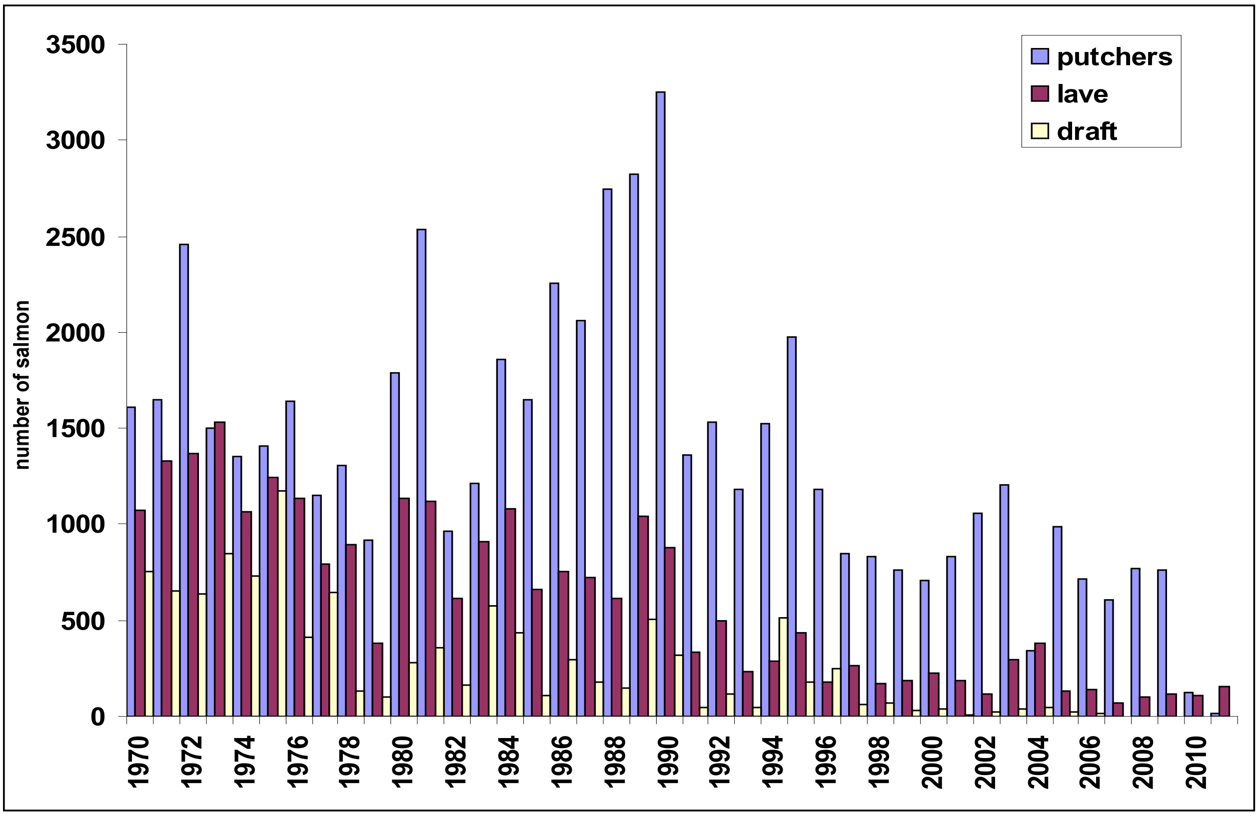
Species	Functional Group	Species	Functional Group
Five-bearded rockling *Ciliata mustela*	MARINE MIGRANTS	Snake pipefish Entelurus aequoreus	MARINE STRAGGLER
Flounder *Platichthys flesus*	MARINE MIGRANTS	Solenette Buglossidium luteum	MARINE STRAGGLER
Garfish *Belone belone*	MARINE MIGRANTS	Sprat Sprattus sprattus	MARINE MIGRANTS
Golden mullet *Liza aurata*	MARINE MIGRANTS	Tadpolefish Raniceps raninus	MARINE STRAGGLER
Goldsinny wrasse *Ctenolabrus rupestris*	MARINE STRAGGLER	Thicklipped grey-mullet Chelon labrosus	MARINE MIGRANTS
Greater pipefish *Syngnathus acus*	MARINE STRAGGLER	Thinlipped grey-mullet Liza ramada	MARINE MIGRANTS
Greater sand eel *Hyperoplus lanceolatus*	MARINE MIGRANTS	Thornback (roker) ray Raja clavata	MARINE STRAGGLER
Grey gurnard *Eutrigla gurnardus*	MARINE STRAGGLER	Three-bearded rockling Gaidropsarus vulgaris	MARINE STRAGGLER
Hake *Merluccius merluccius*	MARINE STRAGGLER	Three-spined stickleback Gasterosteus aculeatus	ESTUARINE SPECIES
Herring *Clupea harengus*	MARINE MIGRANTS	Tompot blenny Parablennius gattorugine	MARINE STRAGGLER
Hooknose (Pogge) *Agonus cataphractus*	MARINE STRAGGLER	Topknot Zeugopterus punctatus	MARINE STRAGGLERS
Horse mackerel *Trachurus trachurus*	MARINE STRAGGLER	Transparent goby Aphia minuta	MARINE STRAGGLER
John dory *Zeus faber*	MARINE STRAGGLER	Trigger Fish Balistes capriscus	MARINE STRAGGLER
Lemon sole *Microstomus kitt*	MARINE STRAGGLER	Tub gurnard Chelidonichthys lucernus	MARINE MIGRANTS
Lesser spotted dogfish *Scyliorhinus caniculus*	MARINE STRAGGLER	Turbot Psetta maxima	MARINE STRAGGLER
Lesser weaver *Trachinus vipera*	MARINE STRAGGLER	Twaite shad Alosa fallax	ANADROMOUS
Ling *Molva molva*	MARINE STRAGGLER	Whiting Merlangius merlangus	MARINE MIGRANTS
Lumpsucker *Cyclopterus lumpus*	MARINE STRAGGLER	Witch Glyptocephalus cynoglossus	MARINE STRAGGLER
Nillson's pipefish *Syngnathus rostellatus*	MARINE MIGRANTS	Worm pipefish Nerophis lumbriciformis	ESTUARINE SPECIES
Northern rockling *Ciliata septentrionalis*	MARINE MIGRANTS		

Table 3. Top ten ranked fish caught at Oldbury Power Station over different time periods

	1972 to 1977	1998 to 1999	2006 to 2011
Sand Goby	1	2	4
Whiting	2	3	1
Flounder	3	8	6
Bass	4	4	2
Sea snail	5	5	7
Poor cod	6		
Thin lipped grey mullet	7	7	10
Twaite shad	8		
European eel	9		9
Herring	10	6	
Sprat		1	3
5 bearded rockling		9	
Cod			5
Snake pipefish			8
Dab		10	

Salmon catches within the estuary are displayed in Figure 3. A general reduction in numbers of salmon caught was noted through the 1990’s, with a slight recovery in the early part of the 2000’s. Fishing effort in the salmon net fishery has reduced nationally over the past two decades, partly as a result of the phasing out of fisheries that target mixed stock. This could account for some of the decline. However, with water quality improvements the Severn netsmen believe that there have been marked improvements in salmon runs over last 10 years (pers comm. John Powell 13/12/11).

Figure 3. Annual salmon catch return data for commercial putchers, lave and draft nets in the River Severn



The transitional fish monitoring programme for the Severn Estuary involves results mainly from fyke and seine netting. Sites used were mainly in the Upper Estuary (Figure 2) as this is anticipated to be the area most likely to show any impact from low freshwater flows. The most upstream site (Cott Point) is dominated by freshwater species and within the section we call Tidal Lower Severn. The only estuarine or marine species caught were flounder and sea bass. The European eel dominates these sites with general lengths around 400mm. At Bedwin Sands (below Severn crossing) estuarine and marine migrants dominate (common and sand goby and whiting)

Table 4. Fish species occurring in transitional fish surveys by EA from 2007 to 2011 (with top 10 caught fish numbered)

3 spined stickleback	Herring	Sea snail
Angler fish	Hooknose/Pogge	Shad sp
Atlantic salmon	Mirror carp	Silver bream
Barbel	Painted goby	Snake pipefish
Black sea bream	Perch	Sprat
Brill	Plaice 9	Thick lipped grey mullet
Chub	Pouting	Thin lipped grey mullet 5
Cod	River Lamprey	Thornback ray
Common bream	Roach 10	Tub gurnard
Common goby 4	Rudd	Twaite shad
Dover sole 8	Sand eel	Whiting 6
European eel 1	Sand goby 2	
Flounder 3	Sand smelt	
Greater pipefish	Sea bass 7	
Gudgeon	Sea lamprey	

Figure 4. Number of fish caught at Cott Point using fyke nets 2008 to 2011

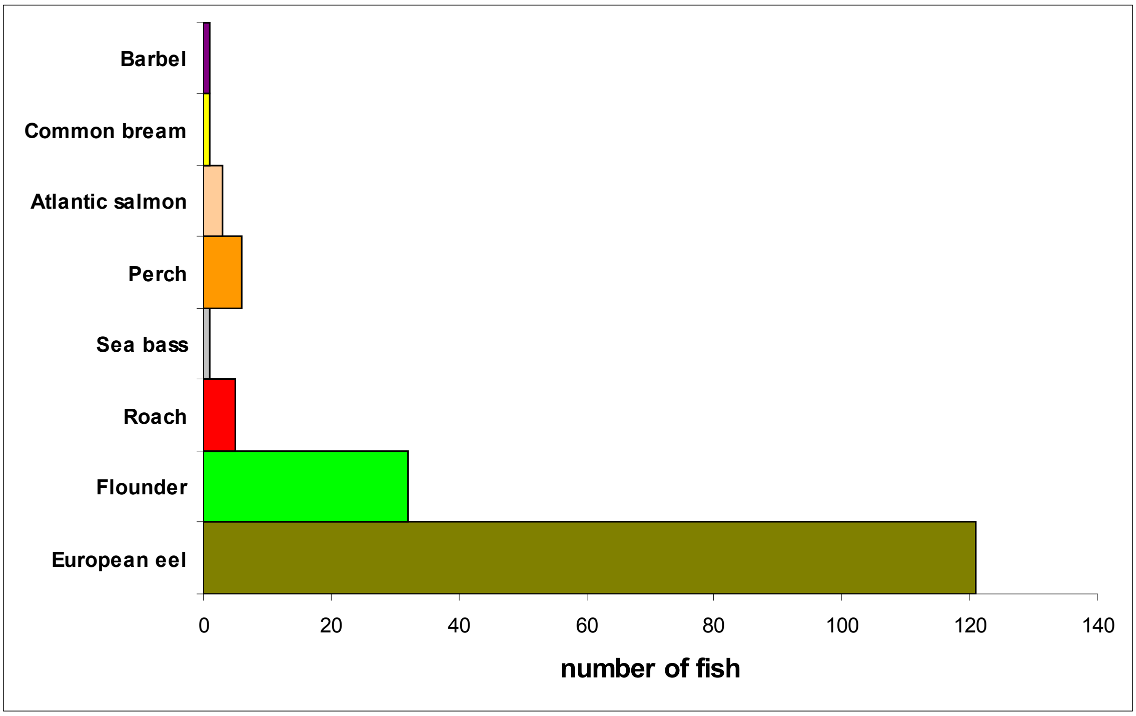


Figure 5. Number of fish caught at Lower Rea Hempstead using fyke nets 2008 to 2011

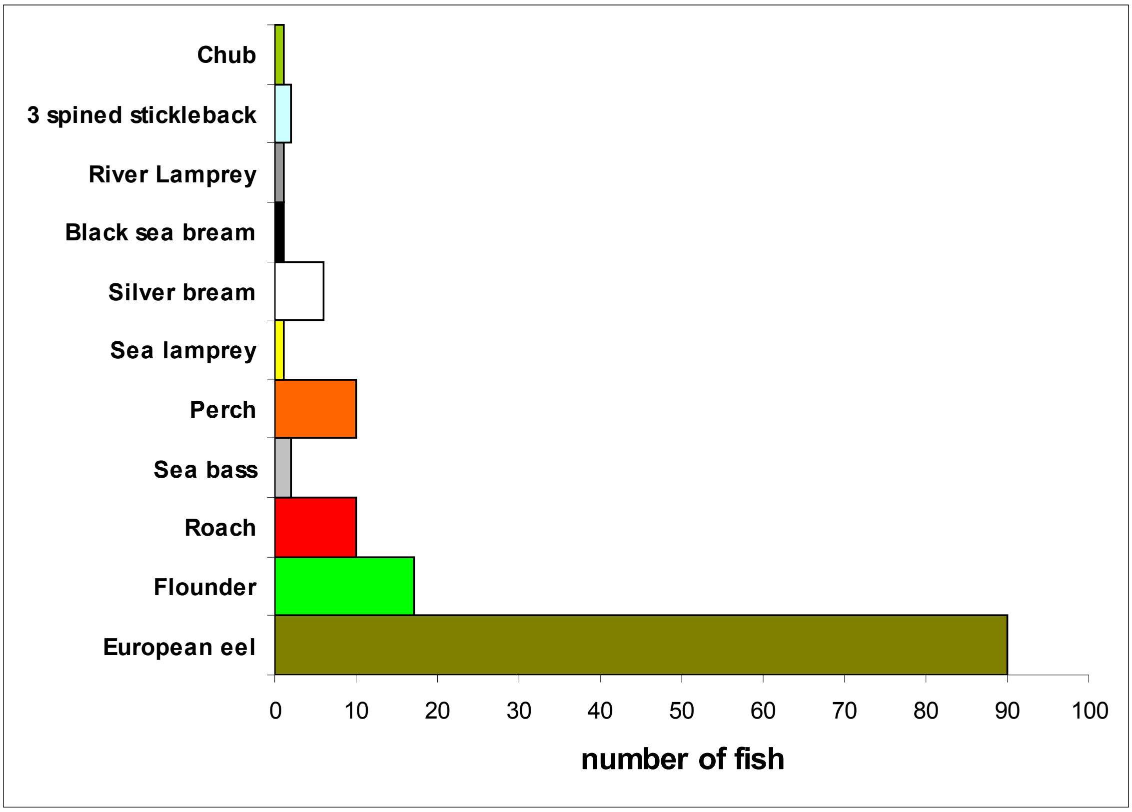


Figure 6. Number of fish caught at Water End using fyke nets 2008 to 2011

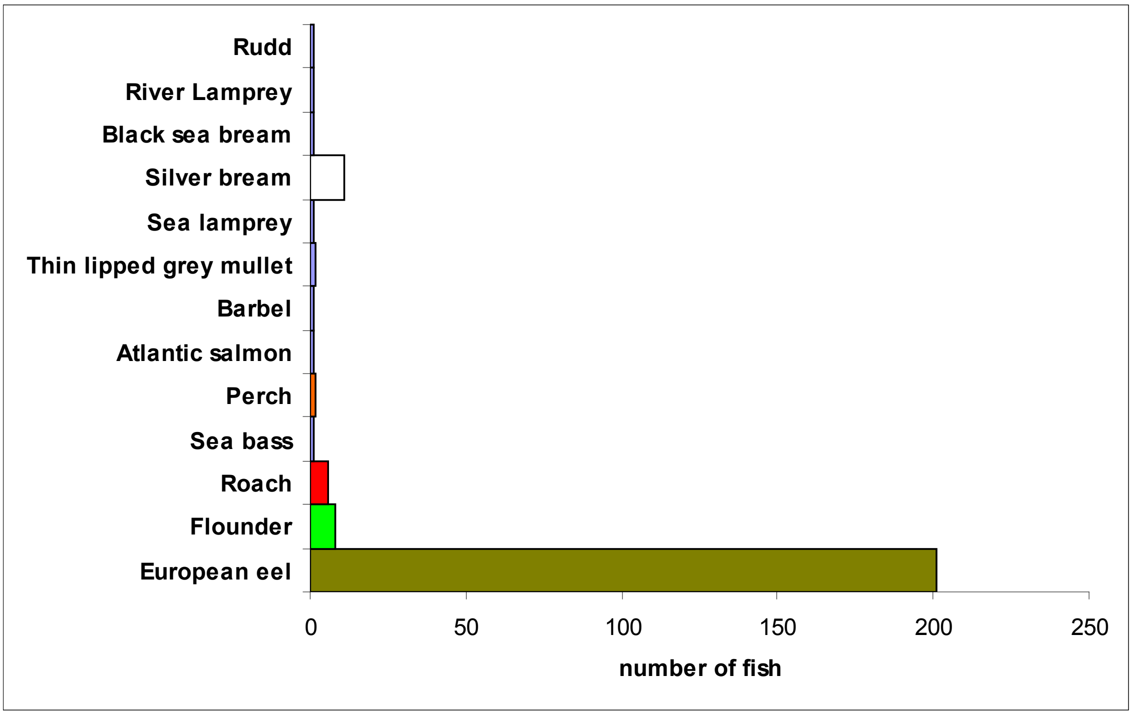


Figure 7. Number of fish caught at Longney using seine nets 2008 to 2011

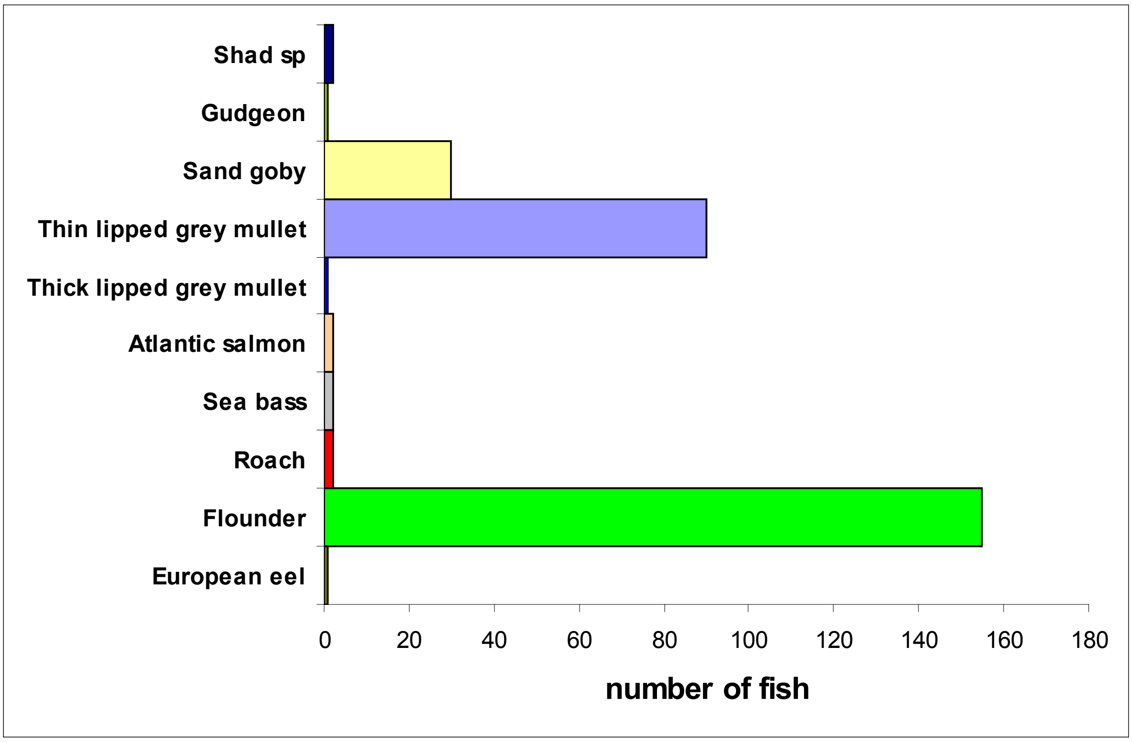


Figure 8. Number of fish caught at Arlingham Pass using fyke nets 2007 to 2011

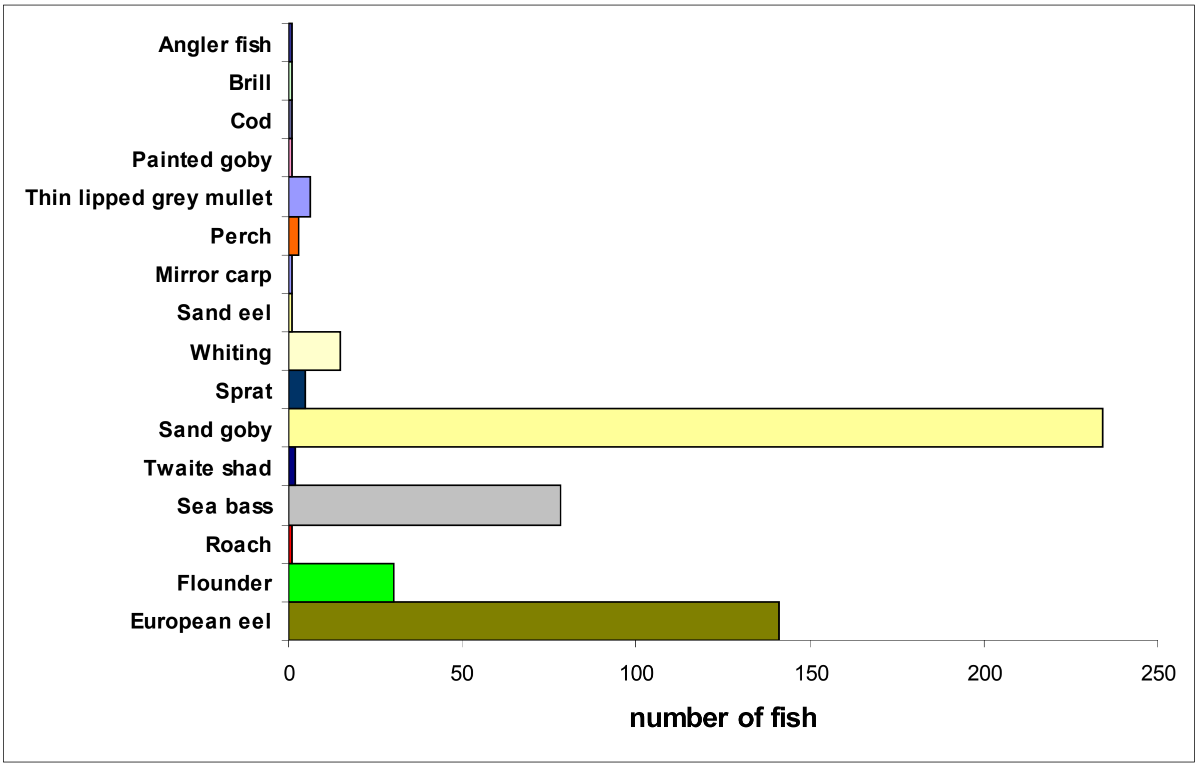
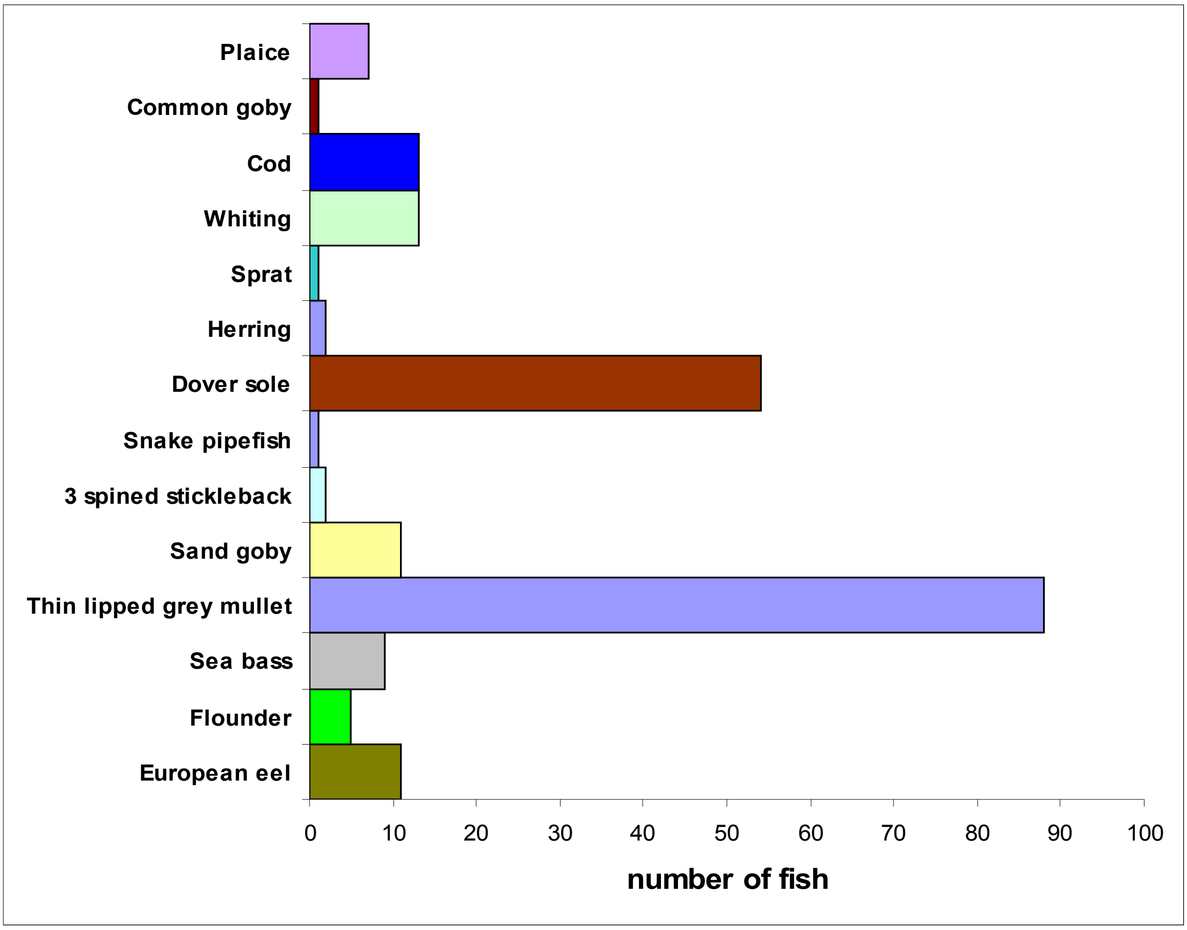


Figure 9. Number of fish caught at Sedbury Park using seine nets 2008 to 2011



Impacts of Lowering Flows

Tidal reaches respond to flow in similar ways to lowland freshwater reaches but are also vulnerable to changes in salinity due to the interactions between freshwater flows, winds and tides. Many tidal reaches exhibit long residence times for the water in them, leading to exacerbation of water quality problems. Tidal rivers are hence vulnerable to low freshwater flows during several periods of the year. In summer the impacts are likely to be associated with water quality, typically the development of mobile zones of low oxygen and high ammonia that can be lethal to fish especially in summer when temperatures are also high. This is especially relevant to salmonids attempting to pass through these zones. Low flows allow the ingress of seawater during spring tides, particularly when exacerbated by storm conditions. These can lead to fish kills especially where fish are unable to escape upstream into freshwater due to physical barriers, or where they become trapped in off-channel areas such as marinas or dykes. As with freshwater lowland reaches, tidal river reaches are commonly heavily modified and these modifications interact with the impacts of flow regimes to exacerbate problems for fisheries.

The Severn Estuary is used extensively by juvenile fish and the majority of these move into deeper water in winter (with higher freshwater flows entering the estuary), but sprat and eel appear to do the opposite and move into the estuary. Many of the fish species living in the Severn Estuary are adapted to tolerate high turbidity and a wide range of temperatures, salinity and oxygen concentrations (Bird, 2008). Therefore these are unlikely to be impacted by slight changes in freshwater flows. The species most likely to be impacted by the lowering of freshwater flows are those that migrate from sea to freshwater as part of their lifecycle (Twaite shad, sea and river lamprey, Atlantic salmon, sea trout and European eel).

The main impacts in the estuary caused by a lowering of freshwater flows could be an increase in the occurrence of dissolved oxygen sags and increase saline intrusion. The reason for the dissolved oxygen sags in the estuary are as follows.

During neap tides, fine silt accumulates. This silt contains organic material of natural origin and from the effluent discharges upstream in addition to the settled sewage from Netheridge. Bacterial action in this silt rapidly uses up available oxygen. It then produces chemicals able to react rapidly with oxygen which becomes available when the silt is re-suspended during spring tides by high inflowing velocities. This reaction causes a rapid depletion of the dissolved oxygen. The effect is repeated on successively low tides, each of which re-suspends more sediment, until very low dissolved oxygen levels can be reached. These effects combined with high water temperatures caused the death of many salmon, eels and other fish at the end of June 1976. (Severn Trent Water, 1977).

In the late 1980's and early 1990's large fish kills were noted in the Severn Estuary. Wade (1992) listed fish kills recorded during this period (see below).

25/6/89 River Severn, Longney 114 salmon, 2 eels, 1 twaite shad, 1 bream and sea lamprey. Cause thought to be low dissolved oxygen (<0.5ppm), fish from Parting to Bollow

10/7/89 River Severn, Epney 45 salmon. Low dissolved oxygen associated with storm water from Netheridge

26/6/90 River Severn, Minsterworth minimum of 30 salmon. High temperatures, low freshwater flows, high spring tides and low dissolved oxygen

7/7/92 River Severn at Kadam Pool, Weir Green and Longney 27 salmon (minimum). Low dissolved oxygen with spring tide influence

He concluded that Netheridge Water Reclamation Works and the abstraction by British Waterways for the Gloucester and Sharpness Canal were having a detrimental impact on dissolved oxygen levels and hence the cause of fish kills. The majority of these reported fish kills and those from the 1976 drought tended to occur in June and July, which is before the main impacts of the modelled drought scenarios. Water quality has improved significantly at Netheridge and now salmon deaths are very rarely recorded.

All the evidence discussed so far in hydrology and saline intrusion section of this document suggests that the main area of concern regarding impacts from a drought and the impact of a Severn Severn Drought Order would be in the Lower Tidal Severn i.e. above the Severn SAC. Therefore the main fish to be impacted are likely to be freshwater and migratory fish.

Specific Fish of Importance to Estuary

Table 5. List of important migratory fish and their key prey species

Prey species Assemblage Species	Key prey species
Twaite shad	Small crustaceans, especially mysids and copepods, small fish, especially sprats and anchovies, and fish eggs (Maitland, P.S. & Hatton-Ellis 2003).
Allis shad	Small crustaceans, especially mysids and copepods, small fish, especially sprats and anchovies, and fish eggs (Maitland, P.S. & Hatton-Ellis 2003).
Sea lamprey	Eel *Anguilla anguilla*, cod *Gadus morhua*, and haddock *Melanogrammus aeglefinus* are all potential prey species for the sea lamprey found within the Severn Estuary (Bird 2008)
River lamprey	Sea trout *Salmo trutta*, shad *Alosa fallax/Alosa alosa*, herring *Clupea harengus*, sprat *Sprattus sprattus*, flounder *Platichthys flesus* and small gadoids such as whiting *Merlangius merlangus* and pout *Trisopterus luscus* are all potential prey species for the river lamprey found within the Severn Estuary (Bird 2008).
Salmon	While at sea, salmon feed on a variety of fish (e.g. herring, sprat, sand eel, mackerel, and various gadoids) and crustaceans (e.g. euphausiid shrimps, prawns, gammarid amphipods and various crabs). (Bird, 2008)
Sea trout	The diet of this species at sea has not been much studied but is believed to include a range of fish species including sprat, young herring and sand eels as well as crustaceans such amphipods (e.g. Corophium), gammarids, decapods such as Crangon and mysid shrimps. Many of these prey items also occur in estuaries where sea trout are known to feed extensively. (Bird, 2008)
Eel	A range of benthic organisms that include crustaceans and small fish. (Bird, 2008)

Twaite Shad

Adult twaite shad enter the Severn Estuary between April and June with males generally migrating upstream first followed by females one or two weeks later (Maitland and Hatton-Ellis, 2003). Adults appear to move up estuaries on spring tides when freshwater flows are not too high (Aprahamian, 1982) and hence this upstream migration is not expected to be impacted by any of the management options.

Juveniles migrate down to the estuary and remain in the upper estuary for their first summer, tending to move seaward over winter. Within the estuary where fresh and saline water meet there is an abundance of prey species (mysids) and these are particularly important to the juvenile twaite shad population. The actual position varies according to the state of the tide and volume of freshwater input to the estuary. Therefore it must be assumed that any activity that affects the salinity regime of the estuary would in turn impact the distribution of these prey species (taken from The Severn Estuary European Marine Site). This might cause the juvenile shad to move further upstream during low freshwater flows as in the acute or Chronic drought scenarios. With the low freshwater flows intermittent dissolved oxygen sags would occur in the Severn and the juvenile shad would be vulnerable. This would be more of an issue in the ' Do Nothing' management option where flows seriously crash in the late summer. Also if British Waterways were to abstract their maximum quantity it is possible that there would be virtually no freshwater flow entering the estuary.

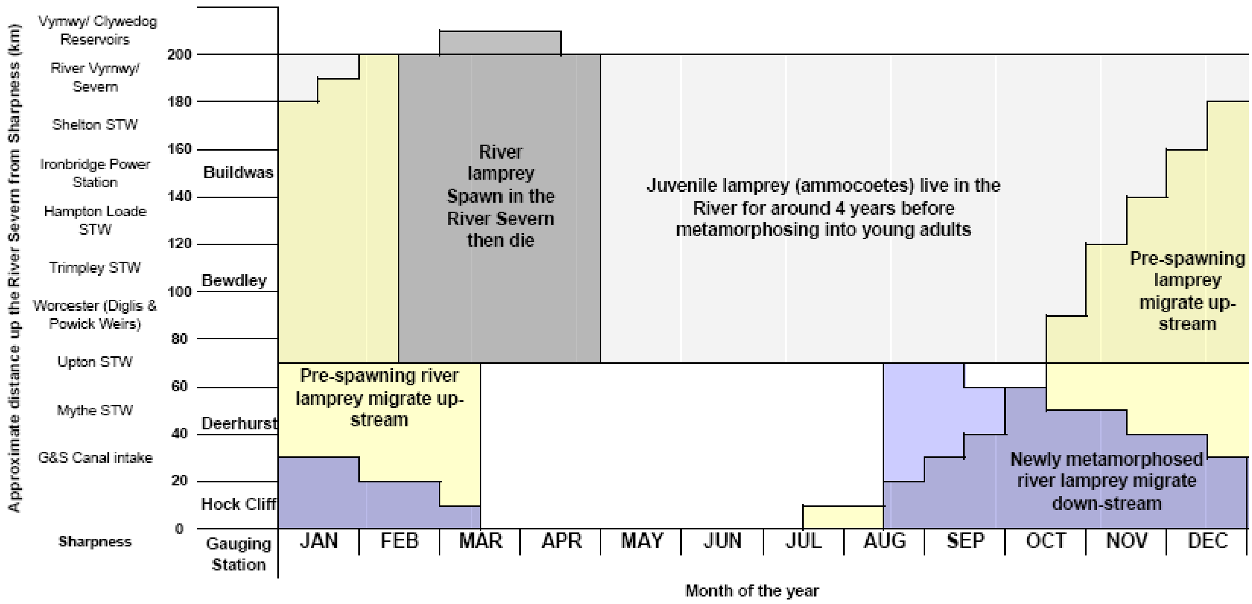
Allis shad are very similar to twaite shad except they tend to be larger and migrate further upstream during migration. Adult fish have occasionally been recorded from samples at Oldbury (Bird, 2008), but this is a rare event. There are no confirmed spawning sites for allis shad in the UK (Maitland,2003) and so it is unlikely that this species would be impacted by low freshwater flows.

Lamprey

Sea and river lamprey are both anadromous and migrate into freshwater to breed. Through the Review of Consent for the estuary it was decided that there would be no impact on sea lamprey by low flows. The best conditions for high recruitment might be relatively high water from April to June to aid upstream migration and increase the areas of spawning gravel available, followed by lower flows from June onwards, which would help larvae to disperse across suitable habitat downstream, but not wash them away (Maitland 2003). This could mean that the lowering of the flow earlier in the year with the Severn Severn Drought Order and full in combination for the Chronic scenario might limit spawning distribution.

The life history of river lamprey is different (see Figure 11) with migration through the estuary and up the River Severn taking place primarily in October to March. The fish adjust their migration to respond to the physical conditions in the river. This means that river lamprey are highly adaptable to flow conditions, but would favour higher flows during the upward migration period of October to March when flows are not considered to be an issue. It is suggested that adult river lamprey do not move far from the coast during adult feeding stage as main fish to have been attacked by lamprey being migratory or brackish water species (see Table 5). The adult river lamprey while feeding in the estuary would be vulnerable to the intermittent dissolved oxygen sags that might increase in frequency in drought conditions.

Figure 11. Approximate movements of river lamprey in River Severn (Taken from RoC)



Atlantic Salmon

Atlantic salmon are anadromous and migrate into freshwater to breed. Adult salmon returning to their home rivers arrive in the estuary in most months of the year, although those entering between January - April inclusive - the so-called spring salmon - have become much depleted over the past few decades (pers. comm. Pete Gough 2012). As salmon enter their natal river estuaries their behaviour appears to be very variable. Some fish move up through the estuary into freshwater very quickly (9 hours) while others have been observed to drift passively with the tide (taking up to 130 days). However, the majority of fish appear to take only a few tide cycles (Tidal barrage report, 1989). High freshwater flows are a key mechanism in triggering upstream migration, although temperature and water quality also have an impact. Solomon and Sambrook (2004) describe the uncertainty and interconnection of various influences upon salmon, with flow being a central factor but not necessarily the strongest influence over successful entry to river. Their study, concluded that high temperatures and at time low dissolved oxygen levels were the major influences for failed river entry during the study period.

Salmon smolts move down into estuary relative to strength of freshwater flows (December to June). Most likely drift passively on tides as acclimatise to saline conditions and then will swim positively seaward. (Tidal barrage report 1989)

Adult salmon within the estuary awaiting to migrate upstream are vulnerable to dissolved oxygen sags, caused by low freshwater flows, and large numbers of salmon were killed during the droughts of 1976 and 1989 usually in June and July within the section tidal lower Severn. One possible reason for salmon deaths in this section during June and July might be due to weaker spring run fish that did not make it up into main river were then caught out by high tides and as already stressed succumbed to low dissolved oxygen levels. Salmon kills are not as frequent in estuary after 1990's improvements on water quality (Netheridge WRW).

A study by Greest (2009) on the impact of freshwater flows into salmon entry to the Rivers Wye and Usk used a statistical model of salmon migration and flow to demonstrate that any reduction in freshwater flow reduces the number of salmon successfully entering freshwater.

Greest (2009) also concluded that water quality is a significant factor at low flows, with flow reductions likely to exacerbate poor water quality.

What needs to be appreciated is that the Bristol Channel and Severn Estuary (SAC) contain populations of salmon derived from a number of salmon-producing rivers. The probability of salmon entering their home river is dependent on freshwater discharge: in high flows this might be prompt however during low flows delay within the estuary or sub-estuary will occur and increased natural loss or mortality then occurs. Prolonged estuary residence is possible in extended low flow periods. The adult fish are a mixed stock of fish from different rivers, ranging from the Severn itself to those along the south coats of Wales including the Wye, Usk and Tywi Natura 2000 sites, to the recovering industrial rivers (Rhymney, Taff, Ogmore, Afan, Neath and Tawe. there is some evidence for fish derived from even further away. The salmon present in the estuary are in the process of identifying their home rivers and a high level of fidelity to those rivers has been widely documented. The fish, whilst resident, will make multiple temporary ascents and descents of the estuary, and may make temporary excursions into sub-estuaries before leaving to locate and enter their own rivers (pers. comm. Pete Gough 2012). Therefore the potential reduction in freshwater flow in the River Severn would reduce attraction of Severn salmon to their home river and hence an extended residence period in the estuary and lower probability of their eventual successful entry to the River Severn. The large scale of the droughts being assessed that would require the implementation of the Severn Severn Drought Order would presumably be impacting the other rivers flowing into the Severn Estuary creating further issues of salmon residing within the estuary for longer. Some salmon waiting to ascend the River Severn tend to wait down below the second Severn crossing (pers. comm. John Powell 2011) while waiting for migratory trigger. This is below the section where impact is to be expected from altering freshwater flows.

Sea Trout

Sea trout are anadromous and a migratory form of the brown trout and breed in rivers from October to February. Very few observations have been made of sea trout within the Severn Estuary with very limited angling interest. Sea trout smolts tend to remain longer in estuarine waters before heading out to sea.

It will be the adults waiting for increased winter flows to begin upstream migration and the smolts feeding in the estuary that are most likely to be impacted by an acute or Chronic drought. As salmonids they require good water quality and so would be vulnerable to dissolved oxygen sags.

European Eel

The European eel is catadromous and is believed to breed in the Sargasso Sea. The adult eels migrate out of the rivers and are most abundant in the estuary in September and October. Spawning takes place out at sea in spring and summer. The planktonic larvae (leptocephali) migrate across the Atlantic via ocean currents (two to three years) and metamorphose into transparent glass eels once they reach the continental shelf (White and Knight, 1997). Due to the south westerly orientation and funnel shape of the Severn Estuary the glass eels enter in large numbers in spring. They then metamorphose again within the estuary to become elvers. While in the estuary they bury themselves in sand or mud and emerge at night to feed. Estuarine migration upstream is slow with some eels staying in the estuary until they migrate back out to sea to breed.

Temperatures of between 14-16oc have been statistically proven to be the best predictor of upstream migration within the Severn Estuary (White and Knight 1997). The elvers move upstream on spring tides from mid-February to mid-May and are caught in large numbers by elver fishermen up to Tewkesbury. During this migration upstream weirs are an obstruction to upstream migration and hence need high tides to get over them. The timing of this migration means that the impacts of the Severn Drought Order would be negligible. Adult eels are more tolerant of low dissolved oxygen than salmonids, but with the exceptionally low freshwater flows (in the ' Do Nothing' management option) to the Lower Tidal Severn there may be small pockets with dissolved oxygen sags that could even cause eel mortality.

Wider Fish Assemblage

The Severn Estuary has been designated as a RAMSAR site due to its fish assemblage. The large diversity of fish (especially for juveniles) within the estuary has been recognised as internationally important and so as a whole needs to be assessed for their response to lowering freshwater flows. A study by Potter et al. (2001) concluded that annual recruitment strengths of the fish assemblage of the Severn Estuary were not correlated to water temperature or changes in salinity. The alteration of freshwater flows impacts the salinity of the estuary and therefore it can be assumed that freshwater flow is not impacting annual recruitment strength.

Hendersen and Bird (2010) highlighted that for fish in the estuary species richness and total abundance reach a maximum in late summer and autumn. This is when any impact of reduced freshwater flows to the estuary from both the drought scenarios (acute and Chronic) would be at its peak. However, as shown in results from transitional fish surveys by the Environment Agency (Figures 4 to 10) the fish within the section most likely to be impacted by low freshwater flows and therefore dissolved oxygen sags are freshwater and migratory fish.

All this evidence suggests that the wider fish assemblage of the Severn Estuary will not deteriorate with lowering of freshwater flows as modelled.

Drought Scenarios

It should be noted that these are just modelled flows and timings could vary in a real life situation. Also the model only takes account of a 300Ml/d abstraction by British Waterways for Gloucester and Sharpness Canal which could be double that quantity, especially in periods of drought (stage two assessment).

Lower Parting

This is the furthest downstream point with modelled flows and is within the tidal range of the estuary (Lower Tidal Severn). Any high tides combined with the low flows of a drought could have a very negative impact on the fish population. This will be due to saline intrusion and increased suspended solids causing low dissolved oxygen levels. Work completed by Hutchinson and Wade (1992) recommended that a flow of 1800Ml/d at Haw Bridge would be required to maintain dissolved oxygen levels above 3mg/l (critical concentration for survival of migratory salmon), prevent suspended solid concentrations of greater than 6000mg/l and prevent saline intrusion for 94% of predicted tides. During the acute drought model for example this flow is not attained for 19% of the year. This suggests potential for fish kills (mainly salmonids). However, water quality within the estuary has been improved dramatically since this study and it is anticipated that lower freshwater flows than 18000Ml/d at Haw Bridge would now suffice.

In the two scenarios the Severn Severn Drought Order and full in-combination are similar so will be discussed together.

Acute

' Do Nothing' – This is the best option for fish up until mid October. Then the freshwater flow crashes very quickly to very low flows (down to 382Ml/d) for a short period. This would impact fish populations in this area, especially salmonids that would be waiting to migrate upstream. As described previously low freshwater flows increase saline intrusion and dissolved oxygen sags.

Severn Severn Drought Order and Full in-combination – At the end of August the freshwater flows drop lower than the ' Do Nothing' management option and stays lower for a month and a half. The initial drop is unlikely to have any different impact on the fish community than the ' Do Nothing'. However, freshwater flows fall lower in October four days earlier than the ' Do Nothing' option. This would be a critical period and if it coincided with a high tide could cause increased saline intrusion and dissolved oxygen sags (with consequences discussed previously). After this period this option is above the ' Do Nothing' management option providing extra freshwater flow and hence buffering impacts of saline intrusion and dissolved oxygen sags. Timing of these events would be critical for implications on the fish community.

Chronic

' Do Nothing' – In the second year of the Chronic drought this option is again preferable for the fish population until October. This crash is even lower and longer than the acute scenario (as low as 310Ml/d for 3 weeks). These low freshwater flows for that length of time could cause large fish kills in this section of the River Severn (chances of a spring tide falling in this period are high). Again salmonids would be most vulnerable to dissolved oxygen sags, but flows so low other species likely to be impacted e.g. shad and eel.

Severn Severn Drought Order and Full in-combination -- Flows would be reduced for much of the second year compared to the ' Do Nothing' management option. It would be anticipated that saline intrusion and dissolved oxygen sags would be a greater problem than with the ' Do Nothing' option for two to three months. However, this time there is no flow crash in October (except at very end of month). This is where these management options really assist the ecology of the estuary.

British Waterways

The potential impact from British Waterways abstraction for Gloucester Sharpness Canal is large. This abstraction is exempt from licensing at present and can abstract up to 680Ml/d (Wade,1992) and would be used to its maximum in drought conditions. Reasons this figure might not be abstracted would be due to siltation and saline intrusion on high tides (Bristol Water drinking water abstraction from canal). Therefore at low tides rate of pumping would be at its maximum leaving very little freshwater in the Lower Tidal Severn.

In both scenarios an extra 300Ml/d would be exceedingly bad for fish within the Lower Tidal Severn (and dependent on discharge back into the estuary) possibly the SAC as well. For the ' Do Nothing' management option there would be times when no freshwater flow could theoretically be entering the Lower Tidal Severn. The repercussions on fish fauna could be disastrous. At high tides saline intrusion would increase (although saline intrusion would halt abstraction into canal). At low tides increased sediment deposition and fish trapped in pools would be at risk from rapid rising of water temperature, lowering dissolved oxygen and predation. With the Severn Severn Drought Order and full in-combination the exceptionally low freshwater flows of the ' Do Nothing' approach are not reached.

Conclusions

The Water Authority Joint Committee on the river Severn Estuary concluded that, apart from saline intrusion at Gloucester, the drought of 1976 had virtually no immediate effect on the estuary (Severn Trent Water 1977). In fact the evidence from the 1976 drought is that moderate increases and decreases in the regulated flow at Bewdley would have little effect on the river or the estuary (Severn Trent Water 1977). The droughts modelled for this report were based on the 1976 drought, but extended. The impacts on fish caused by the different management options are only within the Lower Tidal Severn and not the Severn SAC. However migratory fish that are part of the designation of the estuary as a SAC that might be impacted are:

- Atlantic salmon – during a drought adult salmon migrating upstream are likely to reside for longer in the estuary increasing possibility of them not entering the River Severn to spawn. The main impact likely in Lower Tidal Severn section will be where dissolved oxygen sags could cause mortalities. In both scenarios the ' Do Nothing' approach is beneficial up until October. However, then in October the ' Do Nothing' approach causes a crash in freshwater flows to the Lower Tidal Severn which could cause mortalities to salmon within this section.
- Twaite shad – juvenile twaite shad feed at the saline wedge before migrating to sea at winter. The location of this saline wedge is impacted by tides and quantity of freshwater. Therefore in the Lower Tidal Severn these fish could be vulnerable to dissolved oxygen sags, especially with the very low freshwater flows in the ' Do Nothing' management options.

The fish assemblage of the estuary (qualifying feature of RAMSAR) are generally unlikely to be impacted by the changes in freshwater flows as modelled in the various management options.

There is considerable scope for the abstraction by British Waterways for the Gloucester Sharpness Canal to cause further damage to the fish population of the Lower Tidal Severn and even the fish within the SAC.

Mitigation

Ensuring an agreement with British Waterways on their abstraction from the Severn or change of legislation to bring their licence under control

Any other sources of freshwater for the estuary at times of severe drought.

If large losses of salmon recorded possibility of restocking salmon

Future Monitoring

A fish counter down at Upper Loade/Deerhurst would give a better understanding of salmon migration and could be used to produce a statistical model to assess impact of changes in flows.

Radio tracking migratory fish within different sections of the estuary would be very difficult but give a better understanding of movements within the estuary and could be used in conjunction with fish counter data in production of statistical model

Continued monitoring at Oldbury Power Station

Appendix V

Consultation: Statement of Response

Draft River Severn Drought Order Environmental Report: Statement of Response

On 1 July 2013 we launched a voluntary public consultation of the River Severn Drought Order Environmental Report and its supporting documents. Communication was sent to a variety of interested organisations and local MP's to raise awareness of the consultation and our desire to collect any comments and concerns at this early stage. The draft consultation was also made available to the public on the Environment Agency's website.

The consultation period ended on 18 August 2013. We received representations from the following ten organisations (listed in order received);

1. **Institute of Civil Engineers**
2. **United Utilities**
3. **Dŵr Cymru Welsh Water**
4. **Natural Resources Wales (Strategic Assessment team)/ Cyfoeth Naturiol Cymru**
5. **Canal & River Trust** – two separate representations made (August 2013 and December 2013) due to the addition of an abstraction restriction under the drought order, after the public consultation closed. Refer to the Trust's representation for further detail.
6. **Natural England**
7. **National Farmers Union Cymru**
8. **National Farmers Union Midlands**
9. **Severn Trent Water Ltd**
10. **South Staffordshire Water Ltd**

11. ***Severn Rivers Trust*** *– unable to respond within timescales, would like to be involved going forward.*

This is our Statement of Response (SoR), which shows all the comments we received from each organisation and how we have addressed them. We have separated all the questions and comments into the following table, answering the queries and stating what we have done as a result to amend the documents where appropriate. Where our response has resulted in a change to the documents, we have tried to clearly mark these amendments by highlighting the relevant text in yellow (within the Habitat Regulations Assessment document amended text has been changed to italic font).

In addition to this SoR, we have published the revised River Severn Drought Order Environmental Report documents on our website. Please note, the documents will remain as working drafts and continue to be updated until a formal drought order application is required.

The public consultation process we have held, although not required at this stage, has been a valuable tool for collecting outstanding concerns and potential conflicts so that we can plan how to work through them. This should allow all the organisations involved to work together and make improvements in advance of a real drought event.

Institute of Civil Engineers (ICE)

Section/page	Comment	Action
Do you agree we have assessed the potential impacts on all parts of the river environment and water users? Please tell us if there is anything missing and how we might address it.	yes, nothing appears to be missing. I assume that over time the SWOs and discharges to the river will improve / change and this document should be a live document taking account of the changes.	The reports will remain live documents, allowing for minor updates to be made as appropriate. However a set timetable for comprehensive reviews will also be set as the following; • RSDO Environmental Report and supporting documents (e.g. HRA and SGS ER) to undergo a full review/update every 3-3.5 years or following a drought event. Next programmed update: 2016/17 • RSDO environmental monitoring programme to be reviewed annually (spring time recommended). This will include a summary of the data collected and a review of the sites and methods being used.
Generic concern feedback - The River Severn Drought Order has potential positive and negative impacts; do you have any comments about how this may impact upon you?	this could affect many in the catchment area	No Action required. We agree, and will continue to engage with key organisations. These reports will be externally available and we will ensure the communications plan is followed during a live event.

United Utilities		
Section/page	**Comment**	**Action**
HRA **Non-technical summary; Summary of Environmental Effects; Severn Estuary (Natura 2000 site); Page 17:**	we feel you need to explain what will happen if a River Severn drought order is required prior to agreement with the Canal and River Trust over mitigation as the in-combination Appropriate Assessment is unable to conclude no significant effect on migratory fish.	To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.
RSDO **Non-technical summary; Summary of Environmental Effects; Severn Estuary (Natura 2000 site); Page 17:**	We?d suggest that you should start to consider the case for IROPI and compensatory measures	We considered IROPI as an interim option but felt it could not be justified at this stage. Refer to above for action taken.
RSDO **Section 3.3; Page 41:**	the ability of UU to provide an overdraft against the Vyrnwy waterbank will be dependent on the storage situation of the reservoir and UU?s requirements for abstraction (both for itself and any other abstractors we have agreements with) ? this is mentioned in Section 14.2 (Page 159) but it would be useful to include it in Section 3.3 also	Text amended.

RSDO High level comments	As a general comment it should be noted that in 2012 UU commissioned a new 55km bi-directional pipe, the West-East link, that allows up to 100 Ml/d of water to be transferred between Cheshire/Merseyside and Manchester. This allows UU to transfer more water from Vyrnwy and other sources in the west towards Manchester in the event of constraints affecting the east of our region; likewise it also allows us to provide greater support to the west from the east in the event that the situation were reversed. As part of the Water Resources Management Plan process, UU is in discussion with other water companies regarding the possibility of trading water from Vyrnwy to help support other companies need for water ? if these options were pursued, UU would need to develop new water sources to offset the impact on the Integrated Resource Zone which contains Vyrnwy.	Thank you for this information. We have included it in a new 'Future Considerations' section (18) to enable future work to consider these changes.
RSDO Foreword; Page 3:	UU should also have been consulted regarding the in-combination impact with our proposed Vyrnwy drought permit	Future engagement will be endeavoured. Active consultation during modelling was not pursued because the UU Drought Permit should not reduce compensation releases below 25 Ml/d; an operation already observed when sufficient flows are recorded at Cownwy Weir and the additional 20 Ml/d is retained for the Vyrnwy waterbank. Compared to the magnitude of downstream impact predicted from Bewdley downstream, resource was focused on organisations involved at these higher impact locations.
RSDO Non-technical summary; Summary of Environmental Effects; Water Resources (other	note that UU?s Vyrnwy drought permit would reduce the compensation release from the lake to the Afon Vyrnwy and hence lower flows in the River Severn. Not contradictory to EA?s River Severn drought order	Text amended. Non technical summary and section 5.4 also updated for clarity.

abstractors); Page 16:		
RSDO & HRA Non-technical summary; Summary of Environmental Effects; Severn Estuary (Natura 2000 site); Page 17:	need to explain what will happen if a River Severn drought order is required prior to agreement with the Canal and River Trust over mitigation as the in-combination Appropriate Assessment is unable to conclude no significant effect on migratory fish.We?d suggest that you should start to consider the case for IROPI and compensatory measures	To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.
RSDO Section 2.2.3; Page 35:	please mention UU?s proposed Vyrnwy drought permit in this section which would reduce compensation flow releases to the Afon Vyrnwy from 45Ml/d to 25Ml/d	Text amended.
RSDO Footnote 6; Page 35:	mention that UU is currently working with Natural Resources Wales and the EA to agree flow releases to the Afon Cownwy and Marchnant from the intakes themselves to meet WFD GEP requirements, and that this will reduce inflows to Vyrnwy reservoir	Text amended, footnote from section 5.1.4 applied.
RSDO Section 3.3; Page 41:	the ability of UU to provide an overdraft against the Vyrnwy waterbank will be dependent on the storage situation of the reservoir and UU?s requirements for abstraction (both for itself and any other abstractors we have agreements with) ? this is mentioned in Section 14.2 (Page 159) but it would be useful to include it in Section 3.3 also.	Text amended.

RSDO Appendices Appendix E; Section 2.9.2:	in June 2013 UU published its Final Drought Plan 2013 which still includes the Vyrnwy drought permit option to reduce compensation flow from 45 to 25Ml/d. The triggers have altered since the 2009 plan. It would be useful if further information were provided as to how UU?s drought triggers for Haweswater/Dee have been translated to the Elan Valley ? have you used the position of Trigger 4 at Haweswater in terms of % net storage and just translated that to Elan? An alternative would be to use UU?s own Aquator modelling to indicate when a drought permit at Vyrnwy may be required and use this directly in your model.	Thank you for this information. The water resource modelling was carried out prior to the June 2013 publication date, we will therefore look to incorporate changes to drought triggers in future rounds of modelling and update work. We look forward to working together to achieve better consistency. To clarify the existing approach to modelling UU's Drought permit; The Vyrnwy drought permit modelling was conducted when the integrated planning model by UU was still in development. The drought permit trigger was taken to be the same as the Elan Valley (combined storage) trigger curve used by Severn Trent Water for their Trimpley drought permit. This was considered applicable as it would reflect the approximate period of drought. The model has no knowledge of UU Integrated Planning model except for a transfer of 205Mld from Vyrnwy into the region. Future modelling could look at improving the River Severn model's representation of demand from Vyrnwy to UU, or by using surrogate time series for drought permit implementation at Vyrnwy (both exports from the UU model).
RSDO Section 5.1.5.1; Table 8; Page 66:	the quoted actual summer (June to August) average abstraction rate from Vyrnwy of 211.6Ml/d is very high. Please can you explain in a footnote the record period you used to calculate these actual abstraction rates ? we would recommend that data post 2000 is used to reflect the significant reductions in leakage that were realised after the 1995-6 drought	Unfortunately the period was not audited, therefore we have recalculated the abstraction value based on the period 2000 to the end 2012 and amended the figure to 191.5 Ml/d. The Environment Agency summer abstraction period operates between April and October, this has been added as a note beneath the table.

RSDO Section 5.3.2; Page 69:	the use of only 3 years of modelled data to produce flow duration curves is not representative ? the modelled data for the same period as used for the observed gauged data (1990-2007) should be used. It is unclear why only 3 years of data has been used as surely the modelled period is longer than this? In addition, all flow data sets should be updated to incorporate recent data, at least up to the end of 2010 as drought was triggered in the north west region in 2010.	The short 3 year record was highlighted in the report as skewing the FDC's of this report towards the low flows and appropriate caution was applied, only using the low flow percentiles for interpretation and guidance rather than conclusive analysis. When the report is next updated the duration can be extended. The 3 year record is based on the theoretical drought used in this assessment (1975-1977), where real drought flows were altered to trigger the RSDO activation. The observed record (1990-2007) provides a comparison of more routine high to low flows, but inflows at this time did not reflect a drought of the severity needed to trigger the RSDO and therefore modelling this period would have provided no value to this investigation. The observed flow records (1990-2007) were used to reflect the current Catchment Abstraction Management Strategies (CAMS), for consistency with CAMS and the Review of Consents. They will be updated as these separate work streams are updated in the future.
Section 5.3.3.4; Page 75:	I would expect the resource provided by Vyrnwy to be lower in the in-combination option compared to the do nothing and River Severn drought order alone scenarios due to the implementation of UU?s drought permit to reduce the compensation flow to the Afon Vyrnwy from 45 to 25Ml/d	The Vyrnwy water bank volume is not directly impacted by the implementation of United Utilities (UU) drought permit under these scenarios, the two resources are separate and cannot be transferred outside of the Severn Regulation agreement conditions. Therefore the modelled volume used for Severn regulation did not change between the modelled scenarios. All routine and drought permit compensation releases are deducted from the

		remaining water storage allocated to UU, as a result the implementation of UU's drought permit is reflected inside the modelled reservoir storage percentage rather than the volume of regulation releases made. Modelling indicated a difference of approximately 2% higher storage when UU operated its drought permit.
RSDO Section 5.3.4; Page 76:	this section implies that gauging station rating curves were used to convert flow to water levels, however this may not be indicative of river width as the channel may have been adapted for flow measurement e.g. through construction of a gauging weir. The relationship between flow and water level should be developed for natural river reaches to allow changes in flow to be translated in to changes in hydroecological parameters such as velocity, wetted perimeter etc.	We agree and acknowledged the need for cross sectional surveys in the report, this will be a priority to gather more information in order to improve the report in the future.
RSDO Table 11; Page 80:	this table contains negative flows for Vyrnwy weir for the Q99 and Q99.9. These should be explained in a footnote	Text amended. The negative flows contained in tables 9 and 11 are calculated naturalised (using the decomposition method) flows for observed flows between 1990 and 2007; the negative values are known errors associated with data quality. Work is ongoing to improve the naturalised dataset and remove negative flows.
RSDO Section 5.3.5.2; Page 82:	We would like to have more information over the negative modelled flows in 1977 at Vyrnwy weir. There was a drought in the north west in 1976 but UU did not apply for a Vyrnwy drought order at this time. It may be worth asking Severn Trent Water if they had any remedial works going on that could have affected flows at this time	There were no negative modelled flows in 1977 at Vyrnwy weir for either the Acute or Chronic drought conditions. The report section 5.3.5.2 refers to some irregular compensation flow failures, i.e. a failure to meet the 25 Ml/d compensation flow requirement. As the report states, we are unsure whether these could indicate the reservoir storage beginning to fail (storage modelled at 14%), or errors within the model. The negative flows

		contained in tables 9 and 11 are calculated naturalised (using the decomposition method) flows for observed flows between 1990 and 2007; the negative values are known errors associated with data quality.
RSDO **Section 10; Page 140:**	the Vyrnwy waterbodies should be included in this chapter and it should be noted that UU is currently working with Natural Resources Wales and the EA to agree flow releases to the Afon Cownwy and Marchnant from the intakes themselves to meet WFD GEP requirements, and that this will reduce inflows to Vyrnwy reservoir	Text amended and footnote added to highlight AMP5 investigation work.

Dŵr Cymru Welsh Water

Section/page	Comment	Action
HRA & RSDO **High level comments**	Generally we thought that the Report and HRA were well written. They will provide a helpful model for water companies when preparing similar reports. That said, their length (a total of over 800 pages, including the appendices) significantly hampered our ability to consider the papers in detail. We wonder whether other relevant parties, such as farmers, will realistically be able to engage in the consultation (although we note that their representative groups are incorporated within your communications plan in the event of it looking likely that a Drought Order might be sought).	Thank you for this feedback. We appreciate the documents involved remain a significant size; this is due to the catchment size and complex variety of water resource interests involved. The main reports have been significantly slimmed down and executive summaries provided to help reduce the burden, moving a lot of technical detail into the Appendices. As you identify, during a developing drought the key interest groups will be targeted early via the communication plan, and should an application be made, it would be fully publicised and meetings held to help explain the key messages and reasons behind the application. We can also provide some confidence through the receipt of consultation responses from two National Farmers' Union's, both which have grasped the

		RSDO and not commented on the document size. We are positive the different communication paths we have used and identified will be sufficient going forward. Additional HRA specific: The length of the HRA report reflects the complexity of the Severn Estuary, migratory fish life cycle and whereas general effects of low flows are understood, determining the effects of river regulation and then implementing a drought order is difficult. The Review of Consents process and documentation was similarly complex and assessment and reports equally lengthy.
HRA & RSDO **High level comments**	You say that you are not obliged to prepare a Strategic Environmental Assessment in respect of the Drought Order. A SEA would have been a useful tool to ensure that the in-combination impacts are more thoroughly explored, including in relation to Dŵr Cymru's abstractions from the Rivers Teme and the Wye.	In response to yours and similar feedback we have added an SEA to the Future Work recommendations section. Abstractions for the Wye were considered under the Review of Consents process and investigations have taken place with regard to abstraction on the Upper Teme. Under the drought conditions leading up to application of the RSDO all relevant restrictions would already be in place and depending on the nature of the drought, options relating to the River Wye would also be under consideration.
HRA & RSDO **High level comments**	It is likely that a number of relevant abstraction licences will be amended in the years ahead to reflect the outcome of relevant Habitats Directive Review of Consents, including those for the Rivers Wye and Usk. You might want to note in your Report that some of the licences - and thus the potential impact of the relevant abstractions on the River Severn and downstream estuary - are likely to change in the next few	Thank you for this information. We have added a brief summary to the new 'future considerations' section to help ensure future updates account for any changes. No abstraction licences for the River Severn were amended as a result of the Severn Estuary Review of Consents. The River Wye enters the Severn Estuary >20 km below, and the

	years.	River Usk 45km below the top limit of the designated site therefore any changes to abstractions from these rivers are unlikely to have an impact on either the River Severn or downstream estuary. It should be noted that the effects of drought and benefits of implementation of the RSDO are experienced high up the Lower Tidal Severn and above the designated estuarine site. It was agreed with NE and NRW at the beginning of the HRA process that the Rivers Wye and Usk would not be included apart from a migratory fish perspective
HRA & RSDO **High level comments**	Given that much of the report and supporting documents centre on the potential impact on adjacent Natura 2000 sites, we were surprised that for the hydrological assessment the Environmental Flow Indicators were used as opposed to the more stringent Habitats Directive Ecological River Flow.	We have followed the same principals and methods as used in the Review of Consents work on the Severn, which were agreed with Natural England and the Countryside Council for Wales (now part of Natural Resources Wales). Consultation has not identified any concern with this approach for the RSDO. To provide some confidence, in comparison to the River Wye, the River Severn Estuary has a very large tidal range. The Severn Estuary designations are largely adapted to saline water and less dependent on freshwater than the main River Wye environment, therefore using river flow targets would not be appropriate for this site.
HRA & RSDO **High level comments**	The Environmental Report notes that the Habitats Regulations Assessment (HRA) concluded that there was likely to be a significant effect on the fisheries feature of the Severn Estuary SAC. That being so, we were concerned that you seem to rule out the possibility of a knock-on impact on the protected fish species in the Rivers Wye and Usk SACs.	The precautionary principle required that the migratory fish feature of the Rivers Wye, Usk and Taf were considered. On the basis of technical advice it was determined that implementation of the RSDO would not have a ‘likely significant effect’. Migratory fish were included in the Review of

	The HRA itself explains (in paragraph 2.1) that "It was agreed by both Natural England (NE) and the Countryside Council for Wales (now Natural Resources Wales) pers comm. that potential effects to the Rivers Usk, Wye and Afon Twyi SACs will not be directly considered as part of the assessment. However they will be considered in relation to the Severn Estuary migratory fish feature, specifically in relation to Atlantic Salmon, shad and sea lamprey." It could be argued that, in the absence of firm evidence to the contrary, the precautionary principle requires that the impact on the protected species in the Rivers Wye and Usk SACs should have been included. We feel that these important decisions about the impact to the Rivers Wye and Usk should have been made following a proper assessment.	Consents of the Wye and Usk and will be a major consideration of any drought permit work relating to the Wye and Usk. It was agreed with NE and NRW at the beginning of the HRA process that this approach would be taken.
HRA **High level comments**	One theme that emerges from the report is concern about the impact, particularly on migratory fish, of the potential abstraction into the Gloucester and Sharpness Canal and the apparent lack of adequate regulatory controls. For example, the main report says (at section 9.3.3) "The HRA found Gloucester and Sharpness canal abstractions of >300Ml/d in the lower tidal Severn, particularly the maximum 691 Ml/d, could have the potential to have an adverse effect on the migratory fish features of the Severn Estuary SAC and Ramsar site in combination with the River Severn Drought Order and water company drought orders." However, the HRA notes (page 56) "This abstraction was therefore put through to Stage 3 for Appropriate Assessment but then discounted because it is authorised by Act of Parliament and is therefore not under Environment Agency control." The potential effect of this is to put an unfair share of restrictions onto the other abstractors, a point that is not made in the report. It should also be noted that the discounting of the	We have gone back and looked through all the Review of Consents documentation and found it was not completely excluded from Stage 3 as we had reported - additional text has now been included in the reports to reflect the additional information and that this abstraction was considered at Stage 3 of the Review of Consents. In relation to inflows to the estuary and migratory fish, the approach taken was agreed by NE and NRW at the time. Environment Agency Wales and the Countryside Council for Wales (now part of Natural Resources Wales) were actively involved in the Review of Consents of the Severn Estuary. The Environment Agency carried out Review of Consents for a number of sites in Wales (due to the organisational boundaries at the time); therefore throughout the

	impacts in this way also contrasts with the stance that the (then) Environment Agency Wales took in the Usk Review of Consents when considering the impact of the Canal and Rivers Trust's local abstractions.	Review of Consents process there was regular liaison with Environment Agency Wales and the Countryside Council for Wales's colleagues. At no time was there an overall discussion on abstraction to the different canals and we suggest any perceived discrepancy relates to the fact that each of the sites are very different and have their own site specific issues.
HRA & RSDO **High level comments**	Unless and until the regulators are given more levers over the Gloucester and Sharpness Canal abstraction, you may need to start preparing the case to demonstrate imperative reasons of overriding public interest and consider possible compensatory measures: time to undertake this (difficult) work would be very limited in the event of a Severn Drought Order being warranted.	We agree that IROPI needs careful consideration and pre-planning. We have considered the case for IROPI for the RSDO, but felt it could not be justified without first imposing an abstraction cap on the Canal & River Trust to demonstrate to Defra that all possible options have been explored. A drought order, if granted by Defra, would give us the legal powers to enforce an abstraction restriction for the duration of the drought order operation. The HRA identified safe levels of in-combination abstraction that would prevent significant impact on the Severn Estuary, avoiding the need for IROPI. Therefore, to satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol

		Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.

Natural Resources Wales (Strategic Assessment Team)

RSDO representation (HRA separate)

Section/page	Comment	Action
RSDO Executive Summary	We note the use of the term 'in combination' effects and would suggest that this term, being specific to the Habitats Regulations Assessment process and Habitats Directive, should be avoided and replaced with 'cumulative effect' as used in the SEA Directive	We appreciate the feedback, the terminology has been taken from the HRA process. We chose to use it in both reports to remain consistent and keep it clear to all readers how the different modelling scenario's relate to one another. To avoid confusion we have decided to remain with the existing terminology.
RSDO Non-Technical Summary	We note that the Environment Agency anticipate the River Severn Drought Order 'would be needed on average once in 50 years' and that this figure is based on the number of times that the drought order has been implemented since the construction of Lyn Clywedog. However, it is noted that variations on the Drought Order have been required 3 times in the last 40 years (1976, 1984 and 1989). Clarification is therefore required as to how the Environment Agency/NRW anticipate a once in 50 years operation given previous experience.	Detail is kept to a minimum in the non technical summary, please refer to section 3 for more detail. The Severn Regulation system has been developed to include more water resources since the last drought order implementations. The extra resource has been considered against the severity of drought needed to trigger the drought order during modelling work, to produce the predicted level of service of 1 in 50 years.
RSDO Non-Technical Summary	We note the premise that operation of the Drought Order would prevent the upper reaches of the Severn from drying up however, the consequences of tributaries drying up will not be similarly addressed. Clarification would be welcomed as to	These reports assess the environmental impacts that may occur as a direct consequence of operating the RSDO. The impacts of drought on the tributary catchments is viewed as being outside

	whether consideration has been given to the potential effects of species displacement from tributaries into the main river in the event of severe drought and loss of flow in tributaries and whether mitigation and monitoring measures will be put into place in the event that such displacement occurs.	the remit of this environmental report and has therefore not specifically been assessed, unless stated in section 4.1. The Midlands Drought Plan and routine work by the Environment Agency and Natural Resources Wales will ensure that monitoring and mitigation for species impacted in these areas is carried out. Species which become displaced into the River Severn, are difficult to predict at this time, however consideration was given to migratory fish being unable to reach spawning grounds. The RSDO environmental monitoring programme includes sites along the River Severn which would be used to collect data and ensure available mitigation options are focused where needed, and remain flexible to cater for droughts occurring at different times of the year.
RSDO Non-Technical Summary	Clarification would be welcomed as to whether the Drought Order will seek to enforce reductions to known unlicensed abstractions and unauthorised abstractions.	The RSDO itself will only seek to restrict abstractions stated in the report. Both the Environment Agency and Natural Resources Wales actively regulate abstraction licences and investigate unlawful abstractions as routine work, this work is separate to the drought order and will continue.
RSDO Non-Technical Summary	NRW notes the potential tension between the River Severn Drought Order and water company drought plans and welcomes the intention to ‘meet early’ to discuss such conflicts. It is suggested that Natural Resources Wales should be included within such discussions. Given the need for the River Severn Drought Order to (ideally) be in place in advance of water utility companies’ drought plans and for the need to resolve potential conflicts between these plans before the onset of drought conditions, it is suggested that a	The potential conflict of interests along the River Severn has been recognised. The River Severn Drought Management Group is the intended forum for these joint discussions (including natural Resources Wales) and will be formed at the earliest opportunity, as collaborative working will be needed going forward. During a real event, table 4 in section 3.3 highlights the group would be formed as soon as the Llyn Clywedog 'Alert curve' is crossed,

	timetable for these discussions be drawn up and a provisional deadline for resolution of issues established. It is suggested, given the late stage of development of relevant water company drought plans that these discussions should begin in earnest at the earliest possible opportunity.	this should build in sufficient time to begin the necessary discussions and identify mitigation options appropriate to the drought conditions and water resource situation being experienced. The Environment Agency are also planning to put together a drought exercise during 2014/15 to test the River Severn Drought Order and work through some potential conflicts, which we also plan to run with external partners. One of the aims of this exercise will be to identify and begin discussions on the potential conflicts.
RSDO Non-Technical Summary	The potential benefits to low flow sensitive taxa close to Llyn Clywedog and Llyn Vyrnwy during operation of the Drought Order are welcomed however, clarification would be welcomed as to the potential presence and impacts on high flow sensitive taxa.	The response of macroinvertebrates to changes in flow was assessed for the RSDO, including the potential impact of reduced flow variation. This is very dependent on the individual site and the flow patterns within them. The greatest impact on high flow sensitive taxa is likely to be close to Llyn Clywedog and Lake Vyrnwy, due to the compensation releases. The assessments mainly focused on low flows, as a drought of this severity would naturally reduce high flow events. The RSDO was found to have a benefit to the environment by reducing the period of time that minimum reservoir releases were made, with high regulation releases also helping to imitate some high flow events. We also acknowledge the proposed new cross sectional survey work will collect relevant data to allow more detailed assessments in the future.
RSDO Non-Technical Summary, Severn	Clarification would be welcomed as to whether 'migratory fish' include European Eel.	Yes, European eels are included when discussing migratory fish, please refer to section 7 for more detail. It is important to note how European eels

Estuary SPA/SAC/Ramsar.		differ by spawning out at sea, rather than migrating into freshwater specifically to spawn.
RSDO Non-Technical Summary, Navigation and Recreation	We welcome the consideration of 'temporary cessation of fishing activities' where considered necessary but would welcome clarification as to whether these provisions will apply to eel licenses and the eel fisheries in the Severn Estuary, notably since eel licenses are not spatially specific.	The details of this potential mitigation option will need exploring and will depend on the timing and severity of the drought. We would hold open discussions when considering this option.
RSDO 2.1	Clarification is required as to what is understood by 'too long' in the sentence 'the water bank from Lake Vyrnwy reservoir provides sustainable releases up to 70 Ml/d. higher releases can be made but the available water would soon be used up (if) they continued for too long'.	The open term 'too long' is used because the quantity of water available within the Vyrnwy water bank varies. The 70 Ml/d releases are designed to be sustainable for short periods (a few weeks) but if large amounts of water have been accumulated and not spilled, then releases could last longer. When large releases are made, closer to the maximum 405Ml/d, the waterbank could be drained in a week depending on how much water was present to start with. We do not believe it is appropriate to expand on this concept within the RSDO Environmental Report, as it relates to how efficiently Severn Regulation is managed and operated rather than the impacts associated with the drought order.
RSDO 2.2.3	We note the use of Llyn Vyrnwy as a 'water bank' for use in the Severn Regulation however, it is assumed that releases to support the Severn Regulation in the event of Drought will also need to be considered in the context of the United Utilities' Drought Plan proposals and the potentially conflicting need to maintain adequate water supply to Liverpool.	More detail has been added to section 2.2.3. The Vyrnwy water bank is reserved solely for the use of Severn regulation and cannot be used without prior agreement for any other purposes. United utilities control a much larger portion of water within Lake Vyrnwy, which the Environment Agency and Natural Resources Wales cannot use without prior agreement.
RSDO 2.4	Within the non-technical summary to this Report, it is suggested that the Severn Drought Order 'would be needed	Thank you for the feedback. We have commissioned a separate project to investigate

	on average once in 50 years' and that this figure is based on the number of times that the drought order has been implemented since the construction of Lyn Clywedog. However, it is noted that variations on the Drought Order have been required 3 times in the last 40 years (1976, 1984 and 1989). We welcome the suggestion that the current 'robustness' of the system and development of the Shropshire Groundwater Scheme has meant that the Order has not been required in the last 20 years however, further consideration of predicted climate change effects and resilience of the system as a whole and in the light of predicted climate change would be welcomed.	climate change and will use the results of this work to update the RSDO Environmental Report in the future. A reference to this project has been added to the report.
RSDO 4.5.3	Given that the term 'in combination' effects is specific to the Habitats Directive and HRA process, it is suggested that its use within this Environmental Report is potentially confusing. It is therefore suggested that, unless being used specifically in the context of Habitats Directive assessment, 'in combination' be replaced with 'cumulative'. We note the inclusion of the River Wye at Wyelands (STWL-River Wye) and Trimpley (STWL) permits/orders within this cumulative effects assessment. Both these abstractions are included within the Severn Trent draft Drought Plan however, relevant appropriate assessments (under the Habitats Directive) have not yet been completed for these permits/orders and it may not be appropriate to consider the cumulative effects of the River Severn Drought Plan with these abstractions until such time as Severn Trent have completed the relevant assessment processes.	We appreciate your feedback. The terminology has been taken from the HRA process. We chose to use it in both reports to remain consistent and keep it clear to all readers how the different modelling scenario's relate to one another. To avoid confusion we have decided to remain with the existing terminology. We appreciate this comment. We have included the permits/orders for our modelling based on best available information at the time. We acknowledge this may change and need updating in the future, but we wanted to ensure that all known cumulative impacts were incorporated to comply with the Habitat's Regulations.
RSDO 4.6.1	We assume that 'risk' in this context refers to potential risk of an adverse effect (low, medium, high, indirect). We would	Thank you for the feedback. The method for how to represent/categorise the potential impacts could

	suggest that it would not be appropriate or useful to group potential beneficial effects with potential low risk (adverse effects). In addition, the potential risk of adverse effects occurring on any environmental receptor may be determined by the sensitivity of the receptor and by timing.	have been presented in several ways. For a catchment of this scale and complexity we did not feel it was appropriate to determine impacts on a scale low-high and used the level of risk being concluded as an indication of potential impact. The method for risk assessment can be reviewed for future updates as better information and prediction tools become available.
RSDO 4.1	With regard to the additional category relating to spawning fish in Section 4.1, it is assumed that reference is made to 'migratory fish trying to reach their spawning grounds', no consideration has been given to eels or the potential effects of application of the Drought Plan to eel migration both up and downstream. The European Eel is a feature of the Severn Estuary Ramsar Site and the species is worthy of consideration within this assessment process.	The high level reference to migratory species includes European Eels, detail is contained within table 7 (section 4.2). The potential impact of the RSDO has been assessed specifically for this species; please refer to section 7.2 and 7.5. Section 7.5.4 concluded no significant impact on eel populations, although the baseline drought conditions could impact the upstream movement of elvers.
RSDO Figure 9	Reference should be made to the Montgomery Canal's status as a SSSI and SAC.	Figure amended.
RSDO 5.3.3.4 and 5.3.5.4:	See comments above on 4.5.3 regarding the use of the term 'in combination'.	We appreciate the feedback. The terminology has been taken from the HRA process. We chose to use it in both reports to remain consistent and keep it clear to all readers how the different modelling scenario's relate to one another. To avoid confusion we have decided to remain with the existing terminology.
RSDO 7.2.1.2	Information should be provided on eel licenses and catch in the River Severn together with a consideration of eel trends throughout the catchment.	Due to the conclusion of no significant impact on the European Eel populations, we could not justify collecting this extra data for RSDO purposes, at this time.
RSDO Table 23, HRA	We note the screening conclusions indicate a risk of likely significant effects for the Severn Estuary SAC and Ramsar	*Refer to HRA consultation responses.*

screening conclusions.	Site. See separate comments on the HRA for this Drought Order.	
RSDO Section 9	See separate comments on the HRA for this Drought Order. With respect to species movement within the Severn Estuary and River Severn, further consideration of alien and invasive species would be welcomed, notably in respect of potential drought and low flow conditions. We would welcome the establishment of monitoring programmes in respect of alien and invasive species in conjunction with the River Severn Drought Order and consideration of control measures in the event that these species 'benefitted' from drought conditions.	We have added a section (7.6) to consider Invasive Non Native Species on the River Severn, and how the RSDO may impact their populations and spread. Mink was found to be the most likely to benefit during a severe drought through increased predation on stranded fish, however the RSDO was found to mitigate the Mink's advantage. Of the priority top 10 species assessed, no adverse impact was concluded. There is an existing monitoring programme for invasive species, which will continue, however due to the conclusion of no impact this cannot be specifically included within the RSDO remit.
RSDO 9.3.4	We note with concern, the lack of assessment for the Gloucester and Sharpness canal abstraction under the Review of Consents and the potential for this abstraction to cause 'adverse effects' on the lower tidal Severn, Severn Estuary and migratory fish species (including eels). Given this assessment's conclusion for the Full In Combination scenarios that 'it was not possible to conclude no adverse effect (on the Severn Estuary SAC/Ramsar), particularly due to the potential significance of the Gloucester and Sharpness Canal abstraction', it would not be appropriate to implement the Full In Combination scenarios for this Drought Order until such time as these issues have been resolved. The Habitats Directive requires that, in order for a plan or programme to be approved and implemented, there must be a demonstration of 'no likely significant effect' on European Sites. We would therefore suggest that a caveat be inserted into the River Severn Drought Order acknowledging that the Full In	Thank you for the offer of assistance and the suggestion of setting a timetable and provisional deadline. To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are

	Combination scenario cannot be implemented until such time as outstanding issues and challenges related to the Gloucester and Sharpness canal abstraction have been fully assessed and appropriate and robust avoidance/mitigation measures put in place. We agree with the premise that 'there is a requirement to find a solution' to this issue and that it 'needs to be in place well in advance of a River Severn Drought Order application'. Given the unpredictability of drought conditions and the need to implement drought measures without delay, it 7 is suggested that a timetable for these discussions be drawn up as a matter of urgency and a provisional deadline for resolution of issues established. Given that the potential impacts involve a European Site in Wales, we would be happy to enable these discussions in any way considered appropriate and in order to bring about a swift and transparent/equitable conclusion.	investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.
RSDO 9.6	See comments above on the need to monitor alien and invasive species in drought/low flow conditions.	There is an existing monitoring programme for invasive species, which will continue, however due to the conclusion of no impact from the RSDO this cannot be specifically included within the RSDO remit.
RSDO 10	Clarification would be welcomed as to whether the proposed River Severn Drought Plan and this Environmental Report have taken and will take into consideration the policies and recommendations made by the UK TAG draft recommendations 'River flow for good ecological potential' (June 2013). The UK Technical Advisory Group on the Water Framework Directive (UKTAG) first published guidance on the classification of ecological potential in 2008. For water bodies used for water supply, storage and power generation guidance was produced on the downstream flows requirement. With the exception of providing a low flow	These documents were still out for consultation and have therefore not been taken into consideration for the RSDO or HRA reports, which took an approach consistent with the Review of Consents. We have provided consultation feedback on the UK TAG reports, and highlighted them in the new 'Future Considerations' section in the RSDO report.

	component of the downstream flow, little advice was provided on flows required for the rest of a baseline flow regime, flows to enable fish migration and flows to maintain river habitats. The purpose of the draft recommendations is to fill this gap in knowledge and are of relevance to this assessment process and the River Severn Drought Order.	
RSDO 11.1	Reference should be made to the Cadw/ICOMOS/CCW Register of Landscapes of Historic Importance in Wales	Section 11.1.8 updated to include reference.
RSDO 21.1	Although a popular area for recreation, no reference has been made to Llyn Vyrnwy and the potential effects of implementation of the Drought Plan on its recreational assets.	Report amended to include more specific information on Lake Vyrnwy recreation.
RSDO 15.2	See comments above on the need to monitor alien and invasive species.	The existing monitoring programme for invasive species will continue, however due to the conclusion of no impact from the RSDO this cannot be specifically included within the RSDO remit.
RSDO Key comments – high level	Our key comments follow below. We note that this Environmental Report has been produced on a voluntary basis and that, in the opinion of the Environment Agency, the statutory requirement for Strategic Environmental Assessment under the Environmental Assessment of Plans and Programmes Regulations 2004, do not apply. In the interests of transparency, particularly with respect to the need for water companies to subject their Drought Plans to the full SEA process, it is suggested that the full transcript of the SEA screening determination for the River Severn Drought Order be published within the final version of the 'Order' itself.	Strategic Environment Assessments are not a statutory requirement, and would be more appropriate for the main RSDO report than the HRA. In response to yours and similar feedback we have added an SEA to the Future Work recommendations section of the main report.

Natural Resources Wales (Strategic Assessment Team)

HRA representation (RSDO separate)

Section/page	Comment	Action
HRA Executive Summary	We note the reference within this Executive Summary to the potential abstractions for the Gloucester & Sharpness Canal. Clarification would be welcomed as to whether the options for major abstraction between the Severn and the Thames (presented in Thames Water's draft Water Resource Management Plan 2014 as feasible options) have also been considered within this assessment process. Whilst it is accepted that the Severn Thames transfer options are not identified within Thames Waters' preferred options, it is suggested that it might be useful to maintain a watching brief on this draft Water Resource Management Plan in the event that these options are brought forward and/or change status. We note with concern the potential for the Canal and River Trust's maximum abstraction (in combination with the Severn Drought Order and water company Drought order operations) to have an adverse effect on the lower tidal Severn and the Severn Estuary SAC/Ramsar sites. While we acknowledge the difficulties in reconciling this issue and the commitment to finding 'a solution to protect the Severn Estuary designation before a drought order application is needed', it should be pointed out that the Habitats Directive embodies the precautionary principle and that unless 'no likely significant effect' can be demonstrated in respect to these 'in combination' effects, it would not be possible to implement the Drought Order without consideration of IROPI issues, alternatives and compensatory measures. . We would	Thank you for this feedback. We have included additional text in the HRA Section 2.7.2.3 In Combination Assessment to address this representation. If the Severn Thames transfer option is progressed it will be subject to its own HRA. We have also added a brief summary to the new 'future considerations' section to help ensure future updates account for any changes. Thank you for the offer of assistance and the suggestion of setting a timetable and provisional deadline. We recognise the implications, to satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal &

	therefore suggest that a caveat be inserted into the River Severn Drought Order acknowledging that the Full 'In Combination' scenario cannot be implemented until such time as outstanding issues and challenges related to the Gloucester and Sharpness canal abstraction have been fully assessed and appropriate and robust avoidance and mitigation measures put in place. Given the unpredictability of drought conditions and the need to implement drought measures without delay, it is suggested that a timetable for these discussions be drawn up as a matter of urgency and a provisional deadline for resolution of issues established. We would be happy to enable the progression of these negotiations, if considered appropriate and to assist in any way that brings the discussions to a swift and transparent/equitable conclusion.	River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.
HRA 1.1	In the interests of transparency, particularly with respect to the need for water companies to subject their Drought Plans to the full SEA process, it is suggested that the full transcript of the SEA screening determination for the River Severn Drought Order be published within the final version of the 'Order' itself.	Strategic Environment Assessments are not a statutory requirement, and would be more appropriate for the main RSDO report than the HRA. In response to yours and similar feedback we have added an SEA to the Future Work recommendations section of the main RSDO report.
HRA 1.2	Reference should be made to the latest version of the Birds Directive.	Text has been amended accordingly
HRA Figure 1	Clarification would be welcomed regarding the origin of this flow chart for assessing 'likely significant effects' given that this is not the version issued or referenced to in Tan 5 and/or 'Guidance for Plan Making Authorities in Wales: The appraisal of Plans under the Habitats Directive (amended 2012).	This flow chart is from the Environment Agency's own Operational Instruction 183_01 v.8 Habitats Directive: Taking a new permission, plan or project through the regulations. Since this is an Agency plan and given the cross border and regional nature of the Severn Estuary this flow chart appropriately demonstrates the approach taken to determining 'likely significant effect'. It was

		originally acknowledged as a footnote but got deleted during the various editing processes. It is now referenced in the text.
HRA 1.4	Reference should be made to Regulation 102 of the Conservation of Habitats and Species Regulations 2010 (as amended) given that this Regulation applies to plans.	This HRA has been undertaken for a Drought Order which relates to the management of water resources whereas Regulation 102 refers to Land Use Plans which has been taken to refer to Development Plans, Mineral Plans etc.
HRA 2	We would suggest that reference is made to the precautionary nature of the HRA process and the requirement, where it is not possible to demonstrate no likely significant effect on a European Site, for the process to progress to 'appropriate assessment'.	Additional text has been included to address this representation.
HRA 2.1	We would suggest that specific reference be made to eels and sea trout in the context of migratory fish features of the Severn Estuary Ramsar site.	Table 4 contains this specific detail. This section refers to SACs, SPAs and Ramsar sites in terms of their designations and forms an introduction rather than high level detail.
HRA Table 2	Given that the HRA process requires consideration of significant effects on specific features of any European Site, we would not recommend the use of generic sensitivities or the grouping together of features. The potential for and significance of effects is dependent on the particular sensitivities of the receiving environment and/or species. Whilst grouped species e.g. migratory fish, may appear to have common or generic sensitivities, in reality they may have considerably different responses to different stressors and at different spatial and temporal scales. We would suggest that the following additional 'hazards' be added; • Displacement of species • Changes in the presence/status of invasive and alien	It is difficult to represent detail in summary tables; we believe the groupings used in Table 2 are appropriate for this purpose and were based on Agency guidance. We can confirm that each designated fish species has been taken through the Appropriate Assessment in its own right and their differing life cycles and requirements accounted for, we also have to consider a range of hazards and sensitivities for the different designated habitats and features, not just migratory fish. We can clarify that it was because of the different responses to different stressors and the passage of migratory fish up and down the river and estuary that they were taken through for Appropriate Assessment. To provide confidence, we have addressed the

	species and pathogens • Habitat damage • Changes in water temperature.	individual suggestions; • Displacement of species – we have considered this in some detail in the Appropriate Assessment • Changes in presence/status of invasive and alien species and pathogens – An additional section and text has been included in the RSDO Environmental Report • Habitat damage – was considered under the physical damage and habitat loss aspects of the sensitivity matrices • Changes in water temperature – table amended to reflect this, also considered in relation to water quality within the Appropriate Assessment
HRA 2.4.5: Summary of Likely Significant Effects on the Montgomery Canal SAC	We note and in principle, accept the findings of this assessment. In respect of the potential 'issues' discussed with maintaining channel flow (removal of emergent growth and silt removal), clarification would be welcomed as to whether the site's Core Management Statement includes any specific management proposals in the event of drought, changes in water levels and maintenance of flow in drought conditions. In additional, clarification would be welcomed as to whether it is envisaged that such issues could adversely affect European Protected species in and using the Montgomery Canal e.g. water vole. The statement that the effect of drought 'should only be short lived' is noted however, clarification would be welcomed as to	There is no reference to management related to any of these conditions in the Core Management Statement. Additional text relating to water vole and otter in the Montgomery Canal can now be found in App 1. We consider short lived to be in accordance with natural drought recovery, therefore you may expect

	what is understood by 'short lived'.	to see an impact on populations the following 1-2 years, but full recovery is expected.
HRA 2.5: Severn Estuary SAC/SPA/Ramsar - 2.5.3:	Clarification would be welcomed as to whether the proposed River Severn Drought Plan and this HRA have taken and will take into consideration the policies and recommendations made by the UK TAG draft recommendations 'River flow for good ecological potential' (June 2013). The UK Technical Advisory Group on the Water Framework Directive (UKTAG) first published guidance on the classification of ecological potential in 2008. For water bodies used for water supply, storage and power generation guidance was produced on the downstream flows requirement. With the exception of providing a low flow component of the downstream flow, little advice was provided on flows required for the rest of a baseline flow regime, flows to enable fish migration and flows to maintain river habitats. The purpose of the draft recommendations is to fill this gap in knowledge and are of relevance to this assessment process and the River Severn Drought Order.	These documents are still only draft recommendations and were still out for consultation during the RSDO consultation; therefore they have not been taken into consideration for the RSDO or HRA reports, which took an approach consistent with the Review of Consents. We have provided internal consultation feedback on the UK TAG reports, and highlighted them in the new 'Future Considerations' section in the RSDO report.
HRA 2.5.16	We agree in principle with the summary of likely significant effects on the Severn Estuary however, clarification would be welcomed as to the exclusion of water temperature from the assessment process.	Additional line of text has been included, it is also referred to in the Appropriate Assessment.
HRA 2.7.1.3	Reference should be made to relevant Eel Management Plans and licensing.	Additional text has been included to reference the River Severn Eel Management Plan. The Eels Regulations 2010 have not been included as they are not a permission, plan or project.
HRA STWL	Severn Trent Water. As far as we are aware, Severn Trent water have not yet completed their appropriate assessments for the River Wye at Wyelands and Trimpley abstractions.	We have included the permits/orders for our modelling based on best available information at the time. We acknowledge this may change and need updating in the future, but we wanted to ensure that all known cumulative impacts were

		incorporated to comply with the Habitat's Regulations.
HRA 2.7.4	We note with concern the potential for the Canal and River Trust's maximum abstraction (in combination with the Severn Drought Order and water company Drought order operations) to have an adverse effect on the lower tidal Severn and the Severn Estuary SAC/Ramsar sites. We note with disappointment that the abstraction for the Gloucestershire and Sharpness Canal was 'believed to have the potential to impact on residual flows' but that no Stage 3 assessment (appropriate assessment) was undertaken because the abstraction is authorised by Act of Parliament. Given the requirement under the Habitats Directive for plans and projects likely to have significant effects on European Sites to be subject to appropriate assessment, the avoidance of assessment for this abstraction is unfortunate and appears to be contrary to the 'spirit', if not the word of the Habitats Directive.	To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed. We have gone back and looked through all the Review of Consents documentation and found it was not completely excluded from Stage 3 as we had reported - additional text has now been included in the reports to reflect the additional information and that this abstraction was considered at Stage 3 of the Review of Consents.
HRA 3.2	We agree with this Report's premise that 'there is a requirement to find a solution' to this issue and that it 'needs	To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary

	to be in place well in advance of a River Severn Drought Order application'. Given the unpredictability of drought conditions and the need to implement drought measures without delay, it is suggested that a timetable for these discussions be drawn up as a matter of urgency and a provisional deadline for resolution of issues established. It is further suggested that these discussion be 'mediated' by an appropriate and independent authority in order to bring the discussions to a swift and transparent/equitable conclusion.	principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.
HRA 3.7	We would recommend that, in order to avoid confusion, this section be re-titled Brown Trout/Sea Trout.	Text amended accordingly.
HRA 3.12	Additional consideration should be given to the potential effects of 'fisheries' and enhanced predation on eel during low flows. Given the potential for inhibited migration and concentration of eel below barriers during low flow, there is the potential for eel fisheries (licensed and unlicensed) and predators to take advantage of eel concentrations.	We agree there is the potential for increased pressure on eels, as with other fish species. This consideration has been covered within the reports and some text has been amended for clarity and greater detail; however a quantified assessment of the impact cannot be made at this time. There are too many other factors (e.g. number of predatory species moving in or out of estuary, densities of predators, predator prey interactions, etc) involved, and too little conclusive data available at this time to make more detailed assessments.
HRA 3.15.2	We note with concern the potential for the Canal and River Trust's maximum abstraction (in combination with the Severn Drought Order and water company Drought order operations) to have an adverse effect on the lower tidal Severn and the	To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal &

	Severn Estuary SAC/Ramsar sites. While we acknowledge the difficulties in reconciling this issue and the commitment to finding ‘a solution to protect the Severn Estuary designation before a drought order application is needed’, it should be pointed out that the Habitats Directive embodies the precautionary principle and that unless ‘no likely significant effect’ can be demonstrated in respect to these ‘in combination’ effects, it would not be possible to implement the Drought Order without consideration of IROPI issues, alternatives and compensatory measures. . We would therefore suggest that a caveat be inserted into the River Severn Drought Order acknowledging that the Full ‘In Combination’ scenario cannot be implemented until such time as outstanding issues and challenges related to the Gloucester and Sharpness canal abstraction have been fully assessed and appropriate and robust avoidance and mitigation measures put in place. Given the unpredictability of drought conditions and the need to implement drought measures without delay, it is suggested that a timetable for these discussions be drawn up as a matter of urgency and a provisional deadline for resolution of issues established. It is further suggested that these discussion be ‘mediated’ by an appropriate and independent authority in order to bring the discussions to a swift and transparent/equitable conclusion.	River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.

Canal & River Trust – original representation (August 2013)		
Section/page	**Comment**	**Action**
RSDO Consultation response, high level	The Canal & River Trust (the Trust) is the guardian of 2,000 miles of historic waterways across England and Wales. We are among the largest charities in the UK, maintaining the nation's third largest collection of listed structures, as well as museums, archives, navigations and hundreds of important wildlife sites. We believe that our canals and rivers are a national treasure and a local haven for people and wildlife. It is our job to care for this wonderful legacy – holding it in trust for the nation in perpetuity and giving people a greater role in the running of their local waterways. Over the past two years, the Trust has been involved in negotiations with the Environment Agency (the Agency) about on-going management of the River Severn catchment and the potential impacts of the future operation of the River Severn Drought Order (RSDO) on the Trust. These negotiations have been focused on the impacts on the Gloucester & Sharpness (G&S) Canal, the River Severn Navigation and the Montgomery Canal, all intrinsically dependent on the River Severn. There are still some outstanding issues which need to be addressed before the impacts of the drought order can be fully considered and future collaborative work between the Agency and the Trust is currently being discussed. The 26.5 km G&S Canal is owned, operated and managed by the Trust. The canal is classified as a 'commercial waterway'	No action required, see points below.

	under the Transport Act (1968), and under Section 105 of the Act the Trust has a statutory duty to maintain the G&S Canal in a suitable condition for use by commercial freight-carrying vessels of specific dimensions. The canal consists of one pound linking the River Severn at Gloucester Lock to the River Severn at Sharpness via a single sea lock. At both ends of the canal, vessels lock down to the river. At the time of its opening in 1827, the canal was the widest and deepest in the world. Today, the canal is a popular boating waterway, the only navigable route between the Severn Estuary and the River Severn Navigation above Gloucester, and both Gloucester and Sharpness Docks still operate as commercial ports. The G&S Canal is supported by pumped abstraction from the River Severn at Gloucester Docks, in addition to inflows from a number of surface water feeders. As such, future operation of the RSDO has the potential to compromise the Trust's ability to maintain the many demands on the canal including: our statutory duty to maintain navigation (under the Transport Act, 1968); our statutory duty to maintain Sharpness Dock as an Open Port (under the Harbours Act, 1964); Bristol Water's public water supply abstraction at Purton; environmental & heritage requirements; and losses. The Trust's abstraction from the River Severn at Gloucester, the use of Sharpness Docks and Bristol Water's abstraction at Purton are currently regulated by an Operating Agreement with the Agency, which has been in operation since 1998. This agreement was entered into voluntarily by the Trust and good communication links have been established and maintained between the Agency and the Trust since its inception. The Trust has endeavoured to ensure full compliance with the Operating	

	Agreement throughout the period it has been in effect. The River Severn has always been one of the principal navigations in England with its significant length making it an important trading route for many centuries. The Trust is the authority responsible for navigation of the River Severn Navigation, between Llanthony Weir near Gloucester and Gladder Brook, just upstream of Stourport-on-Severn. The navigation is classified as a 'commercial waterway' under the Transport Act (1968) and under Section 105 of the Act the Trust has a statutory duty to maintain this stretch of the river in a suitable condition for use by commercial freight-carrying vessels of specific dimensions. The navigation provides an important link to a number of other waterways along its course including the navigable Warwickshire Avon, the Worcester & Birmingham Canal, the recently restored Droitwich Barge Canal and the Staffordshire & Worcestershire Canal. The River Severn Navigation receives natural and regulation release inflow at the upstream limit of the navigation and although the Agency is the responsible authority, the Trust strives to manage the navigation efficiently during both low flow and flood conditions. As with the G&S Canal, the future operation of the RSDO has the potential to compromise the Trust's ability to maintain the many demands on the river navigation. The Montgomery Canal has been the subject of an on-going campaign to restore navigation since 1969 and has gone through a number of restoration projects during recent years to reinstate its derelict and infilled sections. Only sections of the canal are currently in water and navigable. The Trust	

	manages and operates 53 km of the total length between Frankton Locks in the north and Freestone Lock in the south. The remaining 4 km of the canal to Newtown is currently privately owned and infilled. The current demands of the Montgomery Canal are met indirectly by the Llangollen Canal at Frankton, and by the Rivers Morda and Tanat to the north of the trough pound, and from the River Severn at Penarth to the south of the trough pound. At present, abstractions from the Rivers Morda, Tanat and Severn are limited during periods of River Severn Regulation under the terms of the Montgomery Canal Agreement (1987). It is noted that although quoted within the consultation document, it is our understanding that there are no proposals to change these restrictions with the future operation of the RSDO. Finally, the potential future water demands for the proposed restoration of the Stroudwater Canal and the Thames & Severn Canal (collectively termed the “Cotswold Canals”) may be affected by the RSDO. Although the Trust is not actively involved in the Cotswold Canals Partnership, a restored Stroudwater Canal would link to the G&S Canal at Saul Junction. It was therefore considered important to highlight this aspect.	
RSDO **High level comments**	The River Severn Drought Order (RSDO) Environmental Report assesses the potential impacts on many parts of the environment and water users, including the Canal & River Trust (the Trust). We are happy that the Trust’s interests have been considered with the information currently available to the Environment Agency (the Agency). However, it has been acknowledged in the report and in on-going negotiations	No action required, future collaborative work to address representation detail. Some more specific comments below;

	between the Agency and the Trust over the past two years that further collaborative work is required to fully consider the impacts of the future operation of the RSDO on the Trust. This further work is required to (The final scope and timescales for the proposed collaborative work between the Agency and Trust is currently under discussion and is still to be mutually agreed.):	
	1) Determine the water resources and therefore the potential abstraction from the River Severn at Gloucester, required to fully meet the demands of the G&S Canal in drought conditions with increased certainty. These demands include: Bristol Water's public water supply abstraction at Purton; lockage demands related to our Statutory Duty to maintain navigation (under the Transport Act, 1968); lockage and shipping demands related to our Statutory Duty to operate Sharpness as an Open Port (under the Harbours Act, 1964); environmental and heritage requirements and; canal losses. Work is also required to determine the safe water level that needs to be maintained to ensure the structural integrity of the canal is not compromised;	1) Action for Canal & River Trust to complete.
	2) Improve model assumptions in relation to the Trust's abstraction from the River Severn at Gloucester. More specifically, it is understood that our abstraction has been modelled at the potential maximum abstraction rate of 691 Ml/d in the 'full in-combination' drought scenario. This is not considered representative of the Trust's likely abstractions under such conditions and represents a "worst case" abstraction scenario;	2) As explained, the Habitat's Directive requires the precautionary principle to be applied when assessing likely significant effect. The Canal & River Trust has the capability to take the maximum quantity; therefore we have to assess the potential impact.

	3) Produce a revised demand/abstraction profile to be used in further modelling work to better represent the likely impact of the Trust's activities in the 'full in-combination' scenario under drought conditions; 4) Determine the impacts of the operation of the RSDO on the Trust in terms of the resultant levels and flows in the River Severn at Gloucester and the availability of water resources to meet the identified demands above, based on a revised demand/abstraction modelling profile under drought conditions; 5) Determine the impacts of the operation of the RSDO on navigation in the River Severn Navigation. More specifically, this should include an assessment of the local impacts of lowering water levels on the ability to navigate safely through locks along the River Severn; 6) Determine the impacts on the lower Severn catchment, macrophytes, fish and saline intrusion with greater certainty than presented here (see section 6) for further details).	3) See response to 2 above. We would however support this further work by the Canal & River Trust and would use the information to improve the overall conceptualisation of the River Severn. 4) Future work. 5) A high level assessment has been included in the report, information is needed from the Canal & River Trust before more local assessment could be undertaken. Future work. 6) The RSDO Environmental Report will remain a live document and we will continue to improve relevant modelling and information as new information becomes available. The monitoring programme aims to help us address the current gaps in knowledge and data.
RSDO **High level comments**	The aims of the RSDO are clearly set out in the Non Technical Summary of the Environmental Report. In relation to the interests of the Trust it is noted that one of the aims is to ration out water by: *'Imposing restrictions on the Canal & River Trust abstractions for the Montgomery canal in Wales (as detailed in the Operating Rules for the River Severn Resource/Supply System)'.* The Trust would like to note that these restrictions are as existing and as outlined in the 1987 Montgomery Canal Agreement with the Agency and that there are no proposals	We confirm restrictions relating to Montgomery Canal are in accordance with the existing 1988 agreement and the Operating Rules for the River Severn Resource/Supply System, no additional changes are planned. We also acknowledge your concerns regarding the Gloucester & Sharpness Canal.

	to change or add to these restrictions at this time. There should therefore be no further impact on the Montgomery Canal as a result of the future operation of the RSDO. Furthermore, it is acknowledged that operation of the RSDO could be of potential benefit to the Montgomery Canal, lowering abstraction quantities throughout the Severn catchment for longer, thereby reducing the potential period when all controlled abstractions to feed the canal are prohibited i.e. when Llyn Clywedog storage falls below 25%. In relation to the other aims of the RSDO, and the potential impacts on the G&S Canal and River Severn Navigation, it should be noted that further collaborative work is still required (as noted in section 1) above) to fully consider the impacts of the future operation of the RSDO on the Trust.	
RSDO **High level comments**	The potential positive and negative impacts of implementing the RSDO are clearly presented in the RSDO Environmental Report. However, as noted in 1) and 2) above, further collaborative work is still required to fully consider both the positive and negative impacts of the future operation of the RSDO on the Trust. Please see section 6) below for further comments on the positive and negative impacts on the Trust presented within the report and based on information available at the time of the modelling work undertaken by the Agency.	The RSDO Environmental Report will remain a live document and we will continue to work with the Canal & River Trust to refine the information and conceptualisation of the lower tidal Severn.
HRA	We have no specific comments to add on the Habitats Regulation Report: Annex 1, providing any errors found in the RSDO Environmental Report and comments noted in this consultation response are taken on board as relevant to all associated documents i.e. Appendices and Annexes 1 and 2.	It is important to note that the Canal & River Trust are also a Competent Authority under the Habitat's Directive, and have a legal obligation to ensure their operations do not damage the Natura 2000 site.
Shropshire Groundwater Scheme Environmental Report	We have no specific comments to add on the Shropshire Groundwater Scheme Environmental Report: Annex 2, providing any errors found in the RSDO Environmental	No action required.

	Report and comments noted in this consultation response are taken on board as relevant to all associated documents i.e. Appendices and Annexes 1 and 2.	
Feedback on the potential impacts from a River Severn Drought Order **6) The River Severn Drought Order has potential positive and negative impacts. Do you have any comments about how this may impact upon you?**	The potential positive and negative impacts of implementing the RSDO are clearly presented in the RSDO Environmental Report. However, as noted in 1) and 2) above, further collaborative work is still required to fully consider and robustly quantify both the positive and negative the impacts of the future operation of the RSDO on the Trust. Based on available information at the time of the modelling work undertaken by the Agency, a number of impacts are presented. In relation to the interests of the Trust we have the following comments: a) Water levels and flows in the River Severn at Gloucester – an indication of the likely levels and flows in the River Severn is given in the report, for various assessment points within the Severn catchment. The full implications of these in terms of the impacts on water resource availability to the G&S Canal and River Severn Navigation need to be further investigated once further collaborative work has been undertaken (see section 1) above). b) Canal closures – the report notes what the potential impacts of reduced flows in the River Severn could mean to the Trust in relation to canal closures. However, this is based on the assumption that canal closures would be implemented by the Trust with a flow threshold in the River Severn of <1150 Ml/d. Although this threshold is based on the flow at which the Trust's Drought Plan for the G&S Canal advises that canal closures be considered; it should be noted that closures may not necessarily be needed with flows at this threshold; and	a) Future collaborative work. b) While we would encourage adhering to this trigger, we do recognise the canal closure trigger used for assessment is for the Canal & River Trust's guidance only. We have added some text to clarify this in the report. For assessment purposes, this was the only available information to allow any impact assessment on the Gloucester & Sharpness Canal and we believe it provides useful context.

	this is just a drought plan action that could be considered. On the other hand, it does not necessarily mean that we will have sufficient resources to meet the demands of the G&S Canal with flows in the River Severn at Deerhurst above 1150 Ml/d. As noted above, the full implications of reduced flows in terms of the impacts on water resource availability to the G&S Canal and River Severn Navigation need to be further investigated once further collaborative work has been undertaken (see section 1) above). c) Canal demands - in relation to the 'full in-combination' scenario the report notes the likely significant effects that could be created if abstraction for the G&S Canal were increased above 300 Ml/d (for both the acute and chronic drought scenarios). The report refers to the Trust's G&S Drought Plan action noted above, and states that the Agency would actively encourage canal closures, with reduced flows in the River Severn. It is acknowledged, however, that some abstraction would need to continue to support Bristol Water's abstraction. The Trust has previously discussed this issue with the Agency, noting that canal closures would be considered as a last resort and that the abstraction by Bristol Water at Purton is not the only demand that would be required to be supported during a drought. Water resources are required to support not only Bristol Water's abstraction but to meet our statutory duties to maintain navigation (under the Transport Act, 1968), to operate Sharpness as an Open Port (under the Harbours Act, 1964), and to meet environmental, heritage and loss requirements. It is also noted that we do not currently know the safe water levels that need to be maintained to ensure the structural integrity of the canal is not compromised. As noted above,	c) We recognise the different abstraction demands on the Gloucester & Sharpness Canal and have added further text to help clarify this within the report. Future collaborative work needed to assess the new abstraction restriction (post this consultation response).

	further collaborative work is required to determine the resources required to fully meet all demands of the G&S Canal in drought conditions. d) Water quality/ecology – it is noted that there are no additional ecological flow target (Water Framework Directive Standards) failures with the future operation of the RSDO. It is also noted that water quality was generally found to improve with the operation of the RSDO because higher minimum flows created increased dilution. However, it is noted that towards the lower reaches of the River Severn, predictions of ecological impacts are more difficult as data availability are patchy. It is also noted that there is too little information to predict the effect of a drought or mitigating impacts of a drought order on macrophytes. The Trust would like to express concerns about the uncertainty in the predictions of ecological impacts and lack of information on the lower reaches of the Severn and on macrophytes, and would welcome the opportunity to discuss this further. e) Fish – it is concluded in the report that although the operation of the RSDO would be beneficial to the fish population in the upper River Severn, further downstream, and in particular near the estuary, the benefits would be greatly reduced. This would be of concern to the Trust and as with the above ecological impacts, we would welcome the opportunity to discuss this further. f) Saline intrusion – it is noted that future operation of the RSDO would reduce flows reaching the tidal Severn, and in combination with other plans and drought permits/orders there is greater potential for saline intrusion, and of saline water entering the G&S Canal.	d) Concern noted. All assessment are based on the best available information at the time; the lower tidal Severn and Estuary create a particular challenge for monitoring due to the rivers size and dynamic behaviour, we have acknowledged this openly within the report. Appropriate monitoring techniques and safety procedures are continuously being developed, and proposals have been made in the monitoring programme and future work sections. Collaborative working is needed between organisations to improve the monitoring programme, where feasible. e) Concern noted. Collaborative working is needed between organisations. f) Concern noted, already acknowledged within the report.

	This would be of concern to the Trust in relation to water quality in the canal, and to Bristol Water in relation to their public water supply abstraction from the canal at Purton. g) Severn Estuary Natura 2000 Site – the report notes that the modelling work undertaken was unable to conclude no significant effect on migratory fish due to the uncertainty around the Trust's exempt abstraction at Gloucester. It is also noted that on-going collaborative work is being undertaken with the Trust to put mitigation options in place in accordance with the Habitats Regulations Legislation. As noted above, discussions around such mitigation options are on-going between the Agency and the Trust and will continue outside this consultation. h) Navigation – it is noted that navigation in the middle and lower Severn catchment would be impacted by the lowered water levels experienced during drought conditions and that the degree of impact is likely to be exacerbated by the operation of the RSDO. It is noted that taking a worse-case approach, navigation by the majority of vessels could largely be prevented until high rainfall events return. The middle and lower Severn catchment includes the whole of the River Severn Navigation for which the Trust are the navigation authority. As such, the Trust would like to express concerns that operation of the RSDO could compromise our statutory duty to maintain navigation in the River Severn Navigation under the Transport Act (1968).	g) Reports updated to include a new restriction on the Canal & River Trust, which we acknowledge the Trust has concerns with - refer to December representation for current concern and our response. h) Concern noted.
HRA & RSDO High level comment	Reference to the Canal & River Trust is inconsistent throughout the report and associated documents. Please refer to us either as the 'Canal & River Trust' or 'the Trust'.	Text amended throughout the RSDO and HRA main reports.

RSDO Section 5.1.5.3. Canal Abstractions:	Canal Abstractions: i. Makes reference to daily abstraction limits during periods of River Severn Regulation, under the Montgomery Canal Agreement (1987). These do not exist in the Agreement which imposes maximum quantities over 7 day periods and not daily maximums as follows: River Severn at Penarth: - 150 Ml in any period of 7 days when no order under the Drought Act 1976 is in force and the amount of water released from Llyn Clywedog exceeds 300 Ml per day but does not attain 500 Ml per day; - 115 Ml in any period of 7 days when such releases attain 500 Ml per day; and - 50 Ml in any period of 7 days during which an order under the Drought Act 1976 is in force. River Tanat: - 49 Ml in any period of 7 days River Morda: - 14 Ml in any period of 7 days ii. Notes that 'at present abstraction [from the River Severn at Penarth to the Montgomery Canal] is at or below 115 Ml in 7 days and will not increase above this level until the canal is fully restored'. This information has not been provided by the Trust and is not a requirement of the Montgomery Canal Agreement (1987). iii. Makes some incorrect assumptions about the Trust's abstractions as follows: - 'Water is abstracted from the East channel of the River Severn at Gloucester, to supplement the canal at times of low flow (typically in summer) when levels normally satisfied by	Points i and ii – we agree, text for this section was taken directly from the 2008 draft Environmental Report. Text has been amended to address this representation. Point iii – we have removed some detail to address this representation. However it was not clear what was incorrect as the assumptions were high level and no alternatives were provided. We need to provide background context to understand the

	several intercepted tributaries (i.e. River Frome, River Cam, Daniels Brook and Sud Brook) are not sufficient.' - 'In most winters the inflows to the canal from the small tributary watercourses satisfies the water demand of both the canal and Purton abstraction. It should however be noted that as the flow entering the canal from the tributary watercourses decreases (with particular reference to the River Frome) there is an increasing demand to augment water resources in the Canal by means of abstraction from the River Severn at Gloucester.' iv. Quotes Bristol Water's maximum abstraction at Purton as both 245 Ml/d and 250 Ml/d. 245 Ml/d is the correct maximum quantity. v. Makes reference to a compensation requirement of 12.2 Ml/d which must be discharged before any abstraction from the G&S Canal by Bristol Water at Purton. This is incorrect. The compensation requirement of 12.2 Ml/d is related to our abstraction from the River Frome at Whitminster under the Gloucester and Berkeley Canal Act 1834/Gloucester and Sharpness Canal (Water) Act 1960 (Part V Miscellaneous, Section 17 Part 2).	system and the potential impacts the RSDO could have. Recent (Spring 2013) discussions had confirmed the draft text was how the abstractions were operated. Therefore some detail has been retained. Point iv – Text amended. Point v – Text removed.
RSDO Section 12.1.4 Lower Catchment:	i. Notes that 'narrow boats need 0.45 m of water' in terms of draught. The Trust would advise that 0.6 m is a more appropriate value to state. ii. Notes that the Trust is required to maintain a navigable depth of 2.4 m in the River Severn, which is normally achieved by dredging. The Trust would notes that these depths are currently under review and specific navigable depths should be removed from the report.	Point i - figure amended. Point ii - footnote added to highlight navigable depths are currently under review.

The initial draft environmental reports went out to public consultation during the summer of 2013 identifying a potential in combination impact on the Natura 2000 site, and that further collaborative work was needed to resolve this issue. Consultation representations received through this process (contained within this Appendix) expressed concern with this outstanding issue, highlighting that until a mitigation option was identified the River Severn Drought Order should not be used in combination or we would be in breach of the Habitats Regulations 2010.

Leaving the River Severn without a drought order option in the interim posed an unacceptable risk to the people and environment which rely on the water. Based on the Habitats Regulations Assessment work, a new abstraction cap of 300 Ml/d (figure subject to change) will form part of the application for a River Severn Drought Order. The abstraction cap from the River Severn to the Gloucester & Sharpness Canal, will only apply when flows at Deerhurst gauge fall below 1200 Ml/d and the River Severn Drought Order is active.

Because our consultation draft reports did not include this abstraction cap condition, the Canal & River Trust did not have an opportunity to respond to the impact in their consultation representation. We have been in discussions and held a meeting with the Canal & River Trust since the official consultation period closed to enable them to submit a more informed representation, and to identify future work. The Canal & River Trust raised concerns that 300 Ml/d could pose a risk to their operation of the canal and their confidence in being able to supply water to Bristol Water for its Purton abstraction. The Canal & River Trust have also expressed concern that their abstraction would be disproportionately restricted under the River Severn Drought Order when compared to conditions applied to the other abstractors.

The Environment Agency have committed to working with the Canal & River Trust to investigate their concerns further. If sufficient evidence can be provided to show a higher abstraction is justified, the Environment Agency is committed to reviewing the restriction volume in the future.

The Canal & River Trust’s response following the introduction of this new abstraction cap, and our statement of response, is contained below.

Canal & River Trust –post consultation discussions and representation (December 2013)		
Section/page	**Comment**	**Action**
RSDO **Section 5.4.3 & 5.4.3.2**	We have highlighted that the abstraction licence held by Canal & River Trust for the Purton abstraction by Bristol Water does already contain specific conditions in relation to the operation of the River Severn Regulation, as well as tide heights and flows in the River Severn.	The report text does already include a general reference to the additional licence conditions on the Purton abstraction. The text has been updated to include/state the conditions are linked to the tide height and regulation of the River Severn, however the licence conditions have not been included as they are not specific to drought order operations and the abstraction is regulated and enforceable.
RSDO & HRA **High level comments**	We are concerned that some sections of the reports, as written, state that abstraction "above 300 Ml/d" could not be concluded to have no adverse effect, whereas in fact there are only two abstraction points that have been modelled/assessed (300 Ml/d [causes no effect] and 691 Ml/d [causes effects]). The answer therefore is logically between these numbers, which is not the same as stating that anything >300 Ml/d will have an adverse effect.	Text amended to clarify the two separate conclusions and that no sensitivity testing between these approximate values has been undertaken.
HRA & RSDO **High level comments**	The Canal & River Trust is concerned that the impact of Clause 7 of the Operating Agreement has been overplayed, to portray the risk of us making the full 691Ml/d abstraction a presumption, as soon as a drought event is deemed to be occurring. We have made a number of edits/comments to explain why we think this is simply not the case. Whilst there is some evidence that significant abstractions took place in previous historical droughts, these pre-date the modern legislative landscape and the Operating Agreement. In fact the Trust would still be required to endeavour to meet the obligations of the Operating Agreement in the event of a drought – Clause 7 in no way allows it to entirely disregard its	Text has been clarified in an attempt to remove any perceived overplay and details of the Trust's environmental obligations have been included within a footnote. However, reference to Clause 7 remains because it is significant to the in combination work. As explained, the Habitat's Directive requires the precautionary principle to be applied when assessing likely significant effect. The Trust's intent to no longer abstract at this volume during a drought is recognised and supported, however in the absence of a licensed and therefore enforceable abstraction volume limit, we are

	obligations under the agreement, it allows the Trust to "miss" those obligations where this is outside of its control. In addition, the Trust is a competent authority under the Habitats Regulations and has its own environmental duties under section 22 of the British Waterways Act 1995. In addition, the Trust, is a charity with objects that include protection and enhancement of the environment. It is therefore entirely unrealistic to suppose the Trust would ever take up to the maximum theoretical pumped capacity in a future drought of the severity that the RSDO is intended to mitigate, and it is absolutely essential to us that the report acknowledges this.	required to assess what the Trust is capable of taking. Clause 7 and historic evidence reinforce but do not drive the need to consider the maximum potential abstraction, in their absence we would still be required to assess this precautionary volume.
HRA **Throughout HRA**	References to the Trust's 'potential maximum' abstraction of 691 Ml/d (track change comment)	We recognise the Trust's concern with quoting an abstraction volume which is rarely taken, only recorded in the 1970s and 1980s, and which their current environmental obligations would strongly discourage them from taking. We have inserted text and footnotes to help further clarify the difference between what is likely and what is precautionary, and to outline the Trust's commitment to the Environment and its obligations. However, we believe the reference to 'potential' fairly acknowledges this volume as something which could possibly (not would) be taken and remains within the Trusts capability to take again, rather than something which will inevitably occur. The term theoretical suggests a hypothetical volume which has never and will never be abstracted; however historic records show that for short periods these volumes were pumped and the pumping capacity still exists.
HRA	The whole assessment relies too heavily on what happened in 1975/6 drought which in no way reflects what the Trust	We recognise your concern. For the 1975/76 event (also 1984 and 1989) we have baseline

High level comments - HRA (track change comment)	would realistically do today.	environmental impact data which provides a benchmark or reality test for our current modelling. These drought order operations are the only time we have been able to record and assess the environmental response to drought flows along the River Severn being regulated below the current 850 M/ld (or historic 730 Ml/d) statutory requirement. Until we have a repeat drought order event, we cannot update this evidence, as we are not legally permitted to allow River Severn flows to reduce to these levels. The 1975/76 event has been predominately used as it represents the most severe drought event we have on record, the minimum flows are therefore the closest we have on record to the minimum flows we have modelled for the River Severn Drought Order environmental reports. We recognise the abstraction regimes have changed since this event, but the Habitat's Directive requires the precautionary principle to be applied when assessing likely significant effect.
RSDO & HRA **High level comments**	Overall, it is our view that the reports give a disproportionate amount of emphasis to the theoretical risk of our abstraction (and then present the restriction at Gloucester as the only possible solution), and both reports come across as more of a justification of why the Canal & River Trust abstraction cannot be left untouched, rather than a balanced overall assessment of the impact of the RSDO on the River Severn European Site and how all abstractors will be affected by the RDSO. Any impact on the River Severn European Site is the result of the total water being taken by all of the abstractions from the river, not purely the one for the Gloucester & Sharpness Canal, and there is no recognition at all of that in the HRA	We recognise there is collaborative work needed going forward to bring all the in combination organisations together to help identify and resolve the remaining potential conflicts. We have made it clear to all our consultee's that the River Severn Drought Order Environmental Report and supporting documents will remain a working draft until an application is needed, with a regular review programme having also been set. The public consultation process we have held, although not required at this stage, has been a valuable tool for collecting any outstanding concerns. This should

	report, which appears to include these other abstractions as part of the “do nothing” baseline.	allow all the organisations involved to work together and make improvements in advance of a real drought event. For the HRA report we have tried to clarify text where appropriate to address this concern. However it is important to highlight the HRA is not intended to be read in isolation of the RSDO Environmental Report. To prevent duplication and the unnecessary increased size of each document, all the modelling scenario detail is contained within the RSDO Environmental Report. Section 4.4 and 4.5 clearly explain what each drought condition (Acute and Chronic) and drought scenario (Do Nothing (Baseline), Drought Order Only and Full In-Combination) involves. The HRA then forms the assessment and discussion around the main influences and uncertainties impacting upon the Habitat's Directive sites.

Natural England		
Section/page	**Comment**	**Action**
RSDO **Section 3.1**	In Section 3.1 the proposals for the RSDO are outlined, however, information on its derivation is brief. For example, it is unclear why an initial 5% reduction on non-spray irrigation licensed abstractions is considered to be adequate. In our view, the rationale underpinning the specific proposals should be more clearly explained, highlighting how the needs of people and the environment have been taken into account. At this juncture in the report it would also be useful to provide an overview of the abstraction licence restrictions that would be triggered leading up to the implementation of the RSDO.	Some further detail has been added to section 3.1 to emphasise the drivers behind each of the conditions/proposals. There is a need to keep the Environmental Report concise and therefore we have to limit how much detail is contained. The initial 5% reduction aims to balance our responsibility with protecting the environment with our responsibility to have regard for public water supply abstractions. Further detail has been added to the report; the reductions could vary between 5-20%. However we are conscious that water companies will already be operating in accordance with their abstraction licences during drought, which may not be sufficient to meet public demand. If we impose too higher additional restrictions, we could prompt the water companies to apply for their own drought permit/orders which if granted by Defra, would allow higher abstractions. We have to find the right balance for all the water resource needs. The overview of abstraction licence restrictions enforced leading up to a drought order implementation falls outside of the remit of the environmental report. However, this information would be available as part of the wider Drought Plan and drought management procedures during a drought event, and could be included as a summary in the River Severn Drought Order application paperwork at Natural England's request.

HRA **High level comments (general layout)**	Whilst Natural England considers that the assessment approach used in the HRA is broadly appropriate, we feel that the analysis of the modelling outputs in relation to the predicted impacts on the designated interest features could be much clearer, allowing a more straightforward comparison of the consequences of implementing and not implementing the RSDO.	Tables have been changed for clarification.
HRA **Tables 5 and 7, Sections 3.5 to 3.12**	In Tables 5 and 7, use of key 'assessment criteria' could usefully be applied as row titles. This would help to more clearly demonstrate how the requirements of the fish species set out in sections 3.5 to 3.12 have been considered in relation to the hydrological and water quality predictions arising from the modelling work that has been undertaken. These criteria could include flow and water quality targets, and other key requirements of the migratory fish species being considered, through their life history stages, and at critical periods.	Tables have been changed for clarification.
HRA **Table 7**	It would also be helpful if the columns in Table 7 matched the modelling scenarios that have been outlined in the Environment Report. For example, we are unclear why the 'Glos and Sharpness Canal Abstraction' has been added as a separate column heading, as this was not a separate model run, as far as we are aware.	Column headings changed accordingly.
HRA **Section 3.14 and 3.15**	In Section 3.14 and 3.15 it would seem appropriate to draw out the key conclusions arising from the comparisons made in Table 7, to assess, on the balance of evidence, whether implementing the RSDO will increase or decrease the risk of there being an adverse effect on the integrity of the Severn Estuary SAC/SPA/Ramsar. Instead much of the discussion appears to be around the potential impacts of a drought scenario more generally.	It is clearly stated in the text that impacts are mainly related to the baseline drought itself and implementation of RSDO allows lower flow to continue over a longer period but prevents the critically low flows expected without the RSDO, especially during an extended drought event. It is difficult to separate the impacts of implementing the drought order in isolation as a drought would be well underway and we would already be seeing the

		environmental effects of this by the time we'd be implementing a drought order. It is important that we include this detail and stress the point for context. HRA conclusions in section 3.14 and 3.15 contain the clarification requested; that implementation of the RSDO, alone, does not have an adverse effect on the designated migratory fish features of the Severn Estuary SAC and Ramsar. This Appropriate Assessment has been carried out based on a specific model of drought conditions and we also recognise that each drought is an individual event and the impacts on the different fish species in relation to the timing of a future drought may be different to what has been outlined in this assessment.
HRA **G&S in-combination conclusions**	We understand that the EA's HRA concludes that an abstraction rate of 300Ml/day into the Gloucester-Sharpness Canal does not represent an adverse effect on the integrity of the Severn Estuary SAC/SPA/Ramsar either alone, or in combination with the RSDO and all other existing drought orders and permits. However, we note that the abstraction agreement held by the Canal and Rivers Trust allows a take of up to 691Ml/day, even under drought conditions. In relation to this issue, the HRA also concludes that 'abstraction over 300 Ml/d and particularly within the region of 691Ml/d alone, and in combination with implementation of the RSDO and other drought orders or permits, will have an adverse effect on the migratory fish features of the Severn Estuary SAC and Ramsar'. It is our understanding that the Canal abstraction was only included in the modelling to a level of 300 Ml/day.	The Canal & River Trust is exempt from abstraction licensing, the operating agreement between ourselves and the Canal & River Trust forms voluntary rules that allow abstraction to vary according to the tide and flows, which the Canal & River Trust are committed to adhering to. The flow modelling work included a maximum Gloucester & Sharpness canal abstraction of 300 Ml/d. After discussions with the Canal & River Trust it was recognised that 300 Ml/d did not fully represent their legal ability to take up to 691 Ml/d. This higher figure contains large uncertainty and assessment of the potential environmental impacts resulting from flow and level reductions greater than what we modelled, was based on historic reports (i.e.

	On this basis we would like the EA to clarify the information underpinning their conclusion above. Based on the information presented it would appear that further modelling and assessment work is required to assess the potential impacts of the abstraction across a range up to 691Ml/day. However, we strongly support the need for further talks with the Canal and Rivers Trust to identify suitable options for ensuring that the features of the Severn Estuary SAC/Ramsar are protected under drought conditions. The additional modelling outlined above would seem to be essential to inform these discussions. The results of this work would also need to be considered by Bristol Water when reviewing their Drought Management Plan.	recorded impacts based on high abstractions), current data and expert interpretation. In response to feedback concerning the in-combination potential impacts of the Canal & River Trust abstraction for the Gloucester & Sharpness Canal, we have added an abstraction restriction to the Drought Order application, which would be legally enforceable if granted by Defra. The abstraction figure will be set at 300 Ml/d when flow at Deerhurst drops below 1200 Ml/d and the RSDO is in force. However the Environment Agency is committed to ongoing collaborative work with the Canal & River Trust to test the sensitivity around this maximum abstraction volume. If evidence can justify and support higher abstraction during severe drought conditions, the abstraction cap will be reviewed.
RSDO Section 17	Natural England supports the recommendations set out in Section 17 of the Environmental Report, and we look forward to further discussion with the EA in the development of this work. In particular, we recognise the need to enhance the fish monitoring programme, particularly in relation to shad.	The development of specific shad monitoring has been identified and recommended as an area of future work, we will keep you informed.
HRA	The ‘Future Recommendations and Monitoring Requirements’ set out in the HRA document	The HRA is a supporting document to the main RSDO report, to avoid too much duplication we have avoided reproducing the same information in both reports where possible. Therefore there is no Future Recommendations and Monitoring Requirements section in the HRA but there is a Mitigation section which is somewhat different and primarily centres on a discussion of the Gloucester & Sharpness Canal abstraction. In the main

		RSDO, Section 9.6 refers to the HRA monitoring gaps and limitations, then please refer to Section 15 for the complete monitoring programme and Section 17 for Future Recommendations.

National Farmers Union - Cymru

Section/page	Comment	Action
RSDO **High level comments**	River Severn Drought Order We have noted carefully how the Environment Agency currently operates its Drought Order (subject to ministerial approval). Whilst the Order has no direct impact on spray irrigated crop farming, we support the proposal to reduce support flows in extreme conditions thereby making water in the Llyn Clywedog reservoir last longer. This seems to be a sustainable option. We note the risks of 'in combination' effects of Orders and Permits and would expect the Agency, NRW and public supply companies to jointly manage the situation to overcome any potential pitfalls. We support the Agency and NRW in your efforts to reach agreement with the Canal and River Trust on sustainable management of the Trust's exempt activity during drought conditions. We presume that Defra (and Welsh Government?) will move shortly to bring this exempt activity into the licensing regime.	The current timetable to begin licensing abstraction exemptions is from April 2014. This report and the drought order are only intended for drought conditions. To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended in the environmental reports, specifically relating to drought conditions (not normal river regulation, which is outside the remit of these reports). We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.

RSDO **High level comments**	Drought action and agricultural restrictions This report (correctly) makes it clear that a Drought Order would only be introduced after a widespread ban on all spray irrigation has already been introduced. Licence backed conditions and the imposition of section 57 restrictions have major impacts on farm businesses and on society. For farmers they cause major business planning dilemmas at best; and at worse lead to major crop and therefore economic losses. For the consumer, crop losses (and the threat of losses) leads to food price volatility as food demand and supply fluctuates. Action taken on farm licences must always therefore be as a last resort. As part of its overall drought planning the EA and NRW must develop good working relationships with the farming sector to mitigate the impacts of the drought, and a full range of options (voluntary restrictions, etc) must be considered before licence bans are introduced. We therefore welcome the reports recognition of the importance of our sector and the intention to openly engage with us when drought conditions develop (p92). We recognise that this plan will not directly affect the situation for livestock producers during a severe drought in the Severn catchment. But given the difficulties this sector experienced during the drought period in 2012 we would welcome more discussions with the EA and NRW on how this sector can be assisted with drought resilience planning. Mitigation options A number of mitigation options should be considered, some by the Agency/NRW alone and some in collaboration with partners as a parallel work stream to the development of a Drought Order including: • Licence flexibility In 2012 the Environment Agency permitted the filling of farm reservoirs at times of high river flow outside of the ‘legal’ winter abstraction season. This flexibility proved invaluable to the farming sector in some catchments, gave confidence to farmers that the Agency would support their needs when (environmentally) possible and reflected an increasingly constructive partnership between the sector and regulator over the past few years. Local options should be explored for licence flexibility in drought conditions.	Thank you for your feedback; this has been shared with the wider drought management groups.

	• Efficiency messages. The Agency and farming organisations should co-ordinated their messages to emphasise the need for farmers to use water resources wisely. • Business planning messages The Agency/NRW could further improve the quality and timeliness of its information made available to farmers on the potential severity of the drought based on current information (aquifer and surface water levels, SMD, reference to historic events, Met Office forecasts). This information is a useful planning tool for on farm drought risk management. • New water abstractor groups Water abstractor groups have existed in some key catchments for many years to share information, act as a forum for discussion and as an important and single point of contact for organisations such as the Environment Agency. New groups may need to be formed (and support may be needed) in some of the Severn sub-catchments at highest risk of drought. • Working with non-agricultural users Farmers need help to liaise with other users in some of the higher risk sub-catchments (especially public water companies) to understand how they use water and to identify opportunities to collaborate on managing limited supply. Farmers are very concerned that agricultural water use may be subordinated to public supply in the context of climate change and/or habitat requirements. Given the on-going large scale leakage losses by water companies and non-essential uses by domestic water consumers, we question such a prioritisation. In the context of concerns about food security, domestic food production should be a higher priority for water share. Drought action and agricultural restrictions This report (correctly) makes it clear that a Drought Order would only be introduced after a widespread ban on all spray irrigation has already been introduced. Licence backed conditions and the imposition of section 57 restrictions have major impacts on farm businesses and on society. For farmers they cause major business planning dilemmas at best; and at worse lead to major crop and therefore economic losses. For the consumer, crop losses (and the threat of losses) leads to food price volatility as food	

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National Farmers Union - Midlands

Section/ page	Comment	Action
RSDO **High level comments**	River Severn Drought Order We have noted carefully how the Environment Agency currently operates its Drought Order (subject to ministerial approval). Whilst the Order has no direct impact on spray irrigated crop farming, we support the proposal to reduce support flows in extreme conditions thereby making water in the Llyn Clywedog reservoir last longer.	Our understanding is that Hands off Flow (HoF) restrictions will continue to be used to regulate abstraction during routine to low flows. For clarification, from normal flows right into many drought periods (e.g. 1995/96 the River Severn Drought Order was not required) the quantity of water put into the River Severn from Llyn Clywedog, Lake Vyrnwy and the Shropshire Groundwater Scheme is all triggered by reducing flows in the River Severn, recorded at Bewdley flow gauge

	However, we would welcome some reassurance about the potential impact on spray irrigation that the proposed change in Drought Order might have. Future restrictions on irrigation licences will presumably continue to be triggered by (low) river flows. Yet the volumes of water put into the system from the Llyn Clywedog reservoir are not triggered by flows but by water availability in the reservoir itself. Is it therefore possible that by reducing daily volumes of discharge into river, flows will be so low over a much longer period that spray abstraction licence conditions could be in force for much longer than under current regime? With seasonal agricultural use meaning that water is ordinarily needed between, say, April and August is it possible that farmers' access to water could be even more constrained than in the current regime? We would be happy to receive a reasoned argument from the Agency explaining that farmers will not in fact be further disadvantaged by these proposals.	(not by storage in the reservoir). It is only when storage levels in Llyn Clywedog drop below warning curves that we would consider operating the drought order and reducing flow support down the River Severn (the drought order itself is triggered by water availability in the reservoir and not flows). In answer to your concern, the drought order would lower flows for a longer period leading into a drought, than if no action was taken. The concern to spray irrigators is the risk of HoF's being triggered for longer periods as a consequence of these lower flows. Theoretically it would only be abstractors with HoF's set below the statutory prescribed flows at Bewdley (and equivalents at other gauges) that could be at risk of additional impact from the drought order. These licences are currently protected from restriction all year round, from normal to drought year (e.g. 1995/6) events, because their HoF triggers were set below the flow we have to maintain along the River Severn. The drought order would allow us to reduce this flow, and potentially trigger the lower HoF's restrictions. However, in reality the independent drought management procedure to seek S57 restrictions begins once Llyn Clywedog storage crosses the drought order 'application' curve (because it is a key indicator of drought severity in the Severn basin). This action would precede the River Severn Drought Order, which is not implemented until a second lower trigger curve is crossed at Llyn Clywedog. Therefore the impact on agriculture would result from the S57's and not the implementation of the River Severn Drought Order. Data from the modelled Acute event (severe summer drought) showed that if the drought order were not implemented, the 'Do Nothing (Baseline)' scenario produced 233 days of potential S57 restrictions from 3 August to 23 March the following year. By operating the

		drought order, the 'Drought Order Only' scenario produced 206 days of potential S57 restrictions from 3 August to 25 February the following year. The 'Full In-Combination' scenario produced 201 days of potential S57 restrictions from 7 August to 24 February. This suggests the River Severn Drought Order would actually be of benefit to spray irrigators, by reducing the potential restriction period. In reality the S57 restriction trigger curve will be used as a guide during a real event rather than a definitive start and stop trigger. When S57 restrictions would be enforced and lifted will vary with each drought event, although they will always be in force before the River Severn Drought Order is implemented. For context, it is more feasible that S57 restrictions would be lifted once sustained rainfall was experienced (it could be assumed that spray irrigation demand would also be reduced/removed at the same time). The modelled drought event ended at the beginning of November although storage in the reservoir takes several months to recover. However with the post drought rainfall modelled, by December S57 restrictions might have been lifted anyway. As the S57 restrictions were triggered at about the same time, whether the drought order was implemented or not, it is more likely the drought order benefits are associated with the recovery period, allowing S57's to be lifted more quickly as storage in the reservoir is better protected under drought order implementation. Therefore no additional negative impact on agriculture in the short term is concluded. It is also important to note the longer term benefit's (second summer drought) of implementing the drought order; *"The longer-term benefit of operating the River Severn Drought Order, as shown by the Chronic condition modelling, is that Llyn Clywedog storage could be protected for a subsequent drought year. If storage could be protected by applying the drought order during an acute drought year, the*

		probability of needing it in two consecutive years, even if the drought persisted, would be greatly reduced. Therefore the long term benefit could be the reduced risk of Section 57 restrictions being needed in two consecutive years, with obvious benefits for agriculture, industry and other abstractors." Text within section 5.4.2 of the report has been updated to include the detail from this additional investigation.
RSDO **High level comments**	We note the risks of 'in combination' effects of Orders and Permits and would expect the Agency, NRW and public supply companies to jointly manage the situation to overcome any potential pitfalls. We support the Agency and NRW in your efforts to reach agreement with the Canal and River Trust on sustainable management of the Trust's exempt activity during drought conditions. We presume that Defra (and Welsh Government?) will move shortly to bring this exempt activity into the licensing regime.	The current timetable to lift abstraction exemptions is April 2014. To satisfy the Habitat's Directive we have been in discussions with the Canal and River Trust and have introduced a new abstraction cap of 300 Ml/d, to come into force when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. This would become legally enforceable under RSDO operation, if granted by Defra. The Canal and River Trust have raised concerns that 300 Ml/d may be too low and could cause them a business risk, therefore we are continuing to work with the Canal and River Trust and if evidence can support a higher abstraction, without harming the Natura 2000 site, then the restriction volume will be revised accordingly.

RSDO **High level comments**	Drought action and agricultural restrictions This report (correctly) makes it clear that a Drought Order would only be introduced after a widespread ban on all spray irrigation has already been introduced. Licence backed conditions and the imposition of section 57 restrictions have major impacts on farm businesses and on society. For farmers they cause major business planning dilemmas at best; and at worse lead to major crop and therefore economic losses. For the consumer, crop losses (and the threat of losses) leads to food price volatility as food demand and supply fluctuates. Action taken on farm licences must always therefore be as a last resort. As part of its overall drought planning the EA and NRW must develop good working relationships with the farming sector to mitigate the impacts of the drought, and a full range of options (voluntary restrictions, etc) must be considered before licence bans are introduced. We therefore welcome the reports recognition of the importance of our sector and the intention to openly engage with us when drought conditions develop (p92). We recognise that this plan will not directly affect the situation for livestock producers during a severe drought in the Severn catchment. But given the difficulties this sector experienced during the drought period in 2012 we would welcome more discussions with the EA and NRW on how this sector can be assisted with drought resilience planning. Mitigation options A number of mitigation options should be considered, some by the Agency/NRW alone and some in collaboration with partners as a parallel work stream to the development of a Drought Order including: • Licence flexibility In 2012 the Environment Agency permitted the filling of farm reservoirs at times of high river flow outside of the ‘legal’ winter abstraction season. This flexibility proved invaluable to the farming sector in some catchments, gave confidence to farmers that the Agency would support their needs when (environmentally) possible and reflected an increasingly constructive partnership between the sector and regulator over the past few years. Local options should be explored for licence flexibility in drought conditions.	Thank you for your feedback; this has been shared with the wider drought management groups.

	• Efficiency messages. The Agency and farming organisations should co-ordinated their messages to emphasise the need for farmers to use water resources wisely. • Business planning messages The Agency/NRW could further improve the quality and timeliness of its information made available to farmers on the potential severity of the drought based on current information (aquifer and surface water levels, SMD, reference to historic events, Met Office forecasts). This information is a useful planning tool for on farm drought risk management. • New water abstractor groups Water abstractor groups have existed in some key catchments for many years to share information, act as a forum for discussion and as an important and single point of contact for organisations such as the Environment Agency. New groups may need to be formed (and support may be needed) in some of the Severn sub-catchments at highest risk of drought. • Working with non-agricultural users Farmers need help to liaise with other users in some of the higher risk sub-catchments (especially public water companies) to understand how they use water and to identify opportunities to collaborate on managing limited supply. Farmers are very concerned that agricultural water use may be subordinated to public supply in the context of climate change and/or habitat requirements. Given the on-going large scale leakage losses by water companies and non-essential uses by domestic water consumers, we question such a prioritisation. In the context of concerns about food security, domestic food production should be a higher priority for water share. Drought action and agricultural restrictions This report (correctly) makes it clear that a Drought Order would only be introduced after a widespread ban on all spray irrigation has already been introduced. Licence backed conditions and the imposition of section 57 restrictions have major impacts on farm businesses and on society. For farmers they cause major business planning dilemmas at best; and at worse lead to major crop and	

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Severn Trent Water Ltd

Section/page	Comment	Action
RSDO **Pages 164 and 165, point 13.**	We agree with several of the recommendations for further work shown on pages 164 and 165. We particularly agree with number 13, "Work collaboratively on any future in combination Drought Order modelling work". We are meeting the EA and others as part	Thank you for your ongoing support. We are committed to continuing to work closely with key organisations, and hope this will expand to include other potential in-combination interests as we move forwards.

	of our drought order work on 22 August and think that working together has the potential to prevent duplicated and potentially conflicting work.	
RSDO Pages 164 and 165, point 14.	We also see benefit in number 14 "test the R. Severn D.0for climate change" and we are keen to work with the EA on points listed under number 11"improve conceptualisation of the R. Severn within the Aquator model."	Climate change work on the River Severn is about to begin and should help provide an indication of whether there is likely to be an impact on the frequency of RSDO applications. We welcome collaborative working on any improvements we can make to the conceptualisation of the River Severn going forward.
RSDO Page 143	It is interesting that on page 143 the report says that the impacts of the EA drought order fall under article 4.6 of the WFD. Article 4.6 provides an exemption to 'the temporary deterioration of WFD status if it is the natural consequence of prolonged drought events". We are keen to find out whether this will also apply to our Trimpley drought permit/ order.	The key points from the RSDO work were the importance of being able to demonstrate the baseline drought conditions and any deterioration in WFD status that could be expected as a result. This helped test any additional positive or negative changes created by the RSDO operation. It is important to note the magnitude of drought expected to trigger the RSDO could be different to droughts triggering water company drought permits/orders. Article 4.6 of the WFD relates to events which ‘could not reasonably have been foreseen’. It is also expected that conditions will have been met such as ‘all practicable steps .....to prevent further deterioration in status.’ The scope of Article 4.6 is given in the ‘Common implementation Strategy for the Water Framework Directive (2006/60/EC) Technical Report’ – 2009. European Commission
RSDO Page 138	We are also interested that on page 138 the report shows that the EA only consider that it is necessary to design, assess and put in place "compensatory measures" in connection with 'Imperative Reasons of Overriding Public	Please note, the mitigation requirement under the Habitats Directive which is covered in section 9.5 states that where an impact cannot be ruled out, alternatives and mitigation must first be considered.

	Interest' in exceptional circumstances. We support this and have taken a similar approach in our revised draft drought plan.	Only if evidence shows no alternatives or mitigation can be found, can a case for IROPI then be considered. If IROPI can be proved, then mitigation options are required. The wording around 'exceptional circumstances' is in reference to proceeding down the road of applying for IROPI. We just wanted to ensure this message is not misunderstood.
RSDO **Page 90**	We agree with the suggestion to meet to discuss any potential conflicts between this drought order and any drought permits I order we may apply for at an early stage as suggested on page 90.	Thank you and we look forward to these discussions.
RSDO **P64, section 5.1.5.1**	On page 64 in section 5.1.5.1 the Ironbridge power station is incorrectly listed as a Severn Trent Water abstraction.	Text amended.
RSDO **p162**	On page 162, the final sentence of the first paragraph would better read "...if we did not apply for....".	Text amended.
RSDO **p162**	The sentence "Under this scenario, flows from Bewdley downstream become more significantly reduced as the water company abstractions were removed" in the final paragraph on page 162 is hard to follow.	Text amended.

South Staffordshire Water Plc

Section/page	Comment	Action
High level comments	South Staffordshire Water supports the need for the Severn Drought Order and regards it as a vital tool in protecting both the environment and public water supply abstractions along the River Severn under severe drought conditions. It supports the programme of collaborative mitigation, in particular the flexible use of abstraction and raw and raw	Thank you for your feedback.

	water storage to optimise use of short term higher river flows and/or low customer demands that intersperse typical droughts.	
High level comments	The Company welcomes the commitment to improve understanding of environmental impacts, particularly in the lower reaches and Severn Estuary. This should explore ways of demonstrating the likelihood whether the impacts experienced in 1976 will be repeated under any reasonably foreseen scenario.	Future work and modelling, including the separate climate change testing, will help to clarify the return periods and current pressures on the system.
High level comments	The Company regards the protection afforded the large abstraction at Gloucester and Sharpness under both normal river regulation and the Drought Order to be anomalous. It welcomes the intention to mitigate these by exploring better forms of agreement wit he Canal and River Trust. These may be best delivered by revision of the regulation arrangements set up in 1979 and the setting of minimum flows at specified points in the catchment.	To satisfy the Habitat's Directive and reduce the risk to the Severn Estuary the precautionary principle has now been adopted and text amended. We have been in discussions with the Canal & River Trust, involving legal representatives from both organisations. The Environment Agency have introduced a new abstraction cap of 300 Ml/d, to come into force only when the drought order is active and flows at Deerhurst drop below 1200 Ml/d. The Canal & River Trust has raised concerns that 300 Ml/d could pose a risk to their operation of the Gloucester & Sharpness Canal and the Bristol Water abstraction it supports, which the Trust are investigating. We have agreed that if sufficient evidence is provided to show a higher abstraction is justified then the 300Ml/d limit will be reviewed.
High level comments	The Company welcomes the recommendation to test the RSDO for climate change and suggests these may offer a more statistically robust alternative to the current manually defined Acute and Chronic scenarios used to artificially "force" a Drought Order in the Aquator model runs.	Thank you for your feedback. The climate change work will initially test the robustness of the Severn catchment to the climate change projections. However we will continue to test short term and long term drought scenarios, beyond what has been experienced. This is to enable us to

		effectively plan and manage droughts in the future, and complies with the current Drought Plan guidance.
RSDO p18	penultimate paragraph suggest replace "exasperated" with "exacerbated"	Text amended.
RSDO P42	make mention somewhere of intention to reduce non spray abstractions by up to 20% somewhere - generally check that additional mitigation options e.g. SGS Drought order cross referenced.	Text amended.
RSDO p158, item 8	not clear why this is a mitigation option?	We view monitoring at sites not currently identified on the programme as being another way of assessing unexpected impacts and thereby enabling mitigation actions (e.g. Fish rescue's, oxygenating water) to be proactively taken.
RSDO p159 item 4	replace with "If SSW can reduce abstraction…" and "..to pay SSW for the water" perhaps make reference to application of the principles of the Section 20 agreement?	Text amended.

Severn Rivers Trust

Section/page	Comment	Action
HRA & RSDO **Unable to respond**	We did want to make a response and were hoping to have a get together to discuss before we sent in our comments, however we simply ran out of time with so much work and projects to deliver before the Autumn. .... there is 169 pages of the report to go through plus another 479 pages of appendix, which we just didn't have the resources to go through, plus we do feel the consultation period was too short. If there is to be any kind of follow up or open meetings to discuss the order before it's finalised please let us know as we would definitely wish to be involved.	We appreciate the document size can present a challenge when time/resources are limited. The public consultation we ran during 2013 was a voluntary exercise to gather comments and any concerns to help inform future revisions of the reports. Once the report is published on our website it will be available for you to download. If you would like to send any comments on this version of the report we would accept them, and try to build them into future revisions. When a River

		Severn Drought Order application is made, there would also be a formal public consultation period.

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