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This report has been withdrawn because it is out of date.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

Environment Agency

Shropshire Groundwater Scheme Drought Order

Environmental Report



25 October 2013

AMEC Environment & Infrastructure UK Limited

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Environment Agency

Shropshire Groundwater Scheme Drought Order

Environmental Report

25 October 2013

AMEC Environment & Infrastructure UK Limited

Report for

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Executive Summary

Droughts are infrequent events in the UK but when they do occur their impact can be significant. The Environment Agency has responsibility for alleviating the effects of drought on people, businesses and the environment through sensible management of water resources in England. These responsibilities are summarised in the Water Resources Act 1991 and the Water Act 2003.

The purpose of this report is to support an application for a Drought Order for the Shropshire Groundwater Scheme (SGS). The application will allow us to increase the volume of water abstracted under the existing SGS licence. This report forms a supporting annex to the River Severn Drought Order Environmental Report, which aims to reduce the impact of a severe drought across the whole Severn catchment.

The River Severn catchment forms part of a large water supply system. Around six million people rely on it for drinking water as well as a huge number of businesses, leisure clubs and wildlife. Ensuring that the River Severn is able to support all of these uses is the responsibility of the Environment Agency and Natural Resources Wales. We must decide how much water needs to be released to the river from both surface water and groundwater storage sources to balance the needs of the river against the demands of abstraction for public water supply; spray irrigation; business; and navigation.

Permo-Triassic sandstone is one of the most important principal aquifers in the UK, second only to the chalk. This makes it ideal for large scale strategic water resource development, as the effects of seasonal abstraction and recovery is more evenly distributed over longer periods. The SGS utilises groundwater from this natural resource, located beneath North Shropshire, to help manage the River Severn.

The resilience of this strategy, under extreme situations such as a prolonged drought, is tested using surface and groundwater models. The scenario presented in this report modelled a severe drought extending over a three to four year period. It found that the River Severn would require more support from water stores than is currently consented. We would only expect to see this type of severe event on average less than once in 100 years.

In the absence of alternative strategic water resources of equivalent volume within the Severn catchment, the preferred option to manage such events is to provide additional groundwater resource by extending the duration of pumping from the existing SGS infrastructure.

SGS has a fixed maximum yield and therefore the rate of abstraction cannot be increased, with the number of pumping days limited by its abstraction licence. Under this scenario an additional 3,680 megalitres (Ml) of groundwater support would be required in excess of the current licence limit. This approximates to 21 days additional pumping support at 190Ml/d. This would supplement and conserve the surface water reservoir storage, thereby allowing a longer period of sustained regulation support for the River Severn during critical low flow drought conditions.

In support of the application we have considered the consequences of extending operation of the scheme on the surrounding environment. Our modelling has found no significant impacts on the environment in terms of water

quality, fish and plant or animal populations in the rivers. Experience of operating the scheme to date prove that groundwater levels have recovered to pre-pumping levels within one to three years of each pumping event and therefore SGS is considered to be operating sustainably. The amount of groundwater sought by the Drought Order will be greater than that previously pumped by SGS. Groundwater levels should therefore make a full recovery, but will take longer to do so from an extreme event.

A large number of streams will either not be affected by, or benefit from, the operation of the scheme. Those that are affected already have flow compensation measures in place. Excluding the River Severn, approximately 41km of tributary rivers and streams will benefit from artificially enhanced flows. These augmented stretches will be in a more favourable condition than non-augmented watercourses, which will be experiencing low flow conditions due to a drought.

The River Severn catchment occupies an enviable geographical position in the UK with high annual rainfall and access to reserves of both surface water and groundwater. The deployment and conservation of these resources are vital to balance the use of the River Severn for people, businesses and the environment. The value of properly managing these water resources, both now and in the future, is becoming more evident. We have to deal with the challenges posed by climate change and the need to adapt the management of these assets to meet the extreme weather patterns it may bring.

Crynodeb Gweithredol

Digwyddiad prin yw sychder yn y Deyrnas Unedig ond pan fydd yn digwydd gall ei effaith fod yn sylweddol. Mae gan Asiantaeth yr Amgylchedd gyfrifoldeb am liniaru effeithiau sychder ar bobl, busnesau a'r amgylchedd trwy reolaeth synhwyrol ar adnoddau dŵr yn Lloegr. Caiff y cyfrifoldebau hyn eu crynhoi yn Neddf Adnoddau Dŵr 1991 a Deddf Dŵr 2003.

Diben yr adroddiad hwn yw cefnogi cais am Orchymyn Sychder ar gyfer Cynllun Dŵr daear Swydd Amwythig (SGS). Bydd y cais hwn yn caniatáu i ni gynyddu faint o ddŵr sy'n cael ei dynnu dan drwydded bresennol SGS. Mae'r adroddiad hwn yn atodiad i Adroddiad Amgylcheddol Gorchymyn Sychder Afon Hafren, sy'n anelu at leihau effaith sychder difrifol ar draws dalgylch cyfan afon Hafren.

Mae dalgylch Afon Hafren yn rhan o system gyflenwi dŵr fawr iawn. Mae tua chwe miliwn o bobl yn dibynnu arni am ddŵr yfed yn ogystal â nifer anferth o fusnesau, clybiau hamdden a bywyd gwyllt. Cyfrifoldeb Asiantaeth yr Amgylchedd a Chyfoeth Naturiol Cymru yw sicrhau bod Afon Hafren yn medru cynnal yr holl ddefnyddiau yma. Rhaid i ni benderfynu faint o ddŵr sydd angen ei ollwng i'r afon o ddŵr wyneb a storfeydd dŵr daear i gydbwyso anghenion yr afon a'r galw i dynnu dŵr i'r cyflenwad dŵr cyhoeddus; dyfrio trwy chwistrellu; busnesau; a mordwyaeth.

Tywodfaen Permo-Driasig yw un o'r prif ddyfrhaenau yn y Deyrnas Unedig, yn ail i Galchfaen yn unig. Mae hyn yn ei wneud yn ddelfrydol ar gyfer datblygu adnodd strategol ar raddfa fawr, gan fod effeithiau tynnu tymhorol ac adfer yn cael eu rhannu yn fwy gwastad dros gyfnodau hirach. Mae'r SGS yn defnyddio dŵr daear o'r adnodd naturiol hwn, sydd dan Ogledd Swydd Amwythig, i helpu i reoli Afon Hafren.

Profir gwytnwch y strategaeth hon, dan sefyllfaoedd eithafol fel sychder hir, gan ddefnyddio modelau dŵr wyneb a dŵr daear. Roedd y sefyllfa a gyflwynir yn yr adroddiad hwn yn modelu sychder difrifol yn ymestyn dros gyfnod o dair i bedair blynedd. Canfu y byddai Afon Hafren angen rhagor o gefnogaeth o storfeydd dŵr nag y mae caniatâd ar ei gyfer ar hyn o bryd. Dim ond lai nag unwaith bob 100 mlynedd ar gyfartaledd y byddem yn disgwyl gweld y math hwn o ddigwyddiad difrifol.

Yn absenoldeb adnoddau dŵr strategol eraill o gyfaint cyfwerth yn nalgylch Afon Hafren, y dewis gorau i reoli digwyddiadau o'r fath yw darparu adnodd dŵr daear ychwanegol trwy ymestyn hyd y pwmpio o'r isadeiledd SGS presennol.

Mae gan SGS uchafswm cynnyrch penodol ac felly ni ellir cynyddu cyfradd y tynnu dŵr, ac mae'r nifer o ddyddiau pwmpio wedi eu cyfyngu gan ei drwydded tynnu dŵr. Yn y sefyllfa hon bydd 3,680 megalitr (Ml) ychwanegol o gefnogaeth dŵr daear yn ofynnol y tu hwnt i gyfyngiad y drwydded bresennol. Mae hyn yn cyfateb yn fras i 21 diwrnod o gefnogaeth pwmpio ychwanegol ar 190Ml/d. Byddai hyn yn ychwanegu at ac yn cadw'r storfa dŵr wyneb mewn cronfa ddŵr, a thrwy hynny yn caniatáu cyfnod hirach o gefnogaeth barhaus i Afon Hafren yn ystod cyfnod o sychder a llif isel.

I gefnogi’r cais rydym wedi ystyried canlyniadau ymestyn gweithrediad y cynllun ar yr amgylchedd o gwmpas yr afon. Ni chanfu ein modelu unrhyw effeithiau sylweddol ar yr amgylchedd o ran ansawdd y dŵr, poblogaeth y pysgod ac anifeiliaid a phlanhigion yn yr afonydd. Mae’r profiad o weithredu’r cynllun hyd yn hyn wedi profi bod lefelau dŵr daear wedi adfer i lefelau cyn pwmpio o fewn un i dair blynedd o bob achlysur ar ôl pwmpio ac felly ystyrir bod SGS yn gweithredu mewn modd cynaliadwy. Bydd cyfanswm y dŵr daear a geisir gan y Gorchymyn Sychder yn fwy na’r hyn a bwmpiwyd yn y gorffennol gan SGS. Dylai lefelau’r dŵr daear felly ymadfer yn llawn, ond bydd hyn yn cymryd mwy o amser ar ôl digwyddiad eithafol.

Mae nifer fawr o nentydd naill ai na fydd y cynllun yn effeithio arnynt o gwbl, neu yn cael budd o weithredu’r cynllun. Mae gan y rhai y mae’n effeithio arnynt gamau yn eu lle yn barod i wneud iawn i’r llif. Ac eithrio Afon Hafren, bydd tua 41km o lednentydd a ddefnyddir gan y cynllun yn cael budd o’r cynnydd artiffisial yn y llif. Bydd y darnau hyn lle bydd y llif wedi ei gynyddu mewn cyflwr mwy ffafriol na chyrsiau dŵr nad ydynt yn cael eu cynyddu, a fydd yn profi llif isel oherwydd sychder.

Mae dalgylch Afon Hafren mewn lleoliad daearyddol manteisiol yn y Deyrnas Unedig gyda glawiad blynyddol trwm a mynediad at gronfeydd o ddŵr wyneb a dŵr daear. Mae defnyddio a chadw’r adnoddau hyn yn hanfodol i gael cydbwysedd yn nefnydd Afon Hafren i bobl, busnesau a’r amgylchedd. Mae gwerth rheoli’r adnoddau dŵr yma yn briodol, yn awr ac yn y dyfodol, yn dod yn fwy amlwg. Rhaid i ni ymdrin â’r sialensiau y mae newid hinsawdd yn eu creu a’r angen i addasu rheolaeth yr asedau hyn i ymdrin â’r patrymau tywydd eithafol y gall eu dwyn.

Non Technical Summary

Purpose of this Report

Droughts are infrequent events in the UK but when they do occur their impact can be significant. The Environment Agency has responsibility for alleviating the effects of drought on people, businesses and the environment through sensible management of water resources in England.

The purpose of this report is to support an application for a Drought Order for the Shropshire Groundwater Scheme (SGS). The application will allow us to increase the volume of water abstracted under the existing SGS licence. This report forms a supporting annex to the River Severn Drought Order Environmental Report, which aims to reduce the impact of a severe drought across the whole Severn catchment.

Background

The River Severn catchment forms part of a large water supply system. Around six million people rely on it for drinking water as well as a huge number of businesses, leisure clubs and wildlife. Ensuring that the River Severn is able to support all of these uses is the responsibility of the Environment Agency and Natural Resources Wales. We must decide how much water needs to be released to the river from both surface water and groundwater storage sources to balance the needs of the river against the demands of abstraction for public water supply; spray irrigation; business; and navigation.

The purpose of SGS is to provide a large strategic volume of groundwater to supplement and conserve the remaining storage in Clywedog reservoir, thereby allowing a longer period of support for the River Severn.

Shropshire Groundwater Scheme

Owned and operated by the Environment Agency, the SGS draws upon groundwater stored naturally within sandstone rocks underlying much of North Shropshire. Groundwater is pumped via boreholes, and then delivered through a network of pipelines, either directly to the River Severn, or via one of its major tributaries.

The scheme can currently deliver up to 190 megalitres per day (Ml/d) of groundwater to support to the river. Designed to be used intermittently, historic use of the scheme to date has averaged once every four years over the past 28 year life of the scheme (1984 to 2012).

Drought Demand Scenario

The resilience of the River Severn catchment, under extreme situations such as prolonged drought, is tested using surface water and groundwater models. The scenario presented in this report modelled a severe drought extending over a three to four year period. It found that the River Severn would require more support from its water stores than is currently consented. We would only expect to experience this type of severe event on average less than once every 100 years.

Water Resources

Permo-Triassic Sandstone is one of the most important principal aquifers in the UK, second only to the Chalk. This makes it ideal for large scale strategic resource development, as the effects of seasonal abstraction and recovery are more evenly distributed over longer periods within the environment. The SGS utilises groundwater from this natural resource, located beneath North Shropshire, to help manage the River Severn.

Experience of operating the scheme to date proves that groundwater levels have recovered to pre-pumping levels within one to three years of each pumping event. Therefore, SGS is considered to be operating sustainably. The amount of groundwater sought by the Drought Order will be greater than that previously pumped by SGS. Groundwater levels should make a full recovery, however this will take longer after an extreme event.

A large number of streams will either not be affected by, or benefit from, the operation of the scheme. Those that are affected already have compensation measures in place. Excluding the River Severn, approximately 41 km of tributary rivers and streams used by the scheme will benefit from artificially increased flows. These supported watercourses will be in a more favourable condition than unsupported watercourses experiencing low flows due to drought conditions.

Small volume private water supply sources (wells and boreholes), drilled to a shallower depth within the aquifer may be more sensitive to pumping operations. Larger volume commercial sources, such as public water supply and spray irrigation boreholes, tend to be more resilient and therefore less sensitive to groundwater level fluctuations. Wherever practicable, derogation risk should be identified before the impact is actually realised to avoid the need to implement emergency temporary supplies.

Groundwater and Surface Water Quality

Within the scheme a network of water quality sampling points is maintained to monitor the quality of the groundwater and the effect of its discharge to rivers. Analyses of historic data on the effect of water quality of rivers receiving groundwater from the operation of the scheme are considered to be overall neutral or beneficial. No significant deterioration in water quality is expected during the extended pumping duration required to support the Drought Order.

Ecology

The report looks at the effects of the Drought Order on; water dependent conservation sites, and aquatic animals and plants. The assessment focuses mainly on the River Tern, River Perry, Potford and Platt Brooks. These smaller tributaries receive multiple discharges from the SGS and are likely to have an ecology that is comparable to the middle and upper reaches of the much larger River Severn. They are regularly monitored and have a more limited capacity than the River Severn to accommodate changes in, for example, water quality or temperature, making them more sensitive to the effects of a Drought Order.

The operation of SGS is predicted to increase the proportion of groundwater to river water. Under summer conditions prolonged release of cooler groundwater could reduce river water temperatures that could have an effect on fish growth and survival, or slow invertebrate life cycles. Effects of groundwater discharge, specifically temperature differences, on fish and invertebrate populations would be localised at the point of release to watercourses. These effects are expected to dissipate within a short distance downstream, with a proportionally greater length of the watercourse benefiting from releases by the scheme under drought conditions. No significant deterioration in aquatic animal and plant populations is expected during the extended pumping duration required to support the Drought Order.

A total of 43 designation conservation sites were identified within the operational area of the scheme. Of these only three out of eight sites, considered to have links with groundwater from the sandstone, potentially may have some level of predicted impact from abstraction. Two out of these three potentially affected sites already have established flow compensation schemes. Trigger levels have been proposed to safeguard the third site.

Archaeology and Cultural Heritage

An appraisal has been undertaken on archaeological sites and scheduled monuments located within the operational area of the scheme. A hydrogeological screening exercise was undertaken to quantify at what depth the water table lies beneath the sites and the potential for changes to groundwater levels by pumping.

No significant deterioration is expected, however in the absence of site specific information on hydrogeological conditions underlying each site it is difficult to draw any quantifiable conclusions as to the potential risk posed to sites by the natural or induced fluctuation in groundwater levels.

Water Framework Directive

In pursuing an application to extend SGS beyond its current licence constraints consideration must be given to any potential impact this modification may have on the Water Framework Directive (WFD) status of the water body in which the scheme operates. SGS sits within the Shropshire Middle Severn Permo-Triassic Sandstone groundwater body. The current WFD assessment considers that the groundwater body is already at poor quantitative status failing for two out the four tests for groundwater.

There is an underlying long term commitment to manage the water body to attain good status and thus be compliant with WFD. The severity of the drought event considered under this scenario is recognised as being extreme with an expected low frequency of return. Any impact from the extended operation of SGS is likely to be relatively short-term; however recovery would be expected to be longer than that foreseen under ‘natural causes’. Further assessment work is required to fully quantify if any impact will be predicted, and whether this may delay the onset of improving conditions and the desired recovery of the body from poor to good status under WFD.

Environmental Action Plan

The Environment Agency has an established environmental monitoring network within the operational area of the scheme. This on-going programme has been specifically designed to collate and capture base line and operational data to assess the operation of the scheme on the surrounding environment.

While the network is sufficiently robust, the environmental action plan identifies a number of key actions to be met. This plan provides the basis with which to monitor and report upon the effects of any extended operational use of the scheme beyond it licensed limits.

Crynodeb Annhechnegol

Diben yr adroddiad hwn

Digwyddiad prin yw sychder yn y Deyrnas Unedig ond pan fydd yn digwydd gall ei effaith fod yn sylweddol. Mae gan Asiantaeth yr Amgylchedd gyfrifoldeb am liniaru effeithiau sychder ar bobl, busnesau a'r amgylchedd trwy reolaeth synhwyrol ar adnoddau dŵr yn Lloegr.

Diben yr adroddiad hwn yw cefnogi cais am Orchymyn Sychder ar gyfer Cynllun Dŵr daear Swydd Amwythig (SGS). Bydd y cais hwn yn caniatáu i ni gynyddu faint o ddŵr sy'n cael ei dynnu dan drwydded bresennol SGS. Mae'r adroddiad hwn yn atodiad i Adroddiad Amgylcheddol Gorchymyn Sychder Afon Hafren, sy'n anelu at leihau effaith sychder difrifol ar draws dalgylch cyfan afon Hafren.

Cefndir

Mae dalgylch Afon Hafren yn rhan o system gyflenwi dŵr fawr iawn. Mae tua chwe miliwn o bobl yn dibynnu arni am ddŵr yfed yn ogystal â nifer anferth o fusnesau, clybiau hamdden a bywyd gwyllt. Cyfrifoldeb Asiantaeth yr Amgylchedd a Chyfoeth Naturiol Cymru yw sicrhau bod Afon Hafren yn medru cynnal yr holl ddefnyddiau yma. Rhaid i ni benderfynu faint o ddŵr sydd angen ei ollwng i'r afon o ddŵr wyneb a storfeydd dŵr daear i gydbwyso anghenion yr afon a'r galw i dynnu dŵr i'r cyflenwad dŵr cyhoeddus; dyfrio trwy chwistrellu; busnesau; a mordwyo.

Diben SGS yw darparu cyfaint strategol mawr o ddŵr daear i ategu at y gofod storio yng nghronfa ddŵr Clywedog a'i gadw, a thrwy hynny gynnig cyfnod hirach o gefnogaeth i Afon Hafren.

Cynllun Dŵr daear Swydd Amwythig

Mae'r SGS, sy'n eiddo i Asiantaeth yr Amgylchedd ac yn cael ei redeg ganddi, yn tynnu ar ddŵr daear sy'n cael ei storio yn naturiol mewn creigiau tywodfaen sydd dan ran helaeth o Ogledd Swydd Amwythig. Caiff dŵr daear ei bwmpio trwy ddyfrdyllau, ac yna ei gyflenwi trwy rwydwaith o bibelli, naill ai yn uniongyrchol i Afon Hafren, neu trwy un o'i phrif lednentydd.

Ar hyn o bryd gall y cynllun gyflenwi hyd at 190 megalitr y dydd (Ml/d) o ddŵr daear i gefnogi'r afon. Dyluniwyd y cynllun i'w ddefnyddio yn achlysurol, mae'r defnydd hanesyddol ar y cynllun hyd yn hyn wedi bod ar gyfartaledd o unwaith bob pedair blynedd dros 28 mlynedd diwethaf oes y cynllun (1984 hyd 2012).

Senario Galw Oherwydd Sychder

Profir gwytnwch dalgylch Afon Hafren, dan sefyllfaoedd eithafol fel sychder hir, gan ddefnyddio modelau dŵr wyneb a dŵr daear. Roedd y sefyllfa a gyflwynir yn yr adroddiad hwn yn modelu sychder difrifol yn ymestyn dros gyfnod o dair i bedair blynedd. Canfu y byddai Afon Hafren angen rhagor o gefnogaeth o'i storfeydd dŵr nag y mae caniatâd ar ei gyfer ar hyn o bryd. Ni fyddem yn disgwyl profi'r math hwn o ddigwyddiad difrifol ond ar gyfartaledd o unwaith bob 100 mlynedd.

Adnoddau Dŵr

Tywodfaen Permo-Driasig yw un o'r prif ddyfrhaenau yn y Deyrnas Unedig, yn ail i Galchfaen yn unig. Mae hyn yn ei wneud yn ddelfrydol ar gyfer datblygu adnodd strategol ar raddfa fawr, gan fod effeithiau tynnu tymhorol ac adfer yn cael eu rhannu yn fwy gwastad dros gyfnodau hirach yn yr amgylchedd. Mae'r SGS yn defnyddio dŵr daear o'r adnodd naturiol hwn, sydd dan Ogledd Swydd Amwythig, i helpu i reoli Afon Hafren.

Mae'r profiad o weithredu'r cynllun hyd yn hyn wedi profi bod lefelau dŵr daear wedi adfer i lefelau cyn pwmpio o fewn un i dair blynedd o bob achlysur pwmpio. Ystyrir felly bod SGS yn gweithredu mewn modd cynaliadwy. Bydd cyfanswm y dŵr daear a geisir gan y Gorchymyn Sychder yn fwy na'r hyn a bwmpiwyd yn y gorffennol gan SGS. Dylai lefelau'r dŵr daear ymadfer yn llawn, ond bydd hyn yn cymryd mwy o amser ar ôl digwyddiad eithafol.

Mae nifer fawr o nentydd naill ai na fydd y cynllun yn effeithio arnynt o gwbl, neu yn cael budd o weithredu'r cynllun. Mae gan y rhai y mae'n effeithio arnynt gamau yn eu lle yn barod i wneud iawn am hynny. Ac eithrio Afon Hafren, bydd tua 41km o is-afonydd a llednentydd a ddefnyddir gan y cynllun yn cael budd o'r cynnydd mewn llif. Bydd y cyrsiau dŵr yma, sy'n cael eu cynnal, mewn cyflwr mwy ffafriol na chyrsiau dŵr nad ydynt yn cael eu cynnal sy'n profi llif isel oherwydd sychder.

Gall ffynonellau cyflenwad dŵr bychan preifat (ffynhonnau a dyfrdyllau), sydd wedi eu tyllu i ddyfnder mwy bas yn y ddyfrhaen fod yn fwy sensitif i weithrediadau pwmpio. Mae ffynonellau masnachol mwy, fel cyflenwad dŵr cyhoeddus a dyfrdyllau dyfrio trwy chwistrellu, yn dueddol o fod yn fwy gwydn ac felly yn llai sensitif i amrywiadau yn lefel y dŵr daear. Pryd bynnag y bydd hynny'n ymarferol, dylai risg o amharu gael ei dynodi cyn i'r effaith gael ei weld mewn gwirionedd i osgoi'r angen i weithredu cyflenwadau dros dro mewn argyfwng.

Ansawdd Dŵr Daear a Dŵr Wyneb

Yn y cynllun mae rhwydwaith o bwyntiau profi ansawdd dŵr yn cael ei chynnal i fonitro ansawdd y dŵr daear ac effaith ei ollwng i afonydd. Yn gyffredinol ystyrir bod dadansoddiadau o ddata hanesyddol ar effaith derbyn dŵr daear trwy weithredu'r cynllun yn niwtral neu fanteisiol. Ni ddisgwylir gweld unrhyw ddirywiad yn ansawdd y dŵr yn ystod y cyfnod hwy o bwmpio sy'n ofynnol i gefnogi'r Gorchymyn Sychder.

Ecoleg

Mae'r adroddiad yn edrych ar effeithiau'r Gorchymyn Sychder ar; safleoedd cadwraeth sy'n ddibynnol ar ddŵr, ac anifeiliaid a phlanhigion dyfrol. Mae'r asesiad yn canolbwyntio yn bennaf ar Afon Tern, Afon Perry, a nentydd Potford a Platt. Bydd y llednentydd llai yma yn derbyn gollyngiadau niferus o'r SGS ac maent yn debygol o fod ag ecoleg sy'n debyg i ddarnau canol ac uchaf Afon Hafren sy'n llawer mwy. Maent yn cael eu monitro yn gyson ac mae ganddynt lai o allu nag Afon Hafren i dderbyn newidiadau mewn, er enghraifft, ansawdd neu dymheredd y dŵr, gan eu gwneud yn fwy sensitif i effeithiau Gorchymyn Sychder.

Rhagwelir y bydd gweithredu SGS yn cynyddu'r gyfran o ddŵr daear i ddŵr afon. Yn yr haf gall gollwng dŵr daear am gyfnod hir ostwng tymheredd dŵr yr afon a allai gael effaith ar dwf a goroesiad pysgod, neu arafu cylched bywyd anifeiliaid di-asgwrn-cefn. Byddai effeithiau gollwng dŵr daear, gwahaniaethau mewn tymheredd yn benodol, ar bysgod a'r boblogaeth ddi-asgwrn-cefn yn cael ei gadw i'r ardal lle byddai dŵr yn cael ei ollwng i gyrsiau dŵr. Disgwylir i'r effeithiau yma ddiflannu ychydig i lawr yr afon, gyda mwy o hyd y cwrs dŵr yn manteisio ar ollyngiadau gan y cynllun mewn sychder. Ni ddisgwylir unrhyw ddirywiad sylweddol yn y boblogaeth o anifeiliaid a phlanhigion dyfrol yn ystod y cyfnod pwmpio hwy sy'n ofynnol i gefnogi'r Gorchymyn Sychder.

Dynodwyd cyfanswm o 43 safle cadwraeth yn ardal weithredu'r cynllun. O'r rhain dim ond tri safle allan o wyth, yr ystyrir bod ganddynt gysylltiad â'r dŵr daear o'r tywodfaen, a all weld rhyw effaith a ragwelir o'r tynnu dŵr. Mae gan ddau o'r tri safle yma, a allai weld effeithiau, eisoes gynlluniau i wneud iawn am golli llif. Cynigiwyd lefelau ysgogi i ddiogelu'r trydydd safle.

Archaeoleg a Threftadaeth Ddiwylliannol

Cynhaliwyd gwerthusiad ar safleoedd archeolegol a henebion rhestredig sydd yn ardal weithredu'r cynllun. Cynhaliwyd ymarfer sgrinio hydroddaearegol i fesur ar ba ddyfnder y mae'r lefel trwythiad dan y safleoedd a'r potensial i lefelau dŵr daear newid oherwydd y pwmpio.

Ni ddisgwylir unrhyw ddirywiad sylweddol, ond yn absenoldeb gwybodaeth benodol am yr amodau hydroddaearegol sydd dan bob safle mae'n anodd llunio unrhyw gasgliadau mesuradwy o ran y risg bosibl y mae'r safleoedd yn ei greu i'r amrywiad naturiol neu sydd wedi ei gymell yn lefelau dŵr daear.

Cyfarwyddeb Fframwaith Dŵr

Wrth weithio ar gais i ymestyn SGS y tu hwnt i'r cyfyngiadau presennol yn ei drwydded, rhaid rhoi ystyriaeth i unrhyw effaith bosibl y bydd yr addasiad hwn yn ei gael ar statws Cyfarwyddeb Fframwaith Dŵr (WFD) y corff o ddŵr y mae'r cynllun yn gweithredu ynddo. Mae SGS yn sefyll yng nghorff dŵr Tywodfaen Permo-Triasig Canol Hafren Swydd Amwythig. Mae'r asesiad WFD presennol yn ystyried bod y corff dŵr daear eisoes ar statws ansoddol gwael gan fethu ar ddau o'r pedwar prawf i ddŵr daear.

Mae ymrwymiad sylfaenol tymor hir i reoli'r corff dŵr i gyrraedd statws da ac felly gydymffurfio â'r WFD. Mae difrifoldeb y sychder sy'n cael ei ystyried yn y sefyllfa hon yn cael ei gydnabod fel un eithafol ac yn anaml y disgwylid iddo ddigwydd wedyn. Mae'n debygol mai cymharol fyrdymor fydd unrhyw effaith o ymestyn gweithrediad yr SGS; ond disgwylid i'r adfer fod yn hwy na'r un a ragwelir dan 'achosion naturiol'. Bydd angen rhagor o waith asesu i fesur yn llawn a fydd unrhyw effaith yn cael ei ragweld, ac a all hyn beri oedi o ran gwella amodau a gweld y corff yn adfer o statws gwael i statws da dan WFD.

Cynllun Gweithredu Amgylcheddol

Mae Asiantaeth yr Amgylchedd wedi sefydlu rhwydwaith monitro amgylcheddol yn ardal weithredu'r cynllun. Cynlluniwyd y rhaglen hon yn benodol i gasglu a chrynhoi data gwaelodlin a gweithredol i asesu gweithrediad y cynllun ar yr amgylchedd o'i gwmpas.

Er bod y rhwydwaith yn ddigon cadarn, mae'r cynllun gweithredu amgylcheddol yn nodi nifer o gamau allweddol sy'n rhaid eu cyflawni. Mae'r cynllun yn cynnig y sylfaen i fonitro a rhoi adroddiad ar effeithiau unrhyw ddefnydd gweithredol estynedig y tu hwnt i'r cyfyngiadau trwyddedig.

Contents

1. Introduction

1.1 General Legal Context

The Environment Agency has statutory duties under the Water Resources Act 1991, and further duties and powers under the Water Act 2003, to take such actions as it considers necessary to conserve, redistribute, augment and secure proper use of water resources in England.

Under the Environment Act 1995 the Environment Agency also has general environmental duties in relation to all of its functions, including the need to conserve and enhance the environment. Section 4 of the Act requires the Environment Agency to take account of sustainability in all its operational and regulatory activities. It thus aims to manage water resources to achieve the correct balance between the needs of the environment and those of abstractors who require water for public consumption, agriculture and industry. An Environment Agency strategy is to achieve the sustainable development of water resources. Section 6 of the Environment Act 1995 requires the Environment Agency to promote nature conservation and amenity of the aquatic environment as well as recreational use of waters and land, associated with such waters.

Droughts are infrequent events in the UK. Nevertheless, the Environment Agency has responsibilities for alleviating the impacts of drought by ensuring that adequate resources are developed to maintain continuity of supply, by operating augmentation schemes, and planning with abstractors ways of minimising drought impact. The Environment Agency may apply to the Secretary of State for the Department for Environment, Flood and Rural Affairs (Defra) for a drought order which enables it to take measures to cope with water shortages during a drought.

1.2 Shropshire Groundwater Scheme Drought Order

The River Severn is a regulated river, which forms part of a large water supply and management system. Under low flow conditions surface water storage reservoirs and a groundwater abstraction scheme are used to augment the river to maintain its good ecological status and balance the demands of abstraction for; public water supply, spray irrigation, industry, and navigation. Prior to the 1980s regulation within the Severn river basin lay solely with large surface water storage reservoirs (Clywedog and Vyrnwy Water Bank) located in mid Wales. Since the 1980s further strategic water resource planning within the basin has focused on the phased development of groundwater storage via the Shropshire Groundwater Scheme (SGS). The location of SGS Phases 1, 2, 3 and 4 infrastructure covered by this report are shown in Figure 1.1.

The Environment Agency is the lead organisation with responsibility for regulation of the River Severn in consultation with Natural Resources Wales. This is statutory controlled through provisions under the Clywedog Reservoir Joint Authority Act 1963, and the Operating Rules for the River Severn Resource/ Supply System. These documents set out a system of operating rules developed for the day to day management of the system to maintain, under normal conditions, a minimum flow of 850 megalitres per day (averaged over five days) measured within the River Severn at Bewdley. The rules serve to provide an early indication of problems in maintaining supply during a drought period, triggering the Environment Agency to put in to place its drought action plans to conserve, redistribute, augment and secure proper use of water resources to safeguard the environment.

Within its drought plans the Environment Agency has identified the potential need for a River Severn Drought Order following a long spell of dry weather affecting the River Severn Catchment. The drought order is designed to protect the environment of the River Severn during a drought by allowing changes to the conditions governing river regulation.

As the Environment Agency is the lead organisation responsible for the regulation of the River Severn system, including ownership and operation of the Shropshire Groundwater Scheme, it is the Environment Agency who applies to Defra for the drought order in respect to the groundwater scheme.

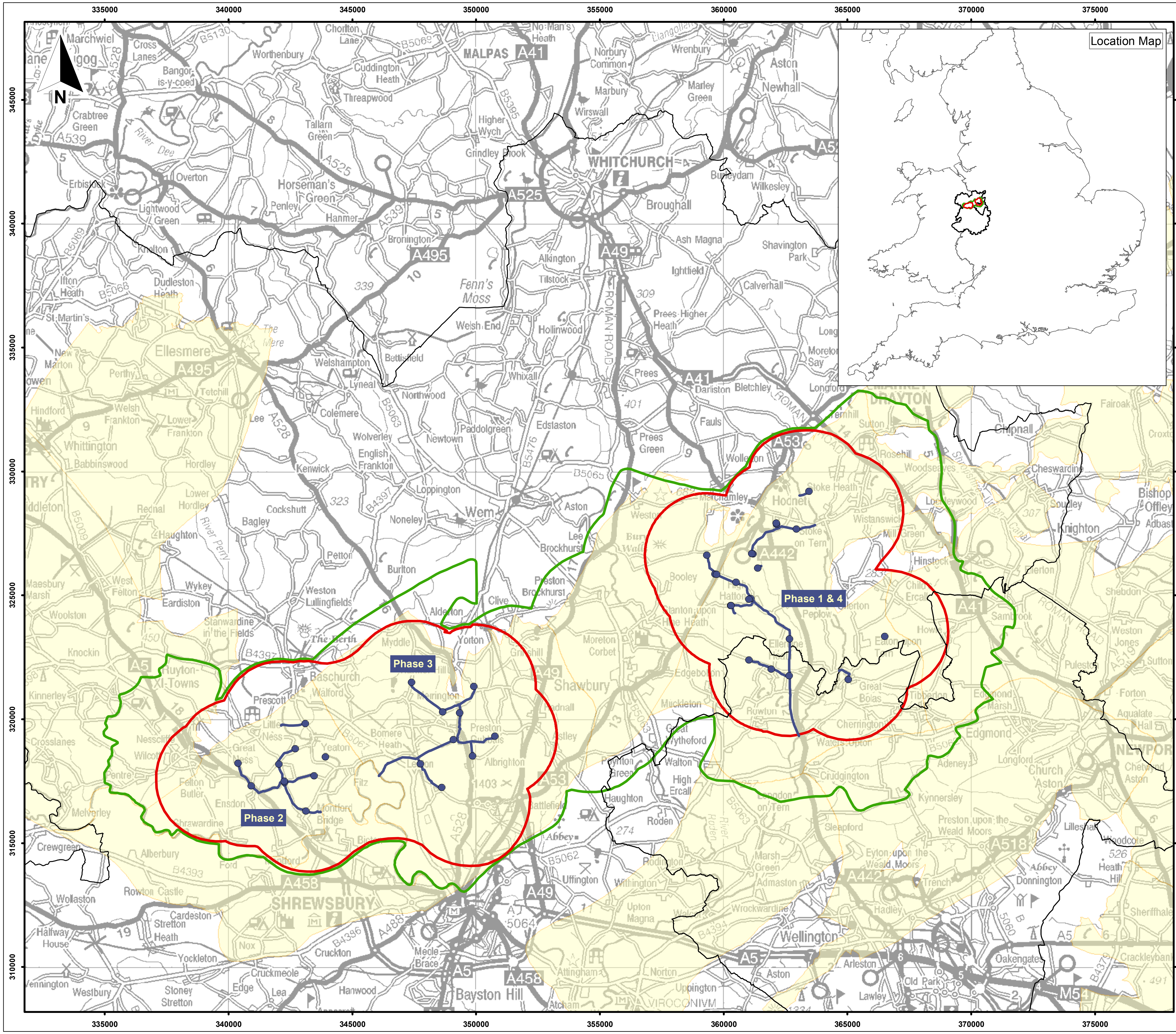
1.3 Purpose of this Environmental Report

It is a requirement that any application for a drought order shall be accompanied by an Environmental Report providing an assessment of the expected environmental effects of the order. The requirements of an Environmental Report are defined in the Defra guidance.

This Environmental Report has been commissioned by the Environment Agency (Midlands Region) to support an application for a drought order to permit an increase to the annual and five year volume limits currently permitted by the SGS abstraction licence to meet an extreme and prolonged drought period. This SGS Environmental Report will form part of an annex to a separate report that has been compiled to support a drought order application for the River Severn system as a whole.

The Environment Agency has set high standards of environmental best practice for itself and this document has been prepared to meet the Defra guidelines (Drought permits and drought orders, May 2011). This document comprises the Non-Technical Summary and the Environmental Report which describes the condition of the current environment, prediction of any impacts and identification of mitigation measures to avoid, reduce or remedy these effects.

Copies of this Environmental Report and Non-Technical Summary are available from the Environment Agency, Midlands Region, in standard hard copy and electronic CD format.



Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Shropshire County Boundary

Project Path: G:/MODEL/PROJECTS/EA-210/22720/Figures/22720s01_Fig1.1.mxd

Environment Agency
Shropshire Groundwater Scheme Drought Order
Environmental Report

Figure 1.1
Shropshire Groundwater Scheme - Setting

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2. Shropshire Groundwater Scheme Drought Order Rationale and Proposal

2.1 Introduction

The River Severn is a major river of national environmental importance. Along its 354 km course it provides a vital supply artery supporting high quality ecosystems and a principal source of water to sustain public drinking water, industrial and agriculture serving the six million population of the West Midlands. The flow in the River Severn is artificially maintained to ensure these needs are met without adversely affecting the natural environment. When rainfall is low and river flows are insufficient to meet these needs, flows are maintained by releasing water from the three storage components of the River Severn Regulation System:

- **Clywedog Reservoir built c1968** – Principle storage component & purpose-built to regulate the River Severn. Maximum storage 50,000 Megalitres (Ml) (50 Million cubic metres) Maximum release 500Ml/d;
- **Shropshire Groundwater Scheme phased development 1982 to present -** Utilises groundwater resources naturally stored within the North Shropshire Permo-Triassic Sandstone formations for river regulation purposes. Maximum licence potential 330Ml/d, current deployable yield 190Ml/d;
- **Vyrnwy Reservoir built c1860 -** supply reservoir for Liverpool. The reservoir exports the majority of its water out of the Severn Basin into the United Utilities supply area. A small proportion of its 59,600 Ml storage is set aside, through the Vyrnwy Water Bank arrangement, for regulating the River Severn.

Prior to the 1980s water resource development within the Severn river basin lay solely with the construction of the large surface water storage reservoirs located in mid Wales at the headwaters of the rivers Severn and Vyrnwy. Since the 1980s further strategic water resource within the Severn supply zone has focused on the phased development of groundwater via the SGS.

2.2 River Severn Regulation System

Operational use of the storage components designed to regulate the River Severn is controlled by statutory conditions laid out in the Operating Rules for the River Severn Resource/ Supply System. These rules govern how much water is released to the river system from both surface water and groundwater storage sources. These rules ensure the river is managed to ensure that abstractor’s needs are met without compromising the river’s ability to support the natural environment.

The control rules require two principle conditions to be met before any releases can be made:

Condition 1 Flow – Minimum Prescribed Flow at Bewdley

Release of water from Clywedog to the River Severn is controlled by the Clywedog Reservoir Joint Authority Act 1963 (CRJA). This Act was revised after the 1976 drought to set a statutory requirement to maintain a minimum flow of 850 Ml per day (Ml/d), averaged over 5 days, as measured within the River Severn at Bewdley. When the river flow approaches the minimum prescribed flow instructions are issued to commence releasing water. Clywedog is the principal storage component of the system, followed by the Shropshire Groundwater Scheme. Additional supplementary releases can be made from the Vyrnwy Water Bank allocation.

Condition 2 Storage – Clywedog Storage Control Curves

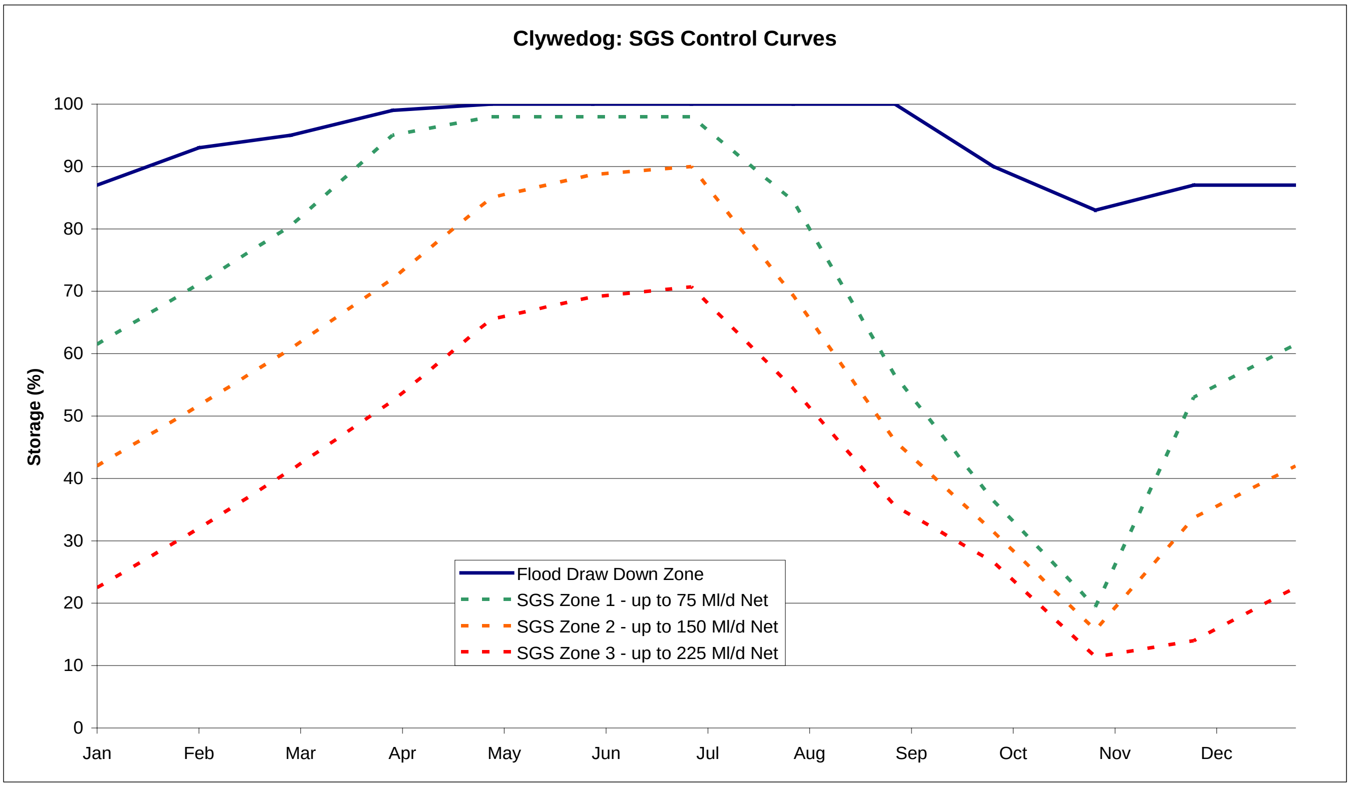
Under average rainfall conditions, the storage at Clywedog is sufficient to meet normal river water demands. Additional support from SGS is only triggered when storage levels in Clywedog fall below the first of a series of SGS Control Curves. The control curves have been devised to make optimum use of water stored at Clywedog and to prevent premature or unnecessary use of the Groundwater Scheme.

The shape of the control curves allows use of the Groundwater Scheme at the on-set of a dry period in the early part of the year. This is designed to safeguard surface reservoir storage in the event of a prolonged dry weather period extending into mid- or late summer when water resources can reach critical levels. To assist with water resource management, additional control curves identify the need to seek and impose drought order contingency plans.

Multiple control curves have been devised to define zones of increasing demand from SGS (Figure 2.1). In practice SGS zone 1 requires the combined out-put from two full Phases of SGS (total gross yield 100 Ml/d), while progression into SGS zone 2 would require the combined deployable yield from all four Phases currently available (total gross combined yield 190 Ml/d).

The reservoirs provide water by gravity,, but as SGS must be pumped, it is only used when it is identified that surface storage could be at greater risk of being drawn down to low levels. Conversely, because of the limitation of maximum discharge rate, Shropshire Groundwater must be used over an extended period to produce a significant volume of water.

Figure 2.1 **Clywedog Reservoir – Shropshire Groundwater Scheme Multiple Control Curves (All Other Control Curves excluded)**



2.3 Shropshire Groundwater Scheme

Owned and operated by the Environment Agency (Midlands Region), the Shropshire Groundwater Scheme is one of the largest groundwater regulation schemes currently operating in the UK.

The Scheme draws water from large underground water supplies occurring naturally within the Permo-Triassic sandstone formations underlying much of North Shropshire. Groundwater is abstracted via boreholes drilled into the sandstone. The pumped groundwater is discharged through a buried network of pipelines, either directly into the River Severn, or via one of the River Severn's major tributaries (Figure 2.2).

Originally conceived and promoted by the Severn Trent Water Authority, the Scheme was empowered by the Secretary of State in October 1981 via the "*The Severn-Trent Water Authority (Shropshire Groundwater) Order 1981*" Parliamentary Order. This granted formal powers governing the development of up to 8 designated phases permitting the abstraction of up to 330 Ml/d, 39,000 Ml per year or 84,000 Ml in any five year rolling period for river regulation purposes.

With the granting of formal permission for the Scheme in 1981, Phase 1, 2 and 3 were developed between 1982 and 1999 to generate a maximum combined gross yield of 145 Ml/d. Government approval for the development of a further gross yield of 100 Ml/d via the construction of Phase 4 and 5 was granted in 1997 to meet a projected resource shortfall. Construction of these phases commenced in 1998. Phase 4 was commissioned in 2005 with a gross projected output of 45 to 50 Ml/d. Originally due for commissioning in 2005, Phase 5 is currently on hold pending an investigation of groundwater quality issues (gross output projected at 60 to 65 Ml/d). Water resource demands up to 2011 have not yet justified the construction of Phases 6, 7 and 8. To date the Agency has invested in the region of £15 million in developing the first 5 of the possible 8 phases.

Table 2.1 Summary of Phase Development Status, Operational Years and Gross Yield

Phase	Development Status	Operational Years	Number of Abstraction Boreholes	Maximum Gross Combined Yield (Ml/d)
Phase 1	Commissioned 1984	1984, 1989, 1995, 1996, 2006, 2010 & 2011	10	40
Phase 2	Commissioned 1991	1995, 1996, 2006 & 2010	10	50
Phase 3	Commissioned 1999	2006, 2010 & 2011	9	50
Phase 4	Commissioned 2005	2006, 2010 & 2011	10	45 to 50
Phase 5	Under development		11	50 to 65
Phase 6	Not developed			
Phase 7	Not developed			
Phase 8	Not developed			

From the outset the Scheme was specifically designed to allow a staged development strategy over a number of years. This strategy permits each Phase to be constructed and operated independently, thereby providing maximum flexibility to meet a wide range of river flow requirements. It also avoids premature expenditure as future Phase development can be delayed until rising water demand justifies further expansion of the Scheme.

The Groundwater Scheme boreholes are designed to be used in short bursts during periods of prolonged low rainfall. It is estimated that the Scheme will only be operated for two out of every five years, averaging between three to fifteen weeks pumping per year. This is based on weather patterns observed over the past fifty years. Operational experience of the Scheme between 1984 and 2011 has seen actual use averaging once every three and a half years with combinations of phases being called upon in the summers of 1984, 1989, 1995, 1996, 2006, 2010 and 2011 to contribute to river regulation. During these summers actual operational support has ranged from one to eleven weeks in total (see Table 3.2).

2.3.1 SGS Abstraction Licence 18/54/04/1118/G

Abstraction of groundwater from the sandstone aquifer by the Shropshire Groundwater Scheme is governed by abstraction licence 18/54/04/1118/G. Granted on 21 August 1981 by the Secretary of State, the licence is unique in that it granted abstraction of groundwater from boreholes that had yet to be drilled and test pumped to prove individual yields. The licence was granted in this way to permit the future phased development of the Scheme as described at the 1979 SGS Public Inquiry.

The licence permits a maximum aggregate gross abstraction not exceeding 330 Ml/d, 39,000 Ml/ year or 84,000 Ml in any five year rolling period from the development of up to 8 Phases as defined by the Severn Trent Water Authority (Shropshire Groundwater) Order 1981.

The licence is sub-divided by Phase to define a group of abstractions with one or more common combined, or stand-alone discharge point. Each Phase has been allocated maximum annual one year and five year rolling licence gross aggregate volumes (Table 2.2).

The abstraction licence ensures that.

- Groundwater can only be abstracted for the purpose of river flow augmentation when storage levels within Llyn Clywedog reservoir cannot meet protected water demands. The only exception to this rule being the abstraction of water for testing purposes. The abstraction licence is therefore linked to conditions laid out in the Severn Trent Water Authority (Shropshire Groundwater) Order 1981 and River Severn Regulation as defined by the Clywedog Reservoir Joint Authority Act 1963;

- All water pumped from the Scheme's boreholes must be individually metered and recorded to ensure that volumes do not exceed the authorised amounts. This includes all water abstracted for "testing" or "maintenance" purposes, which are attributable against the licence;

- Operating under one umbrella licence, each phase has been allocated one and five year rolling volumes. In any five consecutive years the "one year maximum volume" cannot be abstracted more than two and half times, which imposes an operational constraint on the management of the Scheme. This in-built safeguard ensures sufficient time for the groundwater within the aquifer to be recharged from annual winter rainfall to maintain a sustainable water balance.

Table 2.2 Shropshire Groundwater Scheme Abstraction Licence (18/54/04/1118/G) Maximum One Year and Five year Rolling Volumes and Number of Pumping Days by Phase and Scheme

Phase	Maximum Combined Gross Yield Ml/d	Development Status	Maximum Volume Permitted to be Pumped in any One Year (Ml)	Maximum Number of Abstraction Days per Year	Maximum Volume Permitted to be Pumped in Any Five Year Period (Ml)	Maximum Number of Abstraction Days per Five Year Rolling Period
Phase 1 : Tern I	45 Ml/d	Commissioned 1984	6,700	148	14,500	322
Phase 2a : South Perry	9 Ml/d	Commissioned 1991	1,900	211	4,100	455
Phase 2b : Montford	41 Ml/d	Commissioned 1991	4,600	112	10,100	246
Phase 3 : Leaton	50 Ml/d	Commissioned 1999	5,600	112	12,200	244
Phase 4 : Tern II	45 Ml/d	Commissioned 2005	6,700	134	14,600	292
Phase 5 : Astley	60 to 65 Ml/d	Awaiting commissioning	6,500	100 to 108	14,100	216 to 235
Phase 6 : Roden	N/A	Not developed	2,700	N/A	5,700	N/A
Phase 7 : North Perry	N/A	Not developed	4,200	N/A	9,300	N/A
Phase 8 : Tern III	N/A	Not developed	6,100	N/A	13,200	N/A
Total Scheme	**330**		**39,000**		**84,000**	

2.3.2 SGS Infrastructure

Each Phase of the Scheme follows a similar design comprising a cluster of groundwater abstraction boreholes, linked by a network of underground pipelines through which pumped groundwater is discharged to the receiving watercourse. Within each Phase individual abstraction boreholes either discharge via one common outfall or a number of independent outfalls. On the larger outfalls, prior to discharge to the river, groundwater is passed through a sand trap structure (underground settlement tank) to remove large suspended solids. The sand traps also incorporate cascades, designed to increase the dissolved oxygen content of the water before it enters the watercourse.

The following section provides background information on the location and distribution of abstraction and discharge points and distribution mains making up each of the operational Phases of the Scheme. Individual borehole deployable yields and interconnectivity of grouped boreholes to common discharge points are tabulated (Table 2.3 – 2.6) and illustrated (Figures 2.2 and 2.3).

Phase 1 Tern I

Commissioned in 1984, this phase comprises 11 abstraction boreholes spread between 9 individual pumping stations. Located largely on Permian sandstone centred to the south of Hodnet village, North Shropshire, Phase 1 is capable of generating a combined gross yield of 45 Ml/d.

The northern half of the well field comprises two stand alone pumping stations at Helshaw Grange and Hodnet No1, which independently discharge direct to the River Tern at Stoke on Tern. To the south, the main well field comprises Hopton, Lodgebank No1 & No2, Green Lane, Heath House No1 and Ellerdine Heath. The output from all these boreholes is discharged direct to the River Tern via one common outfall at Waters Upton (Figure 2.2).

In addition there are three stream compensation boreholes at Greenfields (discharging to Potford Brook), Heath House No2 (discharging to Platt Brook) and Child’s Ercall (discharging to Allford Brook). Since commissioning in 1984 the Phase has been operationally used to contribute to river regulation in 1984, 1989, 1995, 1996, 2006, 2010 and 2011.

Table 2.3 Summary of Phase 1 Pumping Stations Operational Yields (Summer 1996), Discharge Points and Receiving Watercourses

Pumping Station	Operational Pumping Rate Ml/d	River Discharge Point	Maximum Combined Discharge Rate Ml/d	Receiving Watercourse
Northern Group				
Helshaw Grange	6.5 Ml/d	River Tern at Helshaw Grange	7 Ml/d	River Tern
Hodnet No1	6.7 Ml/d	Stoke on Tern (also used by Phase 4)	7 Ml/d	River Tern
Southern Group				
Hopton	6.7 Ml/d	River Tern at Waters Upton (also used by Phase 4)	30 Ml/d	River Tern
Lodgebank No 1	5.4 Ml/d			
Lodgebank No 2	5.4 Ml/d			
Green Lane	7.0 Ml/d			
Heath House No 1	3.8 Ml/d			
Ellerdine Heath	4.1 Ml/d			
Stream Compensation				
Green Fields	2 Ml/d	Potford Brook at Greenfields	2 Ml/d	Potford Brook
Heath House No2	2 Ml/d	Platt Brook at Heath House Farm	2 Ml/d	Platt Brook
Child's Ercall	2 Ml/d	Allford Brook Culvert at Child's Ercall	2 Ml/d	Allford Brook

Phase 2 South Perry and Montford

Centred on the disused airfield at Forton Heath, Phase 2 is located approximately 5 km north west of Shrewsbury, North Shropshire. The Phase comprises ten abstraction boreholes distributed between nine individual pumping stations. These generate a combined gross yield of 50 Ml/d. Two out the nine pumping stations (Frankbrook and Grafton) discharge groundwater direct to the River Perry via independent outfalls. The remaining seven (Ensdon, Bank House, Forton, Forton Heath, Nib Heath, Knolls No1 & No2 and Rodefern) form the main group discharging direct to the River Severn, via one common outfall situated approximately 1.5 km downstream of Montford Bridge (Figure 2.3). Commissioned in 1991 Phase 2 has contributed to river regulation during 1995, 1996, 2006 and 2010.

Table 2.4 Summary of Phase 2 Pumping Stations Operational Yields (Summer 1996), Discharge Points and Receiving Watercourses

Pumping Station	Operational Pumping Rate Ml/d	River Discharge Point	Maximum Combined Discharge Rate Ml/d	Receiving Watercourse
Perry Group				
Frankbrook	5.7 Ml/d	River Perry at Adcote	5.7 M/d	River Perry
Grafton	3.4 Ml/d	River Perry at Grafton	3.4 Ml/d	River Perry
Montford Group				
Bank House	5.1 Ml/d	River Severn at Montford Bridge	48 Ml/d	River Severn
Ensdon	5.2 Ml/d			
Forton	6.7 Ml/d			
Forton Heath	5.4 Ml/d			
Knolls No 1	6.6 Ml/d			
Knolls No 2	5.9 Ml/d			
Nib Heath	6.7 Ml/d			
Rodefern	5.2 Ml/d			

Phase 3 Leaton

Centred on the village of Bomere Heath, approximately 4 km directly north of Shrewsbury, North Shropshire, this phase comprises nine individual pumping stations. These discharge a combined gross yield of 50 Ml/d direct to the River Severn via one common outfall at Leaton (Figure 2.3). Commissioned in 1999, this Phase has contributed to River Severn regulation in 2006, 2010 and 2011.

Table 2.5 Summary of Phase 3 Pumping Stations Operational Yields (Summer 2006), Discharge Points and Receiving Watercourses

Pumping Station	Operational Pumping Rate Ml/d	River Discharge Point	Maximum Combined Discharge Rate Ml/d	Receiving Watercourse
Albrighton	5.8 Ml/d	River Severn at Leaton	50 Ml/d	River Severn
Great Wollascott	7.0 Ml/d			
Merrington Lane	6.9 Ml/d			
Newton	7.1 Ml/d			
Pim Hill	5.9 Ml/d			
Plex	6.4 Ml/d			
Preston Gubbals	5.9 Ml/d			
Shawell Cottage	6.7 Ml/d			
Smethcote	7.3 Ml/d			

Phase 4 Tern II

This phase represents the second stage of resource development within the Tern area. Interspersed and physically inter-linked with the Phase 1 Tern I infrastructure, Phase 4 comprises ten abstraction boreholes spread between eight individual pumping stations grouped into northern and southern well fields. The combined gross yield of this Phase is in the region of 45 Ml/d.

The northern half of the well field comprises new pumping stations at Cotton Farm, Espley (No1 & No2) and development of a second abstraction borehole (Hodnet No 2) on the existing Phase 1 site at Hodnet. All three pumping stations discharge direct to the River Tern via the existing Phase 1 outfall at Stoke on Tern. To the south new pumping stations have been constructed at High Hatton (No1 & No2), Woodmill, Windyoak and Ellerdine Station, these link into the existing Phase 1 main pipeline which discharges direct to the River Tern via one common outfall at Waters Upton. In addition, one standalone pumping station has been developed at Great Bolas which discharges direct to the River Tern at Bolas Bridge (Figure 2.2).

Construction of this Phase was completed in 2002 and a five week group commissioning test was completed in summer 2005. Elements of Phase 4 were used in summer 2006, 2010 and 2011 to contribute to river regulation.

Table 2.6 Summary of Phase 4 Pumping Stations Operational Yields (summer 2005), Discharge Points and Receiving Watercourses

Pumping Station	Operational Pumping Rate Ml/d	River Discharge Point	Maximum Combined Discharge Rate Ml/d	Receiving Watercourse
Northern Group				
Cotton Farm	4.1 Ml/d	River Tern at Stoke on Tern (also used by Phase 1)	20 Ml/d	River Tern
Hodnet No2	4.3 Ml/d			
Espley No1	5.7 Ml/d			
Espley No2	5.8 Ml/d			
Southern Group				
High Hatton No1	5.9 Ml/d	River Tern at Waters Upton (also used by Phase 1)	25 Ml/d	River Tern
High Hatton No2	6.3 Ml/d			
Woodmill	5.3 Ml/d			
Windyoak	3.8 Ml/d			
Ellerdine Station	3.7 Ml/d			
Stand Alone				
Great Bolas	7 Ml/d	River Tern at Bolas Bridge	7 Ml/d	River Tern

Phase 5 Astley

Phase 5 has been developed on the sandstone aquifer around the villages of Hadnall and Shawbury, North Shropshire. The phase comprises 11 abstraction boreholes spread between 8 individual pumping stations grouped into one central wellfield and two subsidiary stream and river compensation sources. The anticipated combined gross yield of this Phase is in the region of 60 to 65 Ml/d.

Construction of this Phase was completed in 2002. The first stage of commissioning tests compromising one-day step tests and 7-day constant rate tests were performed on 8 out of the 11 new abstraction boreholes between 2003/04. As a precautionary approach commissioning of the whole Phase was suspended in 2004 upon the detection of trace levels of chlorinated solvents during the Heath Farm No1 & No2 constant rate tests. A groundwater quality investigation is currently underway to delineate the location, extent, composition and concentration of the source of contamination. As a consequence the full potential of Phase 5 remains to be proven as the project has not undergone final commissioning and therefore has not yet been formally handed over to, or accepted by, Midlands Region (West) as an operational Phase of the Scheme.

Consequently this Phase will not be considered under this stage of the Environmental Report. When the fate of this Phase is resolved an addendum to the supporting environmental report will be completed for Phase 5.

Phase 6, 7 and 8

The current projected demands within the Severn supply zone have not yet justified the construction and implementation of the three remaining phases (Phases 6, 7 & 8) of the Scheme. Consequently these Phases have not yet been built and therefore will not be considered under this environmental report.

2.3.3 Operating Rules

SGS operational support is triggered solely by the River Severn Regulation Rules outlined in Section 2.2. The amount of support will be determined by the flow forecasting team with reference to the SGS multiple control zones. The Area SGS team will choose which of the available Phase(s) to operate to meet the regulation demand.

2.4 Objectives of the Study

The purpose of this project is to produce an Environmental Report in support of a drought order application for Shropshire Groundwater Scheme (Phases 1, 2, 3 & 4). The report is to determine how much pumping would be required over and above the Schemes current licensed annual and five year rolling volume limits to meet a prolonged drought scenario, and to review the potential environmental consequences of doing so.

2.5 SGS Proposal Description

Drought Order Option

The Drought Order Option used for the Environmental Report is based on a modelling exercise carried out by the Environment Agency using the Aquator water resources model for the Severn and Wye system. Further details are presented in Section 3.

Operating under one over-arching licence, each Phase of the SGS is individually licensed with set annual and five year rolling limits. The drought order will look to exceed these limits, the amount required to over pump the scheme has been determined by the drought scenario adopted. Based on the water resource modelling, the following drought scenario has been identified as the Drought Order Option to be taken forward for assessment:

1990's+ 76 Scenario

This scenario considers the pumped volume required to support a prolonged drought affecting the River Severn over a number of years. This scenario considers a situation where a severe drought situation (1976) occurs following the historic actual prolonged drought period experienced in the early to mid-1990s. Under this scenario the extreme nature of this event has been further compounded by reducing the amount of rainfall by applying a dry climatic change factor. This is the type of prolonged back to back drought event envisaged by the "chronic drought scenario" under the River Severn Drought Order.

2.6 Statement of Need for Water

SGS sits within and draws upon the significant resource potential offered by the North Shropshire Permo-Triassic Sandstone aquifer. The Permo-Triassic Sandstone is one of the most important principal aquifers in the United Kingdom, second only to the Chalk. The properties of the sandstone mean that it has an excellent capacity to store large volumes of groundwater, making it the biggest strategic store of potable water in the UK. This favours its use for large scale strategic resource development, as the effects of seasonal abstraction and recharge patterns are more evenly distributed over longer periods within the environment. These aquifers tend to respond slowly to discharge and recharge, and are therefore more reliable under drought conditions as baseflow and therefore total river flow is initially maintained for longer.

The purpose of SGS is to provide a large strategic source of groundwater to supplement and help conserve the remaining storage in Clywedog Reservoir. Under drought conditions and implementation of the River Severn Drought Order there may be a need to reduce the maximum quantity of water required to be released so supplies can be maintained for longer. This reduction in releases may be accompanied by a need to decrease the statutory mean flow required to be maintained in the River Severn at Bewdley and to take action to reduce abstraction from the Severn by imposing cutbacks on licensed abstractions.

Modelling work has shown that for the extreme scenario examined in this environmental report we may need to pump greater volumes of water from the SGS than are authorised by its existing abstraction licence. Being able to pump these extra volumes of water from SGS will help conserve supplies in Clywedog Reservoir still further and so lengthen the remaining time regulation releases can be made, benefiting the ecology of the river and water supply from it.

There are a number of vital public water supply abstractions from the River Severn at Shrewsbury, Hampton Loade, Trimpley, Upton, Mythe and Purton (Purton abstraction comes from the Gloucester and Sharpness Canal which is supplied from the Severn). There is also a major abstraction at Ironbridge which provides cooling water to Ironbridge Power Station. All these abstractions are licensed on the basis of regulation releases being made to support them. If regulation were to carry on at normal levels and then suddenly reduce to almost nothing when Clywedog Reservoir ran dry, the sudden fall in river flows along the Severn would have very serious consequences for both public water supply to the population of 6 million reliant upon the Severn supply zone for its drinking water and the wider ecology of the river environment. It would be much more damaging than a gradual reduction over a longer period, which will hopefully allow some degree of support to last until sufficient rainfall occurs to naturally replenish flows in the Severn catchment.

SGS pumps have a fixed maximum deployable yield and therefore the rate of abstraction cannot be increased. The numbers of pumping days are limited by the annual and five licence volume restrictions. While additional licensable resource exists in the remaining undeveloped Phases of SGS, build time scales of between 3 to 5 years means that these resource options could not be brought on-line quickly enough to meet the prevailing drought event. The preferred option sought under this order is to provide additional groundwater resource by extending the duration of pumping permitted under the current licence from the existing SGS infrastructure.

2.7 Alternative Sources Considered

The River Severn Drought Order (including SGS option) is considered to be the last resort the Environment Agency can take to protect the ecological status of the river and the licensed water transfers that rely on this system.

Before a River Severn Drought Order application is made, all necessary water saving measures and communications identified in the Midlands Drought Plan will have been taken. SGS will have been actively supporting Llyn Clywedog, alongside strategic usage of the Vyrnwy Bank system. Section 57 spray irrigation restrictions will have been considered and implemented as appropriate. The Environment Agency will also have been working closely with water companies to ensure they follow their own Drought Plans and manage water resources in a sustainable manner as the drought develops.

Clywedog (50,000Ml) and SGS phases 1 to 4 (25,500Ml) in-combination represent an annual maximum strategic water resource potential of 75,500Ml. Their sole purpose is to regulate water resources in the River Severn. Aside from Vyrnwy Reservoir (59,600Ml), and the bank side storage reservoir at Chelmarsh (3,063Ml), there are currently no alternative strategic water resource structures of equivalent volume within the Severn basin.

The majority of the water from Vyrnwy Reservoir is exported out of the catchment for use by United Utilities to provide public water supplies to the North West. Aside from the normal baseline compensation releases to the River Vyrnwy, any surplus volume between March to October is already accumulated in the 'Vyrnwy Water Bank' to provide an extra volume of water for River Severn regulation. Redeploying a higher proportion or all of the storage at Vyrnwy to support flows in the River Severn would not be an Environment Agency decision, and could not be made without compromising United Utilities resource balance to the North West.

Chelmarsh is a pumped bank side storage reservoir filled from the River Severn, and as such cannot be considered as an alternative source.

The majority of water companies that abstract from the River Severn have an extensive supply network. In some cases this network could allow the water companies to move water from a resource 'rich' catchment, to support supplies (i.e. reduce abstraction) in a 'stressed' catchment. The extent to which River Severn public water abstractions could be supported by re-deployment of their own sources will always depend on the demands and drought stresses in other parts of each company's supply network. It is unlikely that sufficient resources would be available to allow the River Severn abstractions to cease. This is highlighted by the fact that Severn Trent Water, South Staffordshire Water and United Utilities (from Lake Vyrnwy) all have their River Severn catchment sources as potential drought permit/order sites.

Modelling has shown that for reservoir storage to cross the drought order in force curve on Llyn Clywedog, the natural drought conditions across the region would be widespread. Costly environmental impacts outweighing those expected on the River Severn as a result of the Environment Agency's drought order operation would be experienced. No alternative action or resources would be available to the Environment Agency other than to apply for the River Severn Drought Order.

In the absence of alternative strategic water resources of equivalent volume within the Severn basin, this order aims to ration out the remaining resources in Llyn Clywedog and seek to extend pumping of SGS beyond its current abstraction licence constraints. This is required to extend the length of time regulation support can be provided along the River Severn during a prolonged drought to protect the ecology of the river and help secure supply.

2.8 Summary and Conclusions

The River Severn is a regulated river, which forms part of a large water supply and management system. The Environment Agency is the lead organisation with responsibility for regulation of the River Severn in consultation with Natural Resources Wales. This is statutory controlled through provisions under the Clywedog Reservoir Joint Authority Act 1963 and the Operating Rules for the River Severn Resource/ Supply System.

These rules govern how much water is released to the river system from both surface water and groundwater storage sources to balance the ecological needs of the river against the demands of abstraction for; public water supply, spray irrigation, industry, and navigation.

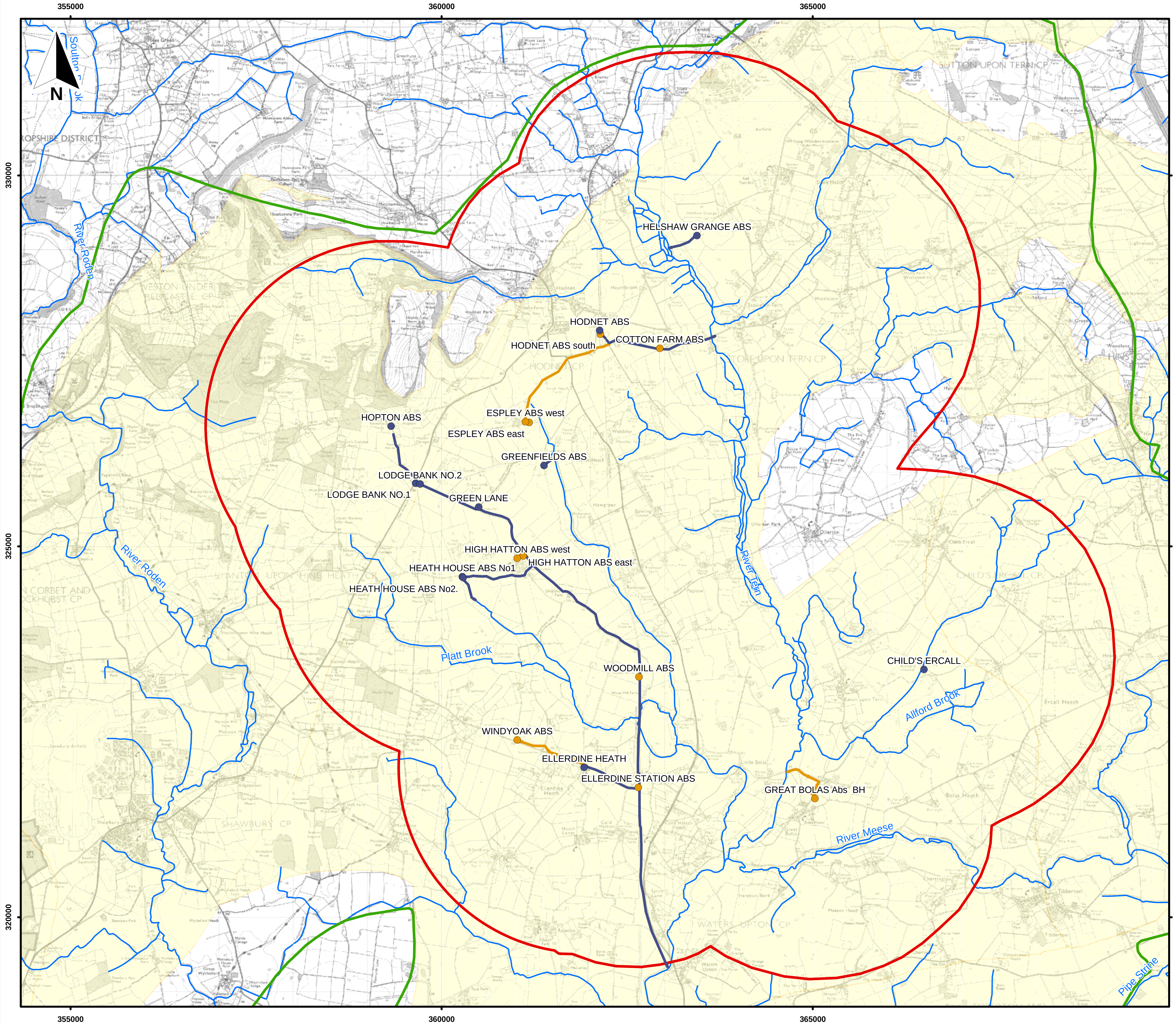
SGS sits within and draws upon the significant resource potential offered by the North Shropshire Permo-Triassic Sandstone aquifer. The Permo-Triassic Sandstone is one of most important principal aquifers in the United Kingdom, second only to the Chalk. The properties of the sandstone mean that it has an excellent capacity to store large volumes of groundwater, making it the biggest strategic store of potable water in the UK. This favours its use for large scale strategic resource development.

The purpose of SGS is to provide a large strategic volume of groundwater to supplement and conserve the remaining storage in Clywedog reservoir to sustain regulation support for the River Severn.

Before a River Severn Drought Order application is made, all necessary water saving measures and strategies identified in the Midlands Drought Plan should have been implemented. The Environment Agency will also have been working closely with water companies to ensure they follow their own Drought Plans and manage water resources in a sustainable manner as the drought develops.

In the absence of alternative strategic water resources of equivalent volume within the Severn basin, no alternative action or resources would be available to the Environment Agency other than to apply for the River Severn Drought Order.

This order aims to ration out the remaining resources in Llyn Clywedog by seeking to extend pumping of SGS beyond its current abstraction licence constraints to counter the effects of an extreme drought event.



Key:

- Location of existing Phase 1 groundwater pumping station and pipeline
- Location of existing Phase 4 groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers

0 1,000 2,000 Metres

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Project Path: G:/MODEL/PROJECTS/EA-210/22720/Figures/22720s02_Fig2.1.mxd

Environment Agency
Shropshire Groundwater Scheme Drought Order
Environmental Report

Figure 2.2
Phases 1 and 4 Infrastructure

May 2012
22720-S02 wills

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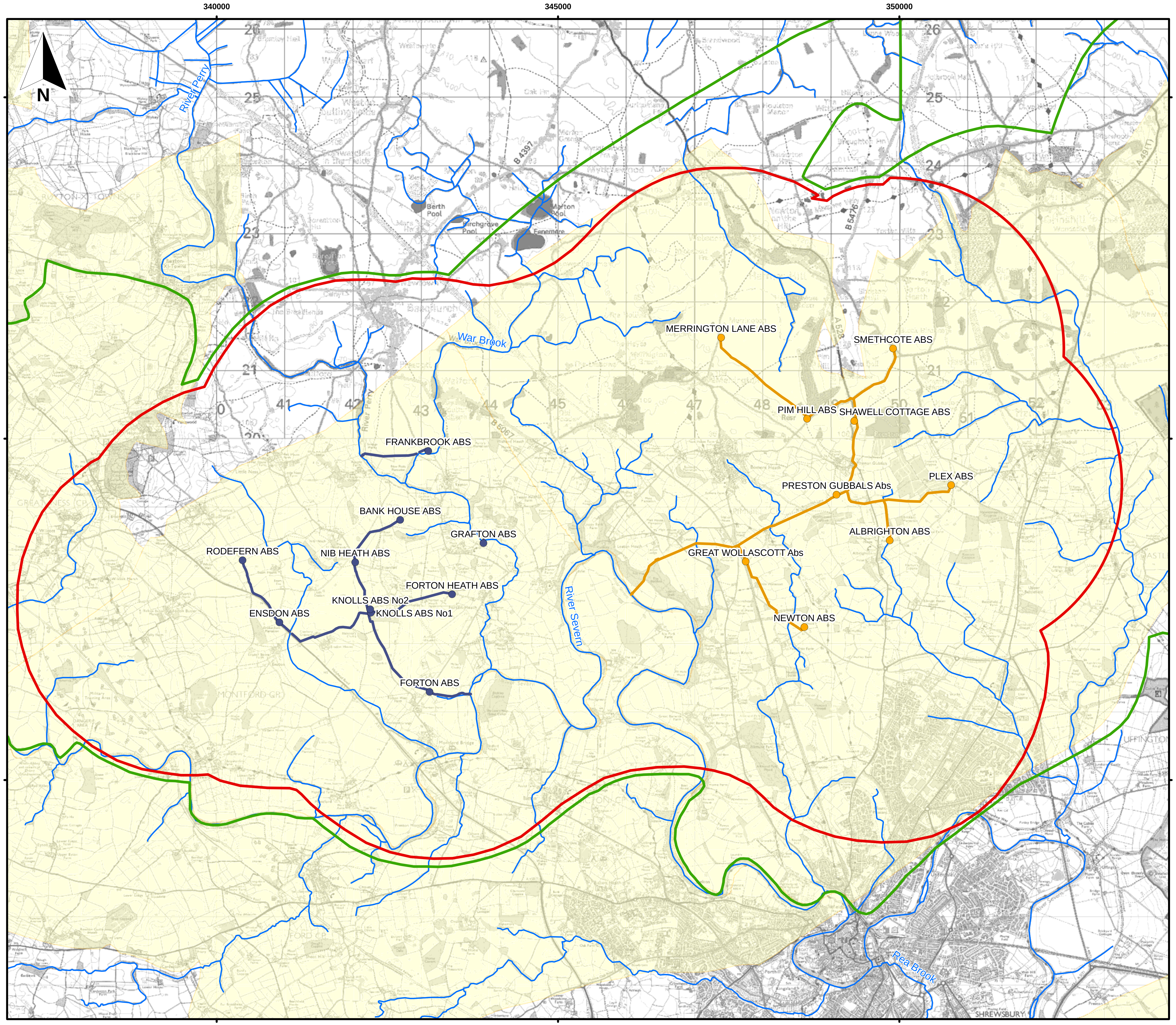

Key:

- Location of existing Phase 2 groundwater pumping station and pipeline
- Location of existing Phase 3 groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers

Project Path: G:/MODEL/PROJECTS/EA-210/22720/Figures/22720s03_Fig2.2.mxd

Environment Agency
Shropshire Groundwater Scheme Drought Order
Environmental Report

Figure 2.3
Phases 2 and 3 Infrastructure

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3. Methods and Modelling

3.1 Regulation Demand Scenarios and Groundwater Modelling

It is important to emphasise the particular drought scenario assessed here is theoretical. It was 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 how a drought will manifest (e.g. timing and duration) until the antecedent conditions are known.

3.1.1 Regulation Demand Scenarios and Water Resource Modelling

Methodology

While both the Severn Drought Order and the SGS Drought Order utilised the Aquator water resources model, separate climatic models were applied to generate demand sequences.

During the course of the resource modelling exercise it became evident that the SGS licence allocation is very robust. This is not too surprising as the licence promoted at the 1979 Public Inquiry would have been influenced by the lessons learnt from the earlier 1976 drought. The inclusion of the dry climate change in the modelling is more extreme than that employed in the main River Severn drought order Aquator model. To push the SGS beyond its licence the predictive recharge scenario envisaged by the model represents a very extreme climate event not observed within the last 100 years. Although given the uncertainty posed by the impacts of climate change and increasing water demand, it should not necessarily be regarded as unlikely.

A critical element underlying the operation of the Groundwater Scheme is an assessment of how much additional water above and beyond the annual or five year licence limits would be required to support river regulation under drought or severe drought conditions. To assist with this task the Severn Trent Water Aquator water resources model for the Severn and Wye system was used to model regulation of the River Severn and the use of SGS. Standard climate change scenarios currently used for water resources planning (UKWIR, 2007) were applied to assess the potential use of SGS under altered patterns of rainfall frequency. Scenarios of different seasonal patterns (baseline, mid range and dry climate change patterns) were simulated to investigate the impact on the licence to support River Severn regulation under short term (acute) and long term (chronic) severe drought conditions.

Overview of the Model

This work was undertaken by Environment Agency Water Resource Planners (Appendix A). The model used a 77 year record of inflow sequences into the Severn catchment to assess water availability. Current supply and demand constraints were built in so that all major licensed abstractions and discharges were accounted for. This ensured regulation of the River Severn and appropriate releases from Clywedog reservoir, Vyrnwy reservoir and SGS are modelled when the flows require it. A series of demand centres are present within the model (representing major urban areas) and these have demand profiles allocated to them based on patterns of demand for water supply in 1995, a dry year of high demand. Demand was assumed to be the same as the dry year demand which Severn Trent plan to for their baseline deployable output. This is effectively the demand profile of the 1995 dry year multiplied by a factor of 1.025. This demand factor was obtained from estimation of the deployable output: the model was run repeatedly for the period of run-off data (currently 1920-1996) at variable levels of demand, converging on the optimum factor at which demand is maximised and all demand centres can still be supplied. The amount of water which can be supplied is termed the deployable output of the system.

The model was set-up on the known deployable yields from the current commissioned Phases 1, 2, 3 and 4 of SGS. The licence amounts set in the parameters reflected the actual licence amounts used for the daily, annual and five year licence (Environment Agency, 2008). Initial runs used the single SGS control line to control switching on and off of the scheme (original method). This was replaced with the updated method (EA October 99 method) which uses multiple control curves for the later runs. Following comparison of the two methods it was agreed that using the multiple control curves provide better operational efficiencies and a more accurate representation of how the SGS scheme has been operated in more recent years.

The output from the model generated a predictive sequence of operational releases from SGS to provide the basis for the environmental assessment used in this report. The results of the modelling were used to determine the simulated start dates and end dates for SGS operational releases. From this the number of operational days were determined from which abstraction volumes were calculated, based on deployable yield rates, and compared against licence limits.

Drought Scenario

Modelled drought scenarios were run to test the potential use of the annual and five year licence all using the inflow sequences from 1920 to 1996 and a range of climate change factors (baseline, mid-range and dry climate change factor). From these sequences, two notably dry five year periods (1972 to 76 and 1992 to 96) were selected for further investigation. Scenarios were then looked at which extended the existing dry periods, by adding a 1976 drought event to the end of these sequences.

The modelling suggested that using the dry climate change factor with a sustained drought period from the 1990s followed by an extreme drought event (1976) would provide the most robust challenge to the system. The “dry” climate scenario uses the same climatic sequence, but the rainfall and the potential evapotranspiration data have been modified using monthly factors defined by the UKWIR methodology. From the six UKWIR scenarios ECHAM2/ OPYC3 was assessed as being the driest and therefore adopted for the purpose of this drought order. Modelled drought scenarios were then run where the inflow sequence from 1970-1996 was used with 1976 repeated again at the end (historical actual sequence from 1993 to 1996 was used with the “1976” event substituted for the 1997). This manipulation was selected as 1976 was shown to be the critical year within the sequence. However, 1995-96 was shown to be a more prolonged drought with an increased pressure on the 5 year licence so the two periods were combined to create a worst case scenario. The Aquator runs confirmed that under the dry climate change scenario the 1990s+1976 scenario provided the most robust challenge to exceed the SGS licence limits. This option has therefore been taken forward as the worse case scenario used in the assessment.

Demand Scenario

A summary of the Aquator model outputs for the five year drought sequence showing the surface reservoir release volumes (Clywedog and Vyrnwy) and a break down by SGS Phase of the number of operational pumping days, volumes pumped and percent usage of annual and 5 year licence limits are presented in Table 3.1. Phase 1 is further subdivided into resource required to supply the main production boreholes (i.e. river regulation support) and the additional compensation releases required to provide flow support to two streams in mitigation of the effects of operating Phase 1 & 4 in-combination. Both the main river regulation and stream compensation pumped volumes need to be accounted for from the SGS abstraction licence. In order for the whole scenario to run without quantities being constrained by the licence limits, the SGS licence for individual phases needed to be increased by up to 20%.

The modelling shows that the annual limit is only just exceeded for two individual Phases 2b (101 %) and 3 (101%) to meet the extreme 1997 ("1976") event demand, culminating in a 92% usage of the total combined annual licence limit of 25,500 Ml. While the licence appears robust enough to meet the historic actual peak demand, it is the cumulative effect of a prolonged back to back drought period, such as that actually experienced in the early 1990s, in combination with an extreme event that may cause exceedance of the 5 year rolling licence limits.

Under the model scenario, operational support from SGS would require authorisation to abstract a total of 59,180Ml over the five year period. This would exceed the combined five year licence volume limit for Phases 1, 2, 3 & 4 of 55,500Ml, by an additional 3,680 Ml, equating to 7% of the combined licence. Distributing this additional resource demand would require between 101 and up to 115% of the five year licence limits across the four operational Phases.

Table 3.1 Breakdown of Surface Reservoir Release Volumes and Annual Licence Usage (Volume Abstracted and Operational Pumping Days for each SGS Phase Modelled during the 5 Year Dry Climate Change Scenario using 1993 to 1997 Demand and Substituting +1976 Demand For 1997)

Model Year (East Shrop. Model)	Phase	Phase 1 (*Main Production)	Phase 1 (*Stream Compensation)	Phase 2a	Phase 2b	Phase 3	Phase 4	Yearly Totals Vol Ml
	1 Yr lic Vol. Ml	6700		1900	4600	5600	6700	25500
	5 Yr lic Vol. Ml	14500		4100	10100	12200	14600	55500
	Days	2	120	7	0	0	0	
	Vol Ml	12.5	361	33	0	0	0	406.5
	% 1yr licence	0.2	5.4	1.8	0.0	0.0	0.0	1.6
	Clywedog release	Volume Ml	17687		Days	72		
1993 (2030)	Vyrnwy release	Volume Ml	885		Days	14		
	Days	17	87	18	20	22	19	
	Vol Ml	674	263	175	610	711	768	3,201
1994 (2031)	% 1yr licence	10	4	9	13	13	11	13
	Clywedog release	Volume Ml	31107		Days	96		
	Vyrnwy release	Volume Ml	1255		Days	33		
	Days	78	150	80	75	75	76	
	Vol Ml	3,278.1	450.7	799.6	2,793.3	3,253.6	3,478.4	14,054
1995 (2032)	% 1yr licence	49	7	42	61	58	52	55
	Clywedog release	Volume Ml	47239		Days	155		
	Vyrnwy release	Volume Ml	5216		Days	81		

Table 3.1 (continued) **Breakdown of Surface Reservoir Release Volumes and Annual Licence Usage (Volume Abstracted and Operational Pumping Days for each SGS Phase Modelled during the 5 Year Dry Climate Change Scenario using 1993 to 1997 Demand and Substituting +1976 Demand For 1997)**

Model Year (East Shrop. Model)	Phase	Phase 1 (*Main Production)	Phase 1 (*Stream Compensation)	Phase 2a	Phase 2b	Phase 3	Phase 4	Yearly Totals Vol Ml
	1 Yr lic Vol. Ml	6700		1900	4600	5600	6700	25500
	5 Yr lic Vol. Ml	14500		4100	10100	12200	14600	55500
1996 (2033)	Days	97	175	103	86	93	95	
	Vol Ml	4,319.5	525	999	3,513.5	4,138	4,518	18,013
	% 1yr licence	64	8	53	76	74	67	71
	Clywedog release	Volume Ml	23985		Days	116		
	Vyrnwy release	Volume Ml	6202		Days	58		
1997/"76" (2034)	Days	123	144	125	117	118	121	
	Vol Ml	5,488	432	1,236	4,668	5,650	6,031	23,505
	% 1yr licence	82	6	65	101	101	90	92
	Clywedog release	Volume Ml	39522		Days	133		
	Vyrnwy release	Volume Ml	8140		Days	70		
5 Year Vol Totals by Phase		15,803		3,243	11,585	13,753	14,795	
% of 5yr lic by Phase		109		79	115	113	101	
Total Combined SGS Release Vol Ml				59,180				
% of Combined 5 year Licence used				107				
Additional vol (Ml) required to meet drought scenario				3,680				

*main production volume calculated from Aquator model, stream compensation volumes calculated from running demand sequence in East Shropshire Groundwater Model.

To put this scenario into context Table 3.2 summarises the actual operational use, including initial commissioning tests, over the entire history of the Scheme. This tabulates the break down per operational year, which of the Phases were pumped and the number of days releases were made. The total volume pumped is also listed and expressed as a percentage of the annual licence volume allocated to that Phase.

Table 3.2 Historic Actual SGS Operating Periods 1984 to 2011

Regulation Year	Phase Operated	Total Number of Operational Days	Total Volume Pumped (Ml)	Maximum Annual Licence Volume (Ml)	Percentage of Annual Licence Volume Used (%)
1984	Phase 1 (commissioning test & regulation)	24	688.7	6,700	10
1989	Phase 1	80	3,677.3	6,700	55
1991/92	Phase 2 (commissioning test)	57	2,820.7	6,500	43
	Phase 1	66	2,781	6,700	42
1995	Phase 2	71	3,661.6	6,500	56
	Phase 1	18	898.4	6,700	13
1996	Phase 2	36	1,651.3	6,500	25
1999	Phase 3 (commissioning test)	38	2,026.1	5,600	36
2005	Phase 4 (commissioning test)	36	1,515.2	6,700	23
	Phase 1	18	1,049.6	6,700	16
	Phase 2	54	2,535.4	6,500	39
	Phase 3	35	1,428.5	5,600	26
2006	Phase 4	7	165.1	6,700	2
	Phase 1	8	33.1	6,700	0
	Phase 2	16	754.5	6,500	12
	Phase 3	10	438.6	5,600	8
2010	Phase 4	7	128.6	6,700	2
	Phase 1	7	139.2	6,700	2
	Phase 3	5	207.6	5,600	4
2011	Phase 4	6	51.4	6,700	1

3.1.2 Groundwater Modelling: East Shropshire Groundwater Model

The East Shropshire Permo-Triassic Sandstone Model (ESM) has been developed to enable the assessment of the impacts on groundwater levels and surface water flows from the SGS (Streetly and Shepley, 2005, ESI, 2008).

Developed in 2005, this well documented model provides credible and acceptable simulation of observed groundwater levels and surface flows within the Permo-Triassic Sandstone in the vicinity of the SGS.

When originally constructed the ESM only provided coverage for Phases 1, 4, 6 & 8 of the SGS. Extension of the groundwater model in 2008 meant that the model can now also be used to predict the impacts from abstraction at Phases 3 and 5 of the SGS. Phase 2 and 7 remain outside the current model area.

The results of the water resource modelling (Section 3.1.1) were incorporated into the groundwater model and predictive simulations have been carried out by ESI to assess the impacts of increased abstractions from the SGS as defined by the Drought Order Option. Three new predictive simulations have been carried out:

- Normal climate with recent actual abstraction rates and no SGS abstractions (ESMDO_01 baseline simulation);
- 'Dry' climate change with recent actual abstraction rates and no SGS abstractions (ESMDO_02 'dry' simulation);
- 'Dry' climate change with recent actual abstraction rates plus SGS abstractions (ESMDO_03 'dry plus SGS' simulation).

All three simulations use a climate sequence which includes a prolonged three year drought, which is represented by the climatic data from the years 1995 and 1996, followed by a "1976" extreme drought event for the third year in the sequence in 1997.

A report by ESI forms Appendix B of this report and contains a concise description of the predictive simulations (Section 2) and discusses the results in terms of the impacts on groundwater levels and surface water flows (Section 5). The predicted impacts of the scenario runs on groundwater levels, flow and baseflow to rivers will be discussed in this report and used in the assessment of effects on Ecology and Groundwater and Surface Water Quality.

3.1.3 Numerical Modelling

For the SGS Phase 2 wellfield area which remains outside of the ESM model, predicted changes to groundwater level and flows have been quantified using a simple approach based on distance drawdown relationships determined from previous pumping test data.

This has been done using a spreadsheet modelling technique owned by the Agency and developed by Water Management Consultants (WMC). The spreadsheet model incorporates a radial flow solution, based on the Cooper-Jacob equation, to resolve drawdown at multiple locations within the wellfield.

The model was initially calibrated using groundwater level data and aquifer parameters from the Phase 2 constant rate test pumping test analysis. Elevated levels of abstraction pumping were then included in to the model to assess the additional impact of licensed and increased abstraction within this Phase of the SGS. The results are discussed in later sections of this report.

3.1.4 Depth to Groundwater and Crop Vulnerability Risk Mapping

When pumped, each wellfield within the scheme can generate effective areas of drawdown influence measuring between 30 and 56 km^2. Abstraction of groundwater on this scale understandably raised concerns from the agricultural and conservation communities about its potential or perceived impact on the surrounding environment. Concern lay with the perceived detrimental effect that groundwater abstraction may have on soil moisture availability for plant growth, and therefore impacts on crop yield/ profit for individual farm businesses and environmentally sensitive habitats.

To address these concerns, the Environment Agency commissioned ADAS and The Arable Group to form a joint working group to quantify the potential risk to crop vulnerability by groundwater abstraction. Using the archive of data from the environmental monitoring network and the application of GIS technology, the project team were able to accurately map, with a high degree of confidence, the depth to water table in the underlying sandstone aquifer. Based on the success of the groundwater mapping an innovative risk based methodology was devised to determine the extent of crop vulnerability to groundwater abstraction throughout the area of the Scheme. The project has successfully mapped an area covering 570 km^2 in North Shropshire. The results of the mapping have been presented on 1:25,000 scale, full colour paper maps with accompanying background and technical notes, and the data captured in ArcGIS format. The methodology adopted by the project team is briefly outlined below.

Groundwater Mapping Methodology

The depth to groundwater maps drew upon 30 years of investigation and monitoring of groundwater throughout the Scheme. The ADAS methodology calculated groundwater levels based on the 95th percentile highest water level observed between April to September (inclusive) each year. The data sets were filtered to ignore all data influenced by artificial lowering of the water table within 1 year of any test pumping programme and 2 years from operational pumping of the Scheme's boreholes. A statistical modelling technique was applied to the data set to provide the best model fit to the borehole data and a Kriging interpolation method was generated to create the water table surface modelled at 25 x 25 m resolution. This predicted surface was subtracted from a digital terrain model (DTM), with a spatial resolution of 5m and an accepted vertical accuracy of +/- 1 m, of the topographic land surface (© Intermap Technologies 2003) to produce the depth to groundwater maps.

The relative depth to groundwater was cartographically represented as gradational shades of blue. The darkest colour blue represents areas where groundwater in the Permo-Triassic Sandstone aquifer is deepest and the light blue shaded areas represent where groundwater is shallowest. A high degree of confidence was placed in the accuracy of the mapping, with the shallowest groundwater areas coincident with surface watercourses known to be in good hydraulic connection with, and receiving discharge from, the sandstone aquifer. The edge of the mapping boundary was taken to be the sub crop area of the Permo-Triassic Sandstone formations. All areas outside of this boundary appear un-shaded. No attempt was made to map groundwater levels in perched drift aquifers hydraulically isolated from the main Permo-Triassic Sandstone aquifer as these tend to be very localised discreet bodies of water.

Crop Vulnerability Risk Mapping Methodology

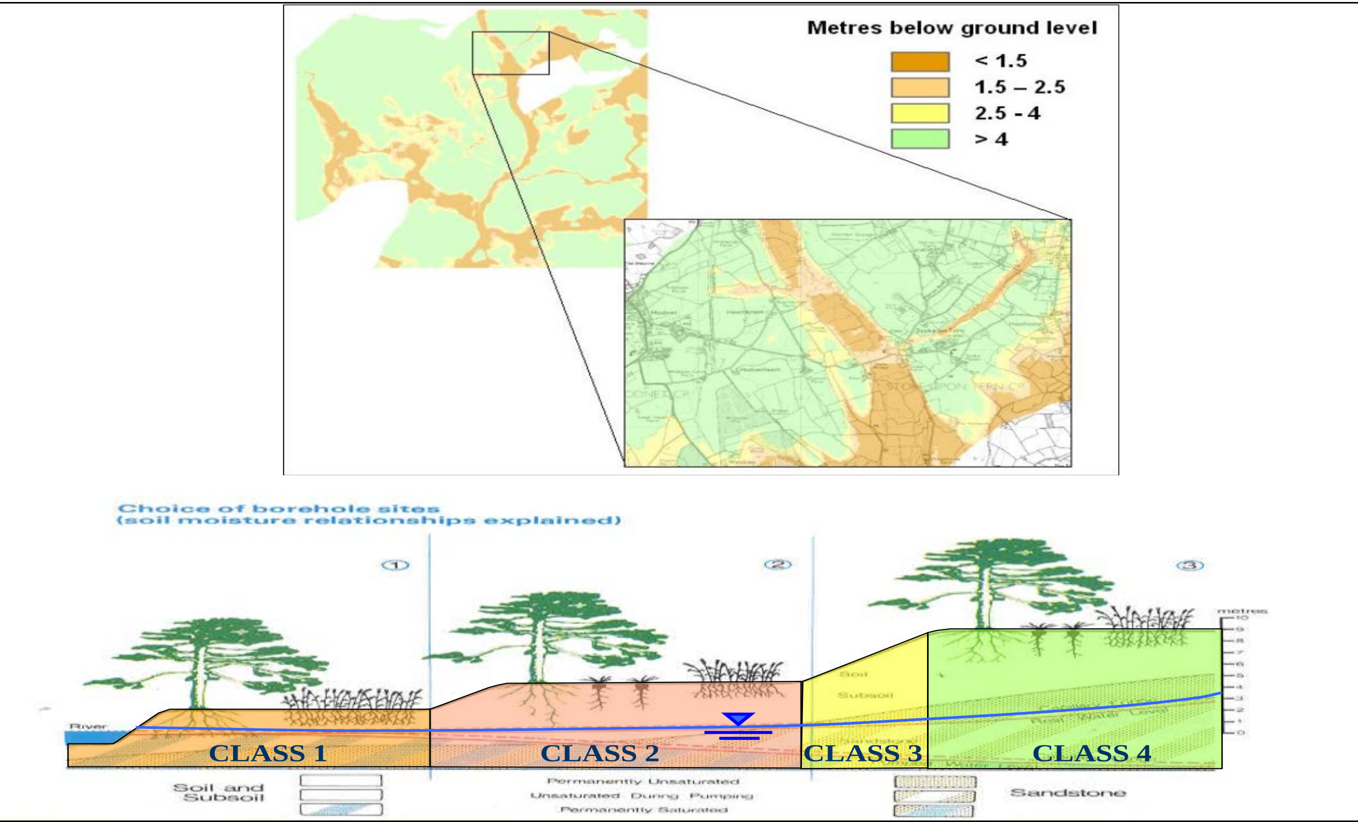
To determine vulnerability the methodology compared the spatial interaction between three key elements:

- Maximum depth of water abstraction by vegetation (effective rooting zone);
- Depth to groundwater in the underlying Permo-Triassic Sandstone;
- Composition and extent of intervening drift types between the rooting zone and groundwater.

This methodology was used to designate and map four categories of risk zones, Class 1, 2, 3 & 4, based on known rooting depths of common agricultural crops and trees and depth to groundwater (Figure 3.1).

- **Class 1 -** Groundwater level less than 1.5 mbgl (metres below ground level). Possible impact on crops abstracting soil moisture up to a maximum depth of 1.5 m. e.g. potatoes, onions, carrots, vegetable brassicas, peas, beans and established grassland on mineral soils;
- **Class 2 -** Groundwater level between 1.5 and 2.5 mbgl. No impact on vegetation or crops in Class 1. Possible impact on deeper rooting agricultural crops abstracting soil moisture to a maximum depth of 2.5mbgl. e.g. cereals, oilseed rape, maize and sugar beet;
- **Class 3 -** Groundwater between 2.5 and 4 mbgl. No impact on vegetation or crops in Class 1 or 2, possible impact on established trees;
- **Class 4 -** Water table deeper than 4 mbgl. Lowering of water table by groundwater abstraction from the sandstone aquifer will not impact upon soil moisture availability to any vegetation.

Figure 3.1 Mapping Extracts and Schematic Cross-section illustrating Crop Vulnerability Classification



Drift Categorisation

In addition to considering the depth to water table, an assessment of soil moisture vulnerability also considered the composition, extent and permeability of intervening soil and drift deposits. Categorisation of drift in to *high (Group A)*, *medium (B)* and *low (C)* permeability drift deposits, added a further refinement to the designation of risk within these zones. The groups were further sub divided e.g. A1, A2…B1, B2…C1, C2… to denote decreasing permeability within the group subset (see table 3.3).

Table 3.3 Drift Categories defined for Use in Soil Moisture Vulnerability Assessment

Drift Category	Permeability Category	Drift Type
A1	**A. High Permeability Drift Deposits**	Bedrock at surface, no drift cover.
A2	Allowing unhindered movement of water between the sandstone aquifer and the rooting zone.	Highly permeable sand and gravel directly overlying bedrock.
A3		Undifferentiated very permeable fluviatile deposits overlying bedrock.
A4		Sand and gravel are the dominant components making up more than 50% of the deposit.
B1	**B. Medium Permeability Drift Deposits**	Significant thickness (>1m) of peat. High storage potential and good interaction where it lies on Permo-Triassic Sandstone. Properties alter where peat overlies other drift.
B2	Complex assemblage of drift types with a wide range of permeability. Composition and extent of drift types influence movement of water between the sandstone aquifer and the rooting zone.	Clay at surface allowing little infiltration unless thin or fractured/weathered. Permeability is enhanced because sand and gravel is the dominant component.
B3		Undifferentiated fluviatile deposits overlying other drift. Potential interaction will depend on the hydraulic properties of the underlying drift.
C1	**C. Low Permeability Drift Deposits**	Sand and gravel at surface. Potential permeability is reduced because clay is the dominant component.
C2	Inhibiting movement of water between the sandstone aquifer and the rooting zone.	Clay at surface allows little infiltration unless thin or fractured/weathered. Clay makes up more than 50% of drift content.
C3		Till and glacio-lacustrine clay deposits dominate drift.

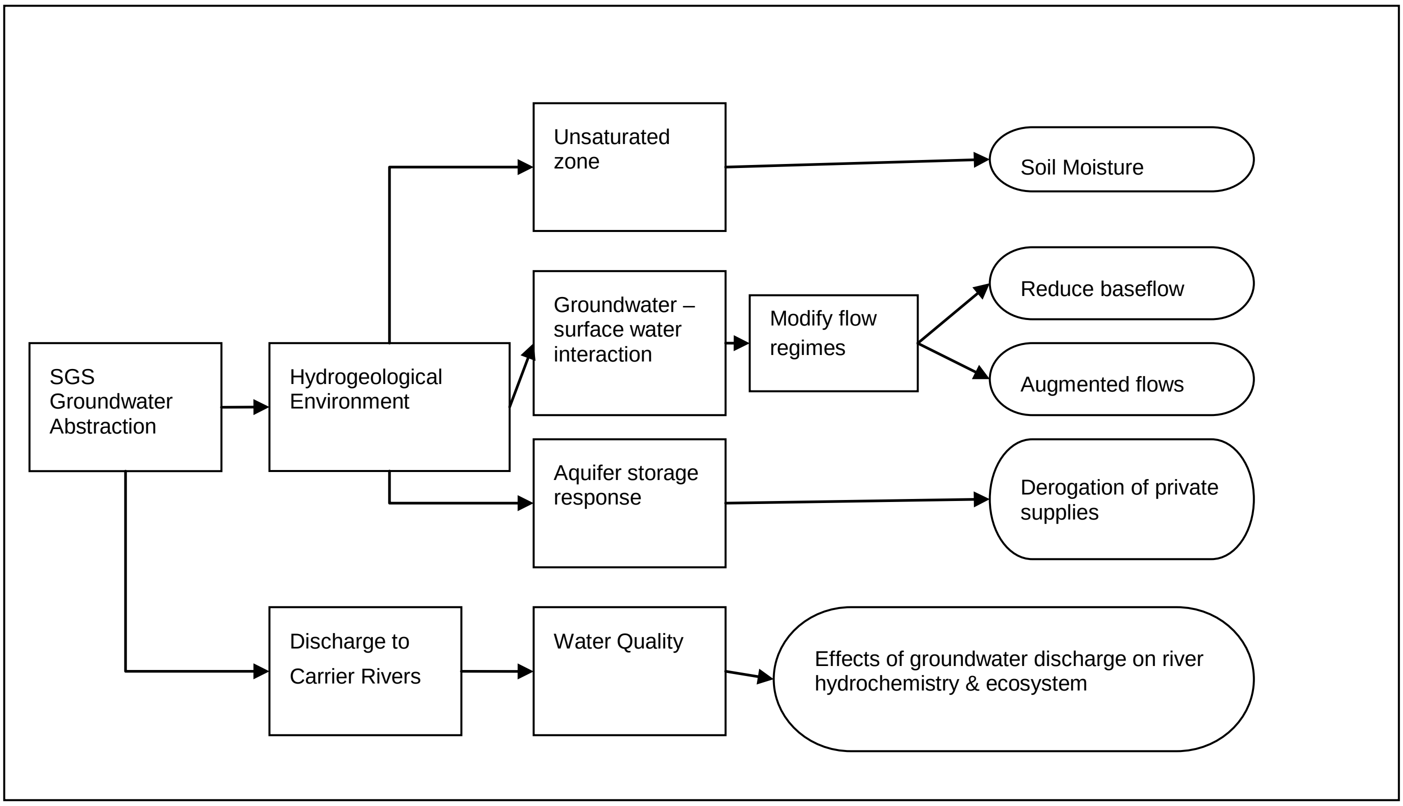
The Soil Moisture Vulnerability Depth Classes illustrate the maximum likely depth of water abstraction by vegetation in relation to the mapped water table levels, and the Drift Categories map the composition and extent of intervening drift types. Areas of potentially highest vulnerability exist where vegetation lies within a Class 1 area with a Drift Category of A1. Class 1 areas underlain by C3 Drift Category clay deposits have significantly reduced vulnerability. Areas of vegetation within Class 3 and 4 are considered not to be at risk from the effects of groundwater pumping regardless of the underlying Drift Category.

Capturing the data sets in a GIS format permitted spatial analysis and manipulation of data generated by the project. By overlying the wellfield footprint over the soil moisture vulnerability map, it was possible to create Phase specific risk assessments within each of the known or predicted areas of pumping influence. Within the footprint of pumping influence the percentage of area covered by each vulnerability class has been calculated. This methodology will be reapplied to assess the risks from any increased amount of pumping from the SGS under consideration by this order.

3.2 Environmental Linkages

Operation of the Scheme involves a complex interaction between subsurface and surface environmental regimes as water is drawn from storage modifying groundwater levels within the aquifer and altering the flow regime of watercourses used as carrier rivers. These modifications can have short term and long term implications for a number of environmental factors within the catchments of each Phase of the scheme during and between operational periods. The magnitude of the effects of the scheme will vary both spatially and temporarily and will be determined by the required duration of operation of the scheme as well as the natural 'background' status of the catchment and the water resource balance.

A summary of the key environmental linkages and pathways are schematically represented below.



To quantify the effect of operating the Scheme on the surrounding wider environment the Agency maintains a comprehensive environmental monitoring network centred on the operational Phases. The network is designed to provide background monitoring data on groundwater levels, soil moisture levels in the unsaturated zone, surface water flows, water quality analysis of both groundwater and surface water systems and the aquatic ecology of the receiving watercourses to which groundwater discharges are made.

In order to assess the potential impacts of extended operation of the SGS on the environment the response of each of the environmental factors identified are considered and analysed using both historical actual data and out puts from modelling.

3.3 Summary and Conclusions

Bespoke numerical water resource and groundwater models have been used to provide an assessment of how much additional water beyond the annual or five year SGS abstraction licence limit would be required to support River Severn regulation under simulated extreme severe drought conditions. Standard climate change scenarios have been applied to assess the potential impact on the storage components of the system.

The modelled scenario looked at a five year period emulating the back to back drought years experienced in the UK in the early to mid 1990s. To provide a robust challenge modelling used a dry climate change sequence incorporating a prolonged three year drought similar to that seen in 1995 and 1996. This culminated in a “1976” extreme drought event in the last year of the sequence. Under the scenario modelled here an additional 3,680 Ml of groundwater support would be required, in excess of the current 55,500 Ml five year abstraction licence limit. Equivalent to 7% of the SGS 5 year licence allocation. This approximates to 20 days of additional pumping support at 190Ml/d, beyond that permitted by the current abstraction licence.

The impact of this level of groundwater SGS abstraction on the surrounding hydrogeology, hydrology and ecological environment in North Shropshire was assessed through the application of the East Shropshire Groundwater Model and a crop vulnerability methodology developed by ADAS and the Environment Agency. The outputs from these models were used as the basis of the environmental assessments in this report.

The prolonged back to back drought sequence modelled by this drought order draws parallels with the “chronic drought scenario” modelled by the River Severn Drought Order. These predictive scenarios represent very extreme climate events not observed within the last 100 years. Although given the uncertainty posed by the impacts of climate change, it should not necessarily be regarded as unlikely.

4. Geology and Soils

4.1 Introduction

The aim of this section is to characterise the solid and drift geological setting of the SGS project area and identify any potential effects of pumping groundwater beyond the current licence constraints on this setting.

4.2 Data Availability and Assessment

Published geological information is available in the form of BGS 1:50 000 scale solid and drift geological maps: Sheet 122 Nantwich, Sheet 123 Stoke, Sheet 138 Wem, Sheet 139 Stafford, Sheet 152 Shrewsbury, Sheet 153 Wolverhampton, Sheet 137 Oswestry, Sheet 151 Welshpool, which have also been provided in digital format by the Environment Agency. The text and some figures in this section are taken directly from the following reference sources:

- Bridge et al. 2002. East Shropshire Permo-Triassic Sandstone Groundwater Modelling Project—Task 1: Geological Framework Study. British Geological Survey Commissioned Report, **CR/02/176**;
- Clark. L, 1977. Shropshire Groundwater Study. Potential Land Subsidence caused by Pumping from the Bunter Sandstone. Water Research Centre;
- Streetly, M. & Shepley, M.G. 2005. Final Report, East Shropshire Permo-Triassic Sandstone Groundwater Modelling Project—Task 8. Report of the Environment Agency of England and Wales;
- Thomas, 1988. The late Devensian glaciation along the western margin of the Cheshire-Shropshire lowland. Journal of Quaternary Science, Vol. 4, pp. 167-181.

4.3 Current Environment

4.3.1 Solid Geology

The geological sequence underlying North Shropshire is richly represented by rocks ranging from Pre-Cambrian through to Jurassic aged formations. The SGS has been developed in the extensive low-lying area occupied by the North Shropshire Plain. This plain marks the subcrop and out-crop area of the Permo-Triassic aged sedimentary rock in-fill sequence. With the exception of the immediate vicinity of the Lower Palaeozoic (Ordovician and Silurian; mudstones, siltstones, sandstones and limestones) and Pre-Cambrian inliers, the Permo-Triassic sequence rests directly upon older folded and faulted rocks of the Upper Carboniferous Warwickshire Group, comprising mudstones and siltstones of the Etruria, Halesowen and Salop Formations.

The area is structurally complex, comprising a series of half-grabens (causing rock sequences to be displaced in to blocks by a series of faults) developed between the main north-east trending controlling fault structures of the Church Stretton, Wem, Brockhurst, Hodnet and Ollerton/ Ercall Mill faults. These structural features define the boundaries of two large depositional sedimentary basins represented by the Cheshire Basin and the Stafford Basin. These basins were formed early in the Permian and remained active throughout the Triassic allowing the accumulation of up 4,500 m of sandstone and mudstone deposits. These sedimentary formations include the Sherwood Sandstone Group (covering both Permian and Triassic aged sandstones), forming the present day principle productive sandstone aquifer in which the wellfields of the SGS have been developed, and the secondary A and B less productive formations of the Mercia Mudstone Group and Penarth Group which do not contain significant quantities of groundwater.

With the development of the SGS straddling both the Cheshire and Stafford basins one difficulty that arises is that rocks of the same age are assigned different names according to whether they lie in the Cheshire Basin or Stafford Basin sequences. Current practice adopts Cheshire Basin nomenclature for the sequence to the west of the Hodnet Fault, in which Phase 2 and Phase 3 wellfields have been developed, and Stafford Basin nomenclature for sequences to the east of the fault where Phase 1 and Phase 4 wellfields operate.

The stratigraphy of the principle Permo-Triassic Formations in North Shropshire, and specifically the Sherwood Sandstone Group is summarised below (*Stafford Basin sequence names appear in italics*).

Permian Formations

Alberbury Breccia – coarse angular breccia and rounded conglomerate sporadically developed basal sequence marking the beginning of the Permian in Shropshire.

Kinnerton Sandstone and *Bridgnorth Sandstone* Formations – red-brown fine to medium grained, pebble free aeolian sandstones considered to represent wind-blown sands forming massive cross-bedded dune sets. The thickness of this formation is highly variable across the basins, with recorded depths of between 30 to >300 m.

Triassic Formations

Chester Pebble Beds and *Kidderminster* Formations – comprise red-brown sandstones, pebbly conglomerates and mudstones. Lying unconformably on the Permian this sequence marks the base of the Triassic and is considered to largely represent deposition under fluvial braided river conditions interspersed with localised aeolian sands. Formation thickness is again highly variable, with recorded thicknesses between 20 to 200 m.

Wilmslow Sandstone and *Wildmoor Sandstone* Formations - are represented by brown to light red sandstones with interbedded silty horizons, with occasional pebbles. These sit conformably on the pebble beds, often in a transitional sequence. These sandstones are dominated by fluvial facies, thought to represent over bank fines and coarser braided river channel deposits inter-bedded with aeolian sands. In the Cheshire Basin the sequence is up to 600m thick, while in the Stafford Basin the sequence thickens progressively from 50 to 150 m.

Helsby Sandstone and *Bromsgrove Sandstone* Formations - are typically red-brown, yellow and grey sandstones with local discontinuous green siltstones. Resistant to weathering this sequence often forms prominent scarps such as Grinshill. Thought to represent fluvial deposits in slow flowing rivers, with over bank deposits forming siltstone interspersed with aeolian sandstones. The sequence varies in thickness from 20 to 75 m.

Mercia Mudstone Group - represented by predominantly mudstone and siltstone sequences with halite. The thin Tarporley Siltstone Formation marks the transitional sequence from underlying Sherwood Sandstone Group through to the massive mudstone. The depositional environment is envisaged to be one of a low-lying continental basin dominated by inland sabkhas or playa lakes. The group is poorly defined in the Stafford Basin, but formal subdivisions have been applied to the Cheshire Basin with the sequence comprising of; Bollin Mudstone Member, Northwick Halite Formation, Sidmouth Mudstone Member, Wilkesley Halite Formation, Branscombe Mudstone Formation and Blue Anchor Formation. At the base of the Wem fault the Mercia Mudstone Group is though to be between 1,500 to 2,000 m thick.

Penarth Group - comprise mudstones, silty limestones, and fine grained sandstones of the Westbury Formation. This formation represents the upper most Triassic sequence in Shropshire recording the quasi-marine transition to the start of the full marine sequence of the Lower Jurassic Lias located at the heart of the Prees synclinal structure.

4.3.2 Drift Geology

The solid geology of North Shropshire is blanketed by a variable thickness of unconsolidated sediments comprising complex mixtures of; pebbles, gravels, sands, silts, clays and peats. Collectively these are referred to as “Drift”, “overburden” or “superficial” deposits. These deposits owe their origin to glacial, periglacial and post-glacial temperate climatic conditions related to the Late Devensian glaciation and the post-glacial Holocene period.

Devensian Glacial Deposits

The Late Devensian glacigenic deposits were laid down in an area of coalescence between the Irish Sea ice sheet advancing from the north, and the Welsh ice sheet advancing from the west (Thomas, 1989). The resulting deposits show significant spatial variation in both thickness and sediment type. They commonly grade compositionally and texturally into one another. Thomas (1989) and Bridge et al (2002) classify the glacigenic deposits into three main components; namely, till, glacio-fluvial outwash and glacio-lacustrine deposits.

Till - most widespread drift deposit, forming sheets and morainic ridges over 30 m thick to the west and north-west of the main Triassic escarpment. To east of Shawbury it is much thinner and patchy. Typically, much of the till is described as a poorly-sorted, unstratified mixture of rock fragments in a matrix of stiff, over-consolidated reddish brown or greyish brown clay or sandy clay. The till types are considered to have been either deposited beneath the ice sheet by lodgement processes or as external ice contact moraines.

In borehole logs, a distinction can be drawn between stiff lodgement tills and deposits of soft, grey to reddish brown clay or silty clay, which commonly occur inter-stratified with, or capping, outwash. These latter clays, which tend to form beds less than 5 m thick, may represent re-sedimented ablation tills, deposited in morainic ridges (Bridge et al 2002).

Glacio-fluvial Outwash - includes ice-contact deposits, outwash fans and valley train deposits, all of which were deposited by meltwater flowing on, in, or under the ice or beyond its margin. The deposits range from coarse gravel, through pebbly sands to clayey sands. The most extensive deposits occur in the north-west of the area in the region of Whitchurch and Prees Heath, around Shawbury, north-east and north-west of Shrewsbury, and north of Wellington. The sands and gravels of the Shawbury area were probably laid down as alluvial fans or fan deltas in front of an ice sheet that lay to the north of the Triassic escarpment, the water issuing from the Yorton and Lee Brockhurst Gaps in the escarpment. The deposits around Shrewsbury itself are probably also outwash deposits and form part of a more extensive body of sand and gravel that fills a buried channel system beneath the Severn, hereabouts. The proven thickness of sand and gravel is commonly in excess of 20 m. In the east, the superficial deposits are thinner and more dissected. However, isolated ridges and tracts of clean sand and gravel may reflect sub-glacial deposition as narrow, linear eskers.

Glacio-lacustrine - commonly recorded in boreholes, particularly in the west of the district, but are not widely mapped. Typically, they consist of soft, brown, pebble-free, laminated clays. Many of the deposits recorded as silty clay in boreholes may have originated in a proglacial glacio-lacustrine environment, suggesting that ponding of meltwater between the ice margin and ice-free higher ground was a frequent occurrence during deglaciation. An extensive area of lake clays (~120 m) has been mapped infilling the "Severn Trench" in the vicinity of the Melverly to Pentre area. This currently forms the flood storage area for the River Severn (Bridge et al 2002).

Holocene Post-Glacial Deposits

During the 13 000 years since the ice retreated, silts, sands and gravels, derived in part from the glacigenic deposits have been reworked and incorporated into modern day river terrace and alluvium deposits.

River Terrace Deposits - form distinct benched surfaces along the valleys of both the River Tern and River Severn. The terraces reflect former floodplain surfaces of the rivers and are probably all of Holocene age. The composition of the individual terraces varies, although they typically comprise pebbly clayey sands, reflecting the reworking of the glacigenic deposits within the river catchment. Within the upper reaches of the River Tern catchment, only a single terrace is identifiable just above the modern floodplain. Only downstream of Rodington on the River Roden and downstream of Isombridge on the Tern does a second terrace become apparent. Along the course of the River Severn, within the investigation area, three terrace benches rising 3 to 6 m, 6 to 12 m, and 12 to 18 m above the Severn can be identified.

Alluvium - consists of clay, silt, sand and gravel, locally with lenses of peat or humic deposits. Many deposits have gravel at the base. Present on the floors of most modern valleys, and is continuous in the valleys of the Perry, Tern and the Severn (up to 8 m but commonly less than 5 m thick). Elsewhere in the area, isolated basins eroded within the rockhead surface have been infilled with soft alluvial deposits, the composition of which often reflects the immediately local bedrock or superficial geology.

Peat - commonly fills glacial drainage channels and the silted-up sites of lakes such as Aqualate Mere and Fenn's & Whixall Moss, the latter an enclosed lake basin within a thick till sequence north of Wem. Also extensive tracts of peat along the valleys of the River Strine and its tributaries between Crudgington and Newport. All these features lie outside the area of interest and outside the designated development area for the Shropshire Groundwater Scheme. Within the Scheme's area of pumping influence only a small number of peat deposits have been mapped occupying small isolated areas (Bridges et al 2002).

4.3.3 Geology of the Tern Catchment: Phases 1 and 4

With the exception of one pumping station, the Phase 1 and 4 boreholes are exclusively developed within a block of Permian Bridgnorth Sandstone. The block is bounded to the west by the north-east to south-west trending Hodnet Fault. Its westerly down throw of approximately 400 m displaces the Permian Bridgnorth Sandstone to the east against a sequence of Triassic Chester Pebble Beds, Wilmslow Sandstone and the Bollin Mudstone Member of the Merica Mudstone Group around Hodnet to the north, and contemporaneous Permian Kinnerton Sandstone to the south. The Permo-Triassic Sandstone is underlain by older mudstones and siltstones of the Carboniferous Salop Formation which out crops at High Ercall, Ollerton and Woodseaves. These sequences are displaced by a further two north-east to south-west trending faults at Ollerton/ Ercall Mill Fault and Childs Ercall Fault. Figure 4.1 presents the solid geology in which the Phase 1 and 4 wellfields have been developed.

The northern part of the wellfield sits in wedge of Bridgnorth Sandstone that increases in thickness east to west from 50 m to 200 m against the Hodnet Fault. The central and southern parts of the wellfield record a similar geometry, complicated further by thinning of the Permian Sandstone to between 25 and 75 m thickness above a fault block between the Ollerton and Child Ercall Faults. East of the Child Ercall Fault the Permo-Triassic Sandstone sequence increases again to approximately 200 m thickness. A conceptual hydrogeological cross section through part of the Phase 1 and 4 wellfield has been drawn in Figure 4.5.

In comparison to the Phase 2 and 3 wellfield, the drift geology of the Phase 1 and 4 is generally thin and patchy ranging up to 8 m thick in the river corridor, but more commonly less than 5 m between extensive areas of sandstone out crop. The dominant drift type is glacial till, overlain or sitting side by side with three bodies of glacial out-wash sand and gravels around Hodnet, Hine Heath and Stanton upon Hine Heath. The course of the River Tern has cut down through the glacial drift and within the river corridor raised river terraces sit above alluvium infilling the current day floodplain. These deposits largely directly overlie the Permian Sandstone. There are no substantive peat deposits within the wellfield area. The drift geology of the area is summarised by Figure 4.3

4.3.4 Geology of the Perry Catchment: Phases 2 and 3

Phase 2 Wellfield

The ten abstraction boreholes making up the Phase 2 wellfield area are all developed within the Permian Kinnerton Sandstone Formation. With an average drilled depth of 150 m the boreholes only partially penetrate the contoured 300 to >500 m thick sequence mapped by the BGS (Bridges et al 2002). The sequence dips and becomes progressively thicker and younger towards the north-east where a sub-crop horizon of Chester Pebble Beds marks the start of the Triassic sequence and the transition to the Wilmslow Sandstone Formation and the Phase 3 wellfield to the west. The solid geology of area is mapped in Figure 4.2.

To the south the Permian sequence thins out against older Palaeozoic aged rocks on the southern margin of the Cheshire Basin. To the north-west the Sherwood Sandstone Group is faulted against the Mercia Mudstone Group, along the north-east to south-west trending Wem Fault. The maximum throw of the fault is estimated to be around 2 600 m at the base of the Permo-Triassic succession near Wem, with the throw gradually diminishing to the south where the Sherwood Sandstone Group is once again in contact either side of the fault boundary. A series of smaller east–west trending splay faults emanate from Little Ness to displace the Wilmslow Sandstone, Helsby Sandstone and Tarporley Siltstone outcrop scarp at Great Ness. Conceptual hydrogeological cross sections through the Phase 2 wellfield have been drawn in Figures 4.6 and 4.7.

With the exception of the scarp feature at Nesscliffe and Great Ness the vast majority of the sandstone aquifer is covered by drift deposits. The deposits vary in thickness from 5 to 85 m thick across the wellfield. Interpretation of geological logs shows the drift to be very complex in nature with a high degree of vertical and horizontal variation in the composition and geometry of individual drift types. Glacial till (predominantly composed of clay) is the dominant drift type in the intermediate and marginal edges of the wellfield and a central body of glacial out wash sands, gravels and pebbles at its heart. This sand and gravel body in part lies directly on top of the sandstone or is underlain by till at depth.

To the west of the wellfield glacio-lacustrine deposits in-fill a deeply incised trench feature. While a more permeable deposit in-fills another linear incised feature running south from Baschurch towards Shrewsbury between the Phase 2 and 3 wellfields. The course of the River Severn cuts down through the glacial drift where raised river terraces sit above alluvium infilling the current day flood plain. There are no substantive peat deposits within the wellfield area. The drift geology of the area is summarised by Figure 4.4.

Phase 3 Wellfield

With the exception of two boreholes out of the nine abstraction boreholes, the Phase 3 wellfield is largely developed within, and partially penetrates the Triassic Wilmslow Sandstone Formation block sub-cropping between north Shrewsbury and Harmer Hill. Conformably overlying the Chester Pebble Beds, the formation dips and becomes progressively thicker and younger to the north and north-east where the top of the Wilmslow Sandstone forms a prominent scarp feature capped by the Helsby Sandstone at Harmer Hill and Grinshill. This in turn is overlain by the Tarporley Siltstones and Bollin Mudstone Member representing the basal units of the Mercia Mudstone Group. Along the scarp this sequence is cut by a number of localised north-south trending faults. Beneath Harmer Hill the whole of the Permo-Triassic Sandstone is estimated to be 1,600 to 1,800 m thick (Bridge et al 2002). The solid geology of area is mapped in Figure 4.3.

To the north-west the Sherwood Sandstone Group is faulted against the Mercia Mudstone Group following the north-east continuation of the Wem Fault structural boundary. To the east the north-south trending Brockhurst Fault forms another prominent structural feature, its 1,200 m throw displaces the Triassic Sandstone sequence to the west against Permian Kinnerton Sandstones to the east long the line of the fault. To the south the Sherwood Sandstone Group terminates as a fault boundary contact against Carboniferous Salop Formation along the southern extension of the Hodnet Fault in Shrewsbury. Conceptual hydrogeological cross sections through the Phase 3 wellfield have been drawn in Figures 4.6 and 4.8.

South of the rock out crop at Harmer Hill, Grinshill and isolated out crop patches around Harwicke Grange below a surface elevation contact line of 100 mAOD the vast majority of the sandstone aquifer is covered by drift deposits. The deposits vary in thickness from 2 to 45 m thick across the wellfield. Towards the northern and central part of the wellfield the drift is dominated by an extensive 30 to 40 m thick sheet of clay till. To the east, beyond a 50 m thick infill sequence running parallel with the Brockhurst Fault, the till sequence becomes progressively thinner. In the southern central and southern parts of the wellfield the drift assemblage becomes progressively more complex with a discontinuous till sheet overlying an alternating deposit of outwash sands and gravels and discontinuous wedges of till.

Adjacent to the River Severn, up stream of Shrewsbury, a thick sequence of glacio-fluvial sands, gravels and silty sands is mapped directly overlying the Permo-Triassic Sandstone. These in turn are overlain by more recent river terrace and alluvial deposits associated with the current day course of the River Severn. An arc of alluvial deposits possibly underlain by till occupies a cut off meander forming the Old River Bed SSSI and SINC. Within the wellfield area there are substantive peat deposits mapped at Harmer Moss Plantation and around Fenemere and Marton Pools. The drift geology of the area is summarised by Figure 4.4.

4.3.5 Soils and Land Use

Soils

The predominant soils types mapped in North Shropshire within which the groundwater scheme lies are listed in Table 4.1. By area the predominant soil type is Salop and Pinder overlying clayey drift, followed by Bridgnorth and Newport and to a lesser extent Delamere and Crannymoor overlying more sandy drift or sandstone out crop areas.

Table 4.1 Predominant Soil Types within North Shropshire (Source: Cranfield University, SSLRC Database)

Soil Name	Soil Description	Dominant Soil Properties
PINDER	Seasonally wet deep loam	Slowly permeable seasonally waterlogged fine loamy and fine silty over clayey soils
SALOP	Seasonally wet deep red loam to clay	Slowly permeable seasonally waterlogged reddish fine loamy over clayey fine loamy and clayey soils
CREWE	Seasonally wet deep red clay	Slowly permeable seasonally waterlogged reddish clayey and fine loamy over clayey soils often stoney
CONWAY	Seasonally wet deep silty	Deep stoneless fine silty and clayey soils variably affected by groundwater
HODNET	Silty over red shale	Reddish fine and coarse loamy soils with slowly permeable subsoils and slight seasonal water logging
SALWICK	Deep red loam	Deep reddish fine loamy soils with slowly permeable subsoils and slight seasonal water logging
BRIDGNORTH	Sandy over red sandstone	Well drained sandy and coarse loamy soils over soft sandstone
NEWPORT 1	Deep sandy	Deep well drained sandy and coarse loamy soils
CRANNYMOOR	deep sandy	Well drained sandy soils mostly under woodland and very acid with a bleached subsurface horizon
DELAMERE	sandy over sandstone	Well drained sandy soils commonly with a bleached subsurface horizon over sandstone
ADVENTURERS' 1	peat	Deep peat soils
WITHNELL 2	loam over sandstone	Well drained loamy soils over rock. Sometimes reddish
WICK 1	deep loam	Deep well drained coarse loamy and sandy soils locally over gravel
ELLERBECK	stony loam over gravel	Very stony well drained loamy soils locally on hummocky ground
EARDISTON 2	deep red loam	Well drained often reddish coarse loamy soils over sandstone
BROMSGROVE	deep loam	Well drained reddish coarse loamy soils mainly over soft sandstone but deep in places

Land Use

Within the area of the scheme the predominant land use type is mixed agricultural comprising; grass, cereals, and root crops, with minor areas occupied by woodland. Shrewsbury and Telford represents the largest single areas of conurbation development, followed by a scattering of smaller urban developments clustered around villages and small hamlets.

4.3.6 Land Subsidence and Groundwater Abstraction

Globally there are a number of documented case studies recording land subsidence due to drainage of water from drift deposits. These cases generally relate to large sedimentary basins with very thick unconsolidated drift sequences. Local to Shropshire, but outside the development of SGS, there is evidence of shrinkage of peat deposits at surface, believed to be as a result of groundwater abstraction around the Edgmond Marsh area near Newport, Shropshire.

The potential for the effects of groundwater abstraction to manifest at surface as ground subsidence or “shrinkage” is wholly dependant upon conditions where unconsolidated drift deposits lie in hydraulic contact with groundwater levels. The mechanism for subsidence relies upon under drainage of the drift deposits causing changes in the pore pressure leading to consolidation or “shrinkage” of the drift deposit. The degree of consolidation is then determined by the hydraulic conductivity of the sediments, their compressibility, the magnitude of drawdown and duration of pumping (Clark 1977).

4.4 Assessment of Impact on Current Environment

A theoretical assessment of the potential effect of a summers’ regulation pumping on two pilot areas in the SGS development area was undertaken by Clark (1977). The report concluded that the hydrogeological conditions of the Tern Catchment (Phase 1&4) do not make it largely susceptible to potential subsidence effects of groundwater abstraction on surrounding drift. This is because the groundwater is largely contained within the body of the sandstone rock with limited hydraulic connection to saturated drift. By applying bulk values to the drift for coefficients of consolidation and volumetric compressibility, the report concluded that the potential consolidation following a summers regulation pumping is unlikely to exceed between 1 and 3 mm in the Phase 1 & Phase 4 wellfield. This situation also applies to the underlying conditions of the Phase 3 where groundwater is also largely sits within the sandstone throughout the heart of the wellfield.

Only in the Phase 2 area do conditions exist where the greater thickness of saturated drift confines and lies in hydraulic continuity with the underlying sandstone potentiometric head. Here the theoretical consolidation will be slightly greater because of the presence of saturated deep drift. The theoretical consolidation beneath Frankbrook, assuming 10 m of drawdown due to pumping acting on a confined head 23 m above the base of the 40 m thick clay till sequence, was calculated to be about 10 mm.

Between April 1978 and October 1979 Severn Trent Authority carried out pumping trials at a borehole in the North Perry pilot area at Lower Frankton (53 m thick clay sequence) and Greenfields (5 m thick clay sequence) in the Tern pilot area. These two sites, plus four other control sites outside the area of influence of the pumping tests, were instrumented with levelling stations to precisely measure changes in ground level. The trial concluded that no level changes could be detected at Lower Frankton, while only 1 mm of change at Greenfields was attributed to pumping. The control sites clearly showed that appreciable movement can take place at ground level as a result of natural variations in soil moisture content and by freezing, and that changes due to pumping were negligible in comparison.

To date, over the past 30 year operational existence of the scheme no incidences of land subsidence have been reported, observed or attributed to any of the operationally pumped Phase areas. Operation of the scheme across the Phase 1, 2, 3 and 4 wellfields to date has therefore not considered to have had a detrimental impact on consolidation of drift and or propagation of these effects as subsidence to ground level.

4.5 Predicted Impacts

Based on the nature of the geology in which the groundwater scheme has been developed and is operated, no impact is anticipated to arise on the structural fabric of the solid geology from the extended pumping regime envisaged to provide additional groundwater support under drought conditions.

While there is evidence of shrinkage of peat deposits at surface, believed to be as a result of groundwater abstraction around the Edgmond Marsh area near Newport, Shropshire, large bodies of peat in hydraulic contact with sandstone water tables do not exist within the operational SGS areas. Therefore such effects have not been, and are not expected to be, replicated under the extended pumping conditions envisaged under the drought order. The absence of any observed or reported incidences of land subsidence, based on the historic pumping regime of the scheme to date, further support the conclusion that any subsidence due to pumping is likely to be negligible. Under the onset of drought conditions seasonal climatic wetting and drying cycles will be amplified as natural dessication of surface soils builds. From the available studies natural ground level fluctuations due to expansion and contraction of soils at surface, are more likely to have a greater influence on near surface ground levels, and therefore structures, than dewatering of unconsolidated drift deposits at depth.

4.6 Mitigation and Monitoring

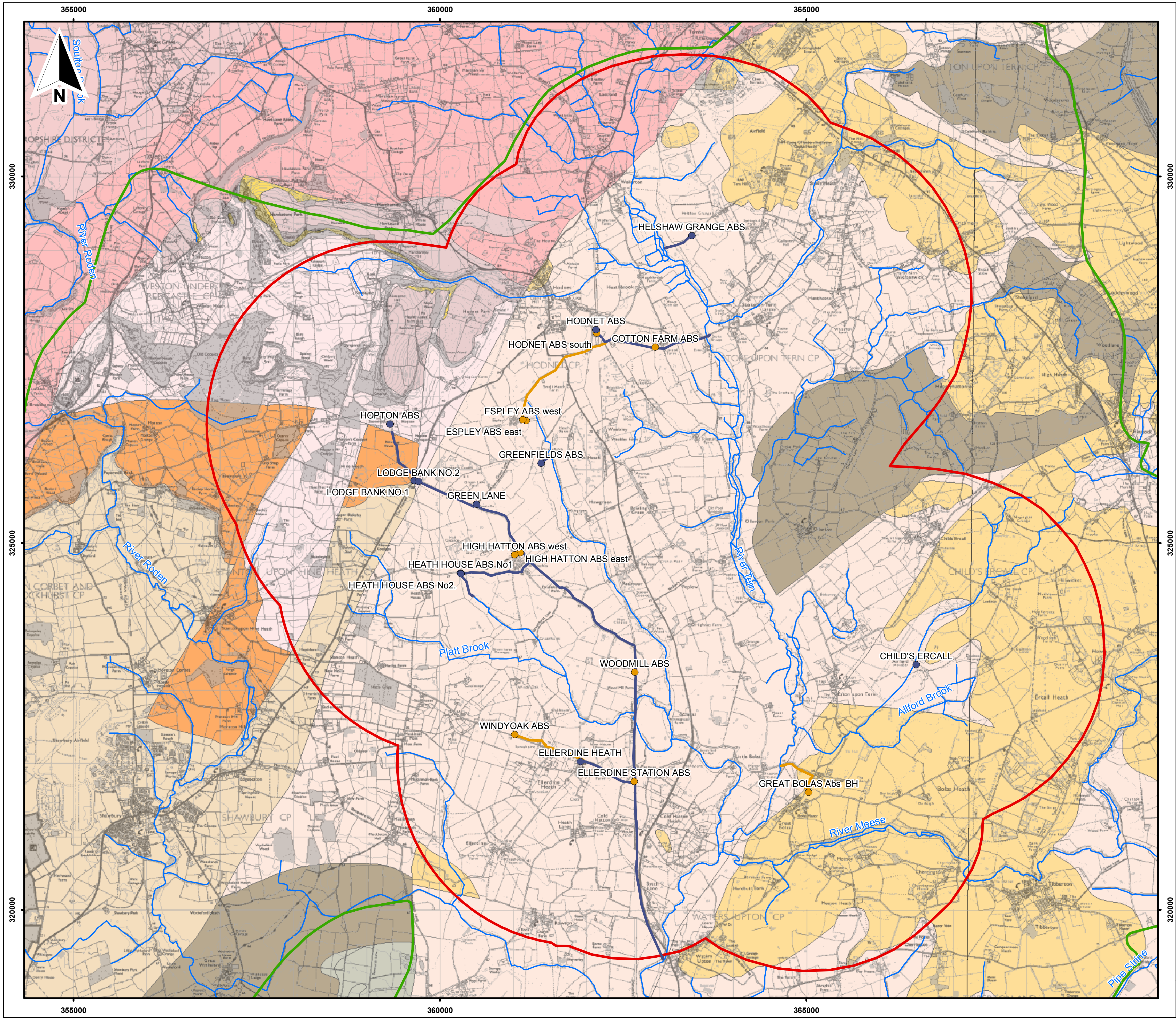
In the absence of any predicted impact upon the fabric of the surrounding geology and soils through the normal operation or extended operation of the scheme then no mitigation or monitoring measures are deemed necessary.

4.7 Summary and Conclusions

The SGS has been developed in the extensive low-lying area occupied by the North Shropshire Plain. These plains mark the subcrop and out-crop area of the Permo-Triassic aged sedimentary rock in-fill sequence. These sedimentary rock formations include the Sherwood Sandstone Group, forming the present day principal groundwater bearing aquifer in which the wellfields of the SGS have been developed.

The rock formations of North Shropshire are blanketed by a variable thickness of unconsolidated sediments. These deposits owe their origin to glacial, periglacial and post-glacial temperate climatic conditions related to the Late Devensian glaciation and Holocene period.

Based on the nature of the geology in which the groundwater scheme has been developed, no impact on the structural fabric of the local geology due to pumping has been observed to date due to the historic operation of the scheme. No impact is anticipated to arise from the extended pumping regime envisaged to provide additional groundwater support under drought conditions.



Key:

- Location of existing Phase 1 groundwater pumping station and pipeline
- Location of existing Phase 4 groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers

Solid Geology

- Lias Group
- Dyrham Formation
- Sidmouth Mudstone Formation
- Bollin Mudstone Member
- Tarporley Siltstone Formation
- Helsby Sandstone Formation
- Wilmslow Sandstone Formation
- Chester Pebble Beds Formation
- Kidderminster Formation
- Kinnerton Sandstone Formation
- Bridgnorth Sandstone Formation
- Salop Formation
- Enville Member

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Figure 4.1
Phase 1 and 4 Solid Geology

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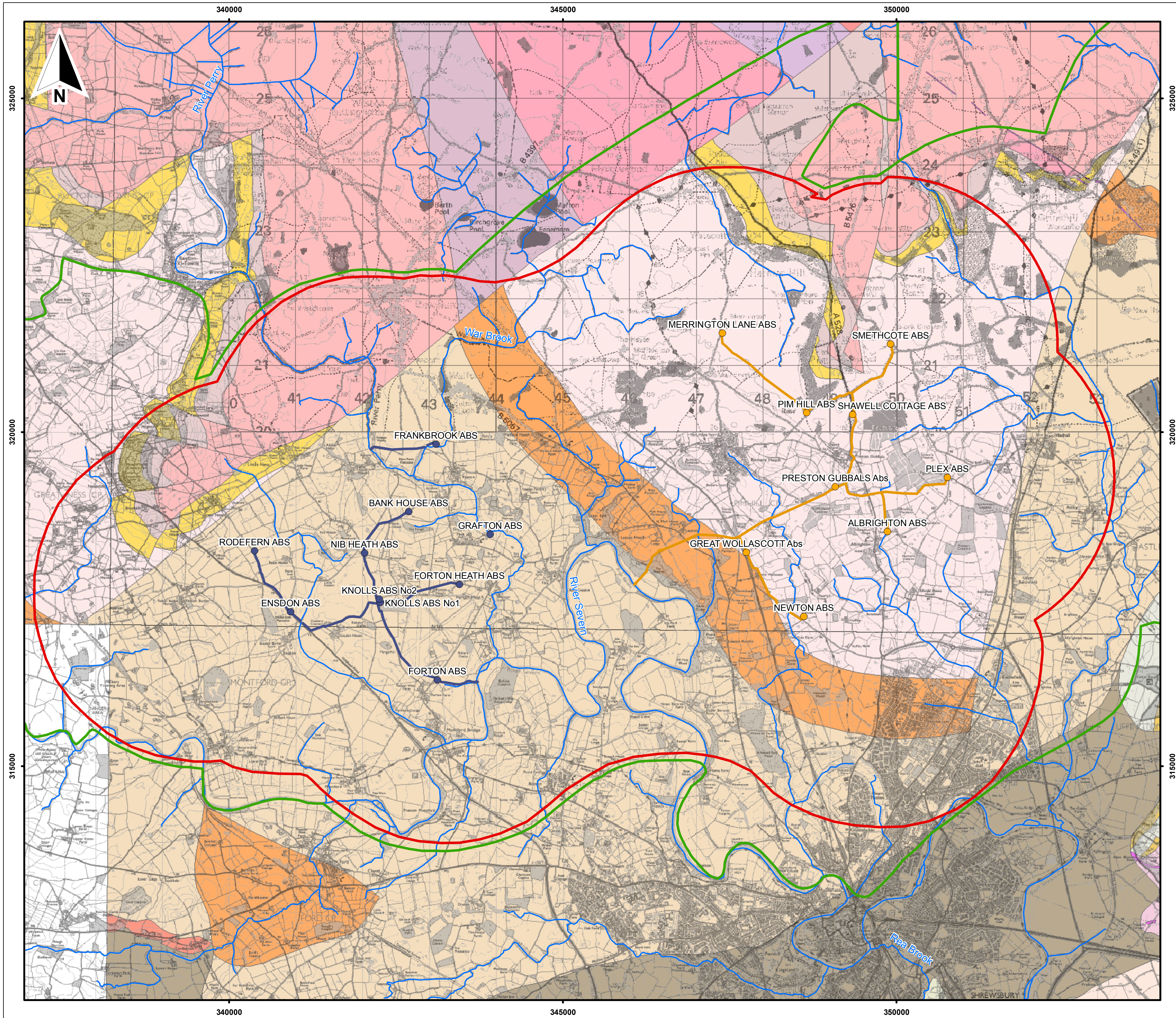

Key:

- Location of existing Phase 2 groundwater pumping station and pipeline
- Location of existing Phase 3 groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers

Solid Geology

- Branscombe Mudstone Formation
- Wilkesley Halite Member
- Sidmouth Mudstone Formation
- Northwich Halite Member
- Bollin Mudstone Member
- Tarporley Siltstone Formation
- Helsby Sandstone Formation
- Wilmslow Sandstone Formation
- Chester Pebble Beds Formation
- Bridgnorth Sandstone Formation
- Kinnerton Sandstone Formation
- Alberbury Breccia
- Salop Formation
- Halesowen Formation
- Bayston-Oakwood Formation
- Bayston-Oakwood Formation
- Portway Formation (Stretton Group)

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Figure 4.2
Phase 2 and 3 Solid Geology

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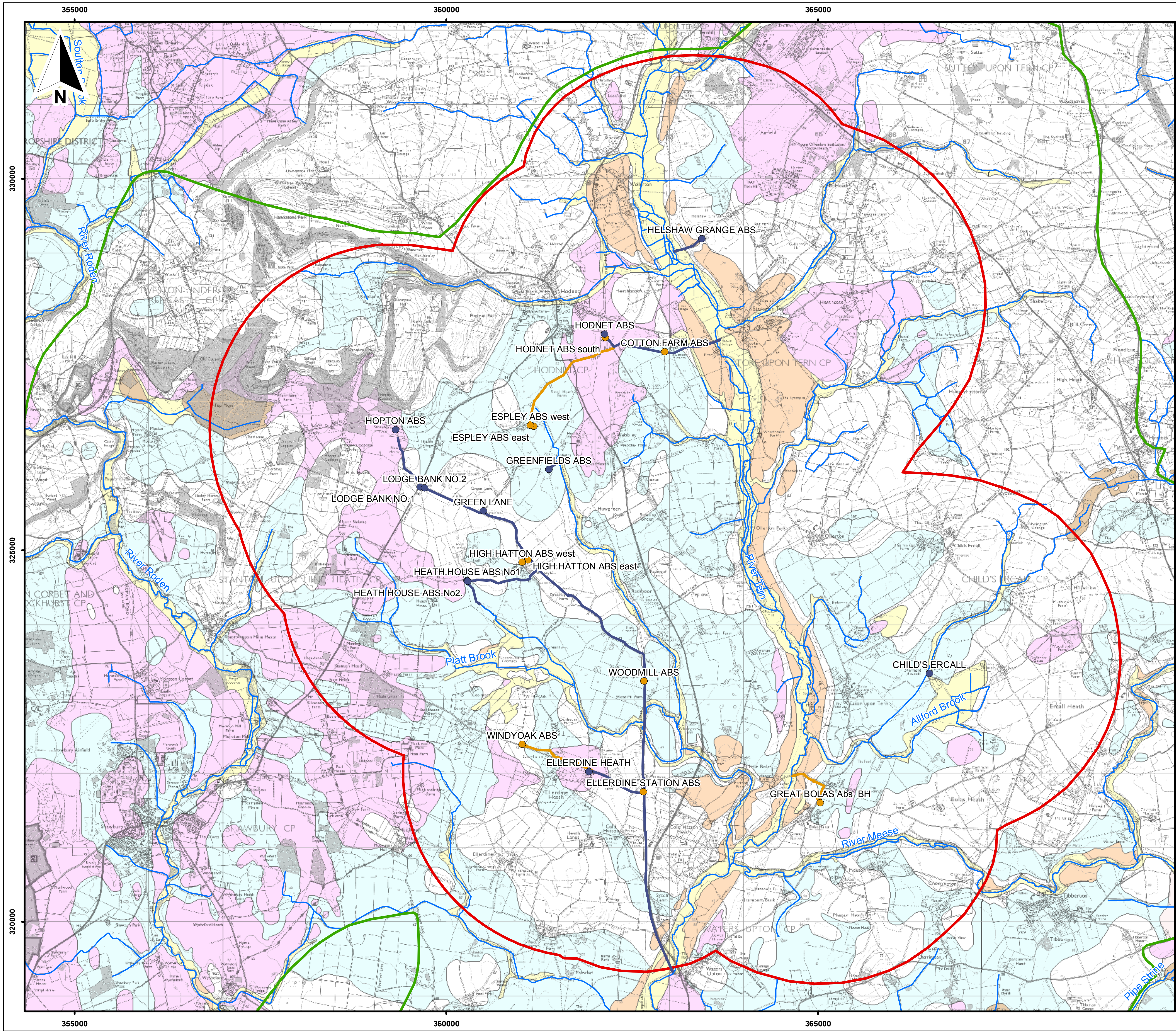

Key:

- Location of existing Phase 1 groundwater pumping station and pipeline
- Location of existing Phase 4 groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers

Superficial Deposits

- Alluvium
- Peat
- River Terrace Deposits
- Glaciofluvial Deposits
- Glaciolacustrine Deposits
- Till

0 1,000 2,000 Metres

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Figure 4.3
Phases 1 and 4 Drift Geology

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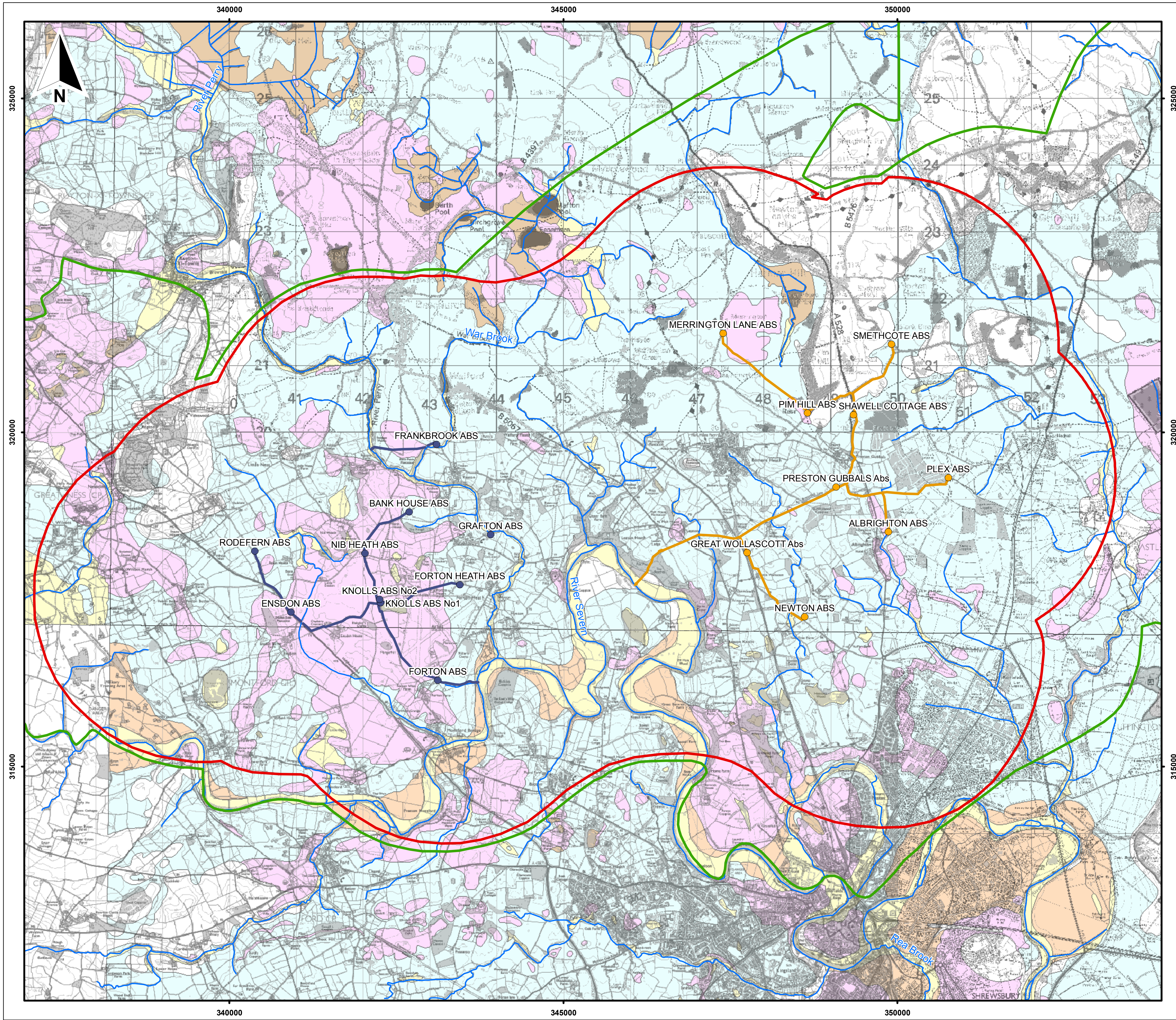

Key:

- Location of existing Phase 2 groundwater pumping station and pipeline
- Location of existing Phase 3 groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers

Superficial Deposits

- Alluvium
- Peat
- River Terrace Deposits
- Glaciofluvial Deposits
- Glaciolacustrine Deposits
- Till

0 1,000 2,000 Metres

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Figure 4.4
Phase 2 and 3 Drift Geology

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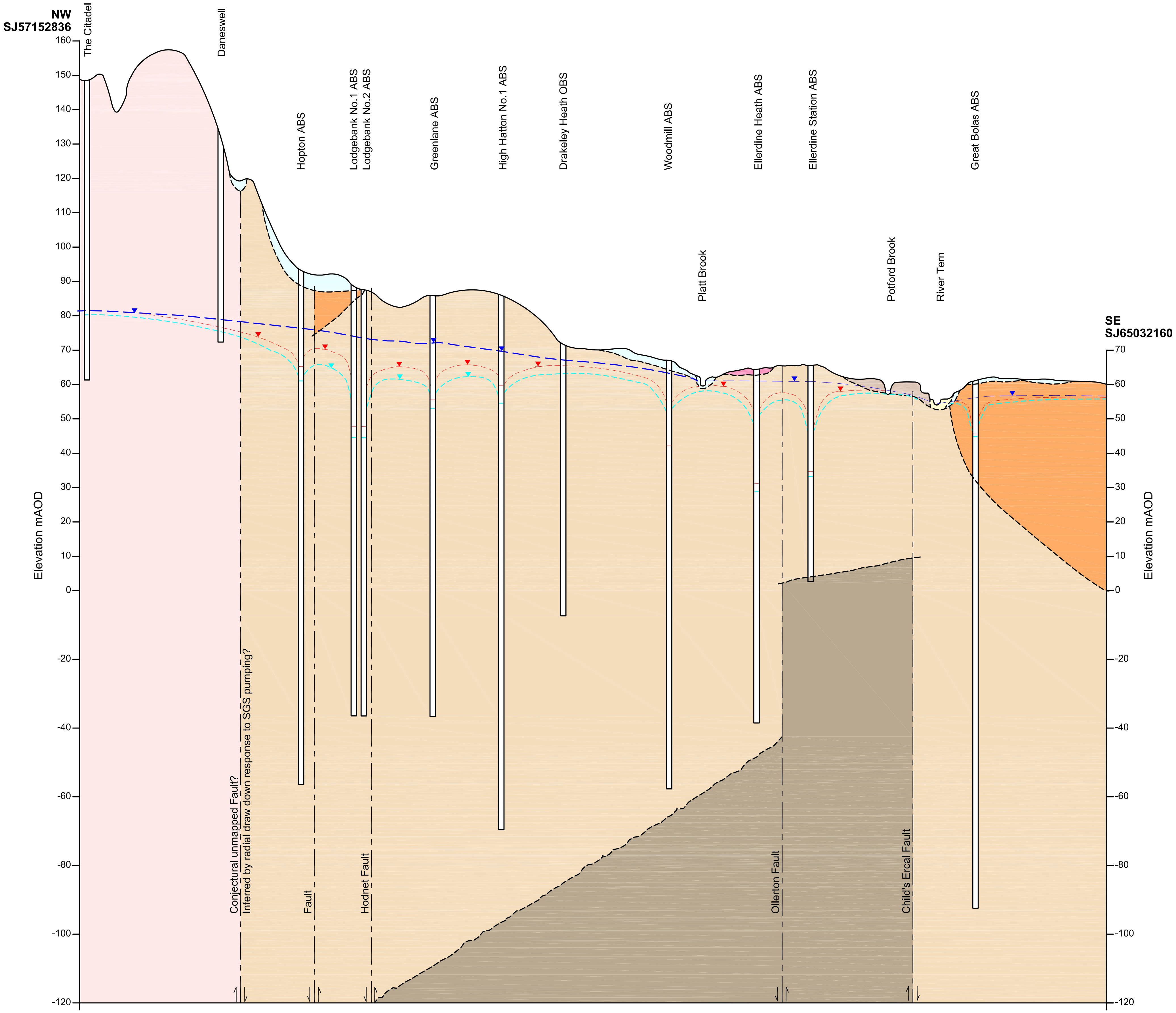

Key

- Alluvium
- River Terrace
- Sand and gravel
- Clay
- Wilmslow Sandstone
- Chester Pebble Beds
- Kinnerton Sandstone
- Salop Formation
- Natural rest groundwater level (no pumping)
- Maximum groundwater drawdown observed under normal operational pumping conditions
- Modelled groundwater drawdown projected under drought order pumping scenario

Note:
Vertical exaggeration: 10 times.

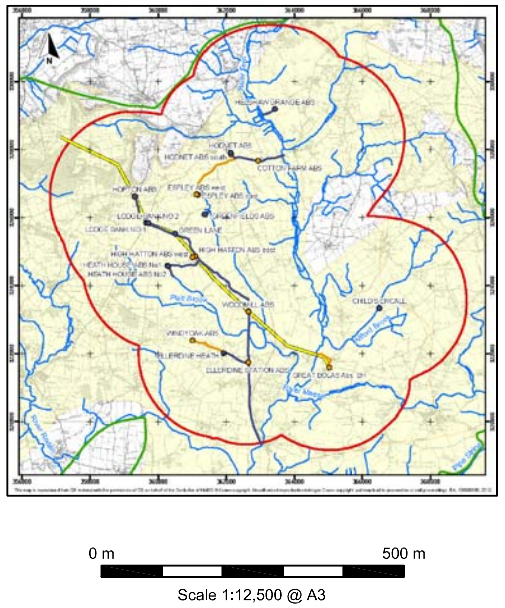

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Figure 4.5
Weston and Great Bolas (Phases 1 & 4) Conceptual Hydrogeological Cross Section

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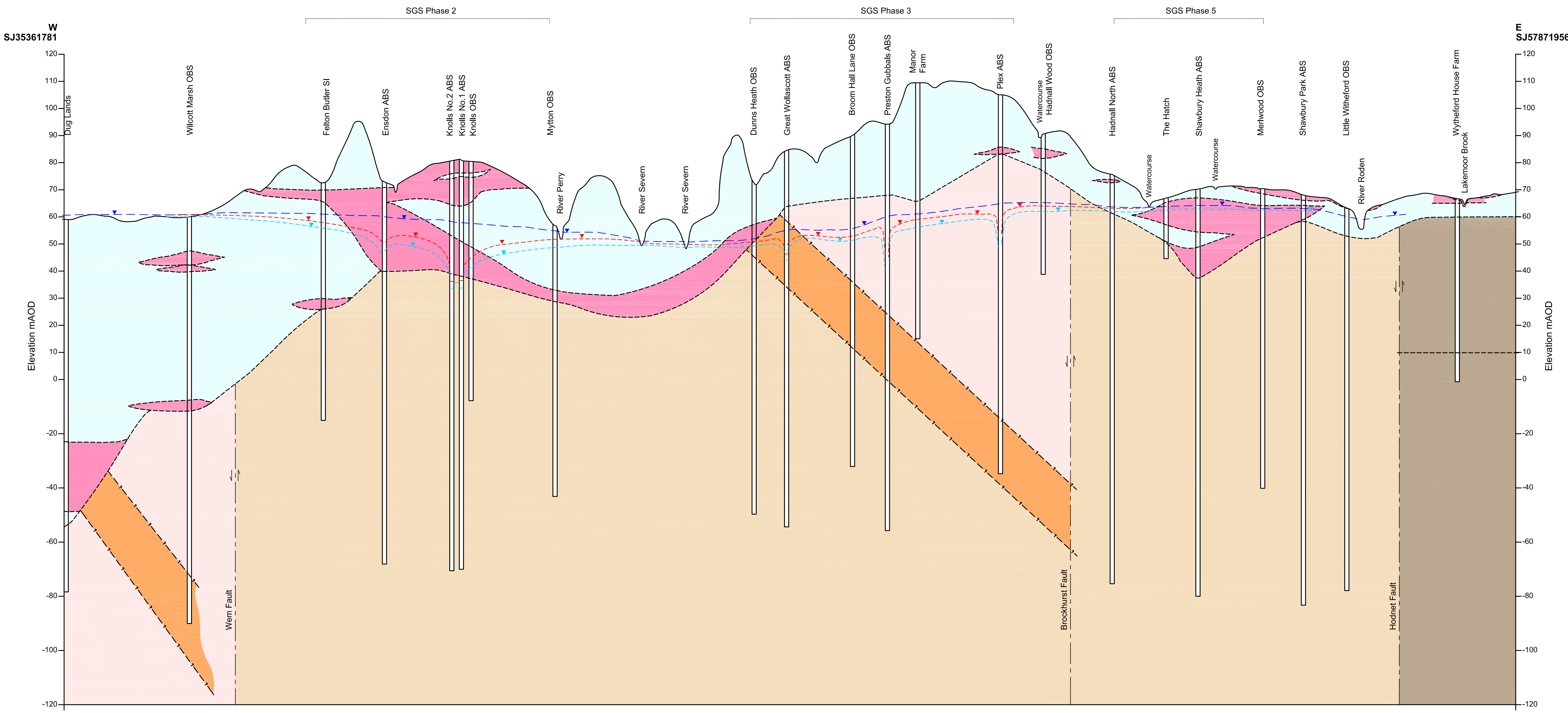

Key

- Sand and gravel
- Clay
- Wilmslow Sandstone
- Chester Pebble Beds
- Kinnerton Sandstone
- Salop Formation (Sandstone above and Mudstone below dashed line)
- Natural rest groundwater level (no pumping)
- Maximum groundwater drawdown observed under normal operational pumping conditions
- Modelled groundwater drawdown projected under drought order pumping scenario

Note:
Vertical exaggeration: 50 times.

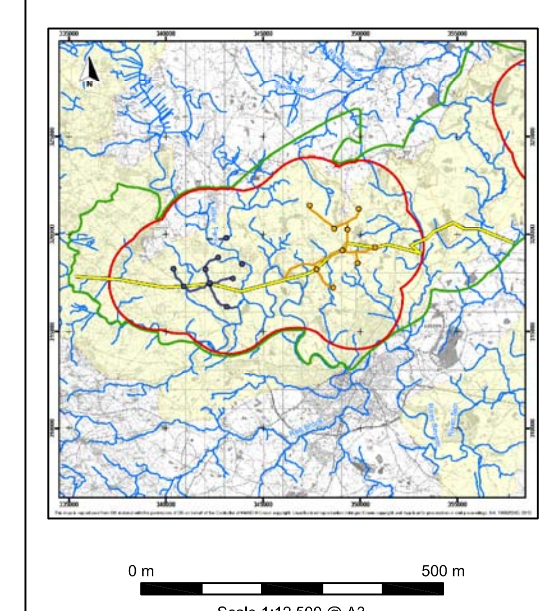

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Figure 4.6
Pentre to Great Witheford (Phase 2 & 3) Conceptual Hydrogeological Cross Section

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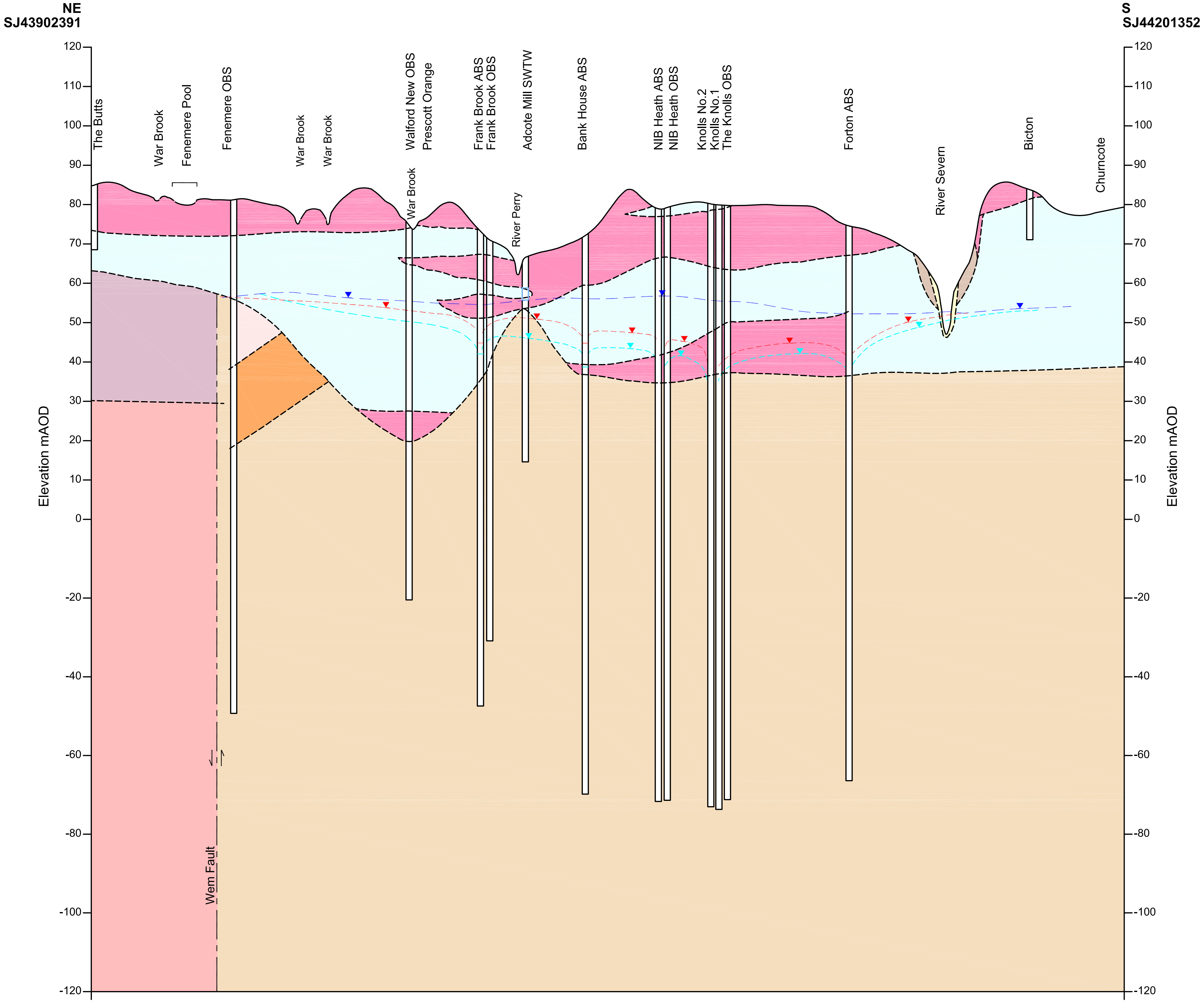

Key

- Alluvium
- River Terrace
- Sand and gravel
- Clay
- Northwich Halite
- Bollin Mudstone
- Tarporley siltstone
- Wilmslow Sandstone
- Chester Pebble Beds
- Kinnerton Sandstone
- Natural rest groundwater level (no pumping)
- Maximum groundwater drawdown observed under normal operational pumping conditions
- Modelled groundwater drawdown projected under drought order pumping scenario

Note:
Vertical exaggeration: 50 times.

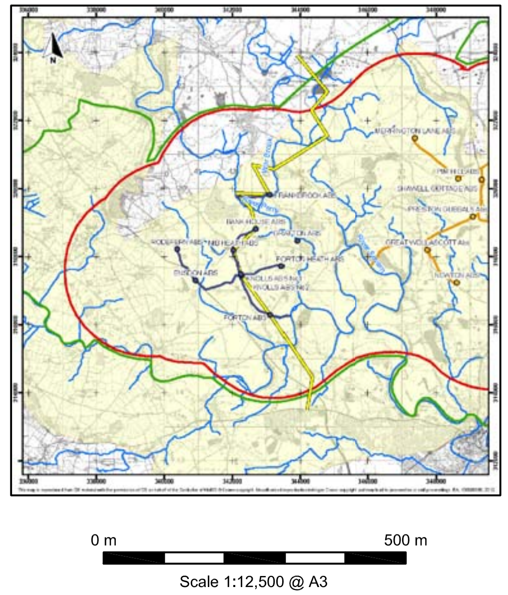

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Figure 4.7
South Perry and Montford (Phase 2) Conceptual Hydrogeological Cross Section

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5. Water Resources

5.1 Introduction

The aim of this section is to characterise the hydrogeological and hydrological setting of the SGS wellfield areas, and to summarise the current conceptual understanding of the interaction between groundwater and surface water, and intervening soil moisture environment. The purpose is to identify any potential effects of pumping groundwater beyond the current SGS licence constraints on these regimes.

5.2 Data Availability and Assessment

The Environment Agency operates an extensive range of hydrometric monitoring sites throughout the SGS area. Data is collected, automatically and manually, from field stations that record parameters such as river flow, groundwater level and rainfall intensity and volume.

The hydrogeological and hydrological conceptual understanding is well developed within each of the Phase wellfield areas. This is based on interpretation of data gathered during construction of the scheme and observation of the effects of performing both individual and multiple borehole pumping tests and operational pumping in each of the Phase areas. The findings from this work have been documented in a series of technical reports in the 1970s and subsequent specific reports on each of the Phases as they were developed. This data set was used to construct and calibrate the East Shropshire Groundwater Model. The reports from the modelling and the model itself have been used as principal data sources for this section to describe the current hydrogeological environment and quantifying the projected effects of over pumping the scheme on both the hydrogeological and hydrological regimes.

An assessment of groundwater abstraction on the soil moisture regime has been made using the crop vulnerability mapping and methodology jointly developed by the Environment Agency, ADAS and The Arable Group.

5.3 Description of the Current Environment

5.3.1 Hydrogeology

The Permo-Triassic Sandstone is the second most important principal aquifer in the United Kingdom, second only to the Chalk. Despite its much smaller outcrop, the sandstone's high porosity and low transmissivity means that it has an excellent capacity to store and slowly discharge large volumes of groundwater, making it the biggest strategic store of potable water in the UK, (Shepley, 2010). These properties favour a slow response time, tending to distribute the effects of seasonal abstraction and recharge patterns more evenly and over longer periods within the environment. In practice this means that the effects of abstraction in the short term are supported by storage in the aquifer with a small reduction in baseflow to streams and rivers. This culminates in high net gains to augmented river flows, making use of groundwater from these aquifers more efficient and effective for large scale strategic resource development. In the long term the pay back for replacing the pumped storage comes from a diminishing reduction in baseflow to connected streams and rivers as recharge replenishes groundwater levels.

The Permo-Triassic Sandstone formations, described in detail in section 4, provide the principal aquifer system in which the Shropshire Groundwater Scheme abstraction boreholes operate. The sequence of formations is considered to comprise two relatively homogeneous and permeable formations (Bridgnorth and Wildmoor Sandstones) that alternate with more heterogeneous/ lower permeability formations (Kidderminster and Bromsgrove Sandstones). The geometry of the aquifer system is influenced by faulting, displacing principal aquifers and secondary aquifers to influence groundwater flow patterns with varying degrees of hydraulic effect. The Carboniferous Salop Formation and Triassic Mercia Mudstone Group underlie, overlie and bound the sandstone and are classified as secondary A & B aquifers. The East Shropshire Model suggests that there does not appear to be a substantial amount of lateral inflow to the Permo-Triassic Sandstone aquifer from these adjacent formations. Therefore it concludes that the sandstone system forms the dominant store and source of groundwater which supports the Shropshire Groundwater Scheme abstraction.

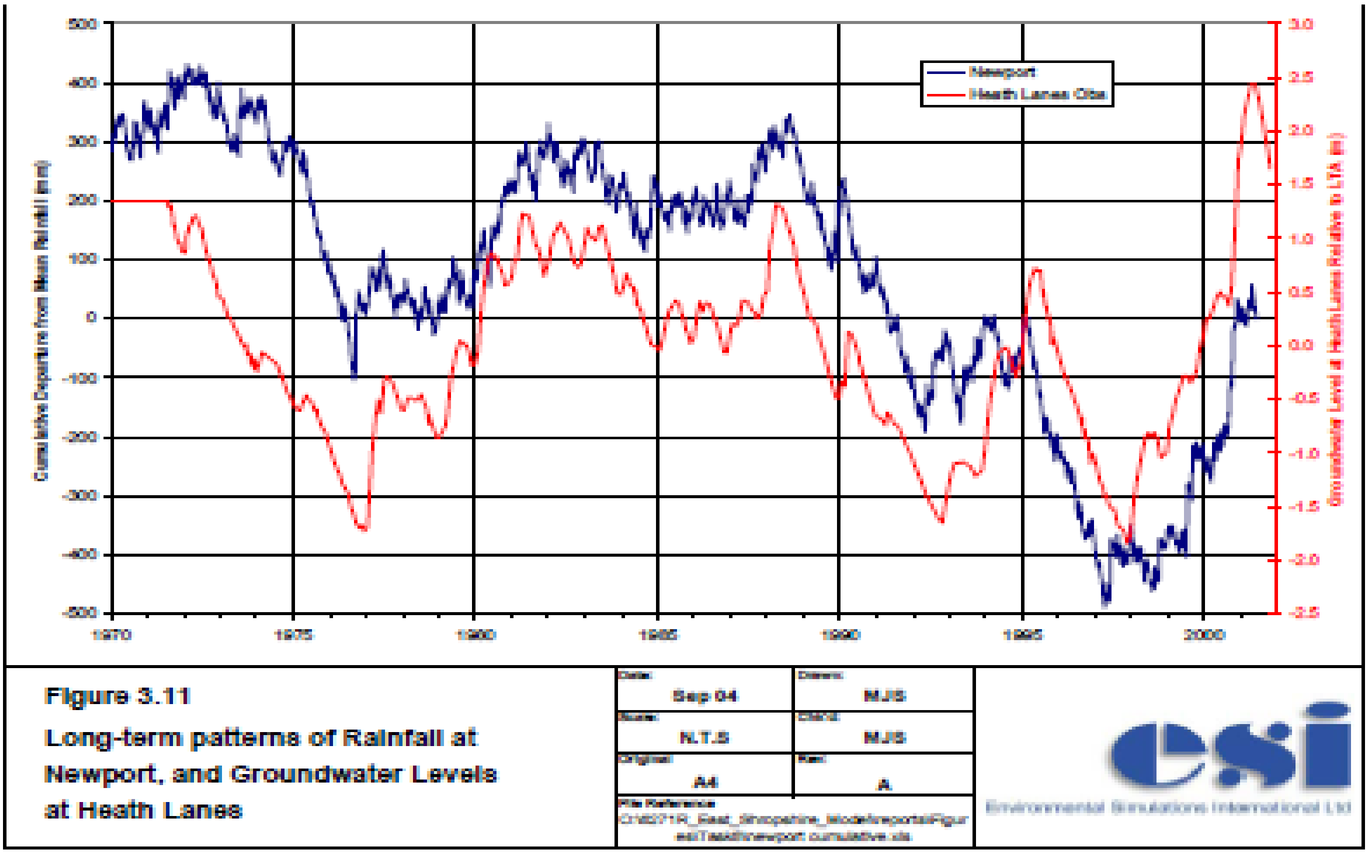
Much of the Permo-Triassic Sandstone aquifer in the area of interest is covered by complex drift with significant vertical, lateral and lithological variation, giving rise to both confined and unconfined conditions across the aquifer. The complexity of the drift at the local scale can merge with the sandstone to form part of the regional aquifer system where it is in hydraulic connection. Alternatively the drift systems can isolate and support hydraulically layered secondary aquifers that provide baseflow to local stream and river systems that are not head dependent on groundwater discharge from the underlying sandstone. The nature of the drift is of critical importance to the estimation of recharge to the Permo-Triassic Sandstone and therefore to the assessment of the groundwater resource balance.

In the following sections the hydrogeological setting of each of the wellfield areas is discussed, with reference to regional groundwater contour and depth to groundwater maps produced by the Environment Agency. The observed effects of the aquifer response to historic SGS pumping events are examined using long term groundwater level hydrographs from key monitoring boreholes.

Groundwater Resource Balance

The term “groundwater resource” is used to describe the long term average volume of water in the hydrological cycle, passing through groundwater storage where it can be drawn upon by pumping. The licensable resource lies in the balance between the assessed amount of recharge to the aquifer and the outflow, or discharge, from it. The balance between these two can be measured as fluctuations in groundwater levels over time. Where recharge exceeds discharge groundwater levels rise, and where discharge exceeds recharge groundwater levels fall. This relationship is best illustrated in Figure 5.1 where changes in long term groundwater level trends in the Heath Lanes borehole (Permian Sandstone aquifer), can be seen to be directly proportional to a prevailing surplus or deficit in mean rainfall measured from a near by rain gauge.

Figure 5.1 **Relationship between Long-term Recharge and Groundwater Level Fluctuations in North Shropshire Permian Sandstone Aquifer**
(Source: Figure 3.11 East Shropshire Groundwater Model – Task 8, January 2005)



The Agency's groundwater resource estimates are based on the principle that all groundwater discharges to surface water in the form of baseflow. Baseflow maintains river flows and the dependent ecology during periods of low flow resulting from dry weather. The licensable volume of groundwater is calculated as the remaining amount of baseflow under low flow conditions after the volume to protect good ecological status has been deducted. This is based on conservative standards set by the Water Framework Directive, and excludes the larger volumes of water that are available at periods of higher flows.

Table 5.1 summarises the groundwater resource balance for each groundwater unit in which the SGS Phases operate. Groundwater resource modelling calculates a total assessed recharge of 106 Ml/d across the four groundwater management units in which the scheme is licensed. The current licensed abstraction of 68 Ml/d, of which SGS accounts for 30 Ml/d, exceeds the desirable licensable resource of 38 Ml/d. This accounts for the reason why 3 out the 4 units are currently designated as being over licensed, even though the actual abstraction for 2010/11 was only 16 Ml/d. Total licensing of resource has not significantly increased over the past 30 years since SGS licence allocation was taken in to account. However the amount of licensable resource has been reduced as a greater proportion of the assessed recharge has been set-a-side for environmental protection.

Table 5.1 Groundwater Unit Resource Balance Containing Operational Phases (Source: Midlands Region Review of Groundwater Abstraction for Licensing Purposes Annual Review 2010/11)

Groundwater Unit Index	Groundwater Unit Name	SGS Phase Operating within Unit	Surface Area (km2)	Recharge (mm/a)	Assessed Recharge (Ml/d)	Licensable Resource (Ml/d)	Licensed Abstraction (Ml/d)	Actual Abstraction (Ml/d)	Unit Class
F.6.4	Ensdon	2	35.55	82	8.07	4.94	9.3	2.55	OL*
F.6.5	Merrington	3	78.33	81	17.35	13.01	13.88	2.67	D
F.6.6	Stanton	1	45.75	178	21.82	6.90	17.71	7.52	OL*
F.6.72	New Radmoor	1&4	102.65	206	59.31	13.69	26.67	3.41	OL*
Totals			262.28	547	106.55	38.54	67.56	16.15	

OL – Over licensed, OL* - Water available to 2013, no presumption of renewal, D – Resource available (Shropshire Middle Severn & Severn Corridor CAMS)

To put in to context the volume increase sought under this drought order, Table 5.2 shows the comparison of the mean daily average abstraction rate permitted under the current licence limit against that sought under this drought scenario. The current full licence 5 yearly volume of 55,500 Ml permits a mean daily average SGS abstraction of 30 Ml/d. To combat the extreme event under the 5 year drought scenario (see Section 3.1.1) would require a marginal increase of 2 Ml/d (to 32 Ml/d) to the mean daily SGS abstraction rate.

Table 5.2 Comparison of Mean Daily Abstraction Rates from SGS Phases - Maximum Licence Volume versus Volume Sought Under Drought Order

	5yr Max Licence Volumes		Projected 5yr Volumes Sought under Drought Scenario		
Phase	**Max Lic. Volume (Ml)**	**Mean Daily Average Abstraction Over 5 Year Period (Ml/d)**	**Vol Required (Ml)**	**Mean daily average Abstraction Over 5 Year Period (Ml/d)**	**Increase in Mean Daily Abstraction (Ml/d)**
Phase 1	14,500	7.9	15,803.3	8.7	0.7
Phase 2a	4,100	2.2	3,243.1	1.8	-0.5
Phase 2b	10,100	5.5	11,585.2	6.3	0.8
Phase 3	12,200	6.7	13,753.1	7.5	0.9
Phase 4	14,600	8.0	14,794.9	8.1	0.1
Combined	**55,500**	**30.4**	**59,179.6**	**32.4**	**2.0**

Phase 1 and 4 Wellfield

Without exception, all abstraction boreholes for these phases have been completed in Permian Bridgnorth Sandstone. Despite the relatively shallow thickness of the sandstone in this area (~50 to 200m thick), only two of the twenty abstraction boreholes penetrate the full thickness of the aquifer. Spatially both Phases effectively occupy the same area of aquifer and, as a consequence, the wellfields over lap one another.

Regional Groundwater Contour Pattern and Flow Direction

Contour lines representing the groundwater head in the Permo-Triassic Sandstone aquifer across the Phase 1 & 4 wellfield when the scheme is not pumping are presented in Figure 5.2. These contours are based on level information from boreholes with long open hole or unscreened sections in the sandstone aquifer. Overall there is good spatial correlation between these points with which to confidently draw contour lines. The contours record groundwater highs of ~90 mAOD on the eastern and western fringes of the Tern catchment and groundwater minima down to ~50 mAOD alongside the River Tern. The most notable feature of these lines is their convergence on, and northward deflection of contours centred along the course of the River Tern, and to a lesser extent some of its minor tributaries such as the Potford, Platt and Stoke Brooks. This reinforces the view that there is good hydraulic connection between groundwater and surface water with the River Tern accreting flow from, and acting as the main drain for, groundwater discharging from the Permo-Triassic Sandstone aquifer.

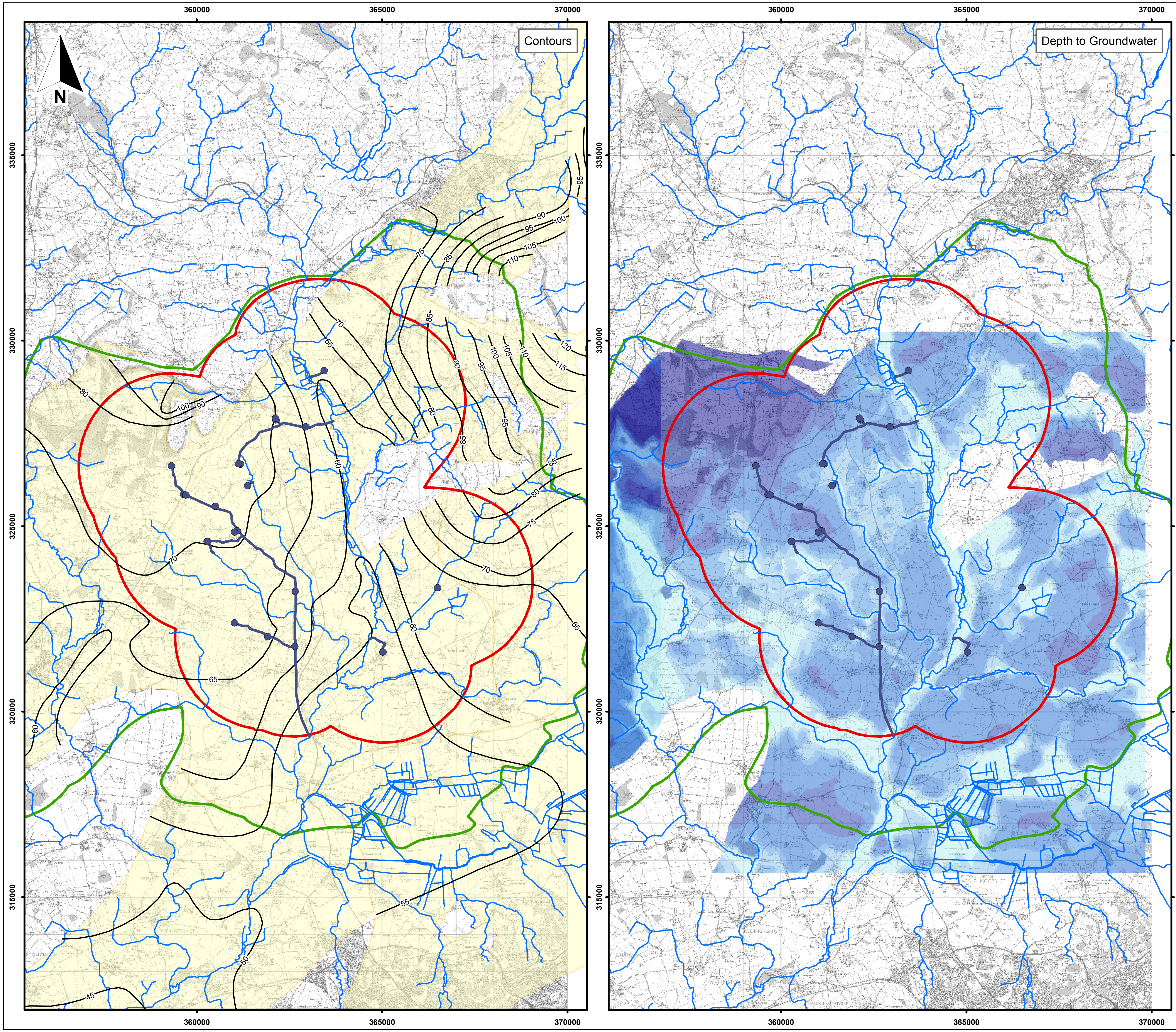
Depth to Groundwater

The depth to groundwater in the Permo-Triassic sandstone aquifer is presented in Figure 5.2, with dark blue representing deep groundwater and light blue shallow groundwater. A good correlation can be seen between the areas of shallow groundwater (<2 mbgl) and corridors of the main rivers, Tern and Roden, and some of the smaller tributary streams such as the Stoke, Potford, Platt and Lakemoor Brooks. Away from the main rivers the depth to groundwater increases on average from 3 to 15 mbgl. These areas were specifically targeted for development of the SGS wellfields to ensure the greatest drawdown was concentrated away from any potentially sensitive zones.

Long Term Groundwater Level Trends

When interpreting the net effect of SGS pumping on groundwater levels within each of the phase areas it is important to have an awareness of the prevailing natural background trends operating within the North Shropshire sandstone aquifer. For this purpose groundwater hydrographs from three “control” observation boreholes located outside the pumping influence of the Scheme are presented in Figure 5.3.

These three hydrographs represent between 30 and 40 years of monitoring. Each records similar amplitude of rising and falling cyclic trends in groundwater levels in response to the underlying prevailing climatic recharge conditions (surplus or deficit of rainfall). Periods of surplus recharge or high groundwater levels are recorded 1980s, mid 1990s and late 1990s to early 2000s, and late 2000s coincident with higher rainfall. Low groundwater levels are recorded with the onset of drier periods in the mid 1970’s, late 1980s to early 1990s, mid to late 1990s, mid 2000s and the current dry cycle that commenced in 2010. Throughout this period mean groundwater levels have remained relatively consistent within a cyclic amplitude of +/-2 m. A slight decline can be seen as the frequency of this cyclic nature of groundwater storage has increased in the last 20 years compared to that observed in the 1970s and 1980s.



Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers
- Contours (m)

Depth to Groundwater (m)

- < 2
- 2 - 4
- 4 - 6
- 6 - 15
- 15 - 30
- > 30

0 1,000 2,000 3,000 4,000 Metres

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Figure 5.2
Contours and Depth to Groundwater
Phase 1 and 4 Wellfields

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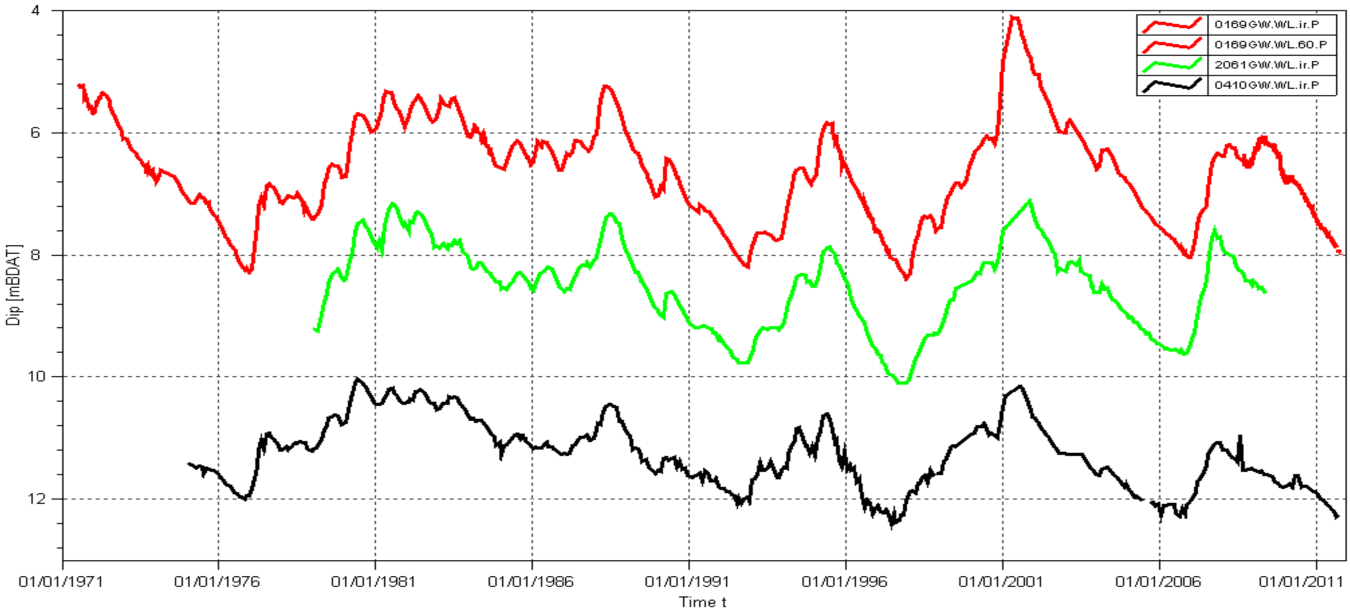
Figure 5.3 Heath Lanes (Red), Childs Ercall (Green) and Warren Farm (Black) Permian Sandstone Aquifer Groundwater Hydrographs Recording the Natural Background Long Term Trends Outside of SGS Pumping Influence



Aquifer Response to Historic SGS Pumping Events

Operationally the cluster of abstraction boreholes making up each Phase is pumped as a group to deliver the required deployable yield. Each point of abstraction causes drawdown of groundwater levels in the adjacent aquifer as the hydraulic signal propagates outward to form temporary cones of depression. Due to the close spatial grouping these cones merge to form one large scale wellfield(s). To quantify these effects for each wellfield contour plots of interference drawdown within the sandstone aquifer have been produced based on the interpretation of data from the observation borehole network.

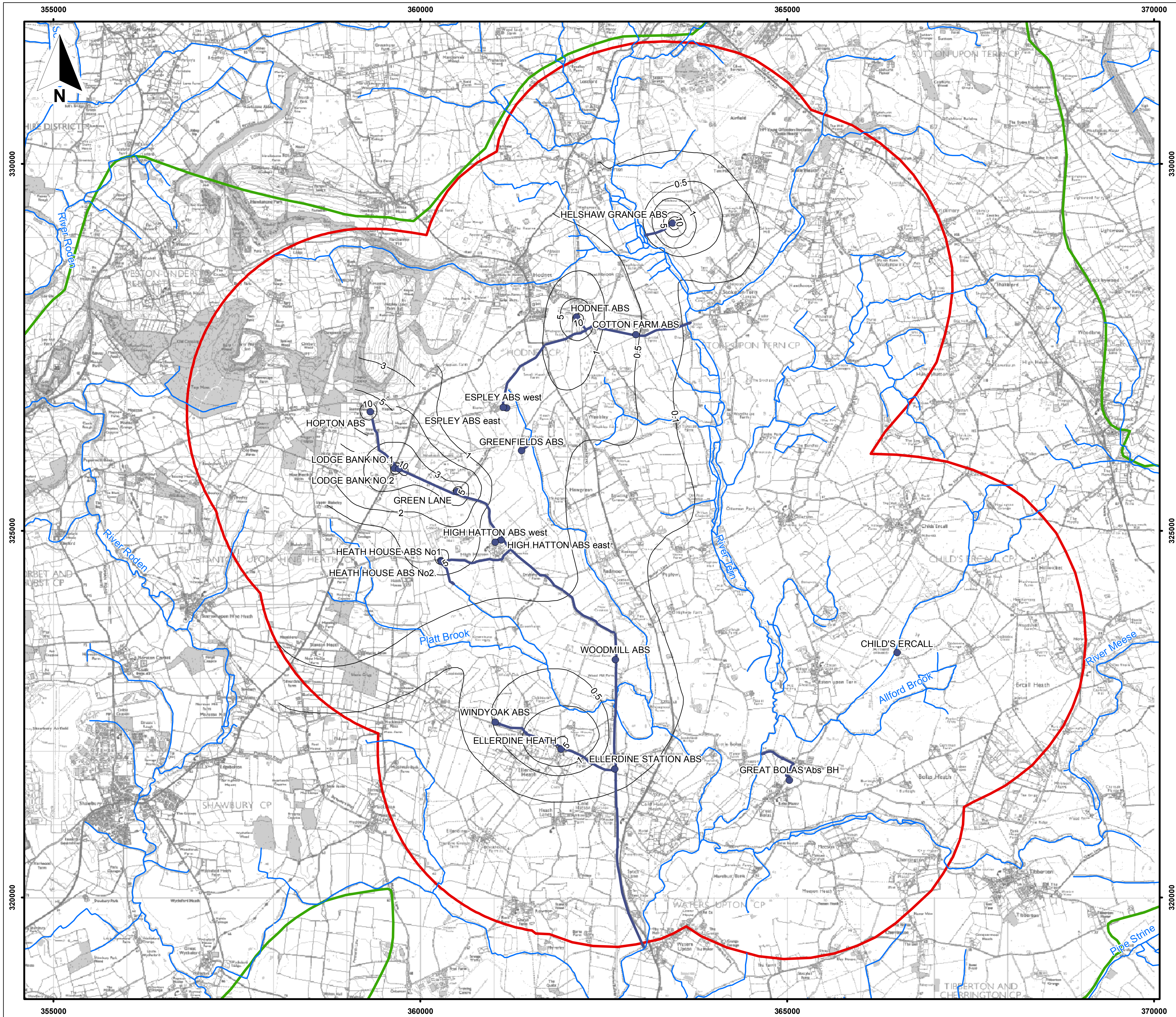
Figure 5.4 illustrates the area of influence observed under operational pumping of Phase 1 in isolation in 1989. This plot is based on the maximum observed drawdown generated by a combined gross abstraction of 3,677 Ml (45 Ml/d) over 80 days of pumping. This accounted for 55% usage of the annual Phase 1 licence volume. The wellfield covered an area of ~32 km^2 with the magnitude of drawdown diminishing exponentially with distance from the heart of the wellfield from 2 to 3 m, to less than 0.2 m at the marginal edges. The extent and magnitude of the wellfield is influenced and restricted by structural faulting and the unconfined nature of the aquifer. A plot for Phase 4 is presented in Figure 5.5. This image was generated by the East Shropshire Groundwater Model for Phase 4 as it represents a longer duration of pumping to that currently seen to date. The plot for Phase 4 illustrates a similar magnitude of drawdown to that seen from Phase 1; however, the extent of the wellfield is increased in the northwest and southeast because of the relative locations of the Phase 4 boreholes.

The plots presented here represent the effects of operating individual Phases in isolation. To date the full in-combination operation of Phases 1 & 4 has not occurred, and has only been simulated using the numerical groundwater model. The modelled contours, which present groundwater levels following an extended period of abstraction from both Phases, indicate drawdowns of up to 5 m in the central part of the wellfield.

To illustrate the short term and long term effects of the entire operational pumping history on groundwater storage trends in the sandstone aquifer, a selection of groundwater hydrographs across the wellfield are presented in Figure 5.6. Spiked hydrograph responses indicate historic operational pumping of Phase 1 in 1984, 1989, 1995 and 1996, Phase 4 in 2005, and largely Phase 1 with partial support from one or two Phase 4 pumping stations in 2006, 2010 and 2011.

The hydrographs record the temporary hydraulic response of the aquifer to pumping and the rebound response when pumping stops. In the short term the hydrographs record a stepped lowering of groundwater levels, in the region of 0.25 and up to 1m, after each successive pumping period. Post pumping periods of at least 3 to 5 years between operational events show groundwater levels recovering at least to, or in excess of, pre-pumping levels. This sequence trend reflects the temporary reduction in groundwater heads due to the volume of water removed from the aquifer by each pumping event. After the initial hydraulic rebound, the subsequent rise in groundwater head represents the effects of natural recharge replenishing the abstracted volume.

Comparison of pre and post pumping groundwater heads in the aquifer have shown that after each successive pumping event the natural flow pattern, in which the Phase 1 & 4 wellfields operate, quickly re-establishes itself. Therefore operational pumping to date has not impacted on the long term natural hydraulic flow regime of the aquifer. Over the long term there does not seem to have been any adverse deterioration in groundwater levels, nor any significant deviation from the natural background groundwater trends. These observations provide a degree of confidence that operation of the scheme to date has not resulted in any persistent variation to the natural groundwater level trends.



Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers
- Contours (m)

0 1,000 2,000 Metres

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Figure 5.4
Phase 1 Observed Groundwater Drawdown under 1989 Operational Pumping Conditions

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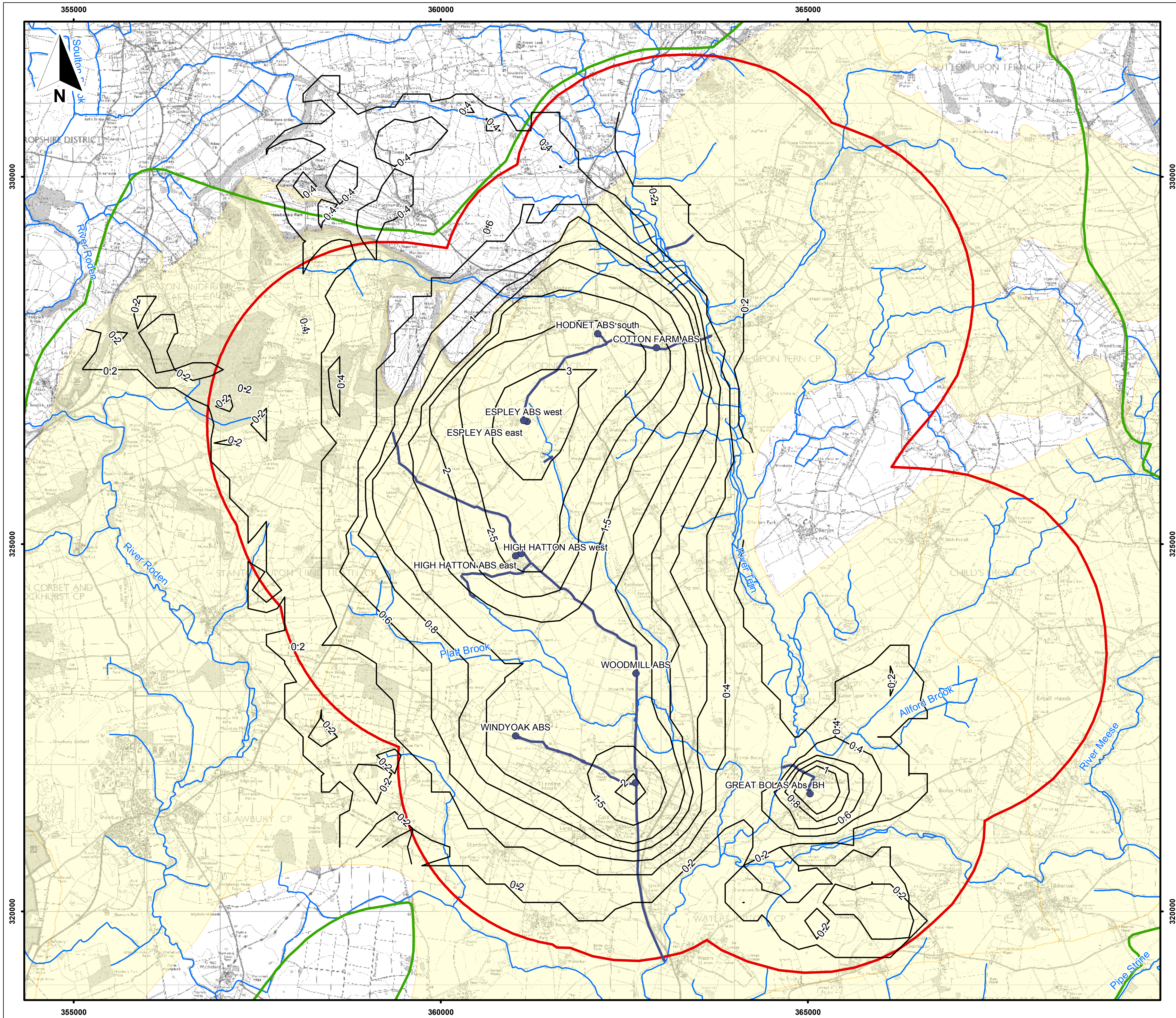

Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers
- Contours (m)

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Figure 5.5
Modelled Contoured Extent of Phase 4 Wellfield Influence Under Average Use

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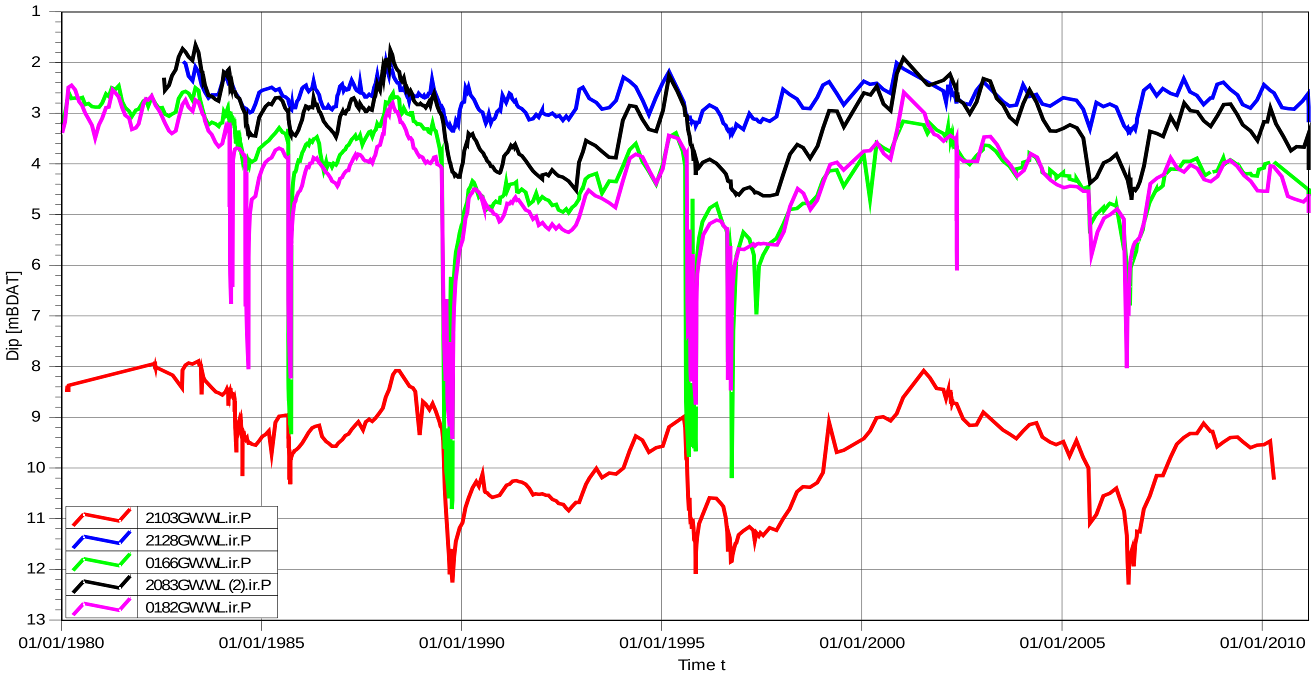
Figure 5.6 **Hodnet 100m (Pink), Small Heath (Black), Green Lane Farm (Red), Heath House 20m (Green) and Greenhurst (Blue) Observation Boreholes Recording Historic Permian Aquifer Response to Pumping Events (1984, 1985, 1989, 1995, 1996, 2005, 2006 and 2010) across the Phase 1 and Phase 4 Wellfield**



Phase 2 and 3 Wellfields

Phases 2 and 3 have been developed as separate areas, each with its own distinct operational wellfield. These wellfields do however overlap on their western and eastern marginal edges and will merge to form one large wellfield if both Phases are operated in combination. Separated stratigraphically by the Triassic Chester Pebble Beds, Phase 2 to the west has been exclusively developed within the Permian Bridgnorth Sandstone Formation, while Phase 3 to the east is solely developed within the Triassic Wilmslow Sandstone Formation. All nineteen abstraction boreholes only partially penetrate the top 150 m of the aquifer sequence estimated to be >500 m thick.

Regional Groundwater Contour Pattern and Flow Direction

Groundwater heads in the Phase 2 wellfield range from between 58 and 60 mAOD against the Wem Fault to between 49 and 50 mAOD adjacent to the River Severn. The contour pattern indicates groundwater flows away from the no flow barrier feature of the Wem Fault (north of Great Ness) in a south-east to southerly direction towards the River Severn.

Groundwater heads in Phase 3 range in level from between 64 and 68 mAOD on its northern edge to 49 to 50 mAOD adjacent to the River Severn. Groundwater is contoured flowing in a south to south-west direction towards the River Severn. On the eastern edge of the Phase 3 wellfield the contour pattern illustrates the influence of the River Roden which is interpreted to show as gaining flow from the sandstone. The Brockhurst Fault is not considered to present a barrier to groundwater flow. However there is evidence to show that faulting at Harmer Hill does have a localised effect.

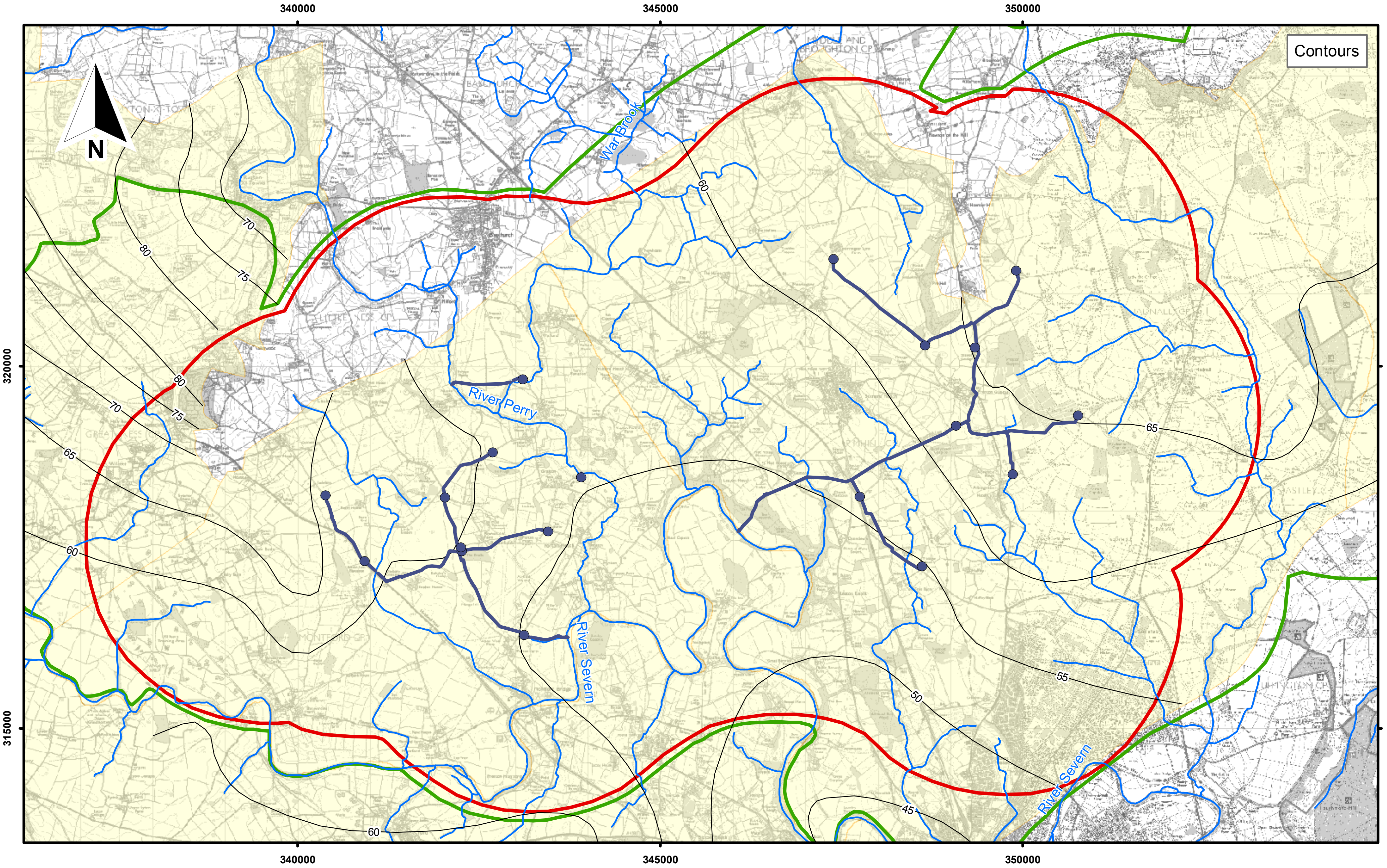
There is a good correlation between the groundwater heads in Phase 2 and Phase 3 area allowing groundwater contours to be drawn through the adjoining areas (Figure 5.7). This suggests that there is good hydraulic connectivity throughout this Permo-Triassic Sandstone sequence. The contours are drawn running approximately parallel with the River Severn which is interpreted to act as the main recipient for baseflow discharge from the sandstone. However the precise nature of this relationship is not fully understood.

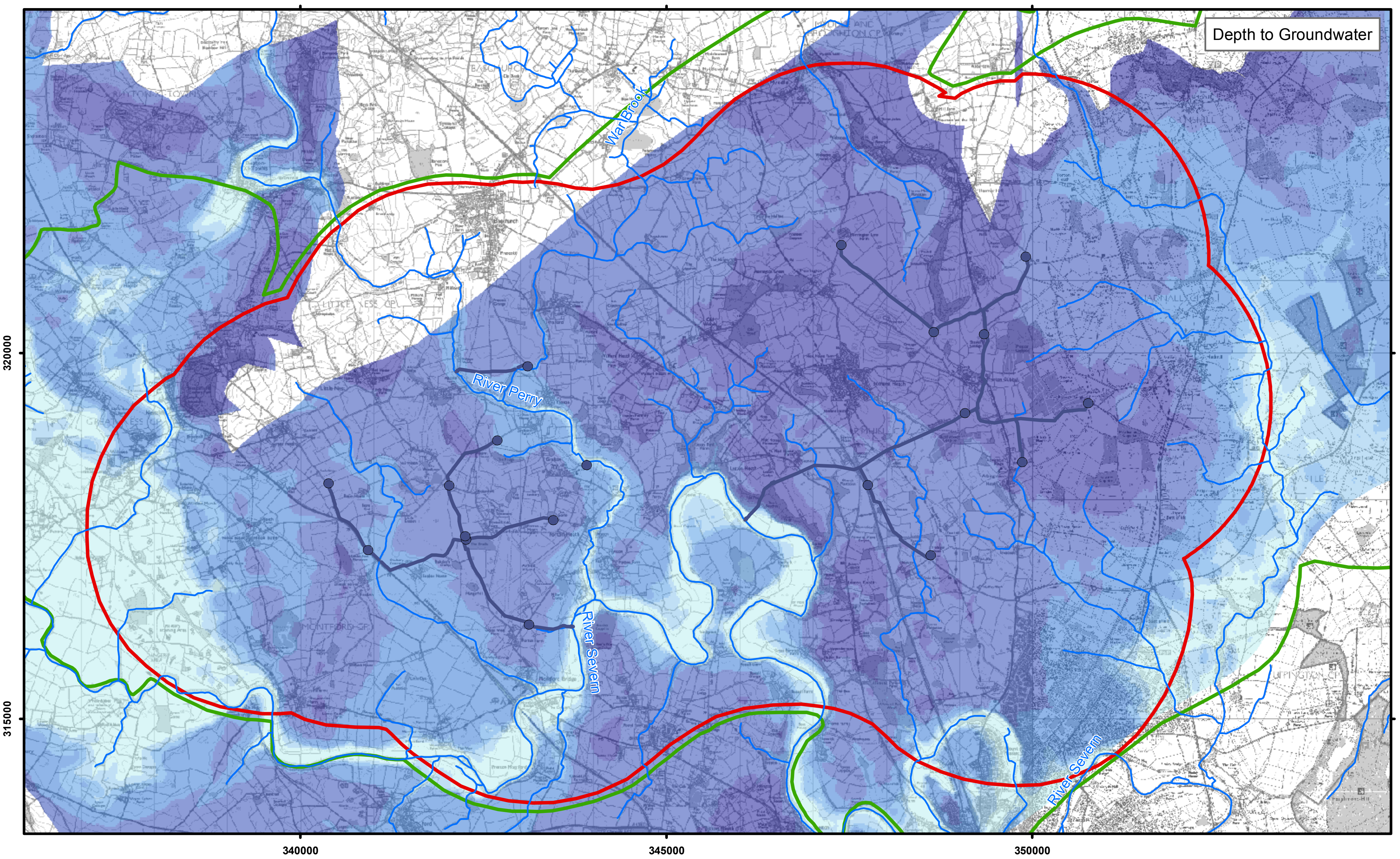
Depth to Groundwater

Over a significant proportion of the Phase 2 wellfield the groundwater level is in excess of 10 mbgl, with a mean depth range of between 10 and 20 mbgl. The areas underlain by shallow water tables (0 to 5 mbgl) are limited to the narrow floodplain corridor of the River Severn, and the lower reach of the River Perry at its confluence with the River Severn. Beneath the Phase 3 wellfield groundwater is encountered over wider range of depths, between 0 and 45 mbgl. However, over a significant proportion of the Phase 3 area the water table is in excess of 20 mbgl, with an average depth range of between 15 and 40 mbgl.

Long Term Groundwater Level Trends

The control borehole for long term groundwater level trends outside the influence of the Phase 2 & 3 wellfields is taken from a deep well developed in the Triassic sandstone at Shotatton (SJ 3651 2285) (Figure 5.8). This broadly records a very similar response to that observed elsewhere in the North Shropshire Permo-Triassic Sandstone. Again the wetter decade of the 1980s is coincident with higher groundwater levels, while the last 20 years record a slight decline as the frequency of the cyclic nature of groundwater storage response to more extreme recharge variability has increased.





Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers
- Contours(m)

Depth to Groundwater (m)

- < 2
- 2 - 4
- 4 - 6
- 6 - 15
- 15 - 30
- > 30

0 1,000 2,000 Metres

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Figure 5.7
Contours and Depth to Groundwater
Phase 2 and 3 Wellfields

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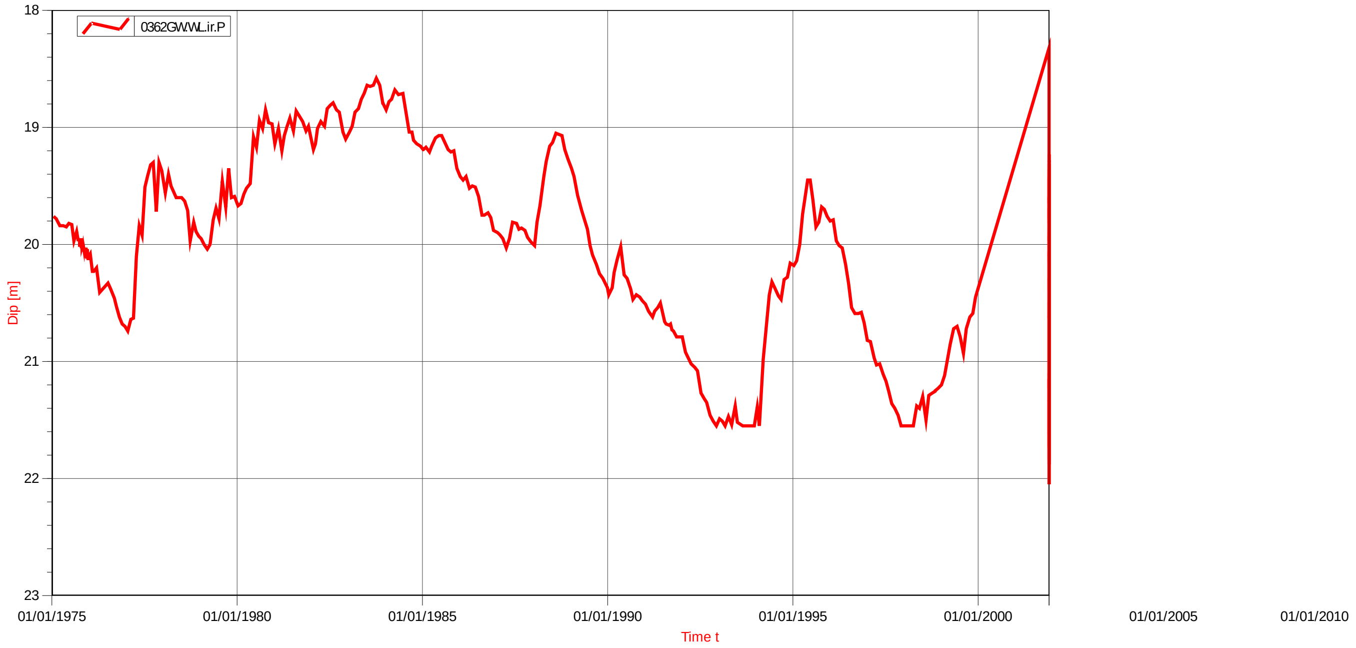
Figure 5.8 Shotatton Well: Triassic Sandstone Aquifer Hydrograph Recording the Natural Background Long-term Groundwater Trend outside of SGS Phase 2 and 3 Pumping Influence

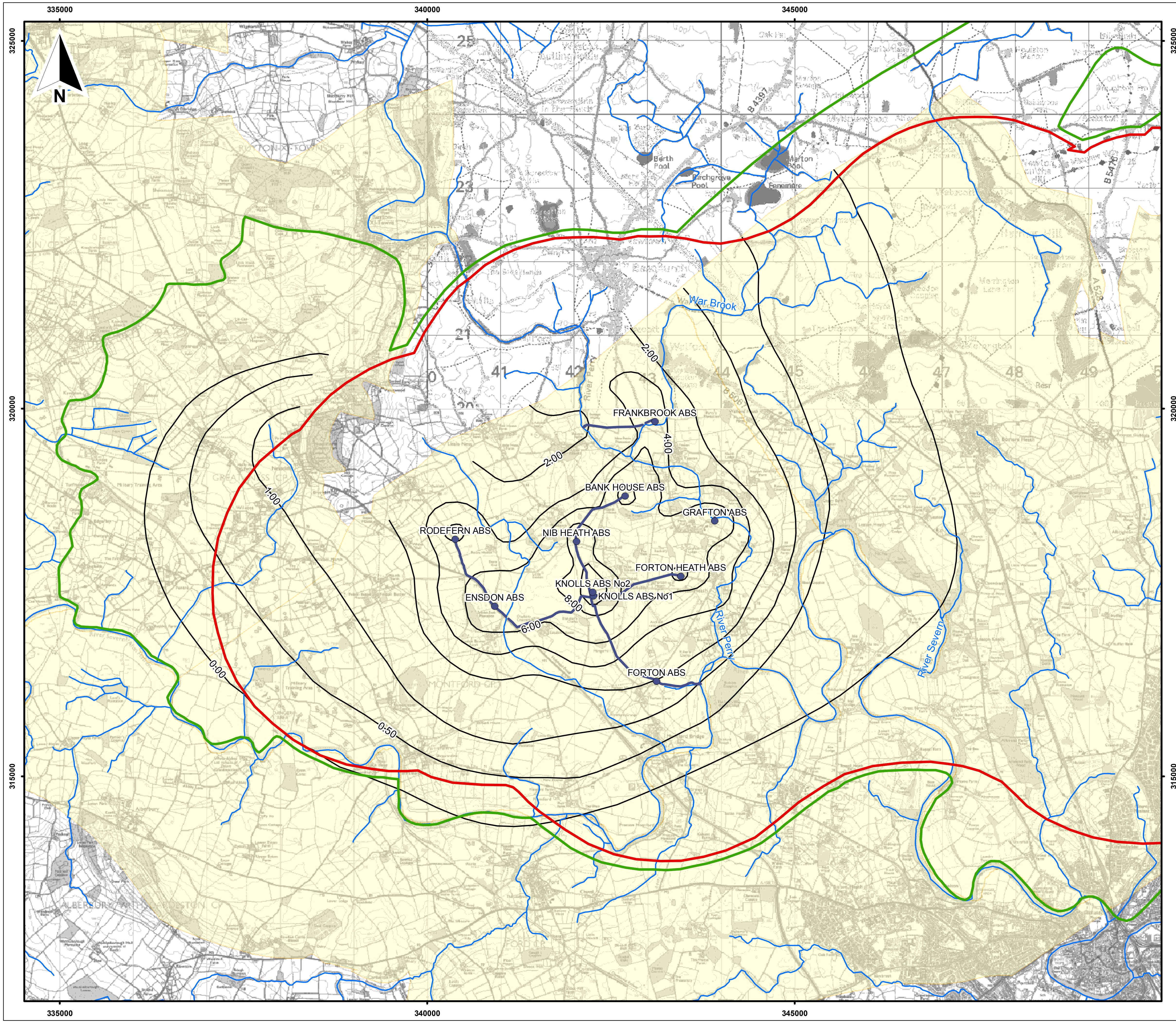


Aquifer Response to Historic SGS Pumping Events

For each wellfield contour plots of maximum inference drawdown within the sandstone aquifer have been produced. These are based on the interpretation of data from the observation borehole network during historical actual operational pumping events for both Phase 2 and Phase 3 operated in isolation of each other and in combination.

Figure 5.9 illustrates the area of influence observed under operational pumping of Phase 2 in isolation in 1995. This is based on the maximum observed drawdown generated by a combined gross abstraction of 3,661 Ml (50 Ml/d) over 71 days of pumping. This accounted for 56% usage of the annual Phase 2 licence volume. The wellfield covered an area of ~56 km^2 with the magnitude of drawdown diminishing exponentially with distance from the heart of the wellfield from 4 to 10 m, to less than 0.2m at the marginal edges. The extent and large magnitude of the wellfield is influenced and restricted by the structural control of the Wem Fault and the confined nature of the aquifer.

A similar plot for Phase 3 is presented in Figure 5.10, for the 38 day group commissioning test performed in 1999. From a combined yield of 50 Ml/d a total volume of 2,026 Ml, or 36% of the Phase 3 annual licence, was abstracted. The test generated a wellfield covering an area of ~54km^2 with the magnitude of drawdown diminishing exponentially with distance from the heart of the wellfield from 2 to 4 m, to less than 0.2 m at the marginal edges. In comparison to the adjoining Phase 2 area the magnitude of drawdown at the heart of the wellfield is smaller due to the unconfined nature of the aquifer.



Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers
- Contours (m)

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Figure 5.9
Phase 2 Wellfield Observed Maximum Drawdown 1995

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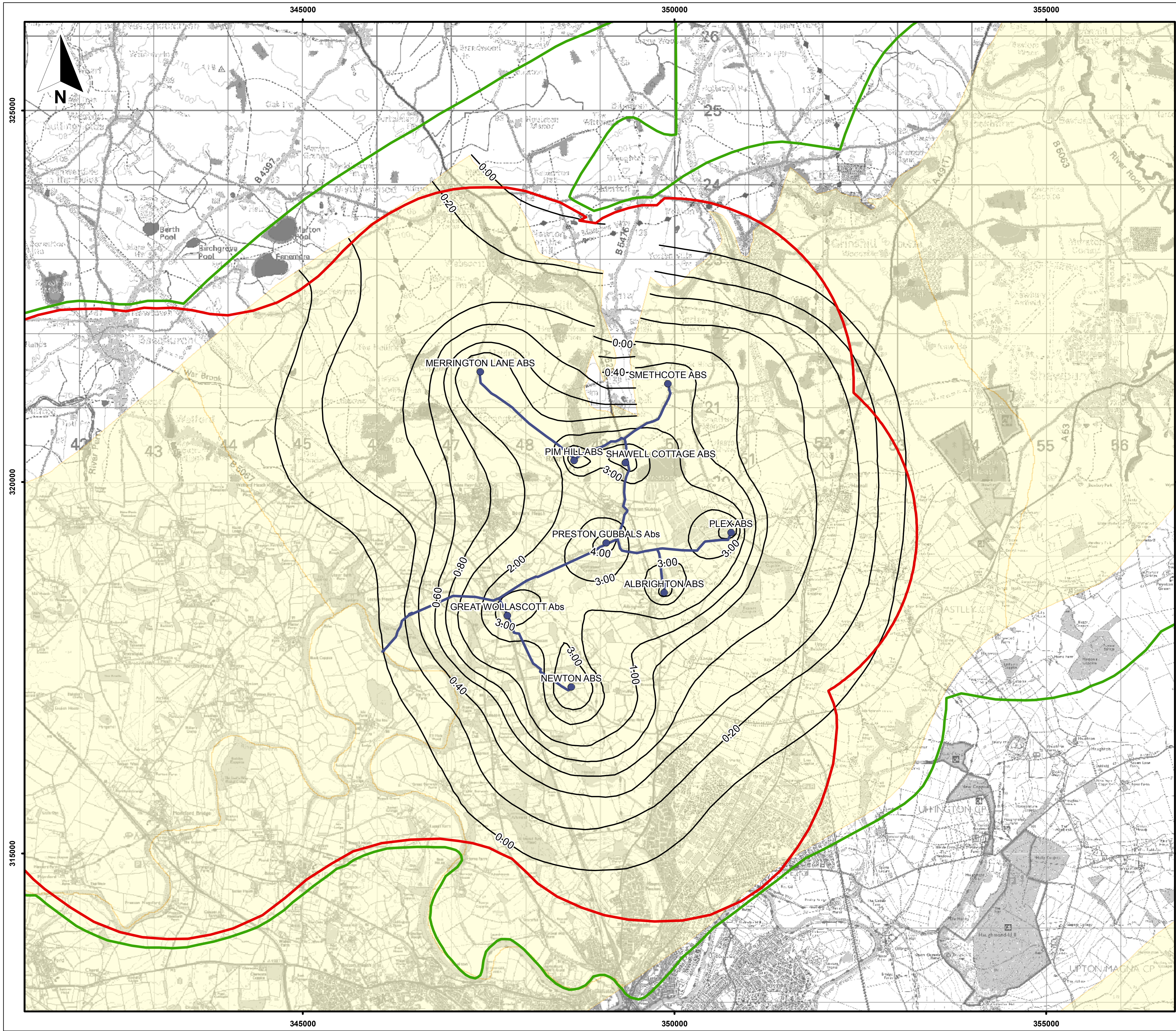

Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Subcrop Area of Permo - Triassic Sandstone Aquifer
- Main Rivers
- Contours (m)

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Figure 5.10
Phase 3 Wellfield Observed Maximum Drawdown 1999

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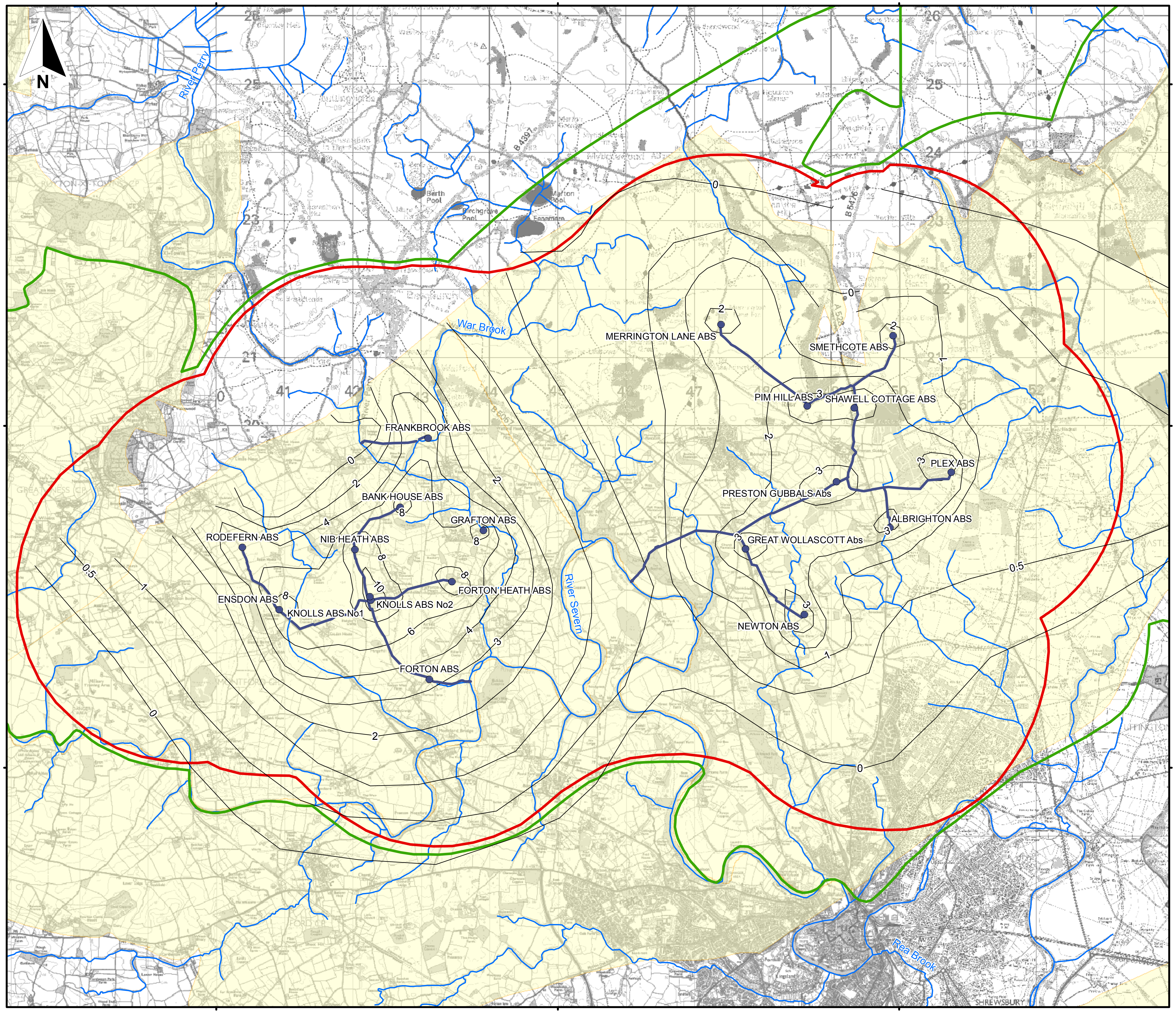

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Figure 5.11
Phase 2 and 3 Observed Maximum Drawdown - 2006

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The in-combination effects of simultaneously running both Phase 2 and Phase 3 in 2006 is illustrated in Figure 5.11. Here the overlap between the eastern edge of the Phase 2 and the western edge of the Phase 3 wellfields merge together to form one large wellfield covering 138 km^2. Both Phases were run in parallel for up to 35 days. The combined abstraction rate for first 19 days was 100 Ml/d, thereafter abstraction was cut back to 82 Ml/d for the remaining 16 days of in combination use.

The short term and long term effects of the operational pumping history of Phase 2 and 3 on groundwater level trends in the sandstone aquifer are illustrated in Figures 5.12 and 5.13. The hydrographs record the same hydraulic response of the aquifer to pumping as that observed in Phase 1 and 4. A temporary reduction in groundwater heads due to each pumping event is again followed by an initial hydraulic rebound reaction. Subsequent rises in groundwater head record the effect of natural recharge replenishing the abstracted volume to, or in excess of, pre-pumping levels.

Again similar to Phase 1 & 4, comparison of pre and post pumping groundwater heads in the aquifer have shown that after each successive pumping event the natural flow pattern quickly re-establishes itself. As such it is suggested that operational pumping from Phase 2 & 3 to date has not impacted on the long term natural hydraulic flow regime of the aquifer in which they operate.

Based on the historic operational pattern to date there does not seem to have been any adverse deterioration in groundwater levels, nor any significant deviation from the natural background groundwater trends. As for Phase 1 and 4, these observations provide a degree of confidence that operation of Phase 2 and 3 to date has not resulted in any significant long term variation to the natural groundwater level trends.

Figure 5.12 Adcote (Red), Little Endson (Blue) and Walford Heath (Green) Observation Boreholes Recording Historic Permian Aquifer Response to Phase 2 Pumping Events (1991, 1995, 1996, 2006 and 2010)

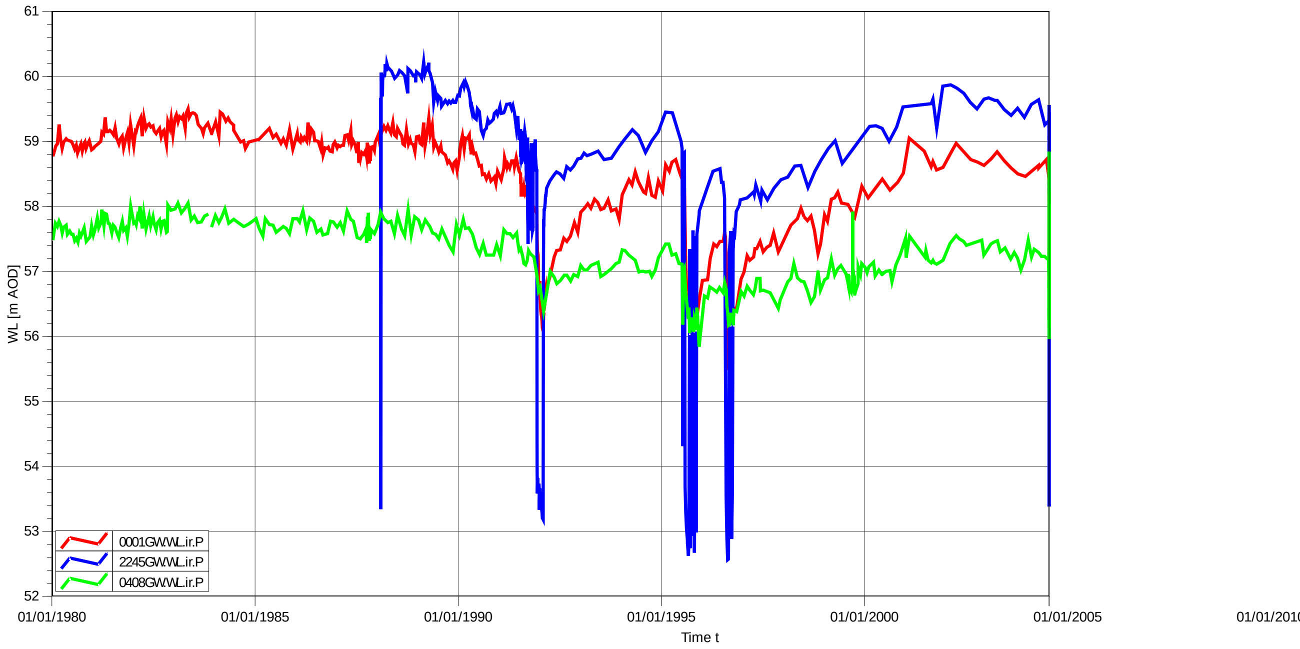
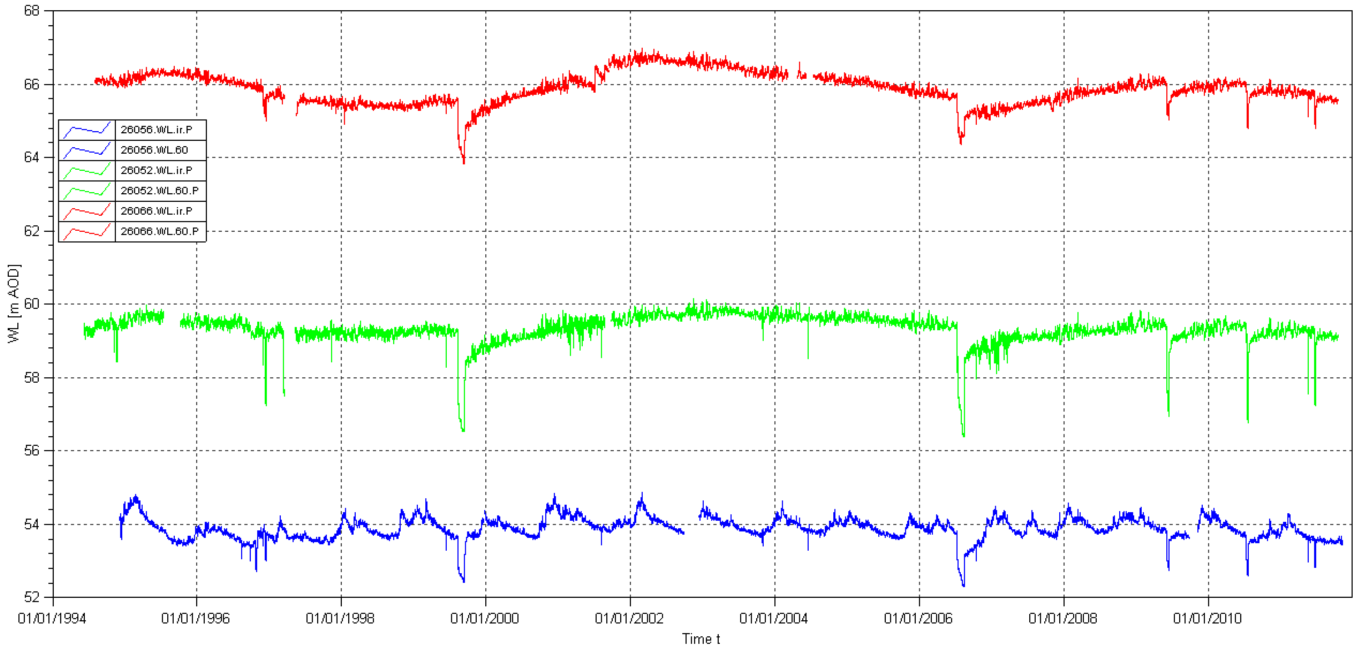


Figure 5.13 Plex (Red), Broomhall Lane (Green) and Dunnsheath (Blue) Observation Boreholes Recording Historic Triassic Sandstone Aquifer Response to Phase 3 Pumping Events (1999, 2006, 2009, 2010 and 2011)



5.3.2 Hydrology

The groundwater scheme lies within the wider surface water catchment of the River Severn which drains from west to east. The operational Phases lie with principle sub-catchment areas centred on the main tributary rivers of the Perry, Roden, Tern, Meese and to a lesser extent the Strine. The Environment Agency maintains a network of permanent flow gauging structures strategically placed throughout the operational area, recording surface water flow data at 15 minute intervals. The groundwater discharge from the operational Phases either discharges direct to the River Severn (Phase 2b, Phase 3), or via a principal tributary such as the River Perry (Phase 2a), or River Tern (Phase 1 & 4). These tributaries are employed as carrier rivers which benefit from higher augmented flows when the scheme operates to deliver flow to the River Severn.

Hydrology of the Phase 1 and 4 Wellfield

The Phase 1 & 4 wellfield sits within the Permo-Triassic Sandstone aquifer underlying the middle reaches of the 883 km^2 River Tern catchment. Land use within the catchment is predominantly agricultural; occupying this low relief catchment, ranging in elevation from 375 mAOD at the head waters of the catchment to 40 mAOD at the confluence with the River Severn. The River Tern drains from north to south. Average annual rainfall is 695 mm. The principal tributaries of the Tern (in order of size) are listed below and shown in Figure 5.14.

- **The River Tern:** The River Tern rises north of Logger Heads and initially flows west then south west to Market Drayton. From here the river drains southwards intercepting flow from its major and minor tributaries before joining the River Severn at Atcham. From its source to its confluence the Tern is predominantly underlain by Permo-Triassic Sandstone aquifer;

- **The River Roden:** This drains the western third of the Tern catchment. The upper 80% of the catchment of the Roden is underlain by drift overlying impermeable Mercia Mudstone Group. The river crosses onto the Permo-Triassic Sandstone outcrop near Lee Brockhurst and flows southwards past Shawbury to join the Tern at Walcot (upstream of the Walcot gauge);

- **The River Meese:** The Meese drains the Permo-Triassic Sandstone underlying the Aqualate Mere area to the east. It joins the River Tern downstream of Eaton on Tern;

- **The River Strine:** The Strine drains the flat, arable land to the south of the Meese. These peatlands were drained for agriculture at the start of the 20th Century and as a result, the river is considered to be the least 'natural' of all the streams in the catchment. The catchment is underlain by Permo-Triassic Sandstone aquifer.

Other minor tributaries of the River Tern in proximity to the Phase 1&4 wellfield include (in downstream order):

- **Bailey Brook**: This rises on drift covered Mercia Mudstone Group to the north outside the wellfield area. It joins the River Tern at Ternhill;

- **Hodnet Brook**: This rises at the northern edge of the Permo-Triassic Sandstone outcrop and flows over drift deposits to join the River Tern near Hodnet;

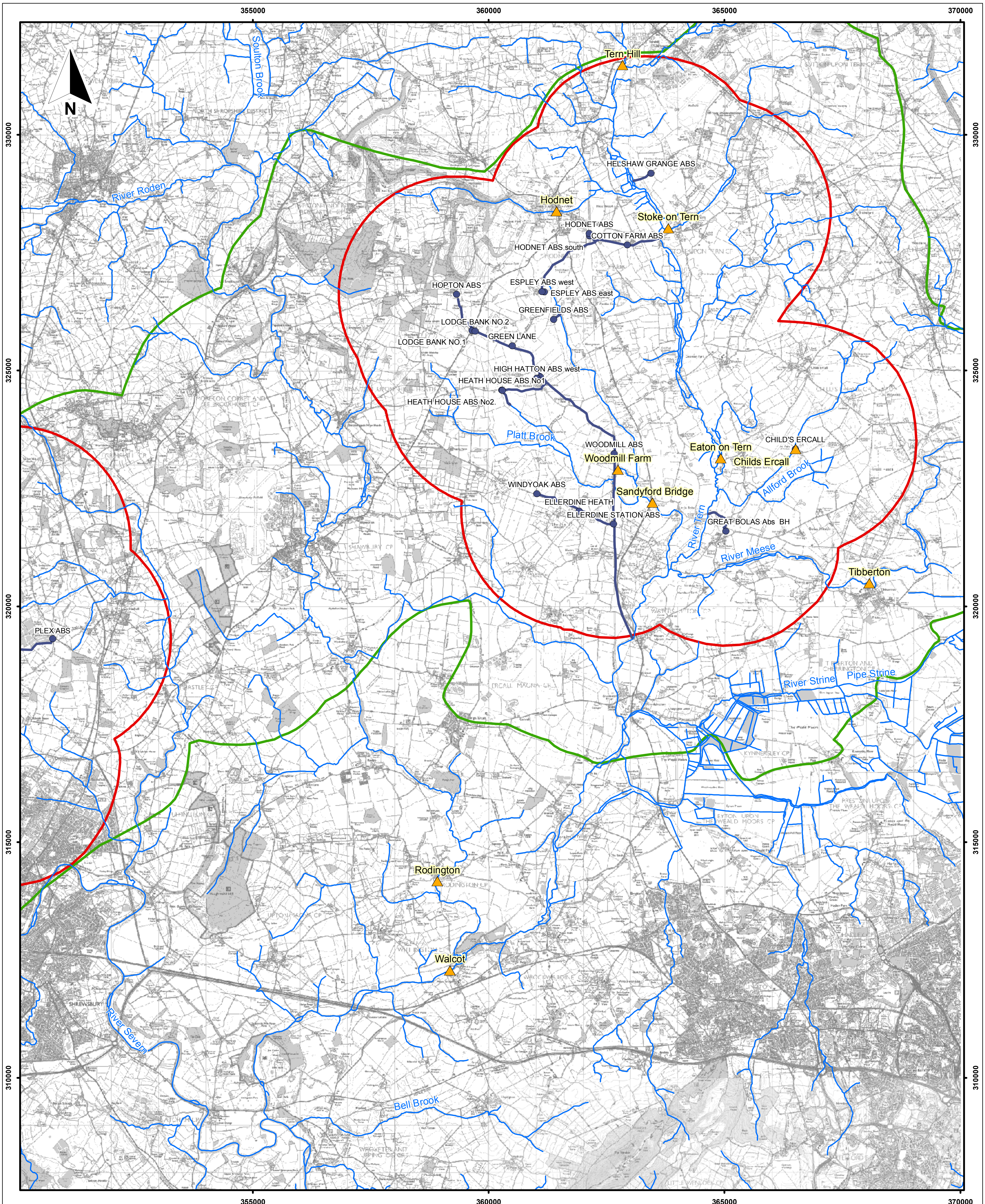
- **Stoke Brook:** The catchment is underlain by Permo-Triassic Sandstone aquifer. The brook drains to the south west, via two artificially impounded pools at Stoke Heath, before joining the River Tern at Stoke on Tern;

- **Stoke Park Brook**: This partly rises on the Carboniferous Salop Mudstone Formation and partly on Permo-Triassic Sandstone aquifer to flow west to join the Tern upstream of the river gauging station at Eaton on Tern;

- **Allford Brook**: This rises on clayey drift overlying the Permo-Triassic Sandstone at Childs Ercall and joins the Tern downstream of the river gauging station at Eaton on Tern;

- **Platt and Potford Brooks**: These rise on the Permo-Triassic Sandstone at the heart of the Phase 1&4 wellfield. The Platt joins the Potford Brook upstream of the Sandyford Bridge gauging station and the latter then flows south east to join the Tern near Great Bolas;

- **Lakemoor Brook**: The catchment of this stream lies largely on clayey drift overlying the Permo-Triassic Sandstone and drains south eastwards on the southern marginal edge of the Phase 1&4 wellfield.



Key:

- Flow Gauges
- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers

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Figure 5.14
Surface Water Drainage System - Phase 1 and 4

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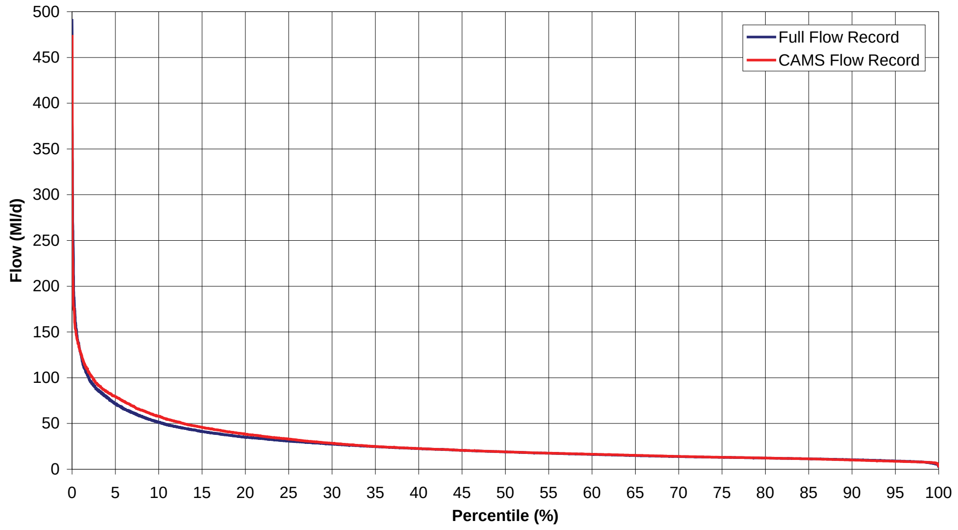
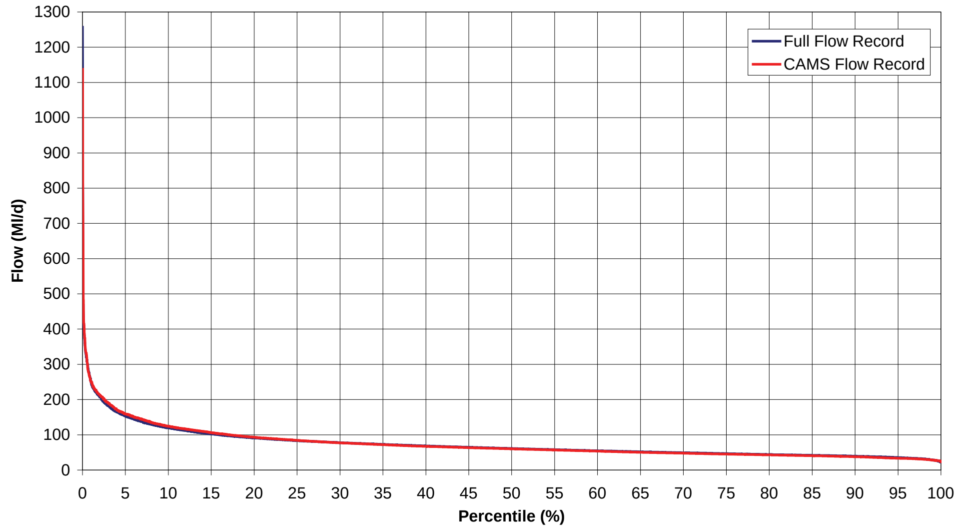
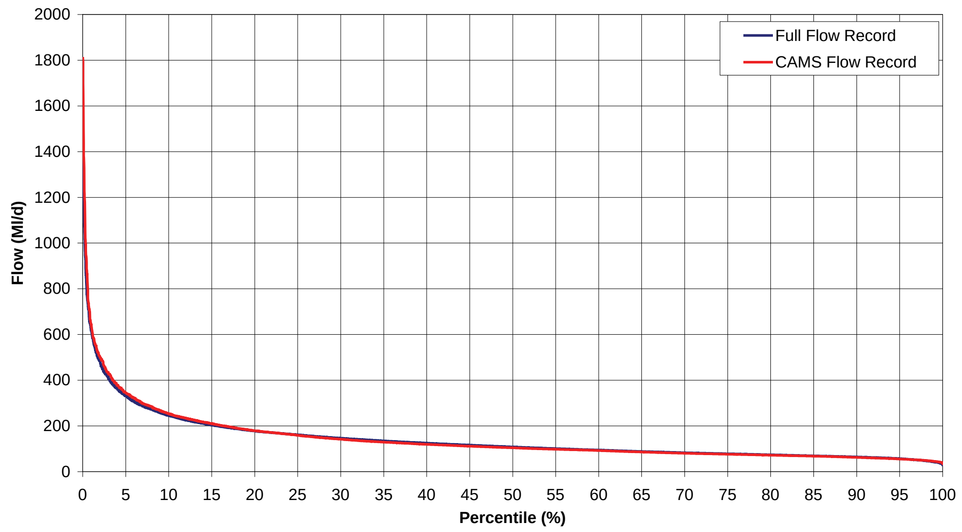
Bailey Brook at Ternhill Flow Durvation Curve



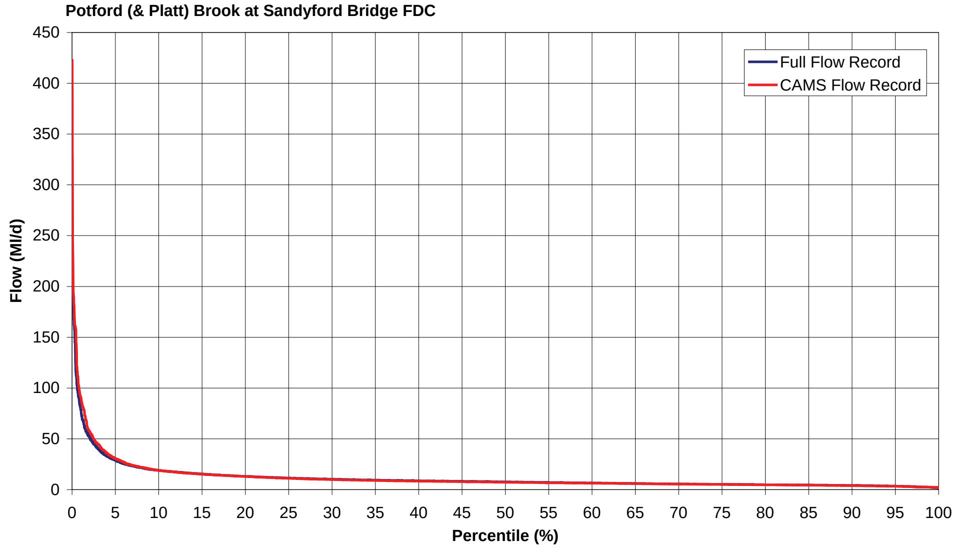
River Tern at Ternhill Flow Duration Curve



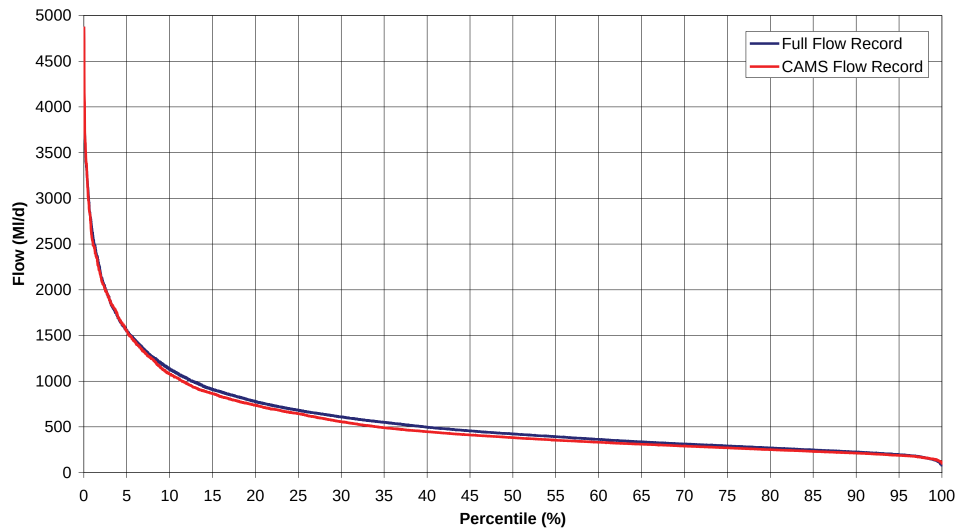
River Tern at Eaton-on-Tern Flow Duration Curve



Potford (& Platt) Brook at Sandyford Bridge FDC



River Tern at Walcot Flow Duration Curve



River Perry at Yeaton Flow Duration Curve

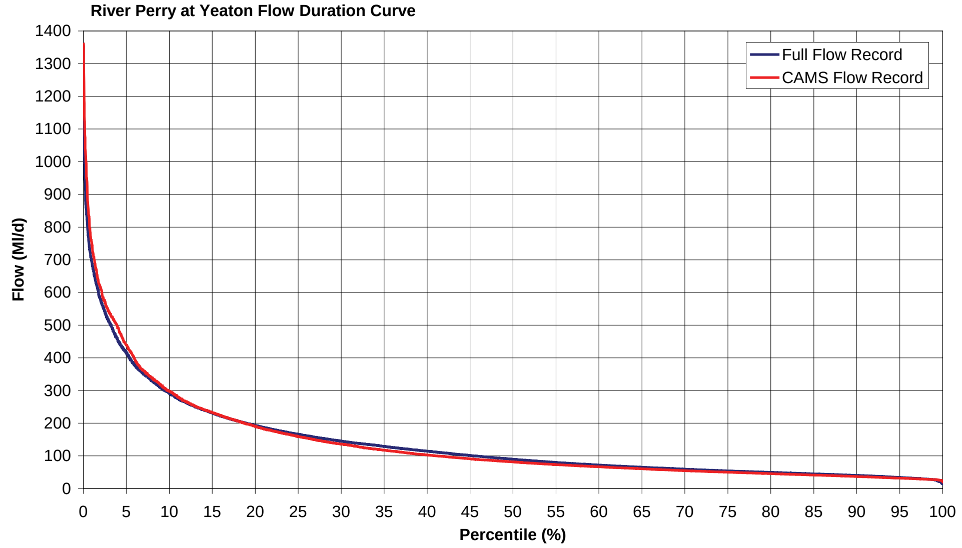


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Figure 5.15
Flow Duration Curves for River Tern and River Perry Gauging Stations

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River and Stream Flow Characteristics

Long term historic river and stream flow hydrographs and flow duration curves taken from key surface flow gauging stations are presented in Figure 5.15. These hydrographs show that each of the gauging points share similar temporal characteristics. The river system responds rapidly to large rainfall events and flows are generally an order of magnitude higher in winter than summer. Summer low flow conditions are largely consistent year on year and flows are maintained even during exceptional prolonged dry weather periods as experienced in 1976, 1989, 1991/92, 1995/96 and 2010/11. Examination of the flow duration curves shows that in general, most of the catchments behave in a similar manner suggesting a broadly consistent pattern of hydrological behaviour in response to the degree of baseflow support provided by the underlying hydrogeology. The exception to this case being the Hodnet and Allford Brooks which appear to be characterised by more flashy flow hydrographs.

Groundwater – Surface Water System Interaction

A review of the available hydrogeological and stream flow data carried out for the East Shropshire Model (ESM) have provided the basis for delineating the degree of interaction between groundwater and surface water systems in the Tern catchment. Based on flow separation techniques and the geological characteristics of the catchment the relative proportion of baseflow to interflow and runoff contribution to surface flows are summarised in Table 5.3.

Table 5.3 Assessed Proportion of Baseflow, Interflow and Runoff Contribution to Surface Flow Characteristics (based on Tables 3.9 and 3.10 East Shropshire Groundwater Model Report January 2005)

	Gauging Point	Surface Flow Statistics (Ml/d)		Proportion of Total Flow Contribution (%)		
		Q50	Q95	Base Flow	Interflow	Runoff
Tern	Ternhill	59Ml/d	34Ml/d	70%	15%	15%
Tern	Eaton-on-Tern	111Ml/d	59Ml/d	58%	22%	20%
Tern	Walcott	423Ml/d	191Ml/d	56%	26%	18%
Roden	Rodington	106Ml/d	36Ml/d	47%	29%	24%
Bailey Brook	Ternhill	18Ml/d	9Ml/d	54%	24%	22%
Stoke Brook	Stoke on Tern	6.3Ml/d	3.4Ml/d			
Hodnet Brook	Hodnet	0.7Ml/d	0Ml/d			
Platt Brook	Platt	5.1Ml/d	2.5Ml/d			
Potford Brook	Sandyford Bridge	7Ml/d	3.4Ml/d			
Allford Brook	Childs Ercall airfield	0.7Ml/d	0.08Ml/d			

Data availability differs with each site, start period varies 1961 to 1973, all have same end point of 2001)

The ESM studies came to the general conclusion that where river and stream systems in the Tern catchment cross Permo-Triassic Sandstone aquifer with a thin or predominantly permeable drift cover they tend to be perennial and largely gaining flow from groundwater discharging from the sandstone. Groundwater baseflow can contribute in the region of 47 to 70% of the total surface flow at specific gauge locations.

The potential head-dependant flow between streams and the sandstone is likely to be an important flow mechanism for large areas of the Tern catchment. However it is important to recognise that not all stream systems benefit from direct baseflow support and therefore the modelling report made the distinction between three categories.

a) *Streams with strong head-dependant interaction with the Permo-Triassic Sandstone aquifer* – groundwater heads are elevated above the stream bed, thus provide the potential to discharge groundwater into the stream. The effectiveness of this discharge will be influenced by the hydraulic properties in the inventing drift which in itself could act as conduit through which drainage of the aquifer to the stream could occur.

Streams falling in this category are River Tern, River Meese, River Strine, middle reaches of the River Roden, middle and lower reaches of the Potford & Platt Brooks, Stoke Brook, and parts of the Stoke Park Brook catchment.

b) *Streams with weak or no head-dependant interaction with the Permo-Triassic Sandstone aquifer* – in this scenario either groundwater heads lie below the stream bed elevation, in which case the head potential would encourage loss of water from the stream to the aquifer via leakage through the bed sediments. Or the intervening drift is of sufficient low permeability to hydraulically isolate the stream from the head in the aquifer, or the aquifer is absent altogether.

The Hodnet Brook and upper reaches of the Potford and Platt Brooks fall within this classification as these sections of the brook are elevated above the sandstone head and tend to be ephemeral in nature, regularly running dry in summer when unsupported by runoff. The Allford and Lakemoor Brooks are characterised by flashy hydrographs and run over more extensive areas of thick clay drift, or partly in the case of Stoke Park Brook where it drains Carboniferous mudstones.

c) Streams with head-dependant interactions with drift aquifers – areas of complex and or thick drift which support the interception, storage and discharge of groundwater in perched aquifer bodies independent to the main sandstone aquifer head.

This would apply specifically to the Bailey Brook which derives 54% baseflow support from extensive drift deposits, where the geology of the catchment is underlain by secondary (B) aquifer of the Merica Mudstone Group.

Assessment of Nett Gain to Stream and River Flow Systems from Groundwater Discharges

The relative position of the Phase 1&4 groundwater outfalls and Environment Agency river gauging stations allow a full analysis of the effect the augmentation releases have on the nett gain increase in river flows to the River Tern. Inversely the impact of abstraction on baseflow to the Potford & Platt Brooks can also be quantified.

An assessment of operational releases made to the River Tern system by Phase 1 in 1996 is summarised in Figure 5.16. In 1996 groundwater discharges was made to the River Tern via three out falls: Helshaw Grange and Hodnet discharged a combined gross yield of 13.27 Ml/d from two separate outfalls 6 km and 5 km upstream of the Agency’s Eaton on Tern gauging station. The third and largest outfall at Waters Upton discharged a combined gross yield of 32.58 Ml/d, downstream of Eaton on Tern. The Walcot gauging station situated 9 km downstream of Waters Upton was therefore ideally situated to gauge the combined effects of the Phase 1 discharge.

Comparing non-augmented river flows on the River Tern at Ternhill over the same period, it is clear that the increase in flows measured on the River Tern at Eaton on Tern and Walcot is as a direct consequence of enhanced augmented flow releases from the Scheme. At Eaton on Tern, the nett gain was in the order of 11 to 12 Ml/d from a combined gross in-put of 13.27Ml/d, equating to a nett gain figure of between 82% and 90%. At Walcot, a nett gain in flow of between 40 to 41 Ml/d was calculated from the entire combined Phase 1 gross out-put of 45.85Ml/d. This equated to a nett gain of between 87% and 89%.

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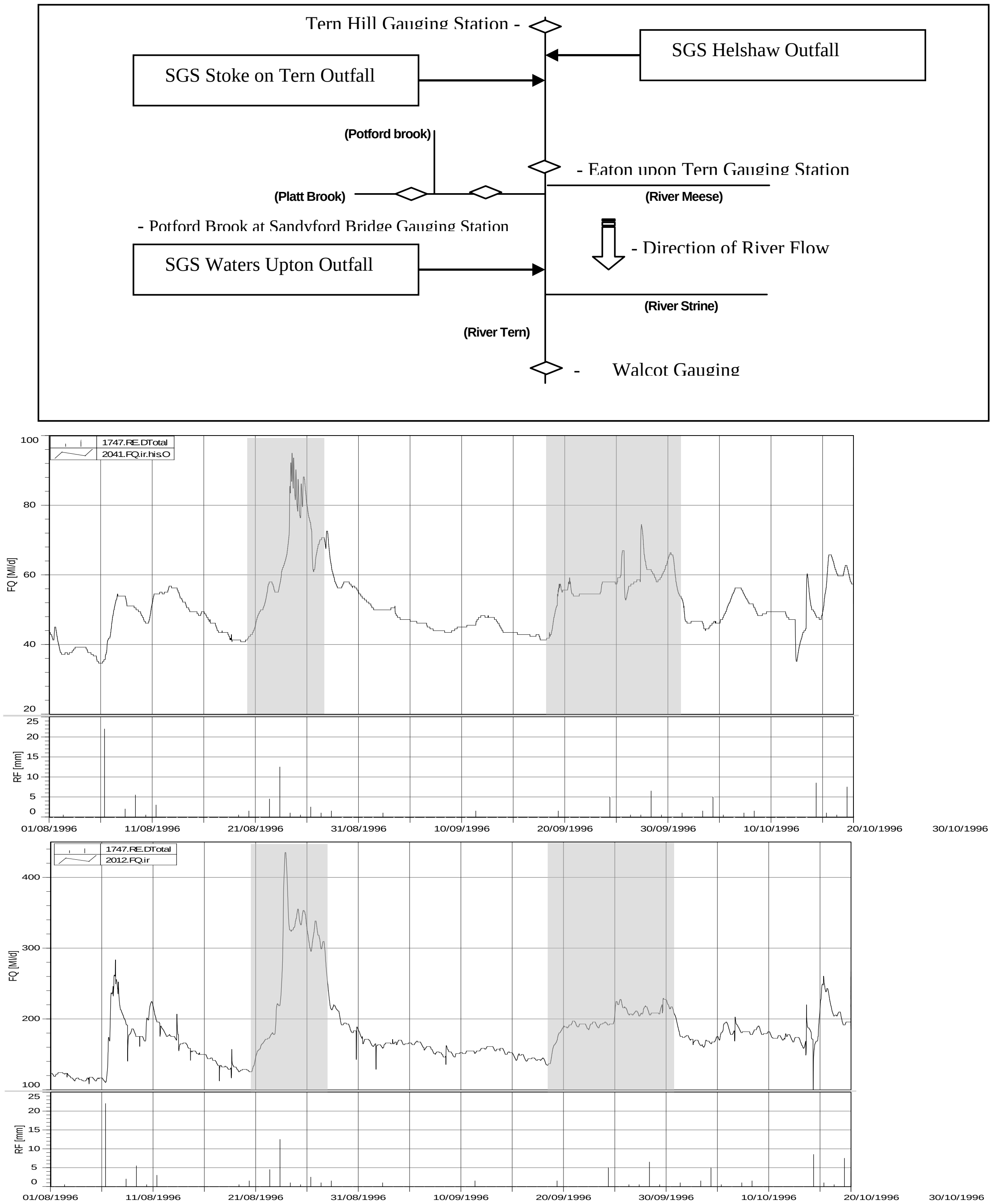
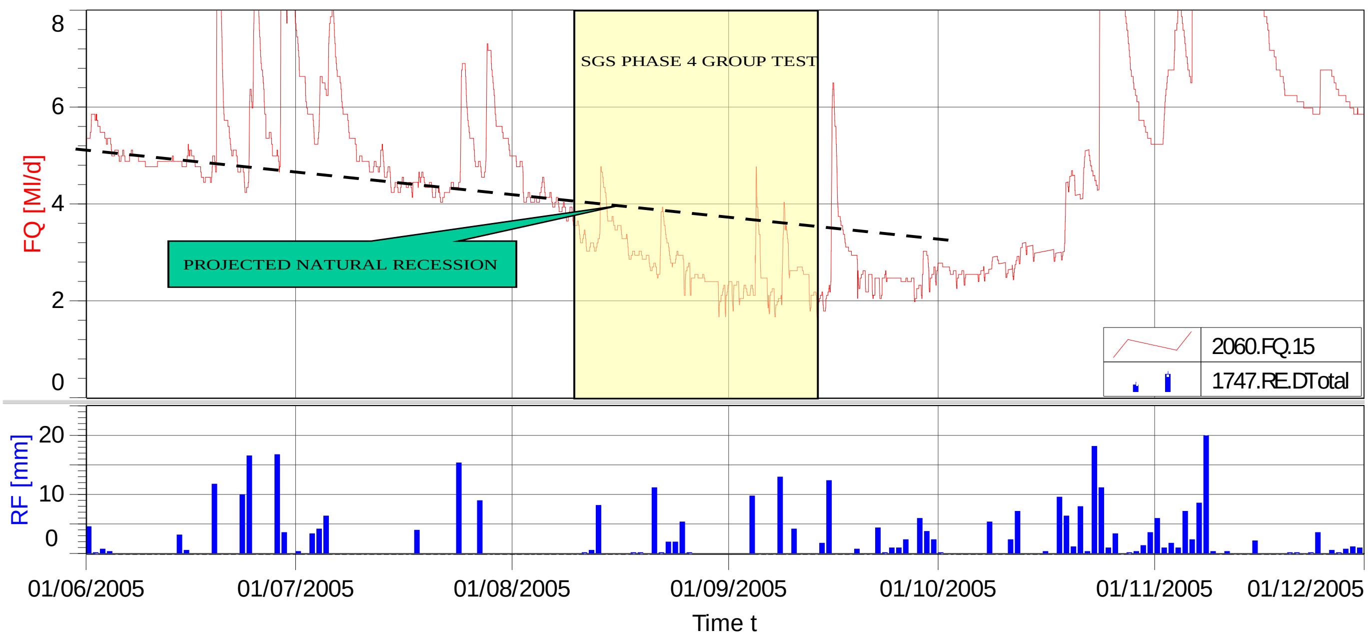
Figure 5.16 Relationship between Phase 1 Groundwater Discharge Points and Surface Water Network (Top Diagram) Observed Nett Gain in Augmented Flow on the River Tern at Eaton-on-Tern (Middle Hydrograph) and Walcot (Bottom Hydrographs) Gauging Stations during 1996 Operational Releases (Shaded in Grey)



While the hydrographs in Figure 5.16 show the positive effects of groundwater discharge increasing flows in the main carrier river system receiving augmented flow, Figure 5.17 shows the inverse relationship. The development and commissioning of the Phase 4 pumping stations in 2005 had an observed impact on gauged flows to the Potford and Platt Brook stream system. The observed 1.5 Ml/d reduction in total flow from this catchment was attributed to the reduction in baseflow to the stream system when the five week Phase 4 group commissioning test reduced groundwater heads in proximity to the middle connected reaches of the stream catchment. Operation of Phase 4 will now require releases to be made to the brooks from the Phase 1 dedicated stream compensation boreholes at Heath House No2 and Greenfields.

Figure 5.17 Impact of Phase 4 Group Test on Gauged Flows on the Potford & Platt Brook Stream System (Gauged at Sandyford Bridge)



Hydrology of the Phase 2 and 3 Wellfield

The Phase 2 and 3 wellfields both lie north of the River Severn which drains from west to east. The land use is predominantly agricultural with the exception of the major urban development centred on Shrewsbury and smaller urban satellite developments of Baschurch, Bomere Heath and Shawbury. The ground elevation is relatively low-lying ranging from highs of up to 192 mAOD on the sandstone escarpments at Grinshill to lows of around 45 to 50 mAOD alongside the River Severn. Generally ground elevation lies between 60 and 100 mAOD. In addition to the River Severn there are only two major tributaries of note within the wellfield areas (Figure 5.18).

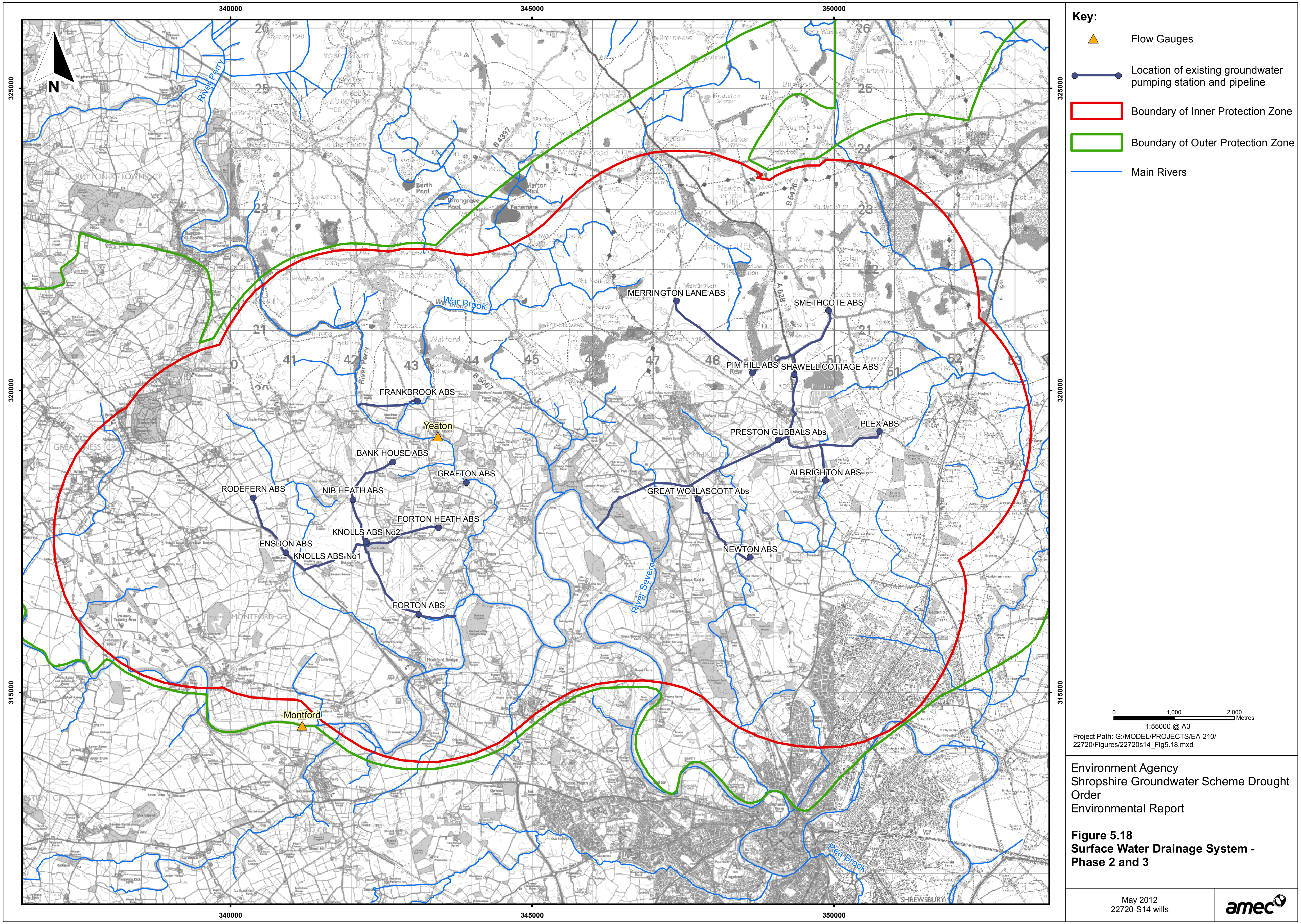


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Figure 5.18
Surface Water Drainage System - Phase 2 and 3

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- **River Severn:** the river flows from west to east over a narrow corridor infilled by modern day alluvial deposits flanked by post-glacial river terrace deposits. Along its course the river is underlain by a complex assemblage of thick glacial drift largely comprising clay till and sand and gravel deposits, overlying Permian Sandstone. Through Shrewsbury the drift sequence overlies Carboniferous Salop Formation on the southern side of the Hodnet Fault;

- **River Perry:** the lower reaches of the River Perry drains southwards through the Phase 2 wellfield. South of the Wem Fault the river is underlain by thick complex glacial drift confining the underlying Permo-Triassic Sandstone aquifer before joining the River Severn at Bromley's Forge. A comparison of potentiometric groundwater head in the sand stone and the bed profile of the River Perry shows that, with the exception of the last 1km of its course, groundwater heads lie below the bed level of the river throughout much of the Phase 2 wellfield;

- **River Roden:** situated on the eastern extreme marginal edge of the Phase 3 wellfield. The upper reaches of the catchment drain extensive drift deposits overlying Merica Mudstone Group. At Lee Brockhurst the river crosses the Brockhurst Fault and on to drift covered Permo-Triassic Sandstone. South of Shawbury the river crosses over Carboniferous Salop Formation between Hodnet and Ercall Mill Faults before crossing over drift covered Permian sandstone at its confluence with the River Tern at Walcot.

Other minor tributaries present within the Phase 2 & 3 wellfield, from west to east are.

- **Un-named drain:** highly modified brook draining south from Little Ness underlain by thick complex glacial drift confining the underlying Permo-Triassic Sandstone aquifer before joining the River Severn at Montford Bridge;

- **War Brook:** The upper reaches drain the cluster of pools at Berth, Birchgrove, Marton and Fenemere, and sits within drift deposits over lying Mercia Mudstone Group. South of Fenemere the brook crosses the Wem Fault river where it is underlain by more thick complex glacial drift confining the underlying Permo-Triassic Sandstone aquifer. The brook passes through impounded pools at Walford, before joining the River Perry up stream of the Yeaton gauge. Flows are largely retained in the brook even under dry weather conditions;

- **Bomere Heath:** The brook drains southward from the village of Bomere Heath passing through Alkmund Park Pool, before joining the River Severn at the Agricultural Show Ground. The catchment is predominantly underlain by a thick sequence of clay till overlying Permo-Triassic Sandstone and routinely runs dry under prolonged dry weather conditions;

- **Harmer Hill Brook:** The source lies on a sequence of thick clay till overlying Permo-Triassic Sandstone where it flows northwards over the Wem Fault to join the upper reaches of the Roden catchment;

- **Bagley Brook**: the brook drains the Old River Bed SSSI wetland, running southward to join the River Severn in the centre of Shrewsbury. The brook lies within the alluvial deposits of the cut off meander which in turn are underlain by older glacial clay till deposits overlying Permian sandstone;

- **Battlefield Brook:** drains southeast from the area around the hamlet of Albrighton before joining the Astely Brook up stream of Sundorne Pool. The catchment is predominantly underlain by a thick sequence of clay till overlying Permo-Triassic Sandstone. The upper reaches routinely run dry under prolonged dry weather conditions;

- **Astley Brook**: The sources lie between Harmer Hill and the village of Clive in a narrow gap in the sandstone escarpment. The brook drains southward flowing through two impounded lakes at Sansaw. The upper reaches are underlain by clay till over Permo-Triassic Sandstone and routinely run dry under prolonged dry weather conditions. At the Village of Astley the brook flows over sandstone outcrop. On its lower reaches the brook passes through impounded pool structures at Sunderton Pool and Sundorne Pool before its confluence with the River Severn at Uffington.

The larger of the surface water bodies of note within the wellfield area fall between two categories of natural and artificially created bodies of open water.

- **Natural Pools:** Folly Pool, Sharwardine Pool, Cottage Pool, Isle Pool, Berth Pool , Birchgrove Pool, Marton Pool, Fenemere Pool, Alkmund Park Pool and Hencott Pool;

- **Artificially Impounded Pools:** Walford Pool, Sansaw Estate Pools, Sunderton Pool and Sundorne Pool.

River and Stream Flow Characteristics

Within the wellfield area the Environment Agency maintains a key number of flow gauging points. On the River Severn the Montford station (ID 2005, SJ 4119 1445) gauges flow upstream of the Shropshire Groundwater Scheme inputs, while the Buildwas station (ID 2134, SJ 6457 0442) captures all inputs approximately 35 km downstream of the last SGS discharge.

The River Perry is gauged at two points, Perry Farm (ID 2045, SJ 3467 3024) on the mid to upper reaches of the catchment lies outside the influence of the Phase 2 wellfield. The Yeaton gauge (ID 2020, SJ 4344 1924) on the lower reaches sits within the centre of the wellfield and records the augmented net gain from one (Frankbrook) out of the ten Phase 2 boreholes. The flow characteristics of the River Roden have already been described.

Flow statistics data for the Phase 2 and 3 Gauges from the National River Flow Archive are presented in Table 5.4.

With the exception of the Bagley Brook, which recently had a level monitor installed for Flood Warning purposes, no flow data exists for any of the minor tributaries listed above as none of these water courses have permanent gauging structures installed. This is largely a reflection of the conceptualised low sensitivity and connectivity of these catchments to head-dependant flow from the Permo-Triassic Sandstone.

Table 5.4 Summarised Flow Statistics for Severn and Perry Gauging Stations (from National River Flow Archive)

	Gauging Point	Surface Flow Statistics (Ml/d)			Baseflow Index (Proportion of Total Flow Contribution)
		Mean Flow	Q50	Q95	
Severn	Montford	3746.7 Ml	2099.5 Ml	515.8 Ml	0.48
Severn	Buildwas	5172.9 Ml	2963.5 Ml	1019.5 Ml	0.54
Perry	Yeaton	138.5 Ml	90.7 Ml	35.1 Ml	0.65
Perry	Perry Farm	53.6 Ml	41.5 Ml	17.6 Ml	0.72

Groundwater – Surface Water System Interaction

In direct contrast to the high sensitivity and connectivity of stream and groundwater systems in the Phase 1&4 wellfields, the hydrogeological mapping and groundwater observation network prove that sandstone groundwater lies below the bed level of a significant proportion of the watercourses draining the Phase 2 & 3 wellfields. Thus the potential head-dependant flow between streams and the sandstone is not likely to be an important flow mechanism in this area. Given the thickness and complex nature of the drift in these areas, stream flow support from groundwater interception, storage and discharge from perched drift aquifers probably plays a more significant role.

a) *Streams with strong head-dependant interaction with the Permo-Triassic Sandstone aquifer* – groundwater heads are elevated above the stream bed thus provide the potential to discharge groundwater in to the stream. The effectiveness of this discharge will be influenced by the hydraulic properties in the inventing drift which in itself could act as conduit through which drainage of the aquifer to the stream could occur.

Stream systems falling in this category are River Severn, which probably acts as the main receptor for groundwater discharge from the Permo-Triassic Sandstone, the lower reaches of the Astley Brook, and the Bagley Brook.

b) *Streams with weak or no head-dependant interaction with the Permo-Triassic Sandstone aquifer* – in this scenario either groundwater heads lie below the stream bed elevation, in which case the head potential would encourage loss of water from the stream to the aquifer via leakage through the bed sediments. Or the intervening drift is of sufficient low permeability to hydraulically isolate the stream from the head in the aquifer, or the aquifer is absent altogether.

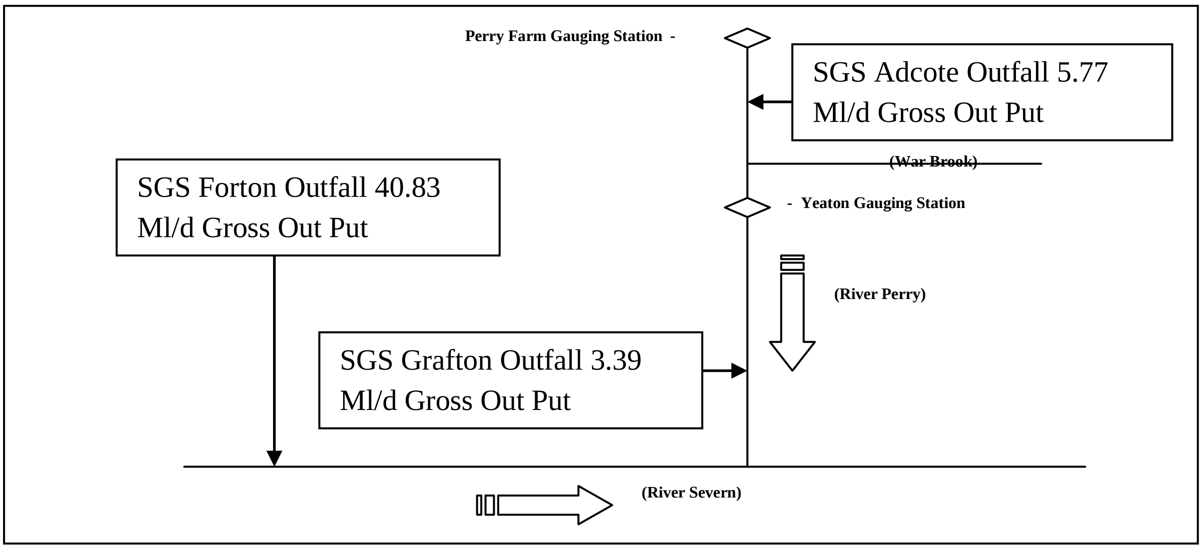
c) *Streams with head-dependant interactions with drift aquifers* – areas of complex and or thick drift which support the interception, storage and discharge of groundwater in perched aquifer bodies independent to the main sandstone aquifer head.

The vast majority of the stream systems would fall between these last two categories. The Phase 2 wellfield contains more complex heterogeneous drift, supporting known localised drift fed spring flow points to the River Perry and War Brook. While the more homogeneous clay till based drift of the Phase 3 area culminates in reduced storage potential and therefore lower baseflow support provided from the drift. This view is supported by the observation that a large number of the minor tributaries, such as the upper reaches of the Astley Brook, Battle Field, and Bomere Heath Brook, routinely run dry under low flow conditions.

Assessment of Nett Gain to Stream and River Flow Systems from Groundwater Discharges

The relative proportion of groundwater release to river flows prevent any meaningful analysis of the nett gain increase in river flows from Phase 2 and Phase 3 to the Severn. Of the ten abstraction boreholes on Phase 2 generating a combined gross output of 50 Ml/d, only the output from the Frankbrook discharge to the River Perry can be assessed in terms of net gain (Figure 5.19). Under operational conditions in 1996 an assessment of augmented nett flow increase of 5 to 5.5 Ml/d on the River Perry at Yeaton was made from the Franbrook borehole gross discharge of 5.7 Ml/d. This equated to a nett gain of between 86% and 95%.

Figure 5.19 Relationship between Phase 2 Groundwater Discharge Points and Surface Water Network (top diagram). Observed Nett Gain in Augmented Flow at River Perry Yeaton Gauging Station (Bottom Hydrograph) during 1996 Operational Releases from Frankbrook Pumping Station (Grey Shaded Blocks). The bottom Histogram Records Rainfall from a nearby Rain Gauge



5.3.3 Soil Moisture

Abstraction of groundwater on the scale permitted by the Scheme raised concerns from the agricultural and conservation communities about potential or perceived impact of pumping upon availability of soil moisture to trees and agricultural crop yields and environmentally sensitive habitats. To address these concerns a statutory duty was placed on the scheme to monitor the natural changes and effects of abstraction on groundwater and soil moisture conditions. Where appropriate a network of specialist soil moisture monitoring sites have been established to monitor soil moisture levels in the shallow rooting zone of crops. These sites comprise of sets of permanent access tubes, installed to depth of generally 2 m and up to 4 m in the unsaturated zone of the surface soil profile. Routine monitoring was originally achieved via Neutron probes; however these have recently been replaced by safer capacitance probe based technology.

Prior to the development by the Environment Agency and ADAS, of the groundwater mapping and soil moisture vulnerability methodology, (see Section 3.1.4), a network of seven permanent soil moisture monitoring sites had been established and maintained. The vast majority of these sites were located in the Phase 1&4 area where the shallowest groundwater levels are found. Through the application of the mapping technology and risk based vulnerability assessment, a greater understanding of the nominal risk posed to soil moisture by the scheme has been gained. This has allowed the network to be reduced in the mid 2000s from seven down to only two sites at present. To quantify the risk posed by the extent and magnitude of drawdown influence within each wellfield, the total area underlain by each vulnerability class has been calculated using both observed and modelled drawdown footprints. This will allow comparison between the extent of influence generated under historic actual with that predicted by modelling the extended pumping footprint required to meet the extreme drought conditions envisaged under this order.

Phase 1 and 4 Wellfield

Mapping indicates that the water table in the sandstone lies beyond the reach of agricultural crops, trees and other vegetation for a significant proportion of the wellfield. However, underlying the main river corridor of the River Tern, plus reaches of some of the smaller tributary steams such as the Stoke, Potford, Platt, and Lakemoor brooks, the water table is sufficiently shallow to be potentially accessible to vegetation rooting zones. However the degree of vulnerability in these shallow water tables areas depends largely upon the permeability of the underlying soil and drift geology. Clay drift beneath the Lakemoor Brook catchment, upper reaches of the Potford Brook at Greenfields and the Platt Brook at Greenhurst, exclude these areas from potential sensitivity as the intervening clay drift will inhibit the degree of connectivity between groundwater and the soil rooting zone.

Within the footprint of historical actual and modelled pumping Table 5.5 and Table 5.6 provide the breakdown of areas underlain by each of the vulnerability classes for each Phase in isolation. To date Phase 1 and 4 have not been pumped together and therefore no historical actual data exists for this in-combination use other than model simulations.

Table 5.5 Phase 1 Analysis of Area Underlain by Vulnerability Classes within 33 km^2 Historic Actual Wellfield Footprint (Generated by 73 Days of Pumping in 1995)

Vulnerability Class	Area (Km^2)	Percentage (%)	Drift Categories	Area (Km^2)	Percentage (%)
			High permeability	0.9	2.7
			Moderate permeability	0.5	1.5
CLASS 1 - possible effect on shallow rooting crops	2.8	8.3	Low permeability	1.3	3.9
			High permeability	1.1	3.3
			Moderate permeability	0.5	1.5
CLASS 2 - possible effect on deep rooting crops	3.3	9.8	Low permeability	1.7	5.1
			High permeability	4.2	12.5
			Moderate permeability	0.6	1.8
CLASS 3 - possible effect on trees only	9.5	28.3	Low permeability	4.7	13.9
			High permeability	11	32.7
			Moderate permeability	0.6	1.8
CLASS 4 - No effect on crops or trees	18	53.6	Low permeability	6.5	19.3

Table 5.6 Phase 4 Analysis of Area Underlain by Vulnerability Classes within 69 km^2 Modelled Wellfield Footprint (Generated by East Shropshire Groundwater Model)

Vulnerability Class	Area (Km^2)	Percentage (%)	Drift Categories	Area (Km^2)	Percentage (%)
			High permeability	2	2.9
			Moderate permeability	1.8	2.6
CLASS 1 - possible effect on shallow rooting crops	6.6	9.5	Low permeability	2.8	4
			High permeability	1.4	2
			Moderate permeability	0.9	1.3
CLASS 2 - possible effect on deep rooting crops only	4.5	6.4	Low permeability	2.2	3.1
			High permeability	5.2	7.4
			Moderate permeability	1.8	2.6
CLASS 3 - possible effect on trees only	12.4	17.7	Low permeability	5.4	7.7
			High permeability	31.3	44.8
			Moderate permeability	2.9	4.1
CLASS 4 - No effect on crops or trees	46.4	66.4	Low permeability	12.2	17.5

The tables show that within 81% and 84% of the pumping footprint, groundwater levels (under rest condition) lie greater than 2.5 mbgl and therefore beyond the reach of agricultural crop rooting zones. Soil moisture will therefore not be impacted in these areas by the effects of abstraction. Land where groundwater is shallow, less than 2.5mbgl, and therefore accessible by both shallow and deep rooting agricultural crop zones (Class 1 and Class 2) occupy the remaining 16% to 19% of the wellfield area.

Within each of the Class 1 and Class 2 zones the degree of vulnerability has been further refined by calculating the relative proportions of intervening high, moderate and low permeability drift deposits. The presence of these deposits is crucial as they will either freely allow or inhibit movement of groundwater from the sandstone to the rooting zone. To further refine the risk, the proportions underlain by high, medium and low permeability drift within each Class area have been calculated as a percentage of the total area considered to be effected by pumping. Therefore in total less than 6%, or $2km^2$, of the land influenced by groundwater abstraction falls within the highest possible vulnerability categories (highly permeable drift over shallow groundwater within <2.5mgbl) Class 1 and Class 2 for Phase 1. While for Phase 4 this figure is less than 5% of the total footprint, or 3.2 km^2. These figures do not represent one whole area but the sum total of a number of smaller parcels of land scattered throughout the wellfield.

Through the application of this mapping technique it is possible to conclude that the Phase 1 & 4 area of the Shropshire Groundwater Scheme sits within a catchment characterised by relatively shallow groundwater. However, a significant proportion of the land is underlain by water tables that lie beyond the reach of agricultural crops, trees and other vegetation with only small isolated areas of land falling within potential sensitivity category. By applying this risked based methodology it is considered that operational pumping from Phase 1 and 4 has to date presented a negligible risk to soil moisture vulnerability within the influence of the Tern catchment.

Phase 2 and 3 Wellfield

In direct contrast to the Tern catchment the Phase 2 & 3 wellfields are predominantly underlain by deep groundwater. Over a significant proportion of the wellfield area groundwater lies in excess of 10 to 15 mbgl, with a mean depth range of between 10 to 30 mbgl. The areas underlain by shallow water tables (0 to 5 mbgl) are limited to the extensive flat flood storage area to the west of Sharwardine, the narrow corridor of the River Severn, the lower reaches of the River Perry and the Astley Brook. The risk mapping indicates that a significant proportion of the Phase 2 & 3 wellfields, groundwater in the sandstone lies well beyond the reach of agricultural crops, trees and other vegetation.

West of Shrawardine, the presence of an extensive area of shallow groundwater designates a wide zone of potential vulnerability to the effects of pumping. When the underlying drift geology is applied, the relative vulnerability can be reduced as the bulk of the area is predominantly underlain by very thick clay (drift category C3). This should significantly inhibit the movement of water between the sandstone aquifer and the rooting zone of vegetation, effectively eliminating any vulnerability of vegetation to groundwater abstraction. The eastern margin of the clay, running from Wilcott Marsh to Shrawardine, is underlain at depth by a mixture of silty clays. This represents a transitional zone from pure clay of the C3 drift category, to a more complex sequence of clay, sand and gravel typified by C2 and C1 drift categories. While the drift categories define the geology at depth, they may not always reflect the surface soils in which vegetation grows. Whereas the underlying drift in this locality is predominantly low permeability clays, the soils are often loamy in texture and naturally well drained.

The narrow corridor of potential vulnerability mapped adjoining the course of the River Severn and bordering the southern edge of the Phase 2 & 3 wellfield, is predominantly grassland prone to winter flooding. Its potential vulnerability is largely negated by the nature of the underlying drift category.

Calculation of the proportion of vulnerability classes within historic actual wellfields for 79 days of pumping of Phase 2 in 1995 are presented in Table 5.7, and 40 days of pumping of Phase 3 in 1999 are shown in Table 5.8. The tables show that between 84 and 98% of the land underlain by pumping, groundwater at rest lie greater than 2.5mgbl and therefore beyond the reach of agricultural crops, trees and other vegetation and therefore will not be impacted by the effects of abstraction. Land where groundwater is less than 2.5mbgl and therefore shallow enough to be accessible by both shallow and deep rooting agricultural crop zones (Class 1 and Class 2) occupies the remaining 2 to 16% of the wellfield assessments.

Within each of the Classification zones the degree of vulnerability has been further refined by calculating the relative proportions of intervening high, moderate and low permeability drift deposits. Even though 16% of the Phase 2 wellfield area falls within Class 1 and Class 2 vulnerability zones, the actual risk is reduced to less than 1%, or 0.4 km^2 due to the presence of intervening low permeability drift. Phase 3 has a small 1.5% area of land falling with Class 1 and Class vulnerability zones. This is further reduced to a negligible 0.4%, or 0.2 km^2, when applying within the highest possible vulnerability categories (highly permeable drift over shallow groundwater within <2.5mgbl).

Table 5.7 Phase 2 Analysis of Area Underlain by Vulnerability Classes within 56 km^2 Historic Actual Wellfield Footprint (Generated by 79 Days of Pumping in 1995)

Vulnerability Class	Area (Km^2)	Percentage (%)	Drift Categories	Area (Km^2)	Percentage (%)
			High permeability	0.3	0.5
			Moderate permeability	1	1.8
CLASS 1 - possible effect on shallow rooting crops	8	14.2	Low permeability	6.7	11.9
			High permeability	0.1	0.2
			Moderate permeability	0.1	0.2
CLASS 2 - possible effect on deep rooting crops only	1.2	2.2	Low permeability	1	1.8
			High permeability	0.5	0.9
			Moderate permeability	0.2	0.4
CLASS 3 - possible effect on trees only	2.3	4.1	Low permeability	1.6	2.8
			High permeability	4.5	8
			Moderate permeability	2.1	3.7
CLASS 4 - No effect on crops or trees	44.8	79.5	Low permeability	38.2	67.8

Table 5.8 Phase 3 Analysis of Area Underlain by Vulnerability Classes within 54 km^2 Historic Actual Wellfield Footprint (Generated by 40 Days of Pumping in 1999)

Vulnerability Class	Area (Km^2)	Percentage (%)	Drift Categories	Area (Km^2)	Percentage (%)
CLASS 1 - possible effect on shallow rooting crops	0.7	1.3	High permeability	0.2	0.4
			Moderate permeability	0.4	0.7
			Low permeability	0.1	0.2
CLASS 2 - possible effect on deep rooting crops only	0.1	0.2	High permeability	0	0
			Moderate permeability	0	0
			Low permeability	0.1	0.2
CLASS 3 - possible effect on trees only	0.5	0.9	High permeability	0.1	0.2
			Moderate permeability	0	0
			Low permeability	0.4	0.7
CLASS 4 - No effect on crops or trees	52.9	97.6	High permeability	5.7	10.5
			Moderate permeability	2	3.7
			Low permeability	45.2	83.4

Through the application of this mapping technique it is possible to conclude that Phase 2 & 3 areas of the Shropshire Groundwater Scheme sit within a catchment characterised by very deep groundwater that is not accessible to agricultural crops, trees and other vegetation rooting zones. It is considered that operational pumping from Phase 2 & 3 does not present any quantifiable risk to soil moisture vulnerability. As a consequence no soil moisture monitoring is carried out as part of the background environmental monitoring activities for these Phases.

5.3.4 Groundwater Abstractors

Through out the development area of the scheme a number of rural areas either do not have direct access to, or are not connected to, the public mains water supply network. As a consequence a proportion of rural properties rely partly, or wholly, upon private sources of groundwater supplied from springs, wells or boreholes for their domestic and or business water supply needs.

It was recognised at an early stage in the development of the Groundwater Scheme that operational pumping could impact, to a lesser or greater degree, upon some existing private sources lying within the influence of the wellfields. In recognition of this the “Model Terms and Conditions Agreement” was drawn up between the original promoter of the Scheme (Severn Trent Water Authority) and representatives of the National Farmers Union (NFU) and the Country Landowners Association (CLA).

The agreement set out policies and practices currently adopted by the Environment Agency during construction and operation of the Scheme. Under the terms of this agreement, inner and outer protected zones were designated to define anticipated areas of influence.

- *Inner Protected Zone* – defines the area around each Phase where drawdown effects from pumping are highly likely to be experienced and therefore may be anticipated to impact upon some private sources;
- *Outer Protected Zone* – it is considered unlikely that pumping effects will extent this far, however additional assurances are provided in the unlikely event that effects extend beyond the anticipated sphere of influence defined by the inner zone.

Prior to the development of the Scheme a register of known private sources of supply was compiled. The register contains details of the location, depth of well or borehole, pump depth and groundwater levels for each source. This register has been maintained and reviewed as each of the Phase areas have been developed. It is used to predict the likely risk posed to each source of supply by the scheme.

Where predicted impacts are recognised the Environment Agency has, and will continue to, carry out remedial works to secure the continuity of supply to mitigate against the effects of the scheme. Remedial works will comprise of one of the following options: (i) lowering the existing water supply pump, (ii) deepening the well or borehole, (iii) drilling a deeper replacement borehole, or (iv) connecting the property to the mains water supply network.

5.4 Assessment of Impact on the Current Environment

As discussed in Section 3 the effects of the increased abstraction from the SGS Scheme have been assessed using the East Shropshire Permo-Triassic Sandstone Model (ESM). The results of the water resource modelling (Section 3.1.1) were incorporated in to the groundwater model and predictive simulations were carried out by hydrogeological consultants ESI. This work is an extension of previous predictive simulations for the SGS that have been carried out as part of the model development. Three new predictive modelling simulations have been carried out:

- Normal climate with recent actual abstraction rates and no SGS abstractions (ESMDO-01 baseline simulation);
- ‘Dry’ climate change with recent actual abstraction rates and no SGS abstractions (ESMDO-02 ‘dry’ simulation);
- ‘Dry’ climate change with recent actual abstraction rates plus SGS abstractions (ESMDO-03‘dry plus SGS’ simulation).

Further details on the modelling are included in the ESI report in Appendix B. The results of the modelling have been summarised and are discussed in the following sections.

When originally constructed the ESM only provided coverage for Phases 1 & 4 of the SGS. Extension of the groundwater model in 2008 meant that the model can now be used to predict the impacts from abstraction at Phases 1, 4 and 3 of the SGS. However, Phase 2 remains outside the current model area. Predicted changes to groundwater level and flows for the SGS Phase 2 wellfield area have been semi-quantified using a simple approach based on distance drawdown relationships determined from previous pumping test data.

The additional risk to soil moisture availability from increased SGS abstraction has been assessed by reapplication of the methodology developed by the EA/ ADAS.

5.4.1 Hydrogeology

Phase 1 and 4 Wellfield

The impact of the modelled drought scenario on groundwater levels at selected observation boreholes within the Phase 1 and 4 wellfield is presented on Figure 5.20. It is important to remember that the drought scenario presented here incorporates a dry climate change factor in addition to the extended drought SGS abstraction and the relative impacts of these factors can be identified on these plots. The hydrographs illustrate clearly the times of maximum impact for each observation point. As would be expected, the time of maximum impact occurs later for observation points further from the SGS abstraction sites.

Simulated contour plots illustrating the spatial impact of the SGS abstractions on groundwater level in the sandstone for two different time periods, 2 months and 24 months after abstraction ceases are discussed in further detail in the ESI 2009 report in Appendix B. These plots further illustrate the spatial variation in the timing of maximum drawdown with distance from the abstractions. Closest to the abstraction wells drawdown is greatest immediately following the abstraction period, whilst further away, at the fringes of the wellfield, the maximum drawdown may occur up to 2 years after abstraction ceases.

It is difficult to make a direct comparison of the additional area affected by abstraction under the drought scenario as the existing plots do not represent an observation of a historic actual event where Phases 1 and 4 have been pumped simultaneously. However, the area of influence of the wellfield will be limited by the same structural faulting and the unconfined nature of the aquifer in this area and does not appear to extend significantly beyond the existing footprint, and remains largely within the SGS Inner Protected Zone. To allow some degree of comparison groundwater levels when the scheme is not pumping, normal operational pumping and the drought pumping scenario have been projected on the hydrogeological cross section presented in Figure 4.5.

Contour plots for each of the phases, each pumping at around 50% of the individual phase annual licence, suggest a drawdown of approximately 2-3 m in the centre of the wellfield (Figures 5.4 and 5.5). As the wellfields for each of the phases are essentially coincident, superimposition, assuming linearity of impact, enables us to predict a simplified idea of the resultant drawdown from a merged wellfield with both phases pumping. This suggests a drawdown of approximately 5-6 m in the centre of the wellfield based on the actual pumped rates, and a possible impact of around 10 m from both Phases pumping at fully licensed rates. These estimates are roughly consistent with those produced by the groundwater model (Figure 5.21) – where simulated abstraction occurs at a maximum of 82% and 90% of the individual annual licence totals for Phase 1 and Phase 4 respectively.

The drawdown simulated by the model for lower annual pumping totals is higher compared to that calculated above based on a single year's abstraction. This is a reflection of the potential cumulative effect of pumping the scheme in successive years under the drought scenario. Current expected use of the scheme is for it to be operated in two out of every five years, allowing a period of recovery between operational periods (also reflected by the 5 year rolling licence total). Use of the scheme to date has followed this expectation and monitoring date indicates that groundwater levels have recovered to pre-pumping levels between operational periods. The modelled hydrographs for the drought scenario indicate that following the initial SGS abstraction period in 2013, the aquifer makes an almost complete recovery before the next SGS abstraction period in 2021. After the final SGS abstraction period (which represents severe drought conditions) the aquifer does not make a full recovery by the end of the modelled time period 6 years later. It is estimated that full recovery might take another six years, based on similar rates of recovery to those occurring from 2015-2021. However, it is important to note that the drought scenario only requires abstraction to be increased to 109% and 101% of the 5 year licence limit for Phases 1 and 4 respectively and therefore, the increase above the potential current full licensed situation will be much less.

Phase 2 and 3 Wellfield

The impact of the modelled drought scenario on groundwater levels at selected observation boreholes within the Phase 3 wellfield is presented in Figure 5.22. As for Phases 1 and 4, the hydrographs illustrate clearly the times of maximum impact for each observation point with the time of maximum impact occurring later for observation points further from the SGS abstraction sites.

Simulated contour plots illustrating the spatial impact of the SGS abstractions on groundwater levels in the sandstone for two different time periods, 2 months and 24 months after abstraction ceases are discussed and illustrated in the ESI 2009 report in Appendix B. Again these plots further illustrate the spatial variation in the timing of maximum drawdown with distance from the abstractions with impacts continuing to increase in areas further away the maximum drawdown 2 years after abstraction ceases.

The ESI report shows that in the centre of the Phase 3 wellfield 2 months after SGS abstraction ceases there is a maximum drawdown of 5 m centred on the Shawell Cottage abstraction. After 24 months the maximum drawdown has reduced to 2.5 m. The impact of the ‘dry’ climate on groundwater levels in this area is approximately 1 m; the combined effects of the applied climate change and SGS abstraction therefore will be up to 6 m in the Phase 3 wellfield. This magnitude of impact is generally consistent with the impact that would be expected based on the observed data.

Comparison of the modelled Phase 3 groundwater contours (Figure 5.23) to the existing wellfield contours (Figure 5.10 generated from operational use) indicate that the area of aquifer affected by abstraction from the scheme will extend further to the east to merge with the area of impact produced from the Phase 1 and 4 pumping near the River Roden. The footprint will also extend slightly further to the south than currently experienced, generating increased drawdown close to the River Severn and the Old River Bed SSSI in an area where there is good connection between the groundwater and surface water systems. The wellfield does not appear to extend significantly further to the west than currently experienced, however, it is important to note that this will be affected by the presence of the model boundary and the absence of the Phase 2 abstraction from the modelled area (although 10% of the Phase 2 abstraction is included in the model as a flux boundary). Generally the predicted area of impact remains within the SGS Inner protection zone, except to the south of the wellfield where it remains within the SGS outer protection zone. The modelled effects of the drought order pumping scenario in comparison with observed historical actual groundwater pumping patterns have been illustrated in the hydrogeological cross sections in Figures 4.6 and 4.8.

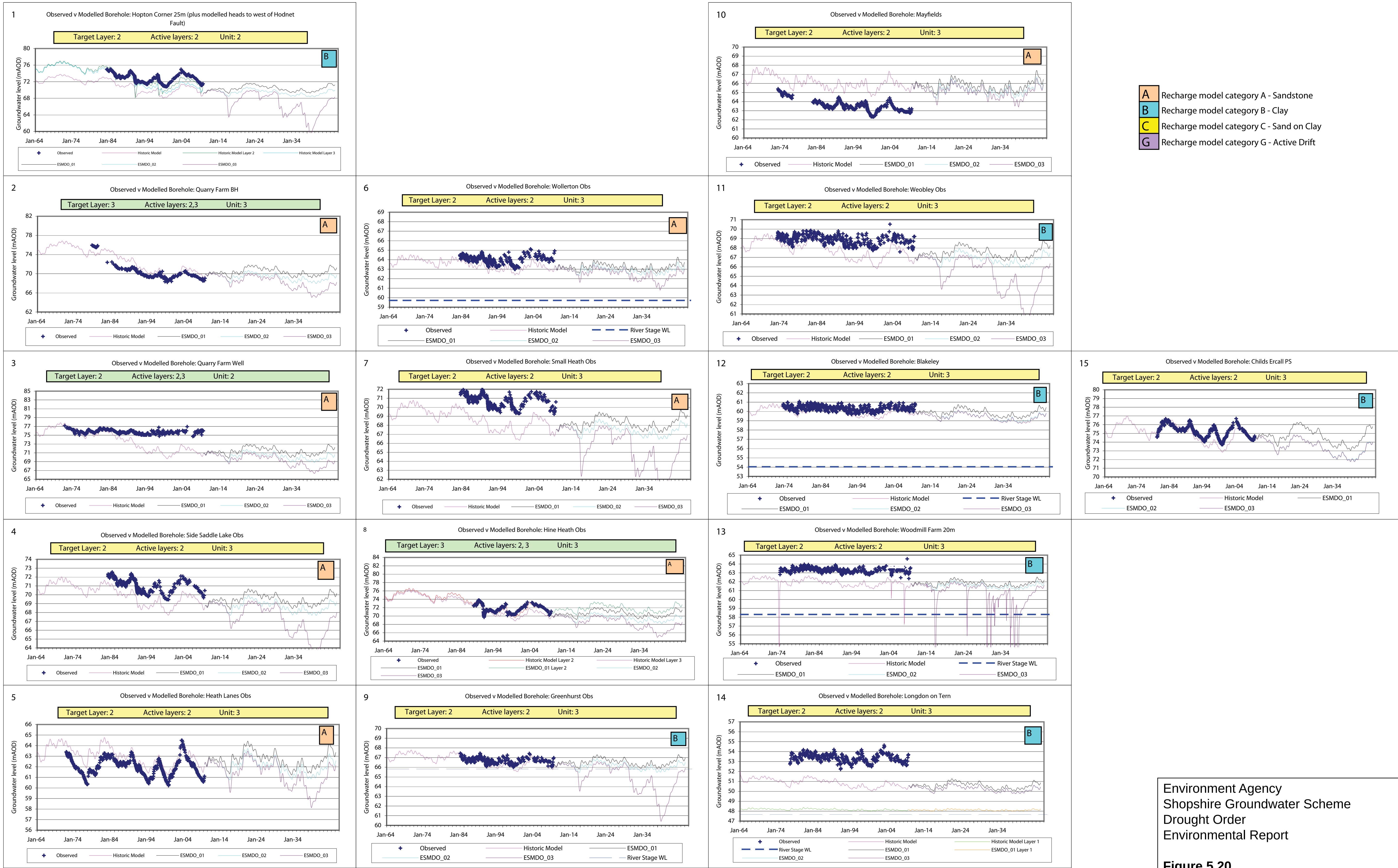


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Figure 5.20
Hydrographs - Phases 1 & 4
(reproduced from ESI, 2009)

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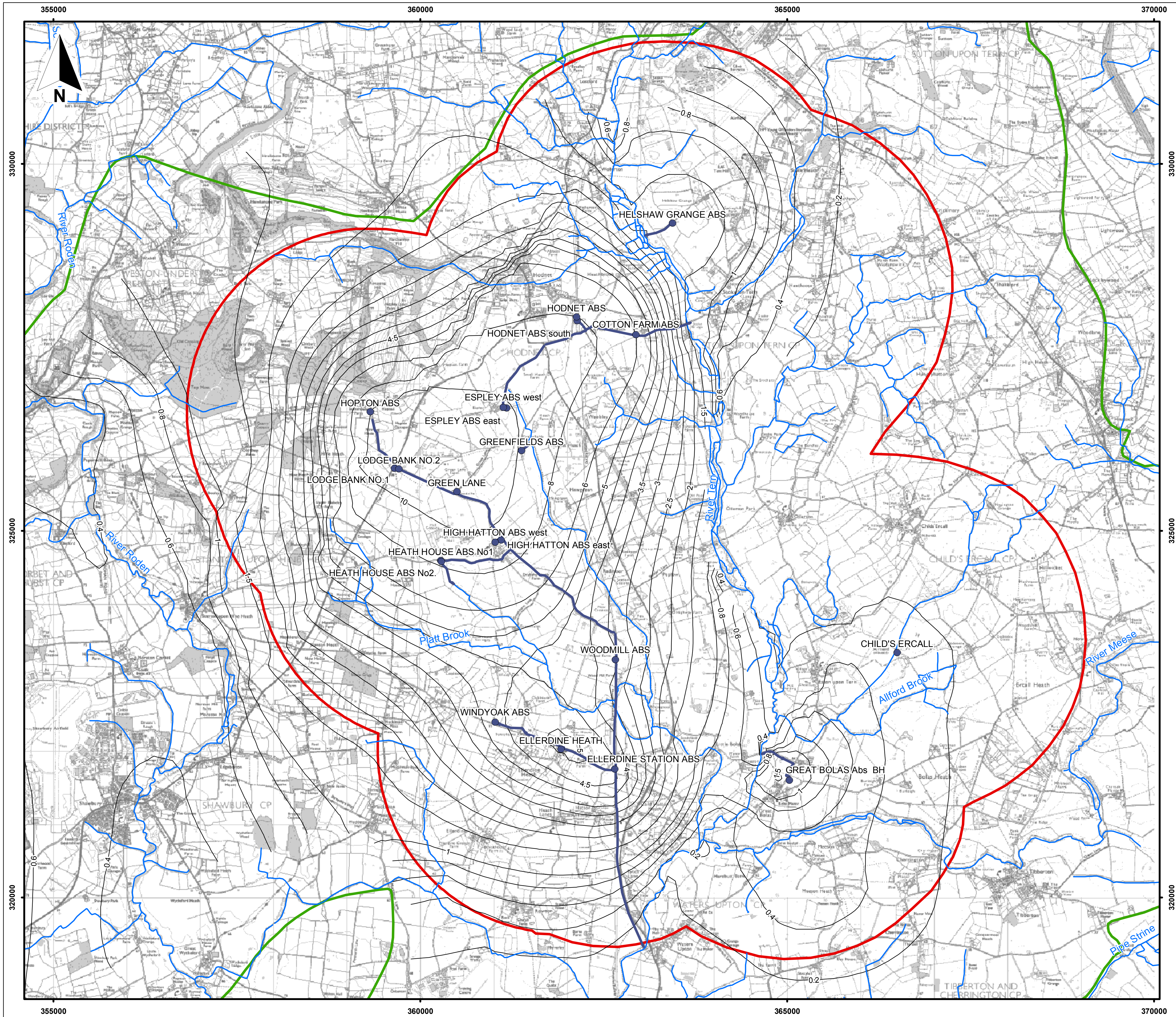

Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers
- Contours (m)

0 1,000 2,000 Metres

1:50000 @ A3

Project Path: G:/MODEL/PROJECTS/EA-210/22720/Figures/22720s15_Fig5.21.mxd

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Figure 5.21

Phases 1 and 4 Modelled Groundwater Drawdown under Drought Order Pumping Scenario

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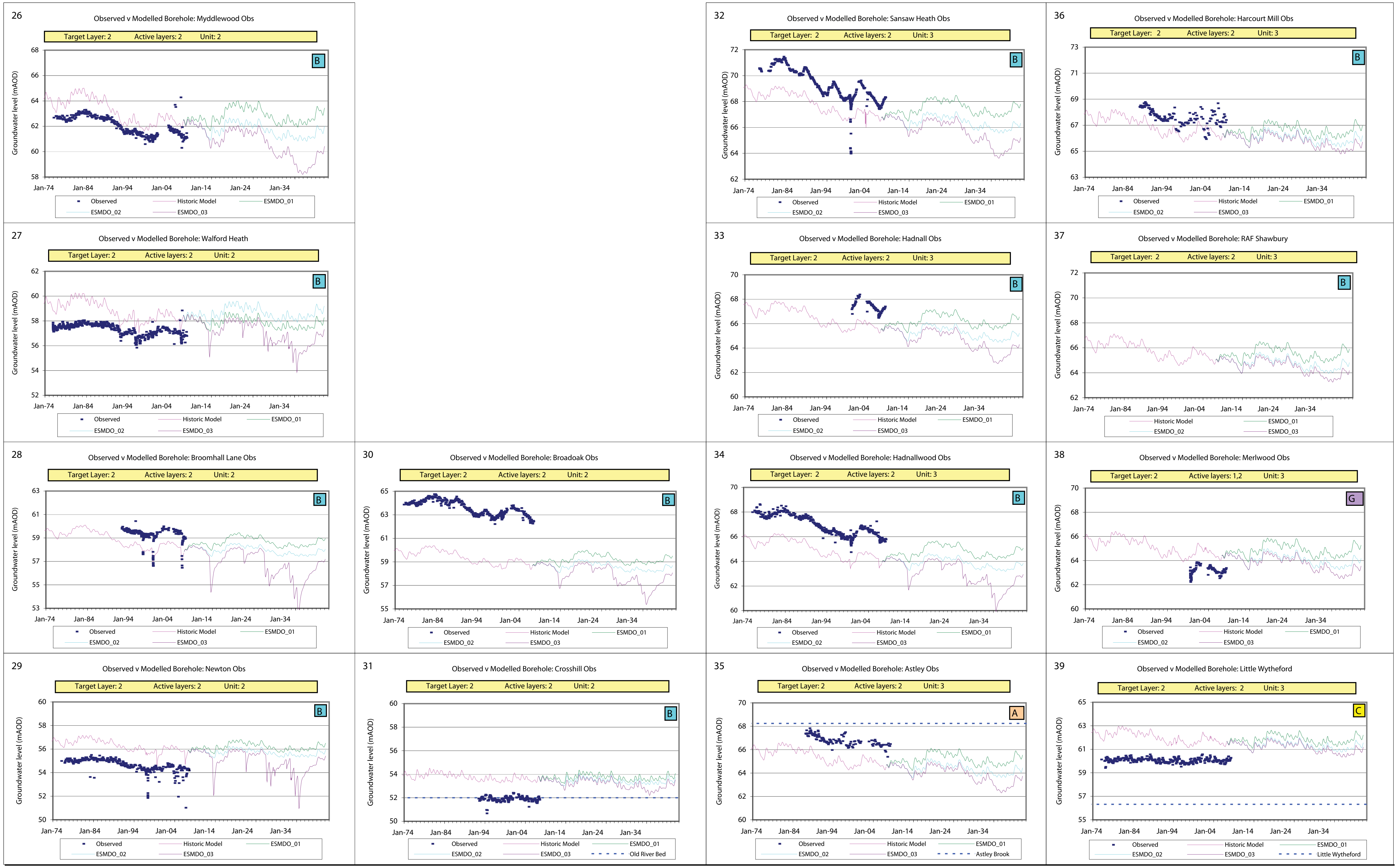

A Recharge model category A - Sandstone
B Recharge model category B - Clay
C Recharge model category C - Sand on Clay
G Recharge model category G - Active Drift

ESMDO_01 - Baseline
ESMDO_02 - Dry
ESMDO_03 - Dry plus SGS

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Figure 5.22
Hydrographs - Phase 3 (reproduced from ESI, 2009)

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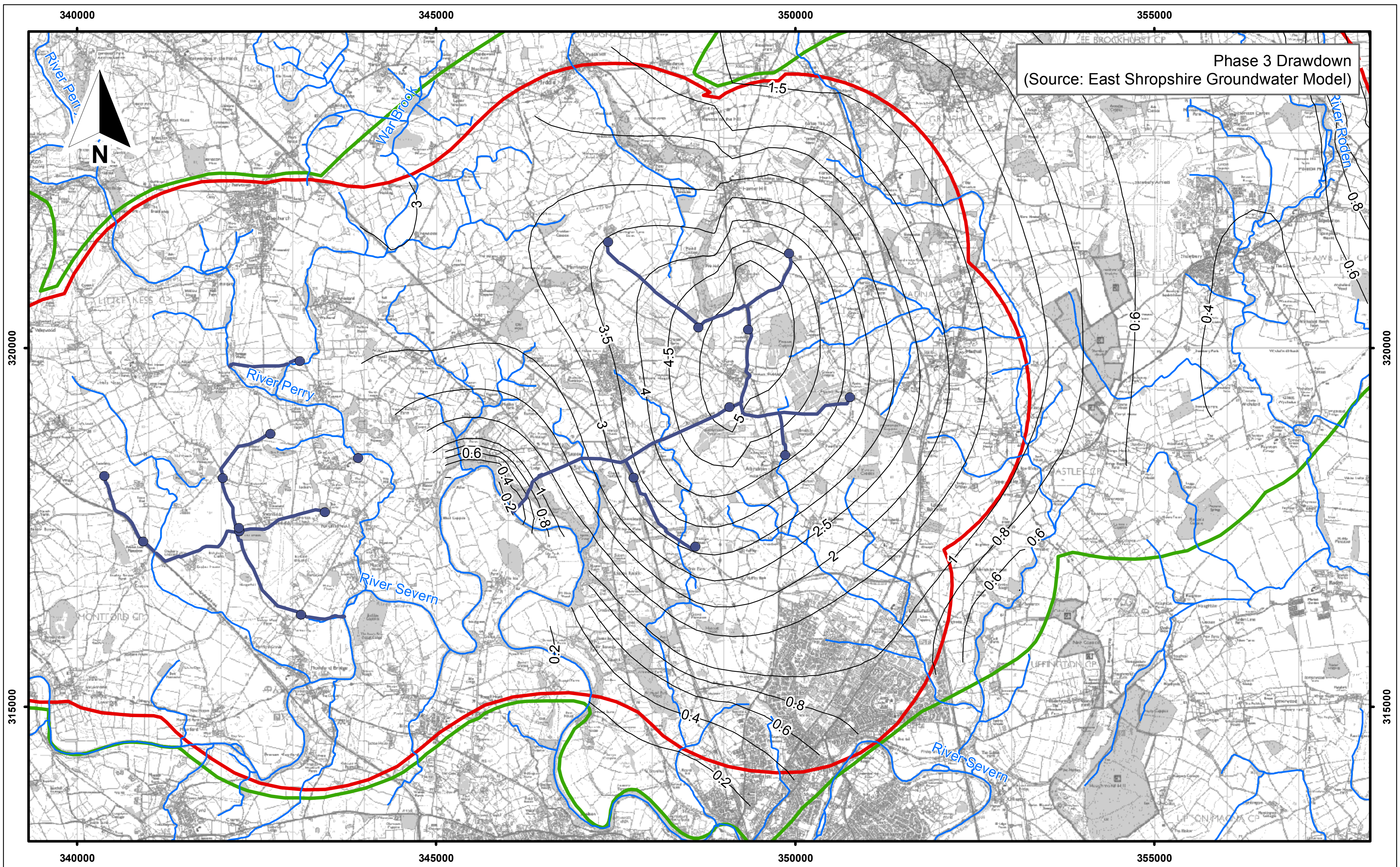

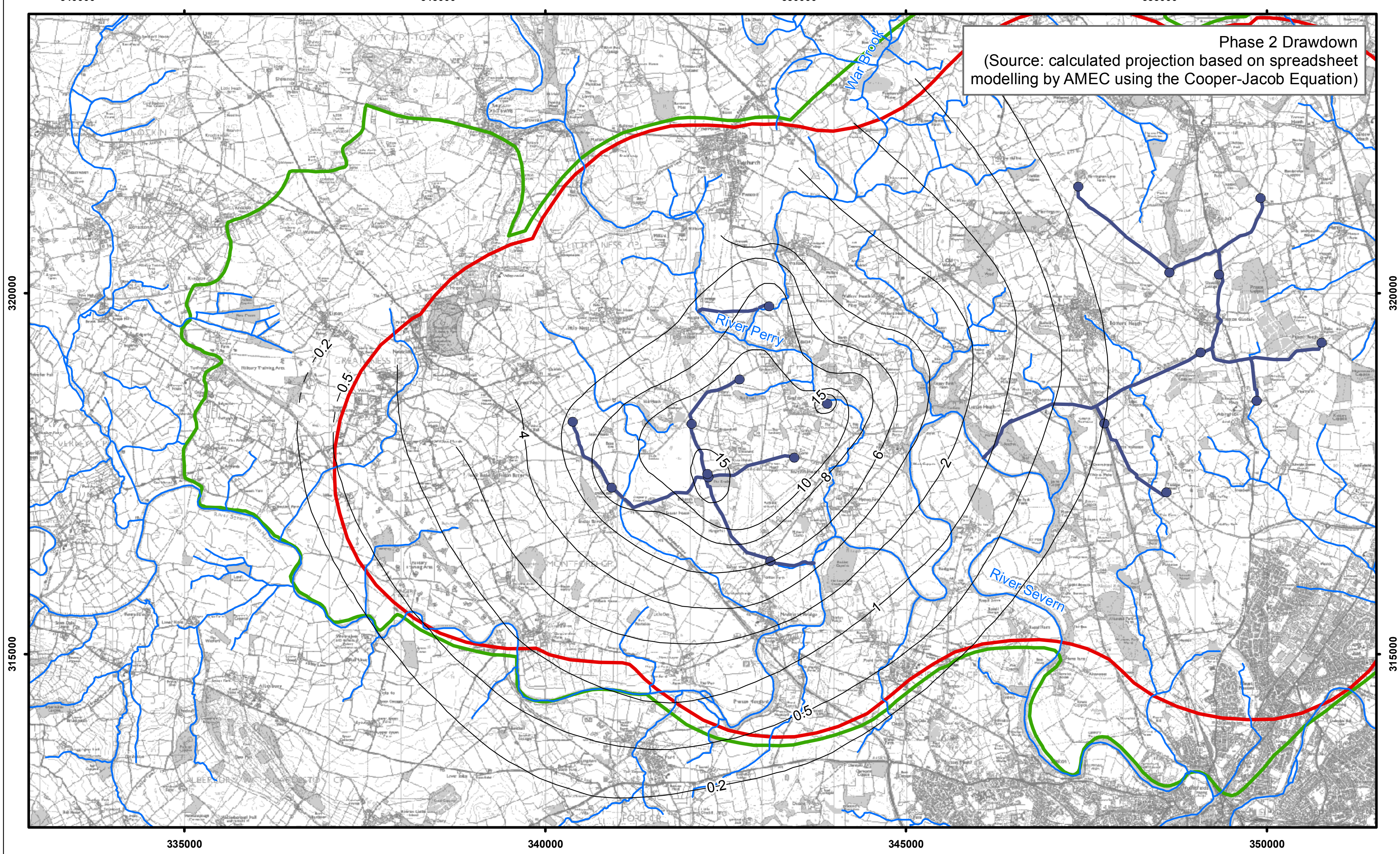

Key:

- Location of existing groundwater pumping station and pipeline
- Boundary of Inner Protection Zone
- Boundary of Outer Protection Zone
- Main Rivers
- Drawdown (m)

0 1,000 2,000 3,000 4,000 5,000 Metres

1:70000 @ A3

Project Path: G:/MODEL/PROJECTS/EA-210/22720/Figures/22720s16_Fig5.23.mxd

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Figure 5.23
Phases 2 and 3 Modelled Groundwater Drawdown under Drought Order Pumping Scenario

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As for Phases 1 and 4 the modelled hydrographs for the drought scenario indicate that groundwater levels are not able to recover in between periods of SGS abstraction. Modelled groundwater levels also do not recover to levels consistent with the dry simulation without SGS abstraction within the modelled recovery period (6 years). However, it is important to note that the drought scenario only requires abstraction to be increased to 113% of the 5 year licence limit for Phase 3 and therefore, the increase above the potential current full licensed situation will be much less.

The impact of the drought scenario on groundwater levels in the Phase 2 wellfield have been estimated using a simple approach based on distance drawdown relationships determined from previous pumping test data see Figure 5.23. The analysis calculates a drawdown for the wellfield following the drought period using the abstraction quantities for the 1976 drought at the end of the drought sequence. The data from this spreadsheet analysis indicate that drawdown in the centre of the wellfield will reach a maximum of approximately 20 m centred on the two SGS abstraction boreholes at The Knolls. Under this abstraction sequence, drawdown in the centre of the wellfield is increased in the order of 2 m compared to the 1995 operational contours (Figure 5.9).

Comparison of the modelled groundwater contours to the existing wellfield contours (generated from operational use) indicate that the area of aquifer affected by abstraction from the scheme will extend slightly further to the south towards the River Severn but is unlikely to extend to the west or north due to the geological structural controls on groundwater flow in this area, projected groundwater levels are shown on the hydrogeological cross sections in Figures 4.6 and 4.7. It should be noted that the spreadsheet model contains no representation of any interaction between the River Severn and groundwater which maybe occurring in this area and which may buffer the effects of abstraction. The extent of the wellfield to the northwest remains uncertain due to a lack of monitoring data in this area, however abstraction is largely focussed away from this area and it is considered unlikely that the effects of abstraction will extend beyond the originally mapped contours. Generally the predicted area of impact remains within the SGS Inner protection zone, except to the south of the wellfield where it remains largely within the SGS outer protection zone.

5.4.2 Hydrology

Phase 1 and 4 Wellfield

Previous sections (Section 5.3.2) have indicated that groundwater baseflow is an important factor in maintaining flows in the rivers of the Tern Catchment, particularly in the Tern itself, middle reaches of the Roden and the lower reaches of the Potford and Platt Brooks. The effects of pumping from Phase 4 of the scheme on the Potford and Platt Brooks have been recognised in the SGS licence which requires compensation releases to be made from dedicated stream compensation boreholes.

The effects of the drought scenario on surface water flows in the Phase 1 and 4 area have been modelled for the Tern catchment at the Walcot Gauging station and for the Potford/ Platt brook at Sandyford Bridge. It should be noted that the modelled simulations do not include surface water anthropogenic influences such as surface water abstractions and discharges, this means that they do not include the SGS discharges from Phases 1 and 4 or any compensation pumping that would be required to support flows in the Potford and Platt Brooks as a result of SGS abstraction.

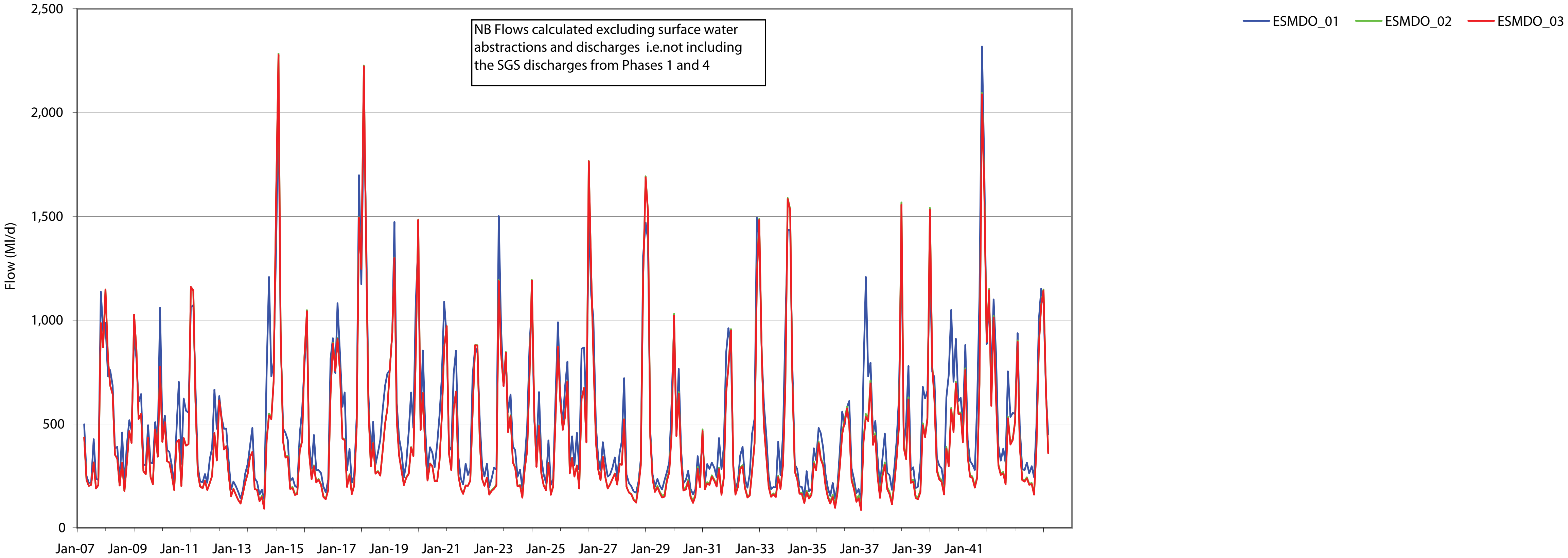
The total stream flows for the Tern at Walcot and the Potford/ Platt brooks at Sandyford Bridge are presented in Figure 5.24. For the Tern at Walcot, the impact on total flow is relatively small in the context of the total flows from the catchment (Q_{95} 191 Ml/d). The effect of the 'dry' climate on total flows can be seen more clearly than the effect of the SGS; flow in the river is maintained at all times. It is important to remember that whilst the scheme is in operation, the flows in the river will be augmented by the discharges from the Phase 1 and 4 outfalls which have not been included in the modelling. Previous investigations have calculated a net gain of between 87 and 89% (based on Phase 1 operational pumping in 1996) at the Walcot Gauge. As a result, overall flows in the main channel of the Tern will benefit from increased flows of approximately 81 Ml/d (43% of Q_{95}) when the scheme is abstracting at full licensed rates. This represents an increase of approximately 20% on average flows.

For the Potford/Platt Brooks the effects of both the dry climate and the SGS abstraction can be clearly seen. Total flows are reduced by approximately 25% by the dry climate, and a further 50% by the SGS abstraction in the severe drought period. Additionally, flows are reduced to zero on several occasions by the SGS abstraction scenario at the end of the modelled abstraction period. There are times when the 'dry' climate prediction results in higher winter flows than the baseline run; this is not unexpected as the scenario includes higher rainfall in the winter months than the normal climate.

For both rivers, although seen more clearly on the Potford/ Platt Brook figures, the impact from climate change alone is initially small, reflecting changes in runoff as a result of the dry climate prediction. However, as groundwater levels begin to fall, and are not able to recover between periods of pumping, the impact increases reflecting a reduction in baseflow.

The changes in baseflow from the modelled scenarios are presented in Table 5.9 and Figure 5.25. For the predictive scenario with a dry climate, the reduction in baseflow to the Tern Catchment at Walcot is approximately 20%. The impact from SGS abstraction is less than the impact of the dry climate; 2 months after abstraction ceases, an additional reduction in baseflow of 11% can be attributed to the SGS abstraction. After 24 months this has reduced to 6%. By the end of the simulated period, the water resource balance has recovered in the catchment such that the reduction in baseflow compared to the normal simulation is just 2%.

For the predictive simulation with a dry climate, the reduction in baseflow to the Potford/ Platt catchment at Sandyford Bridge is predicted to be about 1.5 Ml/d (about 50%). The SGS abstraction causes an additional large reduction in baseflows: 2 months after abstraction ceases, there is a nett flow of 1.6 Ml/d to the aquifer and after 24 months this has reduced to 0.6 Ml/d.



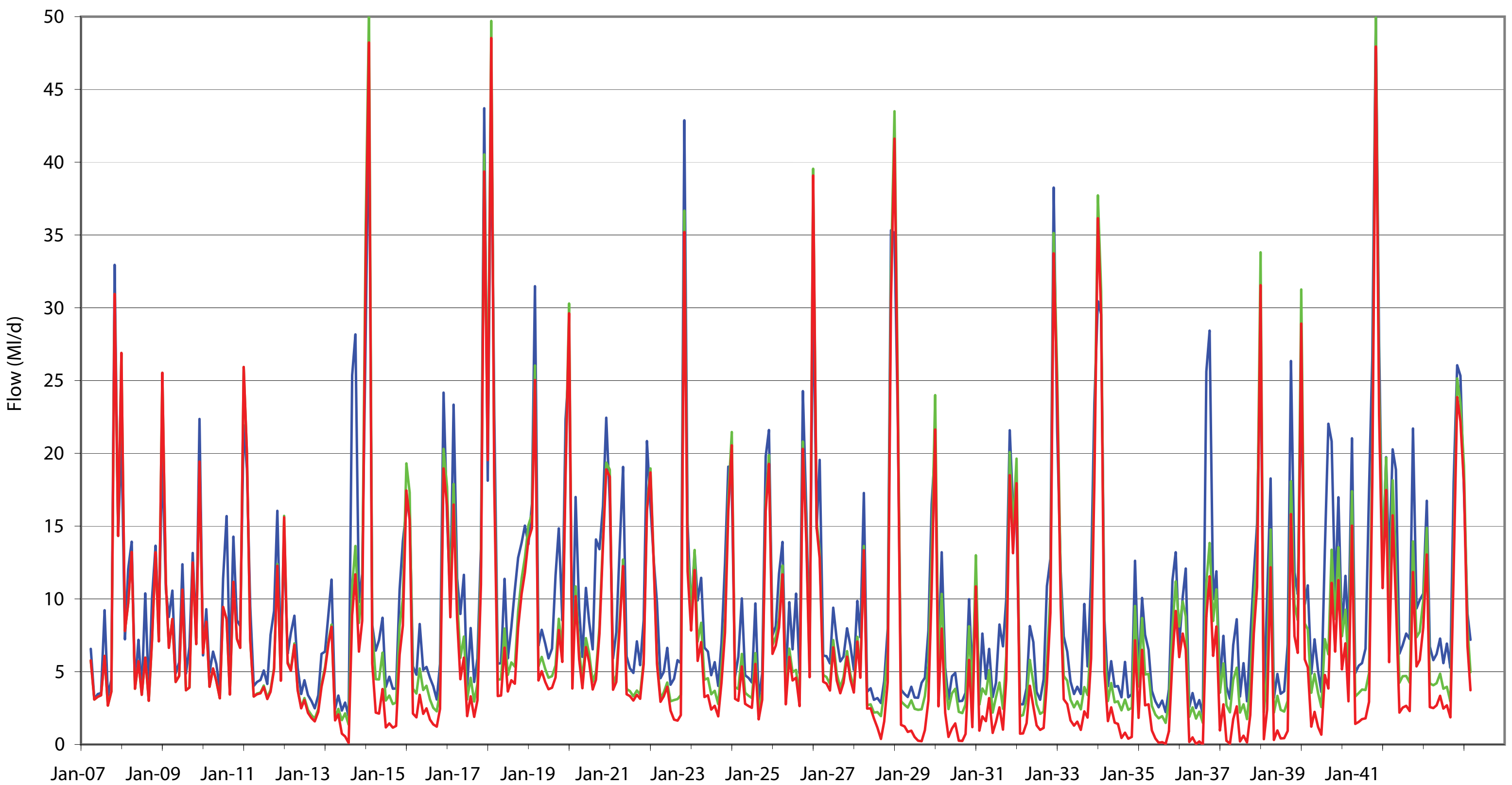


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Figure 5.24

Total modelled river flows Tern at Walcot and Potford & Platt Brook (Sandyford Bridge) (reproduced from ESI, 2009)

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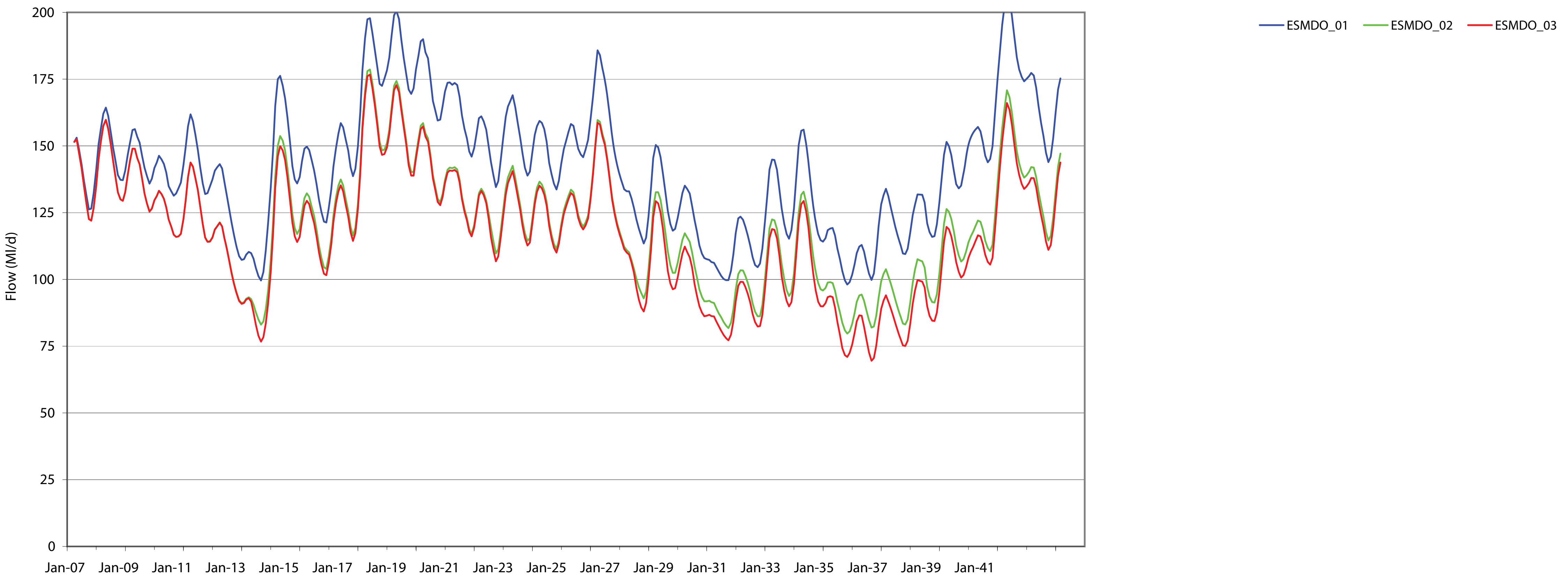

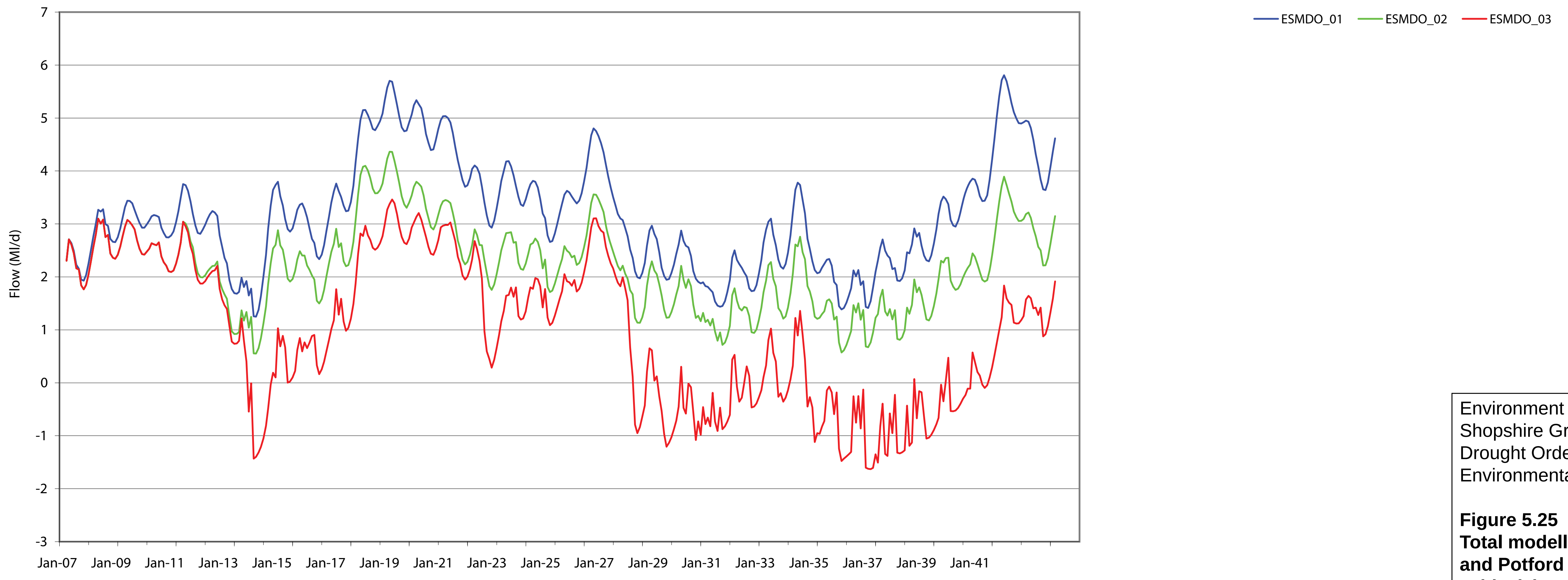

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Figure 5.25
Total modelled baseflow Tern at Walcot and Potford & Platt Brook (Sandyford Bridge) (reproduced from ESI, 2009)

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Although there are limitations to the groundwater modelling, described in Appendix B, it is clear from the results that the impacts on flows in the Potford/ Platt Brooks are likely to be large and may result in some reaches drying up during periods of low runoff, if groundwater levels are below the base of the streams. The areas where the SGS has most effect are the lower reaches of the Potford/ Platt Brook, which are gaining flow in the lower reaches for both the normal and dry climate predictive simulations without SGS. The predictive simulation with SGS abstractions indicates that the streams are losing flow over the entire stream length 2 months after abstraction ceases. 24 months after abstraction ceases, the lower parts of the Potford/ Platt Brooks have started to gain baseflow again, although much of the central part of the Brook is still losing flow. Figure 5.26 illustrates the modelled effects of abstraction on flows in the brooks from one of gaining flow from the aquifer to one losing flow to the aquifer.

These results must be put into context with the existing scheme operation which has acknowledged the effects of the SGS abstraction on the Potford/ Platt Brook. There are two dedicated stream compensation boreholes at Greenfields and Heath House No 2, which may be used to augment flows in the Potford/ Platt Brooks (not included in the model simulations). ESI calculated the compensation flows that may be required from these boreholes under the drought scenario. The calculated compensation flows reach a maximum of 17% of the 5 year licence for SGS Phase 1. This occurs in 2036, two years after the extreme drought of 2032-2034 indicating that mitigation for the drought scenario would require compensation flows outside the periods of operational pumping.

Table 5.9 Simulated Baseflows for the Tern at Walcot and the Potford/ Platt Brook at Sandyford Bridge

		Normal Climate Predictive Simulation	Dry Climate Predictive Simulation	Dry Climate Predictive Simulation with SGS Abstraction	
Time Step (months)	**Date**	**Tern at Walcot baseflow (Ml/d) (Percentage change from Normal Climate Predictive Simulation shown in Brackets)**			**Estimated Reduction in Baseflow due to SGS abs. (Ml/d)****
1	January 2007	151.5	151.5	151.5	0
332	November 2034	109.9	86.4 (-21%)	75.2 (-32%)	11.2 (-11%)
354	September 2036	117.7	93.5 (-21%)	86.3 (-27%)	7.2 (-6%)
408	March 2041	175.2	147.1 (-16%)	143.8 (-18%)	3.3 (-2%)
		Potford/Platt Brook at Sandyford Bridge Baseflow (Ml/d) (Percentage Change from Normal Climate Predictive Simulation shown in Brackets)			**Estimated Reduction in Baseflow due to SGS abs. (Ml/d)****
1	January 2007	2.31	2.30 (-0.3%)	2.30 (-0.3%)	0
332	November 2034	1.54	0.77 (-50%)	-1.63* (-206%)	2.4 (-155%)
354	September 2036	2.40	1.43 (-40%)	-0.65* (-127%)	2.1 (-87%)
408	March 2041	4.62	3.15 (-32%)	1.92 (-58%)	1.2 (-27%)

*net flow from stream to aquifer
**Numbers in brackets are the percentage of the baseflow of the Normal climate predictive simulation

To further put in to context the predicted effects of the drought scenario on the hydrology of the Tern catchment, a comparison has been undertaken of historic actual flows from 1976 compared to the modelled flows for the ESM peak demand year 2034 (simulating 1997/1976 under dry climate change scenario). This comparison has been undertaken for each of the Phase 1 and 4 discharge points as Stoke on Tern, Bolas Bridge and Waters Upton. The results are presented in Table 5.10. For comparison the table also includes historic actual summer flow ranges for the recent 2011 dry summer.

The SGS model scenario predicted flows in the River Tern at each of the Phase 1&4 discharge points at Stoke on Tern, Bolas Bridge and Waters Upton would be in the range of 15 to 19% lower than those actually observed in the drought of 1976 (i.e. a more extreme event). The calculations indicate that under drought conditions the augmented stretches of watercourse will be in more favourable flow condition than surrounding water courses and that the augmented river flows projected under the drought scenario would boost river flows to within the lower range of the normal historic actual summer flow ranges.

Table 5.10 Historic and Modelled River Flows

	Observation of Historic Actual River Flows 1975 to 2011			Effect of SGS Discharge - Projected Augmented River Flows Under Drought Scenario			
	1976 Summer Flow	Normal Summer Flow Range (excluding Extreme Wet Summers Flow Ranges)	2011 Summer Flow	SGS Gross Discharge	SGS net Discharge (88% Nett Gain)	Drought Scenario Modelled River flow Minimum Before SGS Input	Augmented River Flow with Cumulative 88% Net Gain SGS Discharge Input
RIVER TERN	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d	Ml/d
River Tern at Stoke on Tern (SGS Phase 1&4 Stoke on Tern discharge)	31 to 63Ml/d	~45 to ~65Ml/d	35 to 38Ml/d	27	24	25	49
River Tern at Eaton on Tern (SGS Phase 1&4 Stoke on Tern + Bolas Bridge discharge)	38 to 94Ml/d	~60 to ~90Ml/d	39 to 46Ml/d	7	6	32	62
River Tern at Walcott (SGS Phase 1&4 total discharge)	106 to 378Ml/d	~200 to ~300Ml/d	147 to 170Ml/d	93	82	87	199
POTFORD&PLATT BROOKS							
Pot& Platt Brook at Sandyford Bridge (SGS Phase 1 stream compensation discharge Heath House No2 & Greenfields)	1.9 to 11.9Ml/d	~2.5 to ~6Ml/d	2.4 to 3.0Ml/d	3	3	1	3
RIVER PERRY							
River Perry at Yeaton (SGS Phase 2 discharge Adcote & Grafton)	18 to 89Ml/d	~30 to ~60Ml/d	22 to 28Ml/d	10	9	18	27
RIVER SEVERN							
River Severn at Montford (SGS Phase 2 discharge Forton)	415 to 1305Ml/d	~600 to ~2000Ml/d	950 to 1737Ml/d	40	35	415	450
River Severn at Leaton (estim from Montford + Perry Flows) (SGS Phase 2 & Phase 3 discharge)	433 to 1394Ml/d	~630 to ~2060Ml/d	977 to 1766Ml/d	50	44	433	512

Phase 2 and 3 Wellfield

Previous sections have indicated that in contrast to the high sensitivity and connectivity of the stream and groundwater systems in Phase 1 and 4, groundwater-surface water interaction within the Phase 2 and 3 wellfield is limited and the baseflow contribution from the sandstone to streams and rivers is generally not considered to be an important flow mechanism. The exceptions to this are the River Severn, which is considered to act as the main drain for groundwater discharge from the Permo-Triassic Sandstone aquifer, and on a smaller scale the lower reaches of the Astley Brook and the Bagley Brook which lie at the extremities of the wellfield. Streamflow support from groundwater interception, storage and discharge from perched drift aquifers probably plays a more significant part to maintaining surface water flows, particularly in Phase 2, where the drift is more heterogeneous, supporting localised spring flow points into the River Perry.

Application of the extended ESM model in a separate 2008 study looked at the impacts of full licence usage of Phase 2 (attributed only 10% as Phase 2 remains just outside the model boundary), Phase 3 and Phase 5 on surface flows in the River Severn. Modelling predicted that in the short term 90% of the SGS abstraction comes from changes in aquifer storage with up to 10% reduction in groundwater flow to rivers. As consequence nett gains to augmented river flows were assessed as being high in the range 85 to 99%. Over the long term 85% of the SGS abstraction would be provided by a declining reduction in river flows and 15% by a change in storage (long term average reduction in groundwater levels). As the SGS drought scenario looks to exceed full licence in these Phases by between 1 to 17%, it is therefore reasonable to assume that the drought order effects will have a similar magnitude of effect on baseflow and therefore total flow to the River Severn.

In the absence of model outputs, a comparison has been undertaken using minimum historic actual flows from 1976 as a benchmark against which to compare the predicted flow impacts. This comparison has been undertaken at locations representing each of the Phase 2 and 3 discharge points. The results are presented in Table 5.10. For comparison the table also includes historic actual summer flow ranges for the recent 2011 dry summer.

In Phase 2, two of the abstraction boreholes discharge to the River Perry. Based on the observed minimum flow at the Yeaton Gauge the effect of the discharge should increase drought river low flow by approximately 42%. The River Perry is not considered to be reliant upon head-dependant interaction with the Permo-Triassic Sandstone aquifer. Other than a natural reduction in recharge to drift aquifers, no impact would be expected from SGS abstractions as the river is not dependant upon baseflow from the sandstone. Further downstream, the effects of the Phase 2b input to the River Severn, assessed at the Montford Gauge, indicates an increase in total river flow of approximately 8% due to augmentation. An estimation of the flows in the River Severn at Leaton, suggests an increase in river flow of approximately 20% due to the combined augmentation effects of Phase 2 and 3 discharges.

Although the impacts from the drought scenario on flows in Phases 2 and 3 cannot be directly quantified in the current assessment, the results for the more sensitive Tern catchment indicate a reduction in total flows (before SGS discharge) of between 15 and 19% below the 1976 observed minima. The SGS drought scenario would be expected to have less of an effect in the Phase 2 and 3 catchments and therefore the calculations indicate that under drought conditions the augmented stretches of watercourse will be in more favourable flow conditions than surrounding watercourses.

However, it should be noted that, as for Phases 1 and 4, the dry climate may have more of an impact than the SGS abstraction on river flows. Under drought conditions those stretches of the river that are supported by Drift aquifers will experience reduced recharge which will have a subsequent effect on the flows released into the rivers.

5.4.3 Soil Moisture

As described in Section 3.1.4, to quantify the risk posed by the extent and magnitude of drawdown influence within each phase wellfield, the total area underlain by each vulnerability class has been calculated using both observed and modelled drawdown footprints. This will allow comparison between the extent of influence generated under historic actual with that predicted by modelling the extended pumping footprint required to meet the extreme drought conditions envisaged under this order.

Phase 1 and 4 Wellfield

Within the footprint of the modelled drought scenario pumping Table 5.11 provides the break down of areas underlain by each of the vulnerability classes for Phase 1 and 4.

Table 5.11 Phase 1 and 4 Analysis of Area underlain by Vulnerability Classes within 100 km^2 Predicted Drought Scenario Wellfield Footprint (101 km^2)

Vulnerability Class	Area (Km^2)	Percentage (%)	Drift Categories	Area (Km^2)	Percentage (%)
			High permeability	6.15	6.09
			Moderate permeability	0	0.00
CLASS 1 - possible effect on shallow rooting crops	13.62	13.49	Low permeability	7.46	7.39
			High permeability	2.76	2.73
			Moderate permeability	0	0.00
CLASS 2 - possible effect on deep rooting crops	6.29	6.23	Low permeability	3.53	3.50
			High permeability	5.54	5.49
			Moderate permeability	0	0.00
CLASS 3 - possible effect on trees only	12.2	12.08	Low permeability	6.66	6.60
			High permeability	45.95	45.51
			Moderate permeability	0	0.00
CLASS 4 - No effect on crops or trees	68.85	68.20	Low permeability	22.9	22.68

Through the reapplication of the soil moisture vulnerability mapping technique it can be seen that, under the modelled drought scenario, the conclusions of the original mapping remain largely unchanged. Compared to the original analysis the proportion of the area underlain by Class 1 vulnerability has increased slightly, this is due to the extension of the wellfield footprint to the south towards the River Tern and west to the Roden. However, a significant proportion representing 80% or 81km^2 of the area affected by abstraction from Phases 1 & 4, is underlain by water tables that lie beyond the reach of agricultural crops. The remaining 20% of the projected Phase 1&4 wellfield area falls within Class 1 and Class 2 vulnerability zones. Due to the presence of intervening low permeability drift within these classes the over all risk is reduced to 8%, or 8 km^2 of land underlain by highly permeable drift over shallow groundwater within 2.5m of ground level.

As these figures represent the sum of a number of smaller isolated pockets of land falling within potential sensitivity categories, it is considered that operational pumping from Phase 1 and 4 under the drought scenario presents a negligible risk to soil moisture vulnerability within the influence of the Tern catchment. Therefore there is no evidence to support the expansion of the current soil moisture monitoring network under the drought scenario.

Phase 2 and 3 Wellfield

Table 5.12 Phase 2 and 3 Analysis of Area Underlain by Vulnerability Classes within Drought Order Predicted Wellfield Footprint (138.3 km^2)

Vulnerability Class	Area (Km^2)	Percentage (%)	Drift Categories	Area (Km^2)	Percentage (%)
			High permeability	1.6	1.1
			Moderate permeability	1.9	1.3
CLASS 1 - possible effect on shallow rooting crops	10.2	7.3	Low permeability	6.7	4.8
			High permeability	0.4	0.3
			Moderate permeability	0.3	0.2
CLASS 2 - possible effect on deep rooting crops only	2.6	1.9	Low permeability	2.0	1.4
			High permeability	0.4	0.3
			Moderate permeability	0.3	0.2
CLASS 3 - possible effect on trees only	3.1	2.2	Low permeability	2.3	1.7
			High permeability	18.9	13.7
			Moderate permeability	6.0	4.3
CLASS 4 - No effect on crops or trees	122.5	88.5	Low permeability	97.6	70.5

In the reapplication of the soil moisture vulnerability mapping technique the wellfields for Phases 2 and 3 have been analysed together. Phase 2 & 3 areas of the Shropshire Groundwater Scheme sit within a catchment characterised by very deep groundwater that is not accessible to agricultural crops, trees and other vegetation rooting zones. The conclusions of the original mapping remain unchanged. The projection shows that 91% (125 km^2) of land influenced by the projected pumping is underlain by water tables that lie beyond the reach of agricultural crops. Of the remaining 9% within class 1 and 2, only 1% or 2 km^2 falls within land underlain by highly permeable drift over shallow groundwater within 2.5m of ground level.

It is considered that the proposed drought scenario operational pumping from Phase 2 & 3 does not present any quantifiable risk to soil moisture vulnerability. As a consequence there is no evidence to support the introduction of soil moisture monitoring to these Phase areas under the drought scenario.

5.4.4 Effects of the Operation of the Scheme on Groundwater Abstractors

Under the drought scenario considered here the magnitude and extent of drawdown likely to be encountered within the operational wellfields will be greater than that historically recorded. Further more groundwater levels will be lower than that historically observed due to the in-combination effects of; the natural recession brought on by underlying reduced recharge to the aquifer, and the volume of water removed from the aquifer due to abstraction by the scheme to meet the drought order scenario.

Under these extreme conditions additional stress may be placed on less resilient private sources. Small volume domestic sources, drilled to a shallower depth within the aquifer, or having pumps set a shallower level within the borehole, may therefore be more sensitive to pumping operations. The likelihood of potential or actual derogation may therefore increase within this risk category.

Larger volume commercial sources, such as public water supply and spray irrigation boreholes, tend to be drilled at greater depths and therefore have deeper set pumps. These sources are more resilient and therefore less sensitive to groundwater level fluctuations and therefore considered to be at lower risk of derogation.

5.5 Predicted Impacts

Previous studies have described that the effects of operation of the SGS are variable both spatially and temporarily. The geological and hydrogeological setting of the Phase 1 and 4 wellfields, in the Tern catchment, is such that there is good hydraulic connection between the groundwater and surface water systems, with relatively shallow groundwater levels present across some of the catchment. In this catchment baseflow from the sandstone provides an important mechanism for maintaining river flows, although there are areas where the intervening drift reduces this dependency on sandstone water levels.

In direct contrast to the Tern catchment the Phase 2 & 3 wellfields are predominantly underlain by deep groundwater and stream flow support from the sandstone is not considered to be an important mechanism to maintaining flows. Over a significant proportion of the wellfield area groundwater levels are in excess of 10 to 15 mbgl, with a mean depth range of between 10 to 30 mbgl. The area is underlain by significant drift deposits and given the thickness and complexity of the drift, stream flow support from perched drift aquifers is considered to play a more significant role.

Modelling studies using the ESM groundwater model, focussing predominantly on the more sensitive Phases 1 & 4 of the SGS scheme, have indicated that in the short term, approximately 90% of the SGS abstraction is met by water taken from storage within the aquifer, manifesting as a change in groundwater level, while 10% comes from reduced baseflow to rivers. This is the reason for the high calculated net gain figures for flow augmentation. It is also the reason why the Permo-Triassic Sandstone provides a good source of supply for large strategic groundwater development schemes.

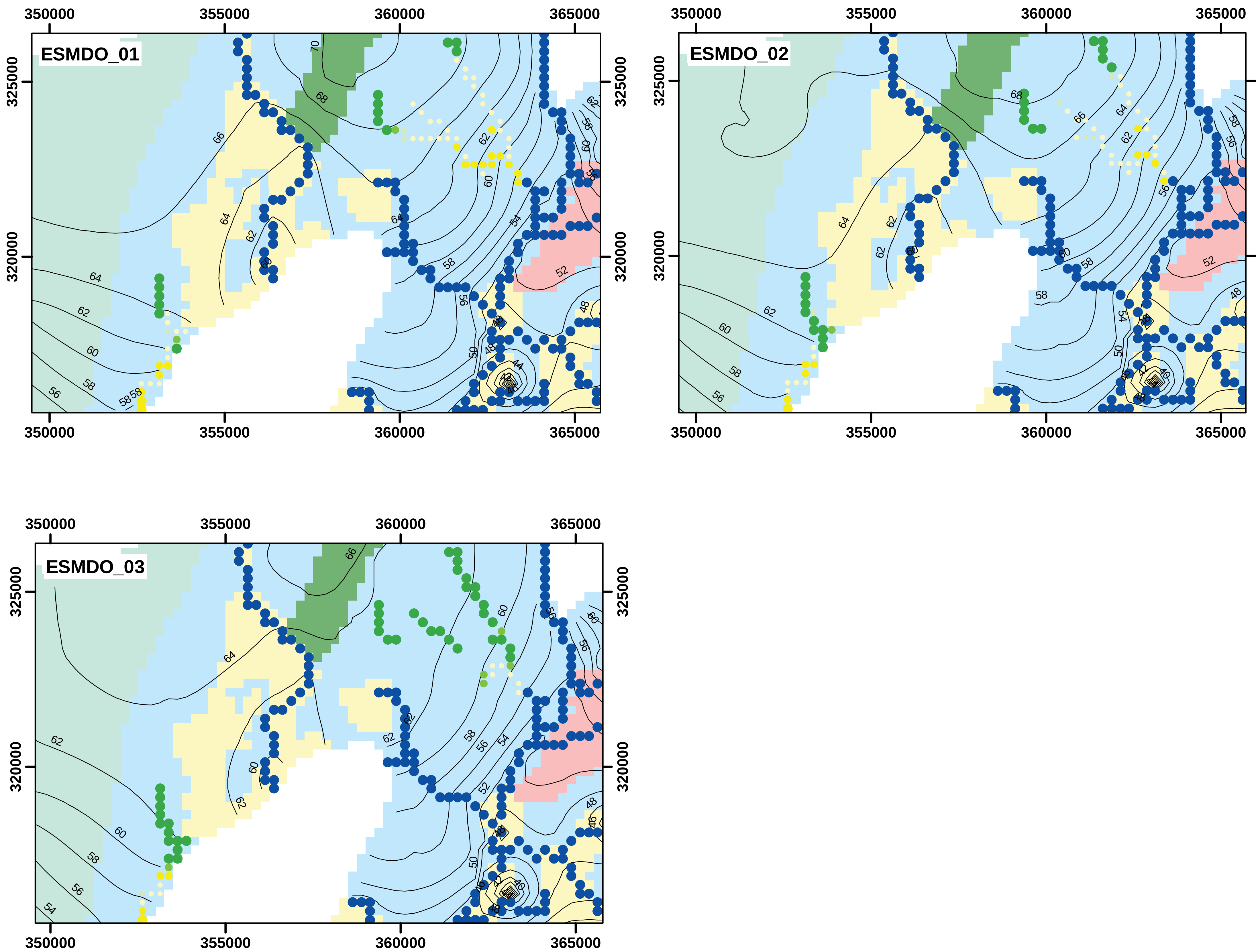
In the long term, the effects of operation of the scheme are apparent largely in the form of 85% impact on baseflow and a 15% change in groundwater heads. The impact diminishes exponentially with time as recharge replenishes pumped storage and groundwater levels recover.

Current expected use of the scheme is for it to be operated in two out of every five years, allowing a period of recovery between operational periods (also reflected by the 5 year rolling licence total). Use of the scheme to date has followed this expectation and monitoring data indicates that groundwater levels have recovered to pre-pumping levels between operational periods. However, the drought order scenario does not allow for the recovery of groundwater levels between operational periods of the scheme. Predicted groundwater level drawdowns are in the region of 11 m in the Phase 1 and 4 areas, reducing to approximately 5 m 24 months following abstraction cessation and approximately 6 m in the Phase 2 and 3 area, reducing to 2.5 m 24 months after cessation of abstraction. Comparison of the extent of the wellfields produced by the drought scenario does not suggest that these will be significantly extended beyond their current extend, and will remain within the SGS outer protection zone.

The significance of the predicted impacts on the environment must also be considered, reduced groundwater levels in the less sensitive Phases 2 and 3 is unlikely to have a direct impact on the environment because of the isolation of the sandstone from the near surface system. In Phases 1 and 4 direct impacts are more likely however, outside the effects on designated sites which will be addressed in a separate chapter, the main impact will be the resultant reduced baseflow to steams and rivers, and subsequent effects on water quality and ecology, which is discussed below and in subsequent chapters.

The extended use of the scheme results in an extended recovery in groundwater level and a resultant deficit in baseflow after the final SGS abstraction period (which represents severe drought conditions) of approximately 11% in the Tern catchment from which the aquifer does not make a full recovery by the end of the modelled time period 6 years later (6%). It is estimated that full recovery might take another six years.

To illustrate this point the recovery response of the aquifer to the balance of groundwater abstraction by SGS (nett out put) and the ability of recharge (net input) to replenish the pumped groundwater volume is graphically represented in Figure 5.27 as a deviation in the storage change line from the zero mid point of the graph. The graph shows that low frequency use (model period 2013 to 2025) of SGS allows sufficient time for full aquifer recovery. This replicates the observed response of the aquifer to historic actual use. The high frequency use (model period 2030 to 2034) envisaged under the extreme drought scenario does not allow for full aquifer recovery by the end of the modelled time period six years later.



Legend

River gaining and losing reaches (Ml/d/cell)

- 0.5 to 1.0
- 0.1 to 0.5
- 0 to 0.1
- -0.05 to 0
- -0.1 to -0.05
- -0.25 to -0.1

Stream gaining and losing reaches (Ml/d/cell)

- 0.5 to 0.25
- 0.1 to 0.25
- 0 to 0.1
- -0.01 to 0
- -0.025 to -0.01
- -0.05 to -0.025

- Water table contours
- Layer 1, Active Drift, Kv = 0.005
- Layer 1, Active Drift, Kv = 0.01
- Layer 2, Bridgnorth (Kinnerton)
- Layer 2, Kidderminster/Wildmoor/Bromsgrove (over Bridgnorth)
- Layer 2, Wilmslow/Chester Pebble Beds/Kinnerton

Positive flows indicate surface water gaining flow from the aquifer

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Figure 5.26
Modelled Phase 1 & 4 Wellfield Impact on Gaining and Losing Reaches for River and Stream Flows in the River Tern Catchment

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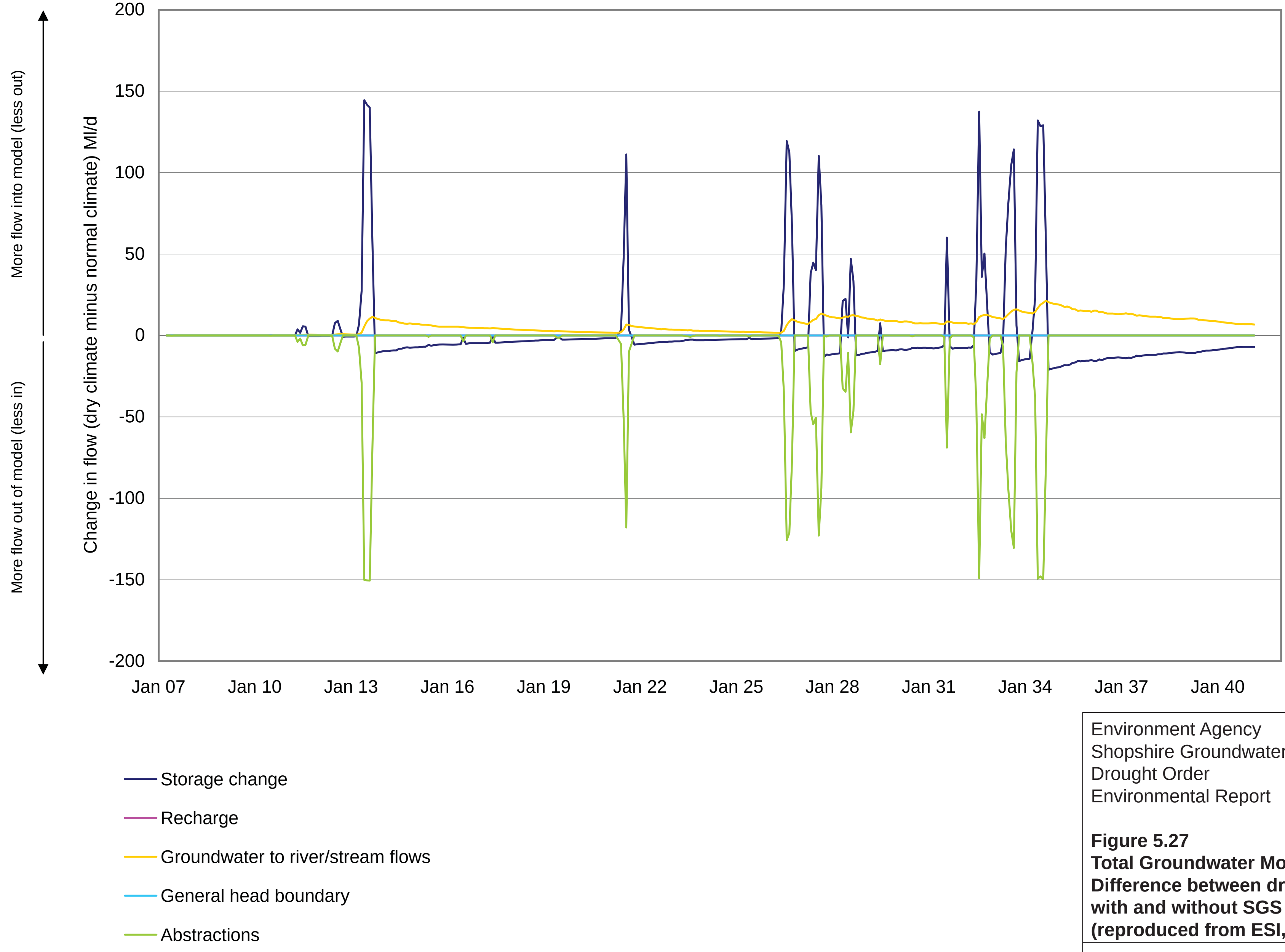


Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 5.27
Total Groundwater Model Balance
Difference between dry climate model runs with and without SGS operation (reproduced from ESI, 2009)

June 2012
22720-S29.ai barkr

amec

The predicted impacts of SGS abstraction on flows in the Potford/ Platt Brooks are substantial and may result in some reaches drying up during periods of low runoff, if groundwater levels are below the base of the streams (Figure 5.26). The effect of the scheme on these watercourses is known and dedicated compensation boreholes have been installed. Calculated compensation flow suggests that support will not only be required during pumping, but for substantive intermittent periods during recovery period when runoff is unable to maintain stream total flows less than Q95. Support may therefore be required for a number of summers after the extreme event while groundwater levels recover via long term recharge.

However, it is important to note that the drought scenario only requires abstraction to be increased to 109% and 101% of the 5 year licence limit for Phases 1 and 4 respectively and therefore, the increase above the potential current full licensed situation will be much less. Additionally the effects of the SGS abstraction on the baseflow is less than the effects of the dry climate scenario alone. Addition of the SGS discharges to the flows, and comparison with 1976 minimum flows, underlines the fact that the SGS modelled scenario is a more extreme event culminating in a 15 to 19% reduction in river flows for the River Tern than that observed in 1976. However, the augmented flows for each watercourse are within the lower end of the normal flow range for each location.

Additionally, excluding the River Severn, approximately 41km of tributary carrier rivers and streams will benefit from artificially enhanced SGS augmented flows, boosting flows by between 42 to 100%. Under drought conditions these stretches of watercourse will be in more favourable flow condition than surrounding water courses which will be experiencing low flow conditions.

Reapplication of the soil moisture vulnerability mapping methodology has indicated that the risk to soil moisture is not significantly increased by the drought scenario.

5.6 Mitigation and Monitoring

The Agency currently maintains a comprehensive environmental monitoring network centred on the operational phases of the scheme. This network is geared to provide background monitoring data on groundwater levels, soil moisture levels in the unsaturated zone, surface water flows, water quality analysis and aquatic ecology.

Of the impacts identified above it is considered that management of the reduced flows on the Potford and Platt Brooks and the lower reaches of the Astley Brook and Sunderton Pool (see section 7.4 and 7.5) and the potential effects of groundwater level derogation on existing groundwater abstractors will require mitigation actions.

Where it is anticipated that the scheme will also be operated the following year, the existing monitoring network should be reviewed, and enhanced if necessary. The status of the resource balance should be and to identify appropriate strategies for its management to optimise use of the scheme, and minimise its cumulative impact.

It is worth emphasising that the drought scenario modelled here is a very extreme event and as such will have a low frequency of return. This should allow sufficient time to balance the management of SGS during this initial aquifer recovery phase. Subject to the conditions following the high frequency use of SGS a greater emphasis should be placed upon the reliance on surface water storage components of the River Severn Regulation system (Clywedog and Vyrnwy Water Bank) to allow time for the aquifer storage to recover.

Potford and Platt Brooks

Mitigation measures are in place for the Potford and Platt Brooks in the form of two dedicated compensation boreholes which must be utilised when Phase 4 of the Scheme is operated. The onset of drought conditions, as described by the drought scenario, requires significant quantities of compensation flow to be discharged to the watercourses both during operation of the scheme and during the recovery phase. Use of the compensation boreholes outside normal operation of the scheme will require additional monitoring to be undertaken on the brooks, to ensure that sufficient flow is being maintained in the river. It will also require a review of the existing groundwater levels monitoring network, identification of suitable observation boreholes to instrument with continuous water level monitoring (if not already existing) and identification of suitable spot flow locations to assess the ongoing efficiency of the augmentation.

Additional use of the compensation boreholes outside the normal periods of operational use of the scheme should also be carefully managed to ensure abstraction is maintained within licensed quantities. Further assessment work is required to refine the flow targets which trigger the need to make compensation releases to the streams. The current target of Q95 is too conservative and should be replaced by more site specific hydro-ecological flow criteria.

Astley Brook and Sunderton Pool

Mitigation measures for this stream and pool system have already been planned and provided in the form of a dedicated compensation borehole at Hadnall No2. This is designed to compensate for the predicted effects of the, as yet, un-commissioned Phase 5 area. The system sits on the projected marginal edge of influence for Phase 3 abstraction effects under drought conditions and therefore the Phase 5 compensation borehole could be used to mitigate for the effects of Phase 3's abstraction.

As Phase 5 has not yet been commissioned compensation operating rules for the stream have not yet been devised. Assessment work is required to define flow targets which govern the need to make compensation releases as no such triggers currently exist for this system. In the absence of a permanent flow gauging structure on the stream, suitable spot flow locations and or continuous water level monitoring on the pool need to be identified to assess the ongoing efficiency of any compensation releases. Again these operating rules should based around an understanding of the hydro-ecological needs and benefits of the system to ensure that it isn't under or over compensated for.

Groundwater Abstractors

The on set of drought conditions and more frequent operational use of the Scheme should trigger the need to carry out more frequent periodic reviews of the spatial and temporal derogation risk posed to private groundwater supply sources.

The register of private sources should reviewed, maintained and periodically updated to retain a good working knowledge of the presence and existence of groundwater users within each of the wellfields.

Groundwater levels and trends should be monitored, both under non-operational and operational conditions, via the established groundwater network. The need to intensify focus on the likelihood of derogation risk should be triggered when groundwater levels begin to approach or fall beyond historic low levels.

The register of sources and groundwater level data should be used to predict sources at likely risk of derogation through the extended operation of the scheme. Wherever practicable, derogation risk should be identified before the impact is actually realised to avoid the need to implement emergency temporary supplies.

Any projected or known derogation attributed to the Scheme should be mitigated for through the application of permanent alternative remedial solutions available under the model terms and conditions agreement.

5.7 Summary and Conclusions

The Permo-Triassic Sandstone in which SGS has been developed, is one of the most important principal aquifers in the United Kingdom, second only to the Chalk. Despite its much smaller outcrop, the sandstone’s properties means that it has an excellent capacity to store and slowly discharge large volumes of groundwater, making it the biggest strategic store of potable water in the UK. These properties favour its use for large scale strategic resource development, as the effects of seasonal abstraction and recharge patterns are more evenly distributed over longer periods within the environment.

Much of the Permo-Triassic Sandstone aquifer in the area of interest is covered by complex drift with significant vertical, lateral and lithological variation, giving rise to both confined and unconfined conditions across the aquifer. This combined with a variable depth to groundwater means that environmental sensitivity also varies spatially across the scheme.

The hydrogeological setting of the Phase 1 and 4 wellfields, is such that there is good interaction between the groundwater and surface water systems, with relatively shallow groundwater levels present across much of the catchment. This catchment is recognised as being more sensitive to the effects of pumping with stream compensation measures for the Potford and Platt Brooks and soil moisture monitoring already in place as part of the normal operating regime for SGS. The extensive drought pumping will culminate in more extended use of these stream compensation schemes.

In direct contrast, the hydrogeology of the Phase 2 & 3 wellfields are predominantly underlain by deep groundwater. Other than the River Severn itself and the lower reaches of the Sundorne Brook and Bagley Brook, on the whole support from the sandstone is not considered to be an important mechanism to maintain stream flows. These phase areas are therefore considered to be less sensitive to the effects of pumping.

The effects of groundwater abstraction by SGS in the short term are supported by taking groundwater stored in the aquifer. In the medium term this will be at the expense of a reduction in the proportion of groundwater supporting stream and river flows. Given the intermittent operational nature of the scheme over the long term this impact will diminish as recharge naturally replaces the water pumped out by the scheme and therefore replenishes groundwater levels.

Under normal demand conditions SGS was designed to be operated in two out of every five years, allowing a period of recovery between operational periods. Monitoring indicates that groundwater levels have recovered to pre-pumping levels between historic operational periods. This indicates that SGS is operating in equilibrium with the groundwater resource balance when used within its licence limits.

The magnitude of pumping sought under the drought conditions will however be greater than that observed to date, as will the impact on groundwater levels in the aquifer. The drought order scenario does not allow for the recovery of groundwater levels between the three year back to back operational periods. The consequence of this being that impacts on stream and river flows will be greater as the recovery period for aquifer recharge may be in excess of 6 years.

Excluding the River Severn, approximately 41km of tributary carrier rivers and streams will benefit from artificially enhanced SGS augmented flows. Under drought conditions these augmented stretches of watercourse will be in a more favourable flow condition than surrounding water courses which will be experiencing low flow stress conditions.

Under the extended use of SGS additional stress may be placed on less resilient private water supply sources. Small volume domestic sources, drilled to a shallower depth within the aquifer will be more sensitive to pumping operations. Larger volume commercial sources, such as public water supply and spray irrigation boreholes, tend to be more resilient and therefore less sensitive to groundwater level fluctuations. Wherever practicable, derogation risk should identified before the impact is actually realised to avoid the need to implement emergency temporary supplies. Any projected or known derogation attributed to the Scheme should be mitigated for through the application of permanent alternative remedial solutions available under the model terms and conditions agreement.

6. Groundwater and Surface Water Quality

6.1 Introduction

The aim of this Groundwater and Surface Water Quality section is to characterise the current quality of the groundwater and surface water bodies, any effect of augmenting river flow with groundwater and the predicted effect of pumping groundwater beyond the current licence constraints.

6.2 Data Availability and Assessment

6.2.1 Source of Data and Water Quality Standards

The Environment Agency provided water quality data for its surface- and groundwater quality monitoring points contained within its SGS Water Quality Database. This data has been downloaded from the EA's Water Information Management System (WIMS). The EA provided adopted Environmental Quality Standards (EQS) in 2009 that were derived from the Water Framework Directive for use in the comparison of water quality at all sampling points in this study. These water quality standards are detailed in Appendix C.

6.2.2 Monitoring Points

The database contained water quality data for 6 types of monitoring point as follows:

1. Wellheads – a groundwater sampling point for an individual augmentation borehole prior to blending with groundwater from other wellheads;

2. Outfall – a groundwater sampling point at the point of entry into the river and following blending with groundwater from other wellheads;

3. Upstream monitoring point – a surface water monitoring point in the river just upstream of the outfall into the river;

4. Downstream river monitoring point – a surface water monitoring point in the river just downstream of the outfall into the river;

5. Extreme upstream monitoring point – a surface water monitoring point in the river upstream of the upstream monitoring point; and

6. Extreme downstream monitoring point – a surface water monitoring point in the river downstream of the downstream monitoring point.

Monitoring points were divided into Shropshire Groundwater Scheme Phases (1 to 4) according to the designations contained within the SGS Water Quality Database. GIS was used to check the coordinates supplied by the EA and to undertake the arrangement of the monitoring points into groupings. Monitoring points were then divided into one or more groupings based upon the following arrangement: Upstream monitoring point > Outfall > Downstream monitoring point (Appendix D), which will be referred to as a *monitoring point triplet*.

Table 6.1 Groups of Outfalls and Wellheads in Phases 1-4 used for Groundwater Quality Section

Group	Outfall Group	Wellheads	Phase	Triplet	Receiving Water Body
1	Adcote	Frankbrook	2	✓	Perry
2	Grafton	Grafton	2	✓	Perry
3	Forton	Bank House, Ensdon, Forton, Forton Heath, Knolls No 1, Knolls No 2, Rodefern, Nib Heath.	2	×	Severn
4	Leaton	Albrighton, Great Wollascott, Newton, Preston Gubbals, Merrington Lane, Pim Hill, Plex, Shawell Cottage, Smethcote	3	✓	Severn
5	Waters Upton	Ellerdine Heath, Green Lane, Heath House No 1, Hopton, Lodgebank No 1, Lodgebank No 2, Ellerdine Station, High Hatton No 1, High Hatton No 2, Windy Oak, Woodmill	1, 4	✓	Tern
6	Childs Ercall	(stand-alone wellhead)	1	×	Allford Brook
7	Great Bolas	(stand-alone wellhead)	4	×	Tern
8	Stoke on Tern	Hodnet No 1, Cotton Farm, Espley No 1, Espley No 2, Hodnet No 2	4	✓	Tern
9	Helshaw Grange	(stand-alone wellhead)	1	×	Tern
10	Greenfields	(stand-alone wellhead)	1	×	Potford Brook
11	Heath House No 2	(stand-alone wellhead)	1	×	Platt Brook

Where a single wellhead discharged to the river channel without blending and without the need for an additional outfall monitoring point, only a wellhead sample was taken. For the purposes of this analysis, some monitoring points were linked to more than one monitoring point group. For example, the Longdon on Tern Bridge monitoring point was made an extreme downstream monitoring point for monitoring point Groups 5,6,7,8,9,10 and 11, which are all located upstream in the River Tern catchment.

6.2.3 Selection of Chemical Determinands

The water quality data was initially inspected to determine which determinands had been analysed for, how many individual analysis results there were for each determinand and which determinands had exceeded either the WFD EQS or Freshwater Fish Directive water quality standards. Determinands were selected for investigation in this study based on the following criteria:

- Inorganic; it was not from a synthetic source as would be the case for pesticides or chlorinated solvents, neither was it a pollutant derived from mineral oil, but the determinand was associated with the aquifer and possibly affected by the pumping of groundwater;
- Redox sensitive and potentially able to reduce the dissolved oxygen content of the receiving surface water, for example iron and manganese;
- A nutrient likely to affect algal growth in freshwater systems, for example, nitrate, ammonia and phosphate; and
- The determinand also exceeded one of the water quality standards.

Organic determinands were not examined in this analysis because these generally represent synthetic or anthropogenic chemicals that are not uniquely found in groundwater compared to surface water. Where significant contamination of the groundwater in an SGS borehole catchment has occurred (e.g. Helshaw Grange), these abstractions have not been used for augmentation. Therefore, organic determinands have not been analysed as part of this investigation.

A list of determinands selected for time series investigation is given in Appendix E.

6.2.4 Data Quality and Availability

The water quality data that was used was quality controlled simply by searching for duplicate samples and duplicate analyses, and then excluding any duplicates that were found. These results represent records with identical sampling point/ date/ time and sampling point/ date/ time/ determinand/ value combinations. All zero values (rather than values reported to a specified level of precision), null data entries and 'greater than' (with a '>' qualifier) entries were excluded from the investigation because these represent either erroneous or low confidence data.

Data was used where it was available and where monitoring point groups allowed an upstream > outfall > downstream assessment, as described in Section 6.1.2. In some instances, data were incomplete, being entirely absent from one or more of these monitoring points, and occasionally being absent from a period of pumping altogether.

Another data availability issue was the length of time series. Groundwater outfall and wellhead waters were frequently only analysed during periods of augmentation pumping, making the determination of baseline groundwater concentrations and the effects of pumping duration very difficult to establish. Such episodic sampling also occasionally occurred in upstream and downstream river monitoring points.

For some determinands, the level of detection has changed through time, as laboratory methods have improved. This results in a series of steps in the time series plots. Time intervals characterised by this pattern could not be used to evaluate the effects of pumping.

6.2.5 Pumping Duration – Concentration Relationships

The presence of any linear relationships between concentrations of the selected determinands and duration of pumping of the scheme was investigated using the square of the Pearson Product Moment Correlation Coefficient (r^2), with values ranging from 0 (weak linear agreement) to 1 (stronger linear agreement).

It was assumed that the scheme operated each phase at an approximately constant pumping rate (K. Voyce. *pers.comm.* 2009). Therefore, pumping duration (the number of days since pumping began) was used, rather than pumped volume.

The calculations of *r* were undertaken in an Excel spreadsheet. Where the number of results used for the analysis (*n*) was less than 5, the phrase "n<5" was returned. Values that were less than the level of detection (LOD) were used at their face value in this part of the investigation, but where all results were below the LOD for a given determinand at a given outfall, the "All < LOD" phrase was returned. In all other cases, an *r* value was returned. A series of manual calculations were made in the spreadsheet at random intervals to check the accuracy of these data.

The results were then divided into different categories of correlation coefficient representing different levels of apparent linear agreement as follows:

- $r^2 = 0.4 – 0.5$
- $r^2 = 0.5 – 0.6$
- $r^2 > 0.6$

The determinands and outfall results falling into r^2 = >0.4 were plotted as scatter plots and examined visually to evaluate any apparent linear agreement.

6.2.6 Time Series Analysis

To investigate the effect of pumping groundwater and augmenting river flow with groundwater, stacked time series were plotted together with the WFD EQS and Freshwater Fish Directive water quality standards. In the cases of copper and cadmium, the values of the EQSs are dependent upon hardness. A summary of hardness of river water on different stretches of tributaries is given in Table 6.2. The water quality standards that were used are summarised in Appendix C. Where available, both the annual average (AA) and the maximum admissible concentration (MAC) were plotted in the time series and used in the assessment of water quality.

Table 6.2 Summary of Mean Hardness for River Stretches (supplied by K. Voyce, 2010)

River	Sampling Point	SGS Phase	Outfall	Mean Total Hardness (1990 to 2005)	EQS Hardness Band[1] (mg/l as $CaCO_3$)
Tern	26950820 Bailey Brook to Allford Brook	Phase 1&4	Helshaw Grange & Stoke on Tern	284	>200
Tern	26949580 Allford Brook to River Strine	Phase 1&4	Bolas Bridge & Waters Upton	289	>200
Perry	29993380 Wykey Bridge to confluence War Brook	Phase 2	Adcote	343	>200
Perry	29991100 Confluence War Brook to confluence River Severn	Phase 2	Grafton	343	>200
Severn	55140 Confluence with River Perry to Monkmoor STW outfall	Phase 3	Leaton	86	50-100

Water quality standards were available for either or both of the *total* and *dissolved* metal determinands. In all cases, the *dissolved* metal standard will be tighter than or equal to the *total* standard. For the purposes of this study, where a standard and data were available for both fractions, they were compared separately. Where both fractions were not available, the tighter of the two standards should be adopted irrespective of the fraction of data available. For example, where necessary, *total* quality data should be tested against the *dissolved* standard as a worst case assessment. Logic says that for a *dissolved* determinand to exceed the standard set for a *total* determinand, the total determinand, if measured, must also exceed the standard. The *total* determinand, however, may not exceed the equivalent *total* standard but may exceed that for the dissolved fraction. In the absence of data for the dissolved fraction, however, the risk of failure cannot be proven and it is advised that the total concentration is compared against the dissolved standard in order to judge the risk of EQS failure. The application of the *dissolved* standard in this way is common practice.

Each group of monitoring points containing the upstream river > outfall > downstream river triplet of monitoring points was plotted (Groups 1, 2, 4, 5, 6, 7, 8, 9, and 10). There was insufficient data to plot time series for Groups 3 and 11. Group 3 at Forton (Phase 2) lacked a downstream river monitoring point. Group 11 at Heath House (Phases 1 and 4) consisted of a wellhead, but had no river monitoring points on either the Platt Brook or the confluence between the Platt Brook and the River Tern.

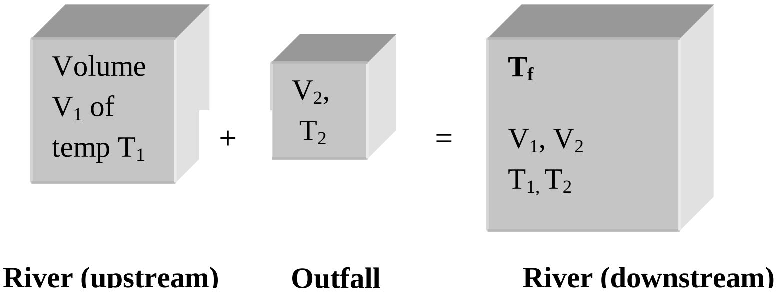
The time series were evaluated to identify samples that exceeded water quality standards (Appendix C), if any, for both groundwater (outfall or stand alone wellhead) and surface water (river monitoring points).

The effects of river augmentation on river temperature was also examined using time series analysis and the reduction in temperature that could result from augmentation was predicted using a simple temperature mixing equation, detailed below.

6.2.7 Prediction of Temperature Reduction

The possible effect on river water temperature of increasing the rate of augmentation pumping rate during the summer months was evaluated using a simple temperature mixing equation, as follows:

$$T_f = \frac{(T_1 \times V_1) + (T_2 \times V_2)}{(V_1 + V_2)}$$



This method relies upon the following assumptions:

- There is complete mixing of the two bodies of water;
- There are no temperature losses from the combined body of water during mixing; and
- There are no other inputs of water (e.g. baseflow) with a different temperature other than those specified in the mixing equation.

6.3 Current Environment

6.3.1 Proof of Evidence

Evidence presented by Severn Trent Water Authority at the Public Hearing, containing water quality data and predicted effects of river augmentation from groundwater, are presented in Brewin (1979). The main points of this document are as follows:

- Rivers in the area of the Shropshire Groundwater Scheme were described as being of generally good quality and classified as Class 1B or Class 2 stretches, which is defined as river water having a dissolved oxygen saturation of at least 40% and a biological oxygen demand (BOD) of no greater than 9 mg/l, and average BOD not greater than 5 mg/l;
- In 1979, the River Tern at Atcham had elevated BOD (mean 2.2 mg/l, max 3.9 mg/l) and ammonia (as N) concentrations (mean 0.3 mg/l, max 1.0 mg/l) mainly as a result of sewage effluent discharges that were deemed to be unsatisfactory, compared to the River Severn (BOD mean 1.6 mg/l, max 3.7 mg/l; ammonia mean 0.1 mg/l, max 0.21 mg/l),. Direct industrial discharges from a creamery, sugar beat factory (now closed and demolished) and engineering works provided additional pressures to river water quality in the River Tern. However, the document states that these did not result in a significant effect on the River Severn downstream of the confluence of the two rivers, and that there was an increase in nitrate concentrations (from 2.0 mg/l as N at Shelton to 2.4 mg/l as N at Atcham) and total dissolved solids;

- The River Perry was characterised as having higher nitrate concentrations (mean 5.4 mg/l as N) compared to the River Severn upstream of the Perry confluence (1.2 mg/l as N);

- Groundwater sampling was carried out at 15 boreholes in the Shropshire area on a quarterly basis, and a further 50 boreholes within the scheme area were pumped and sampled as part of a special survey, for up to 19 determinands;

- Groundwater quality was characterised as being generally good, with the water being hard due to the dominance of dissolved calcium and bicarbonate;

- The quality of groundwater is influenced by the presence and distribution of glacial till in the area. For instance, drift cover in the North Perry area ensures low nitrate (in the order of 0.65 mg/l as N on average), sulphate and chloride concentrations. However, the North Shrewsbury, Roden and River Tern areas are drift-free and more likely to be affected by agricultural activity, so could expect higher nitrate values reaching average concentrations of 12 mg/l as N;

- Boreholes at Adcote and Frankbrook in the South Perry area had high iron and chloride values, respectively, a trait that was unique to these boreholes. However, the Adcote borehole was not developed as part of the final Phase 2 area of the scheme due to concerns about high iron concentrations (K. Voyce, EA. *pers.comm.* 2010);

- The effect of discharging groundwater into the river channels was unlikely to affect the chemical characteristics of the river as the quality of the groundwater and river water was often very similar. In the case of nitrate, the concentration in the river will often be diluted by the input of lower concentration groundwater;

- During initial pilot testing, iron concentrations at the Adcote borehole decreased from 10 mg/l to 3 mg/l over two months, and no ochre precipitates were observed in the river downstream of the discharge. The Adcote borehole was not included within the final scheme due to concerns about iron concentration. At the Frankbrook borehole, chloride concentrations increased from 47 to 270 mg/l;

- Temperature of groundwater was typically 10 to 11ºC, whereas river waters could fall below this range or reach 20ºC, and occasionally 23ºC in July and August. In June and September, river temperatures would normally be within 2 to 3ºC of groundwater temperature. Predicted temperature depressions from discharging 10.5ºC groundwater into river water at peak temperatures indicated that reductions in temperature of up to 2.5ºC in the River Perry and 5.5ºC in the North Perry would be possible; and

- Dissolved oxygen saturation of groundwater was usually 10 to 90%, with an average saturation of 50%. With the river waters having at least a dissolved oxygen saturation of 40%, and the groundwater outfalls being designed with aerating mitigation measures to enhance the dissolved oxygen concentration to a minimum of 75%, it is unlikely that groundwater will reduce the saturation of dissolved oxygen in the river. The proof of evidence states that it is more likely that the input of groundwater will increase the dissolved oxygen saturation of the river.

6.3.2 Baseline Report

The groundwater chemistry of the Shropshire Permo-Triassic Sandstone aquifer has been summarised by the Baseline Report of Smedley *et al.*, (2005). The following is a summary of the background groundwater chemistry detailed in the Baseline Report:

- Groundwater from the Permo-Triassic Sandstone is principally of a calcium bicarbonate (Ca-HCO_3) water type due to dissolution of carbonate detrital grains and cements, and two monitoring points, Frank Brook and Lee Brockhurst are of a calcium-sodium-chloride (Ca-Na-Cl) water type;
- Most groundwaters are fresh with electrical conductivity values in the range 500-600 µS cm^{-1}, although values up to 2000 µS cm^{-1} have been recorded;
- Chloride and sulphate concentrations are usually less than 50 mg/l;
- Sodium had a median concentration of 12.5 mg/l, although reached a maximum of 234 mg/l;
- Dissolved oxygen concentrations were between <0.1-10.5 mg/l, with a median concentration of 5.3 mg/l;
- The Redox Potential of groundwater was characterised as high, with values recorded in the range of 356-435 mV;
- The balance of nitrogen species is typical of dominantly oxic conditions. Nitrate concentrations were recorded in the range <0.1-51.6 mg N/l, with a median of 6.3 mg N/l; whilst concentrations of nitrite and ammonia are generally low (<0.005 and <0.004 mg/l, respectively);
- Iron and manganese concentrations were generally low, but maximum values of 1.3 and 1.5 mg/l were recorded, suggesting that groundwater in the Permo-Triassic sandstone was normally oxidising, but localised reducing conditions do occur;
- In terms of noteworthy trace elements, arsenic concentrations reached a maximum of 26 µg/l; Nickel concentrations reached a maximum of 43 µg/l; lead concentrations reached a maximum of 10.4 µg/l; cadmium concentrations ranged between <0.005 and 1.1 µg/l, with a median of <0.5 µg/l; aluminium concentrations fell in the range <1-67 µg/l with a median of 7 µg/l ; and copper fell in the range <1.2-275 µg/l with a median of 4.9 µg/l; elevated concentrations of copper, lead and zinc have been attributed to corrosion of pipe work at the sample point;
- Dominant hydrochemical processes include the dissolution of carbonate and dolomite cements, although at shallower depths in the aquifer where calcite has been leached, acidic conditions evolve without the buffering effect of bicarbonate at near neutral pH, so the pH of shallow groundwater can become more acidic;
- Where manganese-rich carbonate cements are dissolved in oxic conditions, the dissolved manganese is short-lived and quickly precipitates following oxidation; and
- Locally higher chloride concentrations occur in where the Permo-Triassic Sandstone is associated with either the Hodnet or Wem Faults, bringing the sandstone into contact with groundwater from the Mercia Mudstone or Carboniferous rocks.

6.4 Assessment of Impact on Current Environment

6.4.1 Relationship between Water Quality and Groundwater Pumping

The square of the Pearson Product Moment Correlation Coefficient (r^2), used here to examine the presence of any linear agreement between determinand concentrations at outfalls and pumping duration, is summarised in Table 6.3 for the highest r^2 values (>0.4). The comment included in Table 6.3 follows a visual inspection of the plots of determinand concentration at the outfall against pumping duration, for the same combinations of determinand and outfall group.

Table 6.3 Pearson Product Moment Correlation Coefficients (*r*) between Determinands at Outfall and Pumping Duration where r^2 > 0.4 (see Figure 6.1; Appendix G)

r^2 Category	Group[1]	Determinand	*r*	Comment
0.4 > r^2 > 0.5	8	ALUMINIUM - AS AL	0.407	Low number of samples (*n* =5), 4 of which below LOD.
	1	MAGNESIUM - AS MG	0.475	*n* = 25
	5	NITRATE - as N	0.485	Low number of samples (*n* =5)
	5	OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O	0.420	*n* = 11
0.5 > r^2> 0.6	8	ARSENIC - AS AS	0.594	Low number of samples (*n* =5)
r^2 > 0.6	8	IRON DISSOLVED - AS FE	0.743	Forced by steps in LODs

[1] Group names: Group 1 – Adcote; Group 5 – Waters Upton; and Group 8 – Stoke on Tern.

Most of the determinands in Table 6.3 and Figure 6.1 show the highest *r* values as a result of either a small sample population (low *n* number) or predominance of values below the LOD/at different LODs. However, magnesium at Adcote and dissolved oxygen at Waters Upton appear to show higher r^2 values that are unrelated to these effects, although it should be noted that the r^2 values for these remain at 48% and 42%, suggesting only a low level of agreement.

On the whole, there appears to be little, if any, linear relationship between pumping duration and concentration of determinands. However, the availability of data remains a limitation to this assessment. Unlike river monitoring data, outfall data is only available for periods when the scheme is switched on, so this results in only a small number of data points on which to base this assessment. For this reason, the possible impact on water quality of augmenting river flow with groundwater will be evaluated in the next section using time series analysis.

6.4.2 Time Series Analysis of Water Quality Impacts

Time series for determinands selected in this study are presented in Appendix H. Table 6.4 shows a comparison of concentrations of different determinands against the relevant water quality standards (WFD EQS or Freshwater Fish Directive). The purpose of this table is to identify determinands in groundwater and river water that exceed any water quality standards.

Table 6.4 Frequency that EQS was exceed by Groundwater or Surface Water for Each SGS Group

Determinand	Group 1 - Adcote					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)	No
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	Yes	No	Yes	Yes	Occassionally	Occassionally
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)
Metals - CADMIUM - AS CD - ug/l	Yes	Occassionally	(no WQS)	Yes	Yes	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	Yes	Occassionally	(no WQS)	Yes	Occassionally	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	No	No	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	(no data)	(no data)	(no WQS)	No	No	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	Occassionally	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	Occassionally	Occassionally	(no WQS)	Yes	Yes	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	Yes	Yes	(no WQS)	Yes	Occassionally	(no WQS)

Determinand	Group 2 - Grafton					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	No	No	No	No	No	No
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)
Metals - CADMIUM - AS CD - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	Yes	Occassionally	(no WQS)	Yes	Occassionally	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	(no data)	(no data)	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	No	No	(no WQS)	(no data)	(no data)	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	Yes	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	Yes	Yes	(no WQS)	Yes	Occassionally	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	Yes	Yes	(no WQS)	Yes	Occassionally	(no WQS)

Determinand	Group 4 - Leaton					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)	(no data)
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	No	No	No	(no data)	(no data)	No
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)
Metals - CADMIUM - AS CD - ug/l	Yes	No	(no WQS)	(no data)	(no data)	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	(no data)	(no data)	(no WQS)	(no data)	(no data)	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	(no data)	(no data)	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	(no data)	(no data)	(no WQS)	(no data)	(no data)	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)	No
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	Yes	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	No	No	(no WQS)	Yes	No	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	(no data)	(no data)	(no WQS)	(no data)	(no data)	(no WQS)

Determinand	Group 5 - Waters Upton					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	No	No	(no WQS)	No	No	(no WQS)
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	No	(no WQS)	(no WQS)	No	(no WQS)
Metals - CADMIUM - AS CD - ug/l	No	LOD>WQS	(no WQS)	Yes	Occassionally	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	No	LOD>WQS	(no WQS)	Yes	LOD>WQS	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	Occassionally	Occassionally	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	No	No	(no WQS)	No	No	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)	Yes
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	Occassionally	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	Yes	No	(no WQS)	Yes	Occassionally	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	No	No	(no WQS)	Yes	No	(no WQS)

Determinand	Group 6 - Childs Ercall					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	Yes	Yes	(no WQS)	No	No	(no WQS)
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	No	(no WQS)	(no WQS)	No	(no WQS)
Metals - CADMIUM - AS CD - ug/l	No	No	(no WQS)	Yes	No	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	(no data)	(no data)	(no WQS)	Yes	LOD>WQS	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	(no data)	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	(no data)	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	No	No	(no WQS)	Occassionally	Occassionally	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	(no data)	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	No	No	(no WQS)	No	No	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Yes
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	Yes	Occassionally	(no WQS)	Yes	Occassionally	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	Yes	No	(no WQS)	Yes	No	(no WQS)

Determinand	Group 7 - Great Bolas					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	No	No	Yes	(no data)	(no data)	(no WQS)
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	No	(no WQS)	(no WQS)	No	(no WQS)
Metals - CADMIUM - AS CD - ug/l	No	No	(no WQS)	Yes	Occassionally	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	(no data)	(no data)	(no WQS)	Yes	LOD>WQS	(no WQS)
Metals - COPPER - AS CU - ug/l	Occassionally	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	Occassionally	Occassionally	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	(no data)	(no WQS)	(no WQS)	(no data)	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	(no data)	(no data)	(no WQS)	(no data)	(no data)	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Yes
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	(no data)	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	Occassionally	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	Yes	Occassionally	(no WQS)	Yes	No	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	Yes	No	(no WQS)	Yes	No	(no WQS)

Determinand	Group 8 - Stoke on Tern					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	Occassionally	No	(no WQS)	Occassionally	No	(no WQS)
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	No	(no WQS)	(no WQS)	No	(no WQS)
Metals - CADMIUM - AS CD - ug/l	No	LOD>WQS	(no WQS)	Yes	Occassionally	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	No	LOD>WQS	(no WQS)	Yes	LOD>WQS	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	Occassionally	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	Occassionally	Occassionally	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	(no data)	(no data)	(no WQS)	No	No	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	Occassionally	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	No	No	(no WQS)	Yes	Occassionally	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	No	No	(no WQS)	Yes	No	(no WQS)

Determinand	Group 9 - Helshaw Grange					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	No
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	Occassionally	No	(no WQS)	Occassionally	No	(no WQS)
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	No	(no WQS)	(no WQS)	No	(no WQS)
Metals - CADMIUM - AS CD - ug/l	No	LOD>WQS	(no WQS)	Yes	Occassionally	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	No	LOD>WQS	(no WQS)	Yes	LOD>WQS	(no WQS)
Metals - COPPER - AS CU - ug/l	Occassionally	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	Yes	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	Yes	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	Occassionally	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	No	No	(no WQS)	Occassionally	Occassionally	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	Occassionally	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	No	No	(no WQS)	No	No	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)	Occassionally
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	Occassionally	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	Occassionally	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	No	No	(no WQS)	Yes	Occassionally	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	No	No	(no WQS)	Yes	No	(no WQS)

Determinand	Group 10 - Greenfields					
	Does groundwater outfall exceed:			Does river monitoring point exceed:		
	WFD EQS (AA)	WFD EQS (MAC)	Other	WFD EQS (AA)	WFD EQS (MAC)	Other
Field - ALKALINITY PH 4_5 - as CACO3 - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Field - CONDUCTIVITY @20C - uS/cm	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Occassionally
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - mg/l	(no data)	(no data)	Yes	Occassionally	No	(no WQS)
Metals - ALUMINIUM - AS AL - ug/l	(no WQS)	No	(no WQS)	(no WQS)	No	(no WQS)
Metals - CADMIUM - AS CD - ug/l	No	No	(no WQS)	Yes	Occassionally	(no WQS)
Metals - CADMIUM DISSOLVED - AS CD - ug/l	No	No	(no WQS)	Yes	No	(no WQS)
Metals - COPPER - AS CU - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - COPPER DISSOLVED - AS CU - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD - AS PB - ug/l	Occassionally	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - LEAD DISSOLVED - AS PB - ug/l	No	(no WQS)	(no WQS)	Occassionally	(no WQS)	(no WQS)
Metals - MAGNESIUM - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MAGNESIUM DISSOLVED - AS MG - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - MERCURY - AS HG - ug/l	(no data)	(no data)	(no WQS)	Occassionally	Occassionally	(no WQS)
Metals - NICKEL - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - NICKEL DISSOLVED - AS NI - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Metals - SODIUM - AS NA - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Metals - ZINC DISSOLVED - AS ZN - ug/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Non-metals - ARSENIC - AS AS - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Non-metals - FLUORIDE - AS F - mg/l	(no data)	(no data)	(no WQS)	No	No	(no WQS)
Non-metals - SULPHATE - AS SO4 - mg/l	No	No	(no WQS)	No	No	(no WQS)
Nutrients - AMMONIA - AS N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Yes
Nutrients - NITRATE - as N - mg/l	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)	Yes
Nutrients - NITRITE - as N - mg/l	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)	(no WQS)
Nutrients - ORTHOPHOSPHATE - as P - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - BOD ATU as O2 - mg/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON - AS FE - ug/l	No	(no WQS)	(no WQS)	Yes	(no WQS)	(no WQS)
Redox - IRON DISSOLVED - AS FE - ug/l	No	(no WQS)	(no WQS)	No	(no WQS)	(no WQS)
Redox - MANGANESE - AS MN - ug/l	(no data)	(no data)	(no WQS)	Yes	Occassionally	(no WQS)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	No	No	(no WQS)	Yes	No	(no WQS)

From Table 6.4, the determinands can be arranged in decreasing order of the number of groups that exceed one or more water quality standard across both surface water and groundwater: manganese > cadmium > orthophosphate > dissolved oxygen > nitrate > BOD > mercury > lead > ammonia > lead dissolved > copper dissolved > conductivity > zinc > iron (dissolved) > copper > nickel. With the exception of Group 2 – Grafton, all other groups of monitoring points showed that river water exceeded EQSs for between 1.5 and 9 times more determinands than groundwater did.

Table 6.5 gives a comparison of relative concentration differences between surface water and groundwater, which is further summarised in Table 6.6 below. This displays determinands that are either elevated (or depleted in the case of dissolved oxygen) compared with river water. In Table 6.5 most of the determinands with sufficient data for comparison, show either higher concentrations in river water compared to groundwater or concentrations of both are similar. The exceptions to this, where concentrations in groundwater exceed those in surface water are displayed in Table 6.6.

Table 6.5 Comparison between Groundwater and Surface Water Chemical Concentrations for Each SGS Group

Determinand	Group 1 - Adcote	Group 2 - Grafton	Group 4 - Leaton**	Group 5 - Waters Upton	Group 6 - Childs Ercall	Group 7 - Great Bolas	Group 8 - Stoke on Tern	Group 9 - Helshaw Grange	Group 10 - Greenfields
Field - ALKALINITY PH 4 5 - as CACO3 - mg/l	River>GW conc	River>GW conc	(insufficient data)	River>GW conc	GW = River	GW = River	GW = River	River>GW conc	(insufficient data)
Field - CONDUCTIVITY @20C - uS/cm	GW>River Conc	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc
Field - OXYGEN DISSOLVED (INSTRUMENTAL - IN	River>GW conc	GW>River Conc	(insufficient data)	GW>River Conc	River>GW conc	(insufficient data)	GW = River	River>GW conc	(insufficient data)
Field - TEMPERATURE WATER - CEL	GW<River Temp	GW>River Conc	(insufficient data)	River<GW Temp	GW = River	GW = River	GW = River	GW = River	GW<River Temp
Metals - ALUMINIUM - AS AL - ug/l	(insufficient data)	(insufficient data)	(insufficient data)	River>GW conc	(insufficient data)	(insufficient data)	River>GW conc	River>GW conc	(insufficient data)
Metals - CADMIUM - AS CD - ug/l	GW = River	GW>River Conc	(insufficient data)	GW = River	River>GW conc	River>GW conc	GW = River	GW = River	GW = River
Metals - CADMIUM DISSOLVED - AS CD - ug/l	GW = River	GW = River	(insufficient data)	GW = River	(insufficient data)	River>GW conc	GW = River	GW = River	GW = River
Metals - COPPER - AS CU - ug/l	GW = River	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	GW>River Conc	GW = River	GW>River Conc	GW = River
Metals - COPPER DISSOLVED - AS CU - ug/l	GW = River	GW = River	(insufficient data)	River>GW conc	(insufficient data)	River>GW conc	GW = River	GW>River Conc	(insufficient data)
Metals - LEAD - AS PB - ug/l	GW = River	GW = River	(insufficient data)	GW = River	GW = River	GW = River	GW = River	GW>River Conc	GW>River Conc
Metals - LEAD DISSOLVED - AS PB - ug/l	GW = River	(insufficient data)	(insufficient data)	GW = River	(insufficient data)	(insufficient data)	GW = River	GW>River Conc	(insufficient data)
Metals - MAGNESIUM - AS MG - mg/l	GW>River Conc	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc	GW>River Conc
Metals - MERCURY - AS HG - ug/l	(insufficient data)	(insufficient data)	(insufficient data)	(insufficient data)	River>GW conc	(insufficient data)	(insufficient data)	River>GW conc	(insufficient data)
Metals - NICKEL - AS NI - ug/l	GW = River	GW = River	(insufficient data)	GW = River	GW = River	GW = River	GW = River	GW = River	GW = River
Metals - NICKEL DISSOLVED - AS NI - ug/l	GW = River	GW = River	(insufficient data)	GW = River	(insufficient data)	GW = River	GW = River	GW = River	GW = River
Metals - SODIUM - AS NA - mg/l	GW>River Conc	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc
Metals - ZINC - AS ZN - ug/l	GW = River	GW = River	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	GW = River	GW>River Conc	GW = River
Metals - ZINC DISSOLVED - AS ZN - ug/l	GW = River	GW = River	(insufficient data)	GW = River	(insufficient data)	(insufficient data)	GW = River	GW>River Conc	(insufficient data)
Non-metals - ARSENIC - AS AS - ug/l	(insufficient data)	(insufficient data)	(insufficient data)	GW = River	(insufficient data)	(insufficient data)	GW>River Conc	GW>River Conc	(insufficient data)
Non-metals - FLUORIDE - AS F - mg/l	(insufficient data)	(insufficient data)	(insufficient data)	(insufficient data)	GW = River	(insufficient data)	(insufficient data)	(insufficient data)	(insufficient data)
Non-metals - SULPHATE - AS SO4 - mg/l	River>GW conc	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc
Nutrients - AMMONIA - AS N - mg/l	River>GW conc	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	GW = River	GW = River	River>GW conc
Nutrients - NITRATE - as N - mg/l	GW = River	River>GW conc	(insufficient data)	GW = River	River>GW conc	River>GW conc	GW>River Conc	GW>River Conc	GW = River
Nutrients - NITRITE - as N - mg/l	(insufficient data)	(insufficient data)	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc
Nutrients - ORTHOPHOSPHATE - as P - mg/l	River>GW conc	River>GW conc	(insufficient data)	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc	River>GW conc
Redox - BOD ATU as O2 - mg/l	River>GW conc	River>GW conc	(insufficient data)	River>GW conc	(insufficient data)	(insufficient data)	GW = River	GW = River	(insufficient data)
Redox - IRON - AS FE - ug/l	River>GW conc	River>GW conc	(insufficient data)	River>GW conc	GW = River	GW = River	River>GW conc	River>GW conc	River>GW conc
Redox - IRON DISSOLVED - AS FE - ug/l	River>GW conc	River>GW conc	(insufficient data)	GW = River	GW = River	(insufficient data)	(insufficient data)	GW = River	GW = River
Redox - MANGANESE - AS MN - ug/l	River>GW conc	GW>River Conc	(insufficient data)	River>GW conc	GW>River Conc	GW = River	River>GW conc	River>GW conc	(insufficient data)
Redox - MANGANESE DISSOLVED - AS MN - ug/l	GW = River	GW>River Conc	(insufficient data)	GW = River	GW>River Conc	(insufficient data)	River>GW conc	River>GW conc	(insufficient data)

* For dissolved oxygen, the colour coding is reversed, so that to show that higher concentrations are beneficial to the water.

** Only 2 analysis results were available for each of the river monitoring points at Leaton.

Table 6.6 Summary of Instances where Groundwater Concentrations exceed those of River Water

Outfall Group	Determinands Elevated in Groundwater compared to River Water[1]	Standards Exceeded by Groundwater but not by River Water[2]
Group 1 – Adcote	• Conductivity • Magnesium • Sodium	• Conductivity
Group 2 – Grafton	• Cadmium (total) • Manganese (total and dissolved)	
Group 4 – Leaton	Insufficient data for surface water	• Cadmium (total) • Ammonia (on occasion) • Orthophosphate
Group 5 - Waters Upton	-	-
Group 6 - Childs Ercall	• Manganese (total and dissolved)	• Dissolved Oxygen
Group 7 - Great Bolas	• Copper (total)	• Dissolved Oxygen • Copper (on occasion)
Group 8 - Stoke on Tern	• Arsenic (total) • Nitrate	-
Group 9 - Helshaw Grange	• Copper (total and dissolved) • Lead (total and dissolved) • Arsenic (total) • Nitrate • Zinc (total)	• Copper (on occasion) • Nickel (dissolved) • Nitrate (occasional only in surface water) • Zinc (total)
Group 10 – Greenfields	• Lead (total) • Magnesium	• Dissolved Oxygen

[1] Source is Table 6.5;
[2] Source is Table 6.4; where '-' is given this denotes 'None'.

Although instances of water quality issues have been highlighted above, discharging groundwater to surface water during periods of river augmentation can also have beneficial effects. Iron, nitrate, orthophosphate and sulphate are examples of determinands where their concentrations are usually lower in groundwater than in surface water in all cases (Table 6.5). The one exception to this is the Frankbrook wellhead (Adcote Group), which has been shown to have a Ca-Na-HOC_3-Cl water type and discharge groundwater with elevated chloride concentrations of 200-250 mg/l (Appendix F). With the exception of Frankbrook, levels of conductivity and sodium concentrations are also usually lower in groundwater than surface water. In these instances, groundwater effectively dilutes the concentrations in the receiving water, thereby leading to an improvement in water quality for those parameters.

In terms of surface water quality impacts from groundwater discharges, the only instances where groundwater, rather than surface water, regularly exceeds EQSs are for cadmium (total), dissolved oxygen, nickel (dissolved) and orthophosphate (Table 6.6). In Table 6.6, the Leaton and Helshaw Grange abstractions make up the majority of cases. However, in the case of Leaton, insufficient surface water data were available to make an accurate comparison and in the case of Helshaw Grange this is no longer used for river augmentation as it has been impacted by high chlorinated solvent concentrations. To put this into perspective, the majority of determinands (19 with EQS) analysed at the majority of monitoring points assessed in this study (9 locations), groundwater concentrations are lower than surface water and exceed fewer EQSs. This suggests that as groundwater discharges are more likely to dilute concentrations of chemicals in surface water, water quality effects from groundwater tend to be neutral or even beneficial on the whole.

6.4.3 Temperature and Dissolved Oxygen Effects

The effect of pumping relatively cold (9 to 11ºC), dissolved oxygen-poor groundwater into river water (15 to 20ºC) has been noted as a concern by Brewin (1979) and Environment Agency (2008b). A comparison of temperature in the groundwater at the outfall or wellhead, is given in Table 6.7. Group 1- Adcote, Group 2-Grafton, Group 5-Waters Upton and Group 10-Greenfields have been identified using the time series plots as having groundwater temperature at outfall (or wellhead) that is visibly less that the corresponding river water temperature.

The time series (Figure 6.2) show water temperature at the outfall and river monitoring points, but also plot the temperature difference between the upstream and downstream monitoring points for Groups 1, 2, 4, 5, 8 and 9. There was insufficient temperature data for the upstream and downstream river monitoring points for Groups 6, 7, and 10 for the pumping interval examined. The temperature data available varied in the level of precision being reported between values to the nearest 0.1ºC and those to the nearest 1ºC. The effect on river temperature of augmenting river flow with groundwater has been measured by subtracting the downstream river monitoring point temperature from the upstream monitoring point temperature, to give an indication in change in temperature as a result of the augmentation, downstream of the outfall (Table 6.7). For groups with both upstream and downstream river monitoring points associated with outfalls (Groups 1, 2, 4, 5 and 8), the difference in temperature between upstream and downstream monitoring points suggested a reduction in temperature of up to 5 degrees occurred during pumping. The smallest temperature reduction was recorded for the Group 4 river monitoring points at Leaton, where the groundwater is discharged to the River Severn. Conversely, increases in temperature of up to 3 degrees were also recorded during pumping.

Table 6.7 Range in Temperature Difference between Upstream and Downstream River Monitoring Points

Group	1	2	4	5	6[1]	7[1]	8	9[1]	10[1]
Temperature Reduction (ºC)	-3	-5	0.3	-3	0	0	-3	-3	3
Temperature Increase (ºC)	2	1.4	-	3	1	1	1	1	4

[1] Groups that are characterised by an isolated wellhead without nearby upstream and downstream river monitoring points.

Figures 6.3–6.7 show the downstream temperature trends for Groups 1, 2, 4, 5 and 8. These give the temperature at in-river monitoring points upstream and downstream of the outfall, the temperature of the outfall water and that of any extreme upstream or extreme downstream monitoring points.

The temperature of groundwater at the outfall is usually between 9 to 13ºC, although temperatures at Group 8 Stoke on Tern can reach 15ºC, whilst the river temperature range has been measured at 3 to 23ºC. The river augmentation scheme is usually run during the summer period so Figures 6.3-6.6 usually plot the outfall water as being colder than the river water, so for the purposes of this study, the high outfall – low river temperature scenario will not be covered. For Group 1 at Adcote (Figure 6.3), the fall in temperature downstream of the outfall is usually 2 to 3ºC, although temperature profiling measurements conducted at this outfall have shown that relatively cold water tends to 'stream' along one bank allowing a corridor of normal temperature to remain along the opposite bank suggesting that temperature effects are localised and last 25 m or so (Appendix I). For Group 2 at Grafton (Figure 6.4), the downstream fall in temperature is usually between 1 to 5ºC and temperature profiling at this location (Appendix J) has shown that, like Adcote, the cold water zone is localised to one bank and an in-channel wall structure downstream of the discharge brings about efficient mixing so that water >35 m downstream has returned to pre-discharge temperatures.

For Group 4 at Leaton on the River Severn (Figure 6.5), outfall temperatures varied between 11 and 14ºC, although the temperature measurements on 12/07/2006 and 11/08/2006 showed limited reductions in observed temperature downstream of the outfall of 0.1 and 0.3ºC, respectively. For Group 5 at Waters Upton on the River Tern (Figure 6.6), the downstream fall in temperature is usually 3ºC, but can range from 1to 4ºC. Temperature profiling undertaken at Waters Upton in the River Tern in 1996 demonstrated that within about 100 m of the groundwater discharge the downstream ambient temperature had returned to pre-discharge temperatures (Appendix K). For Group 8 at Stoke on Tern (Figure 6.7), the downstream fall in temperature is usually in the range of 0 to 3ºC, although temperature reductions were usually in the range of 2 to 3ºC.

To summarise for temperature effects, inputs of groundwater (with a lower summer temperature range of 9 to 11ºC) into surface water (with a higher summer temperature range of 15 to 20ºC) results in a localised zone of cooling in the watercourse, although this tends to be localised, streaming along one bank and becomes well mixed within tens to one hundred metres returning to normal ambient temperatures. Furthermore, greater mixing and return to ambient temperatures can be achieved by the placement of in-channel structures to encourage greater mixing of waters with different densities.

In terms of dissolved oxygen, the outfalls or wellheads that discharged water with reduced concentrations compared to the river water were Group 1 at Adcote, Group 6 at Childs Ercall and Group 9 at Helshaw Grange (Appendix H). For Group 1 at Adcote, groundwater being discharged into the river at the outfall had dissolved oxygen concentrations of 8 mg/l (75% saturation meeting the target limit in the Proof of Evidence [Section 6.2.1.]), compared to the river water, which averaged approximately 11 mg/l (98% saturation). For Childs Ercall wellhead the groundwater concentration was 2 to 6 mg/l compared with river water concentrations of approximately 7 to10 mg/l. However, the measurements at Childs Ercall were made for groundwater and river water at different times, so this cannot be considered a definitive comparison. At Helshaw Grange, groundwater dissolved oxygen concentration was only about 1 mg/l less than that of river water. Groups 2, 5 and 8 showed dissolved oxygen concentrations in a similar range to river water. Groups 4, 7 and 10 lacked groundwater dissolved oxygen data to make any comparison.

6.5 Predicted Impacts

6.5.1 Hydrochemistry of Receiving Watercourse

Section 6.3.2 concludes that the effects of discharging groundwater with higher water quality with respect to nutrients (nitrogen and phosphorus), redox-sensitive metals (iron and manganese) and heavy metals (cadmium) (see Table 6.4) into surface water, which often has higher concentrations of these parameters, is more likely to bring about an improvement in water quality in the receiving watercourse. This is likely to be especially so in periods when the augmentation is in operation; in drought periods the watercourses will be supported almost exclusively by baseflow with enhanced evaporative losses and little dilution from rainfall leading to higher concentrations of dissolved solutes. During such periods, river augmentation is likely to be beneficial by moderating solute concentrations.

A monitoring strategy needs to be maintained for assessing any impacts on the hydrochemistry. This will be discussed in Section 6.6.

6.5.2 Temperature of Receiving Watercourse

Section 6.4.3 details the historic temperature impacts of the Shropshire Groundwater Scheme when it is switched on, based on temperature data collected during sampling. This section evaluates the possible temperature-related impacts on the receiving watercourses from augmentation under the conditions of an extreme drought period. Here, a comparison is made between river flow conditions in the 1976 Historic Actual river flow conditions and the East Shropshire Model output for peak model demand year 2034, which simulates an extreme scenario of the 1993 to 1996 climatic conditions with 1997 replaced with 1976, as part of a dry climate change scenario. Benchmarking the modelled river flow data versus the historic actual observed data from the 1976 drought event underlines the fact that the SGS Modelled scenario is a more extreme event. In the absence of modelled data, outside of the area covered by the East Shropshire Model (Phases 2 and 3), it is reasonable to use 1976 historic actual data as a benchmark against which to assess the predicted impacts.

Assessment of Temperature Effect during the 1976 Historic Actual Drought Period

River flows were taken from the historic actual recorded in 1976 between May and September (Table 6.8). The year 1976 represented the extreme drought event scenario used at the end of the 5 year East Shropshire Groundwater Model run. Mean monthly flows were calculated from the mean daily flow data captured by each of the river gauging stations and archived on the Environment Agency's WISKI database. September's mean monthly figures only include the first 21 days as heavy rainfall marking the end of the drought fell on the 22nd September. No flow data were available for the Hodnet, Heath or Stoke Brooks, therefore these will cause an under estimation of the total calculated flows. Flows for the Allford Brook were estimated at 1 Ml/d and the Potford+Platt Brook combined flow at 1.5 Ml/d based on previous work undertaken by the East Shropshire Groundwater Model.

The normal maximum deployable yield of the SGS groundwater discharges were used for each of the SGS outfalls. Where Phase 1&4 share common outfall points then the sum of the two Phases was use to calculate the discharge yield. When calculating the increase in augmented river flow downstream of the outfall, a net gain figure of 90% of the gross groundwater discharge was used. The net gain value was taken from assessment of gauged flows to the Perry & Tern under 1996 operational conditions.

Based on historic readings groundwater temperature for the aquifer was taken as 10ºC (9 to 11ºC range), while river temperatures for the Severn, Perry and Tern were taken on advice from EA Ecology team and based on observed river temperatures (1988 to present).

In terms of what the likely temperature effects would be during pumping in the proposed over-licensed scenario based on the actual flows in the Severn and its tributaries in August 1976, some simple temperature mixing calculations (see Section 6.1.7.) have been carried out for each phase of the scheme (Table 6.9).

Table 6.8 May to September 1976 Historic Actual River Flow Data

River	Gauge Point	Mean Monthly Historic Actual Flow (Ml/d)				
		May	June	July	August[1]	September
Severn	Montford	758.3	499.5	622.1	414.6	247.2[2]
Perry	Yeaton	49.3	33.5	23.4	18.3	25
Tern	Ternhill	42.5	35.5	27.5	25.1	31.7
Baily Brook	Ternhill	12	9.1	6.3	5.6	7.6
Tern	Eaton on Tern	77.5	59.3	42.2	37.6	53.1
Allford Brook	Childs Ercall	1	1	1	1	1
Meese	Tibberton	53.6	39	23.9	21.2	32.8
Pot&Platt Brooks	Sandyford Bridge	4.4	3.8	2.1	1.9	11.9
Tern	Walcott	241.8	192	119.3	106.1	156.2

[1] August showed the lowest flows in the summer period of 1976
[2] The September flow figure for the Severn is considered to be suspect and was not selected as the lowest flow (K. Voyce. *pers.com.* 2010)

Compared with the upstream temperature (T_1), the calculated mixed temperature (T_f) was between 0.9 and 5.5ºC less than the upstream temperature. The temperature reduction was generally higher for higher ratios of groundwater discharged compared with surface water flows. These calculations assume complete mixing and represent the temperature immediately after complete mixing, so therefore assume a worst case scenario. The results are discussed below for each SGS Phase and river stretch, with available data.

Table 6.9 Calculated Temperature Mixing based on the 1976 Flow and Temperature Conditions (see Section 6.1.7)

Receiving Watercourse (Combined Flow Points)	River Parameters (1976)		Groundwater Discharge Parameters		Downstream Mixed Temp.	Proportion Groundwater in TOTAL Augmented Flow at Point of Discharge
	Temp ^{0}C	Flow Ml/d	Temp ^{0}C	Flow Ml/d	Calculated Mixing Temp.	
	T_1	V_1	T_2	V_2	T_f	%
Phase 1& 4 - River Tern at Stoke on Tern (Tern at Ternhill +Bailey Brook at Ternhill)	22	25	10	27	15.8	52
Phase 4 - River Tern at Eaton upon Tern (Eaton on Tern+Allford Brook+90% Stoke on Tern SGS Discharge)	22	57	10	7	20.7	11
Phase 1&4 - River Tern at Waters Upton (+Eaton on Tern+Allford Brook+90% Stoke on Tern SGS DischargeStoke on Tern+90% Bolas Bridge+River Meese+Potford Brook)	22	91.9	10	55	17.5	37
Phase 2b - River Severn (Montford)	20	414	10	41	19.1	9
Phase 2a - River Perry (Yeaton -90% SGS Adcote discharge)	22	18.3	10	5	19.4	21
Phase 2a - River Perry (+90% SGS Adcote discharge)	22	22.8	10	4	20.2	15
Phase 3 - River Severn (Montford+Perry+90% of Phase 2 SGS Discharge)	20	477	10	50	19.1	9

T_1 River temperature up stream of out fall
V_1 River flow up stream of outfall
T_2 Groundwater discharge temperature
V_2 Groundwater discharge rate
T_f Downstream mixed temperature

SGS Phases 1 and 4

Stoke on Tern to River Tern – Combined Phase 1&4 maximum groundwater discharge of 27 Ml/d in to an assessed river flow of 30 Ml/d. The mixing ratio of groundwater to river water at Stoke on Tern discharge point is near enough 1:1, with a 5.6ºC predicted initial cooling effect. Given this ratio and the geometry of the river Tern at this location, the groundwater discharge is likely to dominate the flow down-stream of the outfall. In the absence of any actual temperature profiling data is thought the groundwater discharge will generate a temperature cooling of at least 5.6ºC at the foot of the out-fall. This may give rise to a thermal barrier to fisheries and invertebrate migration. The extent of the thermal cooling downstream cannot be fully determined.

Bolas Bridge to River Tern – Stand alone Phase 4 discharge from Great Bolas of 7 Ml/d in to assessed augmented river flow of 63 Ml/d. Mixing ratio of groundwater to river water 1:9. The higher degree of river dilution is reflected in a lower predicted cooling impact of 1.2ºC. The geometry of the channel is such that the groundwater would be anticipated to preferentially stream to the east side of the channel before mixing fully with the river water. This mixing configuration is therefore unlikely to generate a thermal barrier across the whole channel profile.

Waters Upton to River Tern – Combined Phase 1&4 maximum discharge of 55 Ml/d in to an assessed river flow of 92 Ml/d generates a mixing ratio of groundwater to river water of 1:1.7. The lower degree of river dilution is reflected in a predicted cooling impact of up to 4.5ºC. Temperature profiling has taken place at this out-fall in 1996 when Phase 1 discharged 32 Ml/d into 130 Ml/d river flow (1:4 dilution ratio), causing cooling up to 100 m downstream. Under this scenario, the discharge would be increased by a further 23 Ml/d and the river flow reduced by 40 Ml/d. The net effect should be to increase the stretch of river where cooling takes place. A doubling of the current assessed length of mixing from 100 m to 200 m is considered possible. This mixing configuration is therefore likely to generate a thermal barrier across the whole channel profile and increase the length of downstream mixing by up to double.

SGS Phase 2

Adcote to River Perry – Stand alone Phase 2a discharge from Frankbrook of 5 Ml/d in to assessed augmented river flow of 18 Ml/d. Mixing ratio of groundwater to river water 1:3.7, with a predicted cooling impact of 2.6ºC. The mixing configuration is anticipated to follow that profiled in 2006. The 40% reduction in river flow (1976 vs 2006) will cause the extent of cooling to extend further down stream, perhaps effecting up to 50 m. This mixing configuration is therefore unlikely to generate a thermal barrier across the whole channel profile. The groundwater discharge to the river Perry at Adcote is therefore not considered to pose a significant thermal barrier to the migration of fisheries or invertebrates past the outfall.

Grafton to River Perry – Stand alone Phase 2a discharge from Grafton of 4 Ml/d in to assessed augmented river flow of 22 Ml/d. Mixing ratio of groundwater to river water 1:5.7, with a predicted cooling impact of 1.8ºC. The mixing configuration is anticipated to follow that profiled in 2006. Even allowing for a 37% reduction in river flow groundwater would be anticipated to preferentially stream down the southern side of the channel before mixing fully with the river water at the in-channel wall structure. This mixing configuration is therefore unlikely to generate a thermal barrier across the whole channel profile.

Forton to River Severn - Combined Phase 2b maximum discharge of 41 Ml/d in to an assessed river flow of 414 Ml/d generates a mixing ratio of groundwater to river water of 1:10. The higher degree of river dilution is reflected in a predicted cooling impact of up to 0.8ºC. Given the geometry of the channel laminar flow is likely to prevail thus preventing rapid mixing. Similar to scaled up version of the Grafton release groundwater would be anticipated to preferentially stream along the northern side of the channel slowly diffusing and mixing at distance down-stream. The full extent of the mixing zone is unknown, however as the mixing would not affect the whole channel width this discharge configuration is not considered likely to generate a thermal barrier across the whole channel profile.

SGS Phase 3

Leaton to River Severn - Combined Phase 3 maximum discharge of 50 Ml/d in to an assessed augmented river flow of 477 Ml/d generates a mixing ratio of groundwater to river water of 1:9.5. The higher degree of river dilution is again reflected in a predicted cooling impact of up to only 0.9ºC. The geometry of the channel is similar to the Forton outfall and again laminar flow is likely to prevail. Groundwater would be anticipated to preferentially stream along the eastern side of the channel slowly diffusing and mixing at distance down-stream. The full extent of the mixing zone is unknown, however as the mixing would not affect the whole channel width this discharge configuration is not considered likely to generate a thermal barrier across the whole channel profile.

Further temperature impact investigations have been carried out by the Environment Agency during river augmentation. In-river temperature measurements were taken during Phase 2 augmentation at Adcote and Grafton in July 2006, and Phase 1 augmentation at Waters Upton In August 1996. Details of these investigations are given in Appendices I, J and K, respectively. The main outcomes of these investigations were as follows:

- Complete mixing of the relatively cold (10ºC to 11.9ºC) groundwater and the relatively warm (20ºC) surface waters does not occur immediately but remained separated by a distinct temperature boundary. At Adcote, mixing did not begin to occur until after 5 m downstream and the mixing zone extended for approximately 25 m downstream. For Grafton, little mixing took in the first 10 m downstream of the discharge and the lower temperature mixing zone extended a similar length downstream to Adcote;

- The colder water streams along the same side of the river as the discharge allowing the opposite bank to remain in contact with the warm ambient temperature waters. The colder part of the river channel accounted for a third to half of the channel for up to 10 m downstream at Adcote, whereupon turbulent mixing started to occur. For Grafton, the cooler mixing waters streamed along the bank and temperature stratified waters comprised between a third and a half of the channel width;

- Between 10-25 m downstream, the temperature reduction had diminished to 0.9ºC to 1.7ºC at Adcote and at Grafton between 20m and 35m downstream the temperature reduction diminished to 0.1 to 4ºC;

- The effect of discharging 32 Ml/d of groundwater at 11.8ºC into 130 Ml/d at Waters Upton was to reduce the ambient river temperature from 18.6ºC to 12 to14ºC; a reduction of 4.6 to 6.4ºC. The study was not detailed enough in its measurements to judge the degree of homogeneity of the mixing. The study did indicate that in this case temperatures were lowered by up to approximately 2.2ºC for the stretch 10-100 m from the discharge. Normal temperatures were restored beyond 100 m from the discharge point.

The studies outlined above indicate that augmentation of flows in the Rivers Severn, Perry and Tern result in measurable temperature reductions, but these reductions are likely to be offset by local flow heterogeneities caused predominantly by temperature-induced density differences. This leads to laminar flow, streaming of the colder water and the establishment of a clear thermocline for the first ten metres downstream of the discharge point. This suggests that the channel often retains a path of ambient temperature on the opposite side to the discharge along which temperature-sensitive biota could travel unaffected (K. Voyce. *pers.comm.* 2010). As the waters become turbulent and greater mixing occurs, the temperature reduction effect diminishes to a much lower level that would threaten less species.

Comparison of River Flows between the 1976 Historic Actual and 1997”1976” Dry Climate Scenario

The East Shropshire Model applied the “dry” climate change scenario using a modified rainfall and evapotranspiration sequence. The net effect was a reduction in runoff and recharge, and therefore a reduction in the inputs and outputs from the water balance.

Table 6.10 summarises the predicted river flows at each of the main SGS Phase 1&4 groundwater discharge points to the River Tern. The model year represents a peak demand sequence which used the “1976” profile. It is therefore reasonable to draw a comparison between the historic actual and model periods for the maximum stress period with the lowest recorded river flows in August. As the model does not cover all the rivers listed in Table 6.9, comparison can only be made for the River Tern and Phase 1 and 4 discharges.

Table 6.10 East Shropshire Model Scenario - Predicted River Flows for Model Year 2034 representing Peak Demand Sequence 1997"1976"

River	SGS Discharge	Modelled River Flows (Ml/d)				
		May	June	July	August	September
River Tern	Phase 1& 4 at Stoke on Tern	49	35	39	25	94
River Tern	Phase 4 at Eaton on Tern	60	43	48	32	113
River Tern	Phase 1&4 at Waters Upton	103	75	84	57	217

Table 6.11 Comparison of 1976 Historic Actual and East Shropshire Modelled Drought Scenario River Flows (Ml/d) for Main SGS Phase 1 and 4 Discharge Points to River Tern

River	SGS Discharge	Historic Actual River Flow August 1976 (Ml/d)	Modelled River Flow for August 2034 (Ml/d)	Modelled Flows as a Percentage of 1976 (%)	% Reduction in Flows
River Tern	Phase 1&4 at Stoke on Tern	30.7	25	81	19
River Tern	Phase 4 at Eaton on Tern	37.6	32	85	15
River Tern	Phase 1&4 at Walcot	106	87	82	18

The SGS model scenario predicted flows in the River Tern at each of the Phase 1&4 discharge points at Stoke on Tern, Bolas Bridge and Walcot are in the range of 15 to 19% lower than the flow minima actually observed in August 1976 (Table 6.11). With a predicted reduction in river flow, the proportional amount of groundwater discharge making up total augmented river flow at the point of SGS discharge will therefore also increase. Table 6.9 summaries these relative proportions envisaged under this drought scenario.

Comparison of Calculated Mixing Temperatures (T_f) the 1976 Historic Actual and 1997”1976” Dry Climate Scenario

Application of the modelled drought order scenario river flows versus historical actual benchmark conditions observed in 1976 on the calculated mixing temperatures effect of the SGS groundwater discharge to the river are summarised in Table 6.12. The net effect of the lower modelled river flows, predicted by the drought scenario, is largely similar to that expected had the scheme been operating under the 1976 benchmark drought. At the immediate point of discharge temperature cooling effects of between 1 to 6ºC have been calculated as the proportion of groundwater to river water increases. As discussed in Section 6.4.3, these temperature effects will diminish with distance downstream of the outfall.

Table 6.12 Comparison between the Historic Actual 1976 Scenario and the Modelled (Stress Year 2034) Downstream Mixing Temperature (T_f)

Receiving Watercourse and SGS Discharge	River Temperature	Historic Actual River Parameters (August 1976)		Model Scenario River Parameters (August 2034)		Comparison (1976 Historic Actual - Model River Flow Conditions)		
	Ambient Non-augmented Peak Summer River Water Temperature (ºC)	Downstream mixed Temp - Calculated Mixing Temp Temp Difference from Ambient River in Brackets (T_f , ºC)	Proportion of Total River Flow which is SGS Groundwater at Point of Discharge (%)	Downstream mixed Temp - Calculated Mixing Temp Temp Difference from Ambient River in Brackets (T_f , ºC)	Proportion of Total River Flow which is SGS Groundwater at Point of Discharge (%)	Amount of Additional Cooling under Model Scenario v 1976 Historic Actual River Flow Conditions - Temperature Difference (T_f , ºC)	Additional Cooling Effect on Calculated Mixing Zone (%)	Increase in Proportion of Groundwater in Total River Flow at Point of Discharge (%)
Phase 1&4 - River Tern at Stoke on Tern	22	16.4 (-5.6)	47	15.8 (-6.2)	52	0.6	3.9	5
Phase 4 - River Tern at Bolas Bridge	22	20.8 (-1.2)	10	20.7 (-1.3)	11	0.1	0.5	1
Phase 1& 4 - River Tern at Waters Upton	22	17.5 (-4.5)	37	17.4 (-4.6)	39	0.2	0.9	2

6.6 Mitigation and Monitoring

The SGS outfalls already contain a variety of mitigation measures, designed to ensure that groundwater discharged from wellheads has sufficient dissolved oxygen prior to entering the receiving water and that any solid phase material (e.g. sand particles and any precipitated metals) are settled out of the discharge. These measures include cascades, venture pipes and sand traps. These structures are designed to elevate the dissolved oxygen content of the groundwater in excess of a 75% minimum saturation threshold.

With the exception of Bolas Bridge outfall to the River Tern, this dissolved oxygen target has been achieved on all main operational outfalls to date. Low frequency operation of the stream flow compensation boreholes at Childs Ercall, Greenfields (Potford Brook) and Heath House No2 (Platt Brook) mean that dissolved oxygen levels in these discharges have not been fully quantified. These stream systems will become highly modified and dependent upon the groundwater discharge. These sites will require further characterization and mitigation measures introduced if dissolved oxygen falls below the minimum threshold.

It is well established that the Frankbrook wellhead is affected by elevated chloride concentrations. At present, this is monitored by periodic electrical conductivity (EC) measurements that are taken during visits to the abstraction. If the conductivity exceeds a fixed chloride threshold, abstraction from this wellhead is ceased. Currently this relies on infrequent measurement. We recommend that this discharge is fitted with an EC datalogger, set to record EC at 15 minute intervals, with telemetry to allow frequent comparison against the EC threshold from the office. Based on work undertaken by the Environment Agency, the conductivity triggers for the raw groundwater discharge at Adcote would be 2000 μS/cm (Amber - start more intensive monitoring) and 2300 μS/cm (Red - stop if chloride concentrations in river exceed 250 mg/l). These are based on regression analysis and modelling of the historic actual data in the River Perry downstream of the outfall.

As the effect of discharging groundwater on the temperature of the receiving watercourse is potentially the most important impact of the scheme, additional temperature profiling exercises (as in Appendices I-K) should be carried out to characterise the effect of each discharge upon the receiving watercourse. To provide as accurate a picture of the temperature distribution, temperature measurements should be made within a short period of time. Use of equipment that could provide synchronous measurements within the channel would be advantageous. Measurements should be taken in the channel upstream, at the point of discharge and extending downstream until the ambient temperature returns to upstream values.

The water quality assessment was, for certain monitoring points, not possible due to a paucity of data from the wellhead discharge. To date the sampling frequency has normally comprised two or three rounds of samples during the augmentation pumping period. The effect of this licence variation would be to extend the pumping duration beyond the historical actual maximum of 40 to 80 days to up to 117 to 144 days (depending on the phase) to meet the drought regulation demands. At this pumping duration and using the same sampling frequency, this would result in 5 samples being taken over 4 months, which would provide a better groundwater evidence base on which to assess potential impacts. When the scheme is switched on, a site-specific, risk-based determinand suite should be analysed for first monitoring round. Then for successive monitoring rounds (3-4 samples) analyses should be limited to an operational suite (comprising major ions, nutrients and minor ions) and occasional Gas

Chromatography Mass Spectrometry (GCMS) analysis to provide detailed analysis results for volatile and semi-volatile organic compounds.

6.7 Summary and Conclusions

The aim of this Groundwater and Surface Water Quality section was to characterise the current quality of the groundwater and surface water courses, to assess the chemical and temperature effects of augmenting river flow with groundwater and to predict the effect of pumping groundwater beyond the current licence constraints.

All historical groundwater quality analysis data gathered from the scheme to date was reviewed. These data were compared against Environmental Quality Standards (EQSs) set out within the Water Framework Directive (WFD) and Freshwater Fish Directive.

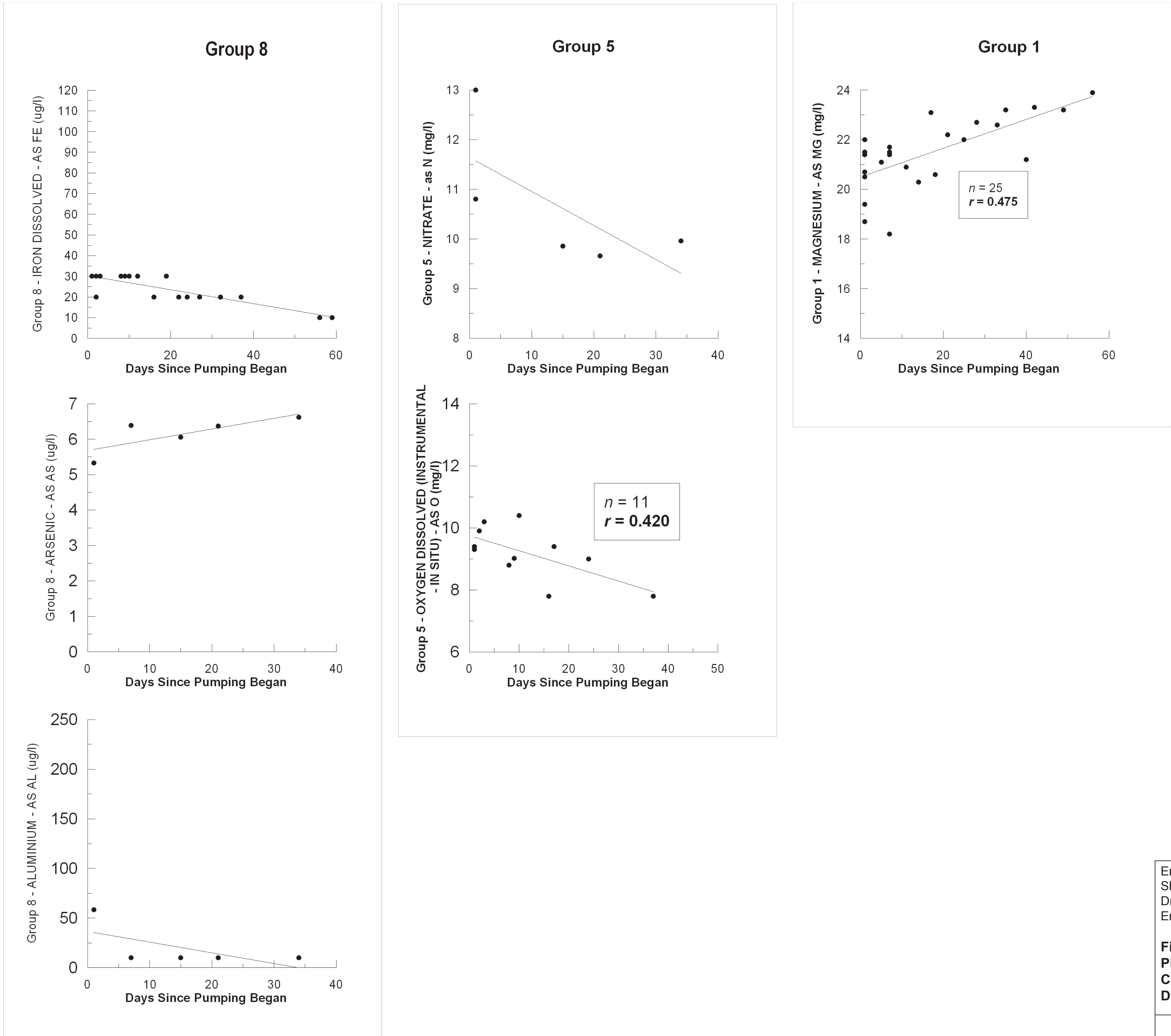
This study concluded that groundwater quality is, on the whole, better than the receiving surface water courses and exceeded fewer EQSs. Water quality effects in rivers from groundwater augmentation are therefore considered to be largely neutral or beneficial.

A limited number of determinands regularly occur at concentrations in groundwater that are higher than both the surface water concentrations and the corresponding EQSs. Additional water quality modelling should be undertaken to determine whether these pose a threat to quality standards under low flow conditions. Any effects are likely to be extremely localised and dissipate within a short distance downstream of the discharge.

No deterioration in groundwater quality has been observed with the duration of pumping seen to date, with the exception of Frankbrook (Phase 2) where rising chloride concentrations need to be monitored closely, and Helshaw Grange (Phase 1) which has been taken out of operational use due to localised solvent contamination. No significant deterioration in groundwater quality is foreseen given the extended pumping required to support the drought order.

The SGS outfalls already contain a variety of mitigation measures, designed to ensure that groundwater discharge has sufficient levels of dissolved oxygen prior to entering the receiving watercourse. With the exception of one marginal site, this dissolved oxygen target has been achieved on all main operational outfalls to date. Low frequency operation of the stream flow compensation boreholes at Childs Ercall, Greenfields (Potford Brook) and Heath House No. 2 (Platt Brook) mean that dissolved oxygen levels in these discharges require further evaluation.

The effect of discharging groundwater on the temperature of the receiving watercourse is to reduce river temperature on a localised scale. Any effects are likely to be extremely localised and dissipate within a short distance downstream of the discharge. Additional temperature profiling exercises should be carried out to better quantify the effect of each discharge upon the receiving watercourse.



Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.1
Plots and Linear Fits of Determined Concentration at Outfall vs Pumping Duration Where r>0.4

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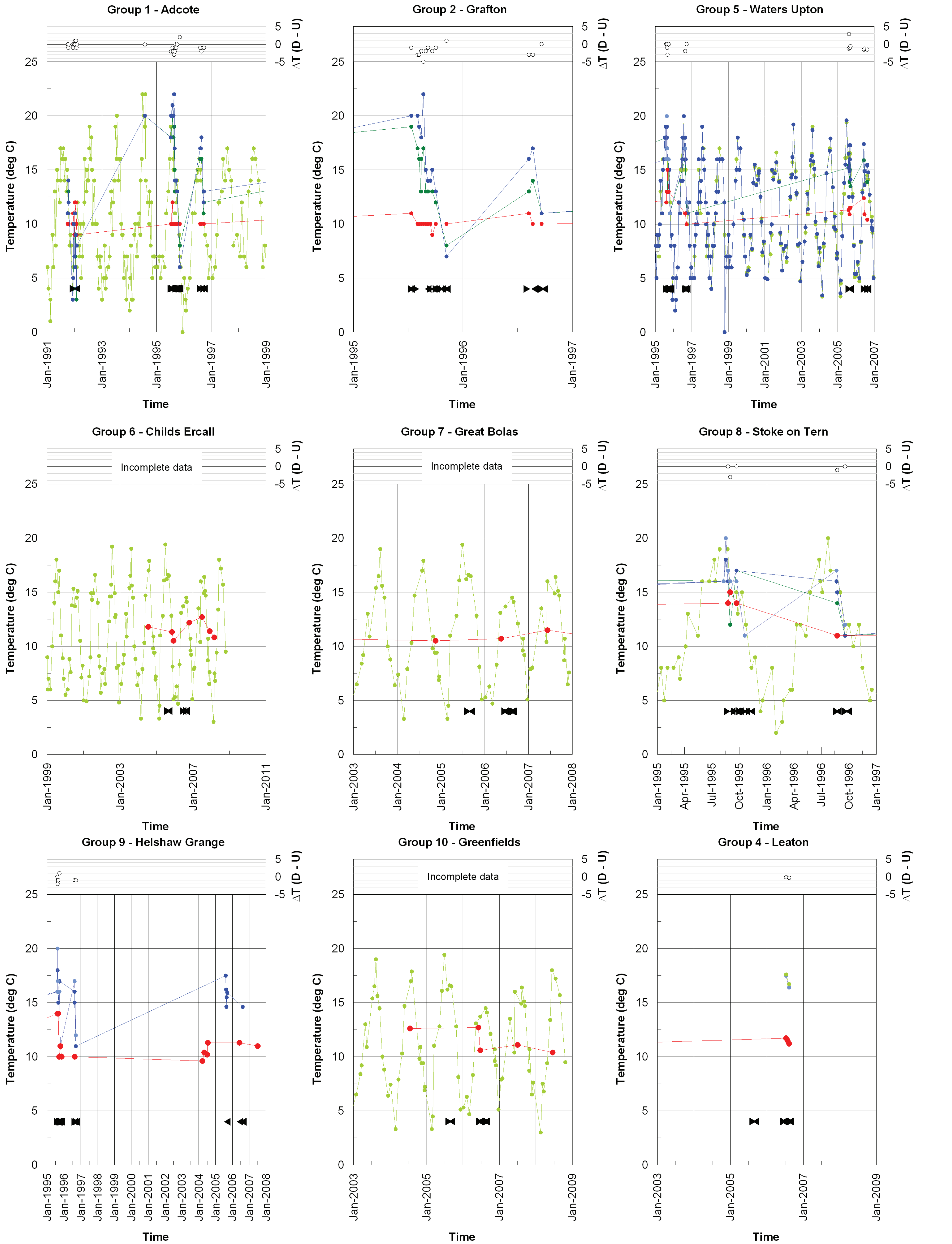

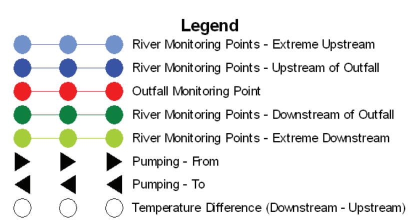

Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.2
Water Temperature Timeseries and Temperature Gradients Across SGS Discharges

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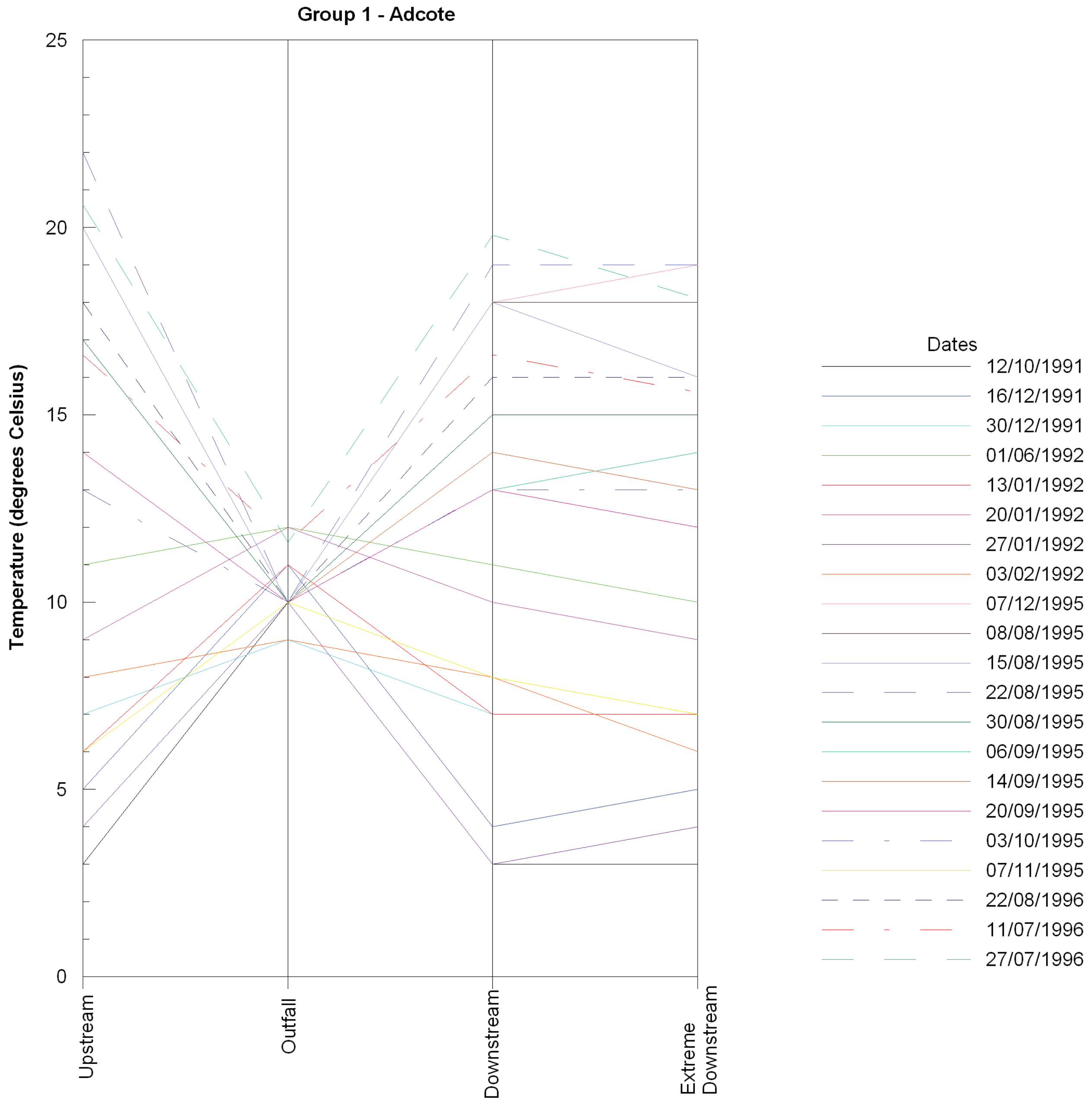

Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.3
Upstream-Wellhead-Downstream Water Temperature Profile - Adcote

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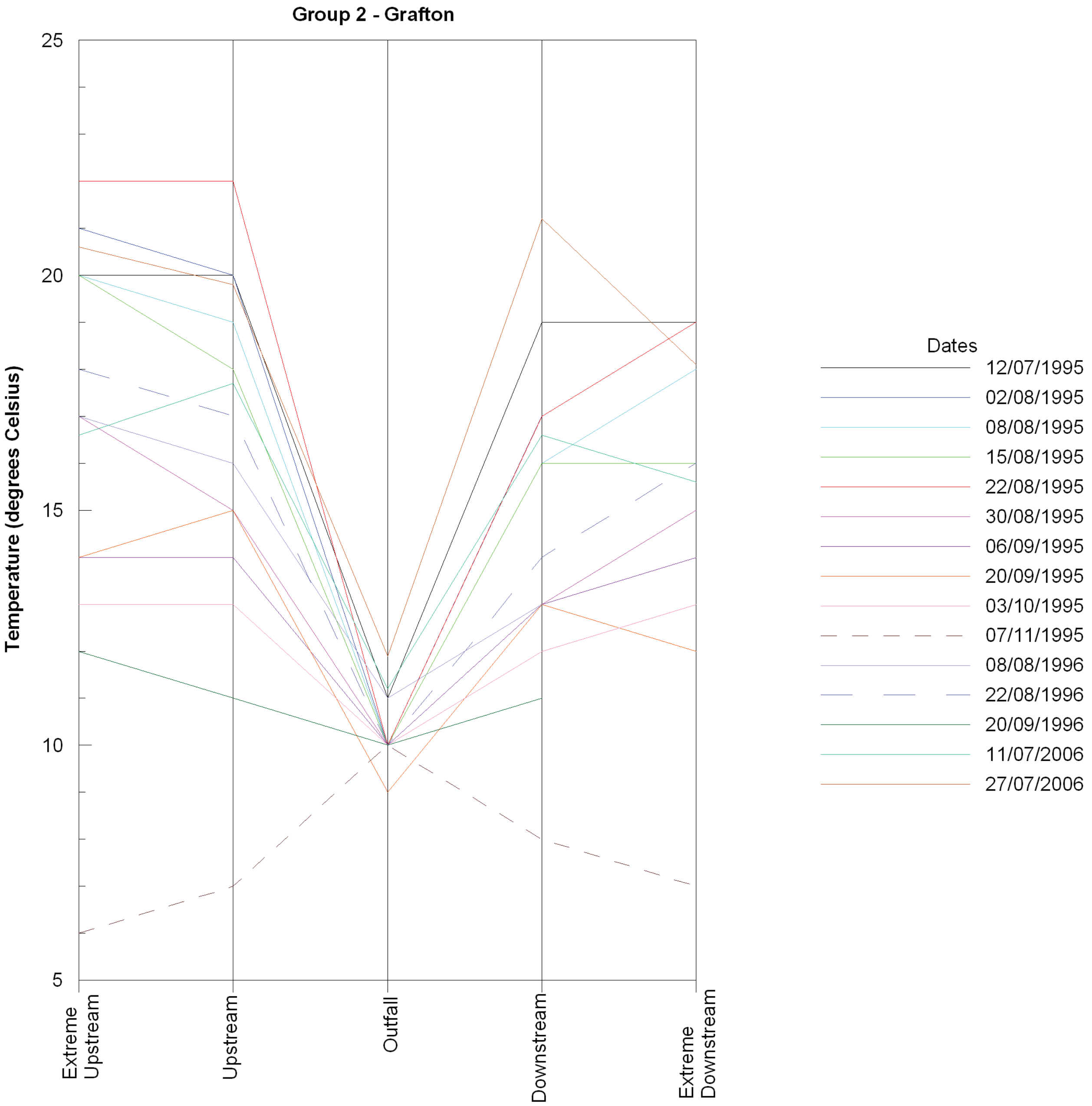

Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.4
Upstream-Wellhead-Downstream Water Temperature Profile - Grafton

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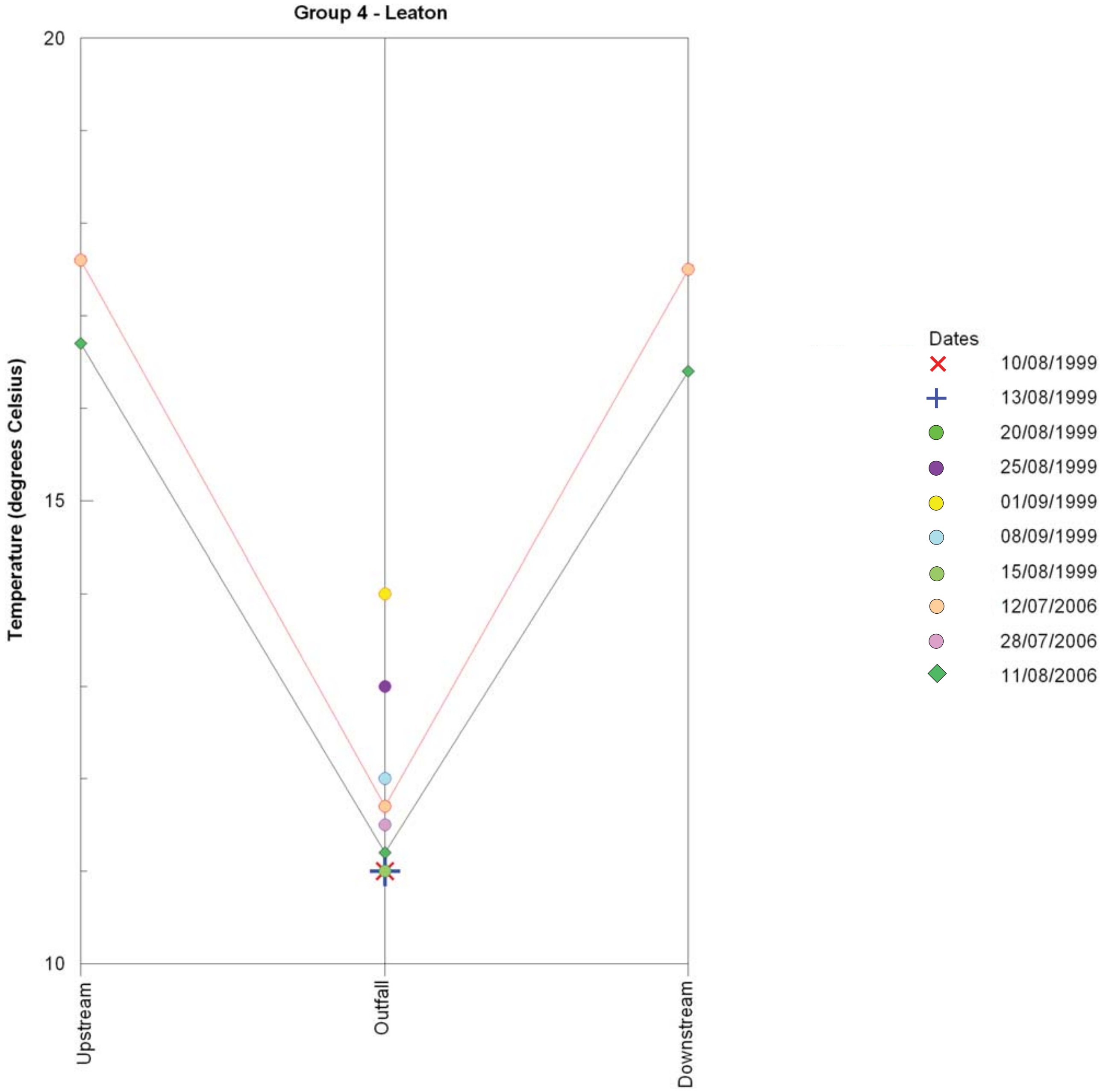

Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.5
Upstream-Wellhead-Downstream Water Temperature Profile - Leaton

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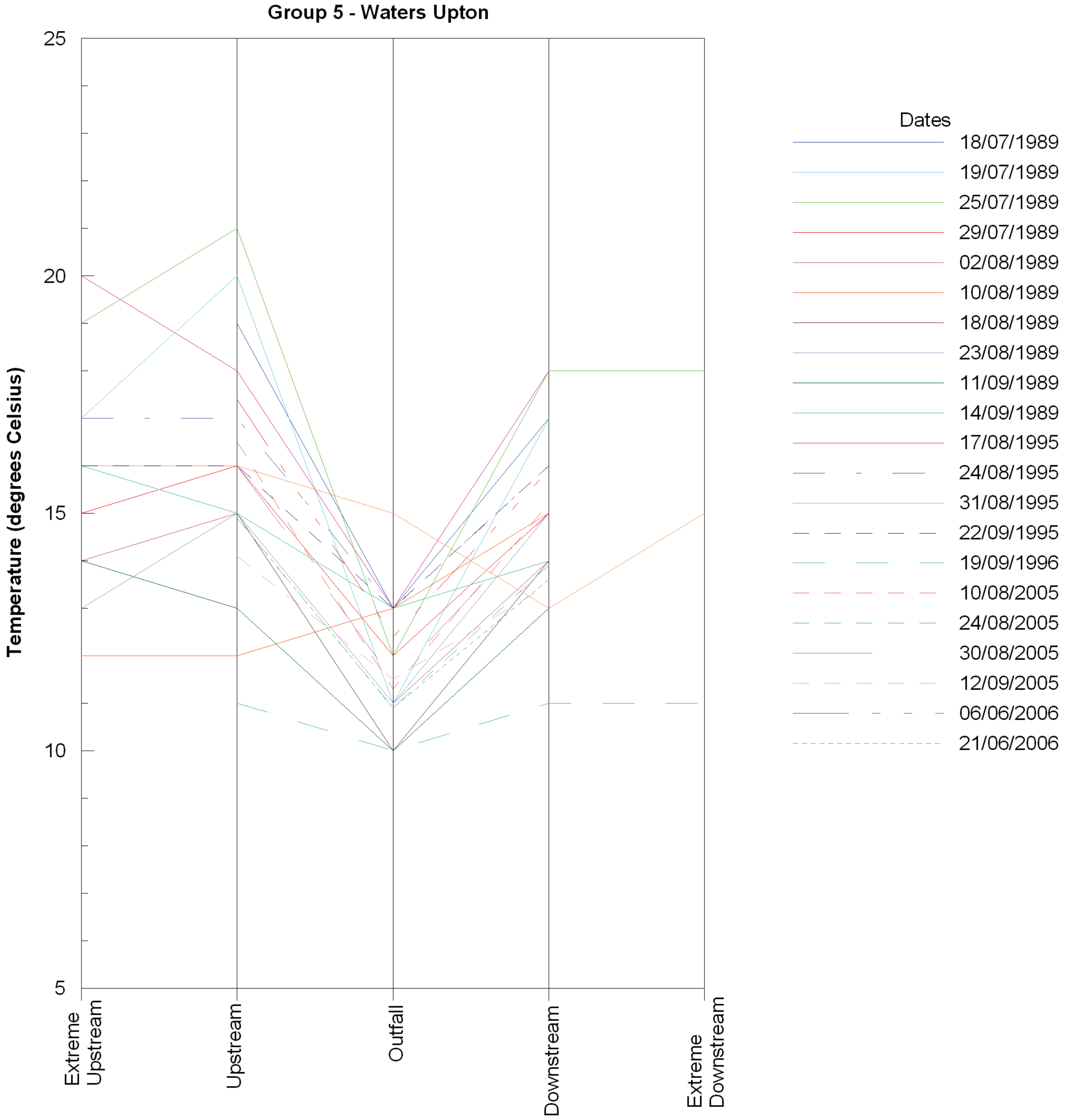

Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.6
Upstream-Wellhead-Downstream Water Temperature Profile - Waters Upton

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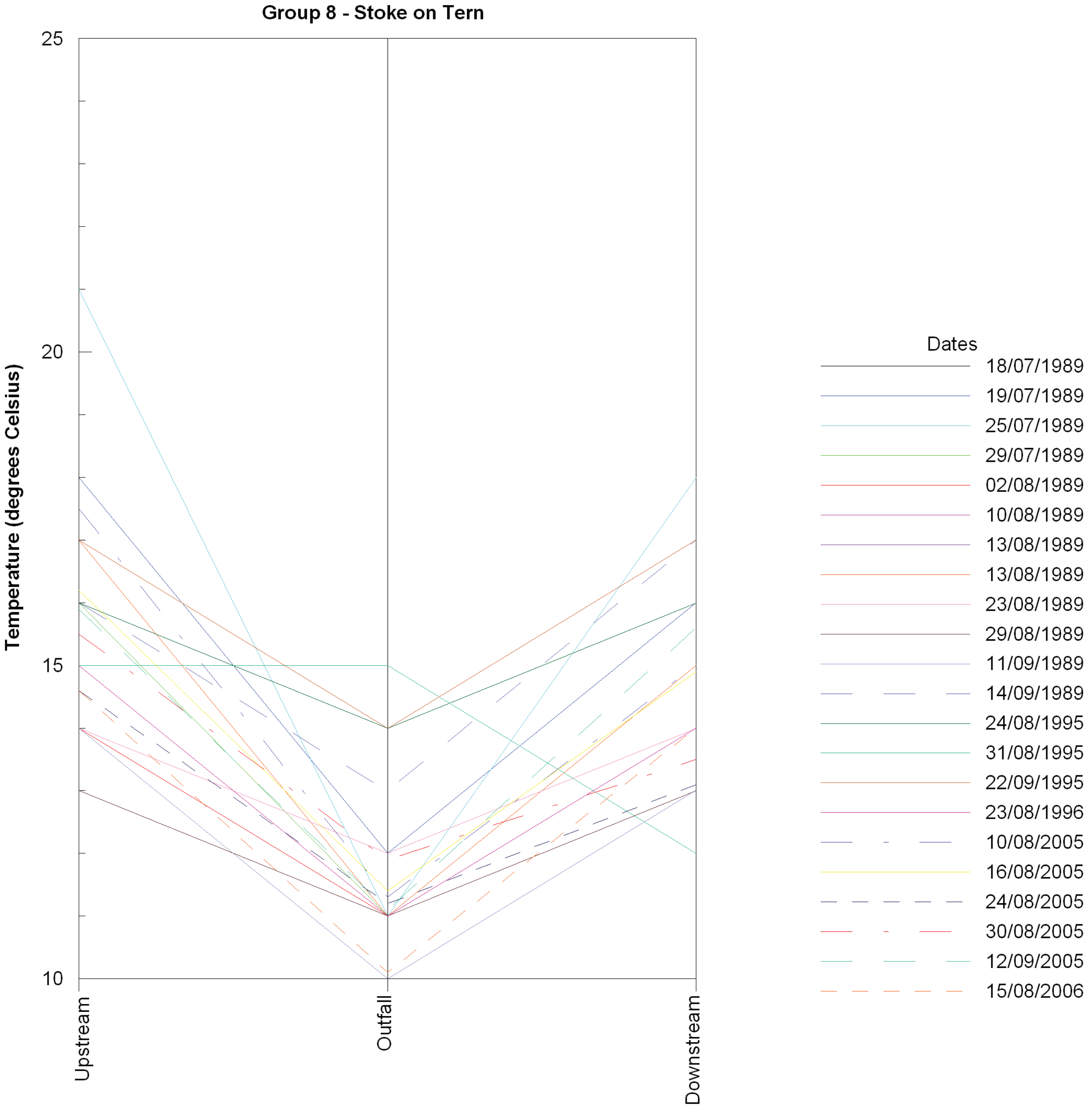

Environment Agency
Shopshire Groundwater Scheme
Drought Order
Environmental Report

Figure 6.7
Upstream-Wellhead-Downstream Water Temperature Profile - Stoke on Tern

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7. Ecology

7.1 Data Availability and Assessment

The assessment of the effects of the Drought Order, and associated changes in the operation of the Shropshire Groundwater Scheme (SGS), on ecological receptors was desk-based. It was informed by a review of fisheries and macro-invertebrate monitoring data. These datasets are summarised in more detail below. The assessment was also informed by a review of the Proof of Evidence (Severn Trent Water Authority 1979[1]), presented on behalf of Severn Trent Water, detailing the assessment of the predicted impacts of the SGS.

The assessment also included a process of 'screening' of statutory and non-statutory designated sites of nature conservation value to identify groundwater-dependent or surface water-dependent sites that are situated within the SGS draw-down zone and are potentially susceptible to the effects of SGS pumping. The predicted effects on this short-list of sites have subsequently been subject to more detailed consideration.

The assessment has also been undertaken with reference to relevant legislation. Legislation of particular relevance to the assessment of the effects of the Drought Order on ecological receptors are briefly summarised in Box 7.1.

Box 7.1 Relevant Legislation[1]

Water Framework Directive (2000): requires EU member states to ensure 'no deterioration' in the ecological status of waterbodies and to achieve their Good Ecological Status by 2015 (Good Ecological Potential in the case of waterbodies categorised as Heavily Modified). Following the categorisation of the ecological status of waterbodies, the Environment Agency prepared River Basin Management Plans, providing the framework for implementing and monitoring 'Programmes of Measures' intended to work towards achieving Good Ecological Status.

EC Directive on Freshwater Fish 2006: this includes provisions to protect and improve the quality of rivers and lakes to encourage healthy fish populations. It sets water quality standards and monitoring requirements for areas of water which are designated salmonid (or cyprinid) fisheries.

Salmon and Freshwater Fisheries Act 1975: this legislation includes provisions to protect spawning fish and their habitats. The Act also includes provisions controlling the obstruction of fish passage.

Eels Regulations 2009: requires EU member states to put in place measures to improve eel escapement and recovery of eel stocks through development and delivery of Eel Management Plans. This is in response to a steep decline in eel stocks reported throughout Europe.

Habitats Directive 1992[2]: This requires EU member states to designate Special Areas of Conservation for the protection of notable populations of species listed in Annex II of the Directive, including a number of fish species.

Conservation of Habitats and Species Regulations 2010: This transposes the Habitats Directive into UK law. It lists UK species that are afforded special legal protection, including some aquatic and riparian species.

Wildlife and Countryside Act 1981 (as amended): This includes provision for the protection of SSSIs and species listed in Schedules to the Act.

Natural Environment and Communities Act (2006): Section 40 of the act places a statutory duty on every public authority, including statutory undertakers to, *'in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity'*. In accordance with Section 41 of the Act, the Secretary of State has published a list of habitats and species of principal importance for conserving biodiversity in England. This list is intended to guide public bodies and statutory undertakers and specifically identifies those species or habitats that should be given priority when implementing their NERC Section 40 duty.

[1]This brief summary of aspects of legislation relevant to the assessment of the effects of the Drought Order/SGS on ecological receptors has been prepared by an ecologist and does not represent legal advice.
[2]EU Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora 1992.

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[1] Peter Ernest Bottomley, Co-ordinator (Fisheries), Directorate of Scientific Services; John Michael Hallawell, Principal (Environmental Aspects); and David John Brewin, Principal (Quality Modelling), Directorate of Scientific Services Severn Trent Water Authority.

Rather than undertaking an exhaustive review of all available ecological data, the assessment of the effects of the DO focuses on ecological receptors (water dependent designated sites; and aquatic taxa) that are likely to be sensitive to the changes in hydrology that the scheme is predicted to bring about. These are also likely to be the most sensitive indicators of any long-term changes in the ecology of the receiving watercourses as a result of the operation of SGS.

The assessment focuses mainly on the River Tern and River Perry. These smaller tributaries receive multiple discharges from the SGS; are likely to have an ecology that is comparable to the middle and upper reaches of the River Severn; are regularly monitored; and are likely to have more limited capacity than the Severn to buffer changes in, for example, water quality or temperature, making them more susceptible to the effects of a DO.

Platt Brook is a tributary of Potford Brook, which is a tributary of the River Tern. There is limited ecological monitoring data available for Potford and Platt Brooks, restricted to approximately four years of macroinvertebrate monitoring data.

7.1.1 Fish

Fisheries monitoring data are available for the three main watercourses (River Tern, River Perry and River Severn) to which the SGS discharges. The monitoring locations are summarised in Table 7.1. The surveys were undertaken by the Environment Agency employing standard electro-fishing methods. The Agency calculated semi-quantitative fish population estimates/ densities based on the standard (Carle and Strub 1978[2]) methodology.

The monitoring data were collected between 1992 and 2010, although the surveys were not undertaken annually (Table 7.1) and some sites have been surveyed more than others. In addition to the surveys summarised below, two further monitoring sites on the River Tern at Waters Upton (SJ6298619318) and Cold Hatton (SJ6387420866), respectively were surveyed on one occasion in 2010.

[2] Carle, F. L. and Strub. M. R. (1978). *A New Method for Estimating Population Size from Removal Data*. Biometrics 34. 621-630.

Table 7.1 Fish Monitoring Locations and their Proximity to SGS Discharges

Monitoring Location	Proximity to SGS Discharge	Monitoring Periods
RIVER TERN		
Hall Farm (SJ 6320 3140)	US of discharges	1992, 2002, 2004, 2006, 2008, 2009, 2010
Stoke on Tern (SJ 6370 2780)	DS of Helshaw Grange (SJ 6309 2900); and upstream of Stoke on Tern (SJ 6368 2781)	1992, 2002, 2004, 2006, 2008, 2009, 2010
Peplow (SJ 6430 2420)	DS of Helshaw Grange; and Stoke on Tern	1992, 2002, 2004, 2006, 2007, 2008.
Crudgington (SJ 6270 1800)	DS of Helshaw Grange; Stoke on Tern; Bolas (SJ 6466 2196) and Waters Upton (SJ 6301 1933).	1992, 1996, 2002, 2004, 2005, 2006, 2008
RIVER PERRY		
Milford (SJ 4210 2100)	US of discharge	1991, 2003, 2005, 2008, 2009, 2010
Frankbrook (SJ 42533 19447)	DS of Adcote (SJ 4213 1975)	2005, 2008, 2009, 2010
Adcote Mill (SJ 4213 1974)	DS of Adcote (SJ 4213 1975)	*No data*
Fitz (SJ 4441 1805)	DS or Adcote and Grafton (SJ 4392 1850)	2005, 2008, 2009, 2010
RIVER SEVERN		
Montford GS (SJ 4200 1450)	US of discharges	1992, 1998, 2003, 2004, 2005, 2006, 2008
Leaton Knowles (SJ 4700 1700)	DS of Montford Bridge (SJ 4370 1624) and Leaton (SJ 4612 1781)	1992, 1998, 2003, 2004, 2005
Uffington (SJ 5262 1428)	DS of Montford Bridge and Leaton	1992, 1998, 2003, 2004, 2005, 2006, 2008, 2009

7.1.2 Macroinvertebrates

Aquatic macroinvertebrate monitoring data are also available for the three main watercourses to which the SGS discharges. The monitoring locations are summarised in Table 7.1. The surveys were undertaken by the Environment Agency employing standard three minute kick sample methods. The standard range of biotic indices (Box 7.2) that describe the flow preferences (LIFE) and tolerance to organic pollution (BMWP and ASPT) of the invertebrate assemblages have been calculated.

Box 7.2 Biotic Indices

Biological Monitoring Working Party (BMWP) score: a biotic index that uses aquatic macro-invertebrates to determine biological quality of running waters in relation to organic pollution. It works on the principle that macro-invertebrates are sensitive to water quality with the most pollution sensitive scoring highly (up to 10) and the most pollution tolerant scoring low scores (1, in the worst case). Most organisms fall somewhere on a scale between the two extremes. The values for each taxon are added together to give an overall total for the sample site.

Average Score Per Taxon (ASPT): The BMWP score alone can be misleading due to the variability of the scores in relation to habitat diversity. By considering a combination of BMWP and the Average Score Per Taxon (obtained by dividing the BMWP score by the number of taxa used to obtain that score) the influence of habitat diversity is reduced. Armitage et al. (1983) recommended the use of ASPT since its value is less sensitive to variations in sampling effort and seasonal change than is the BMWP score.

Lotic-invertebrate Index for Flow Evaluation ('LIFE') score: the method for calculating LIFE scores is described by Extence, Balbi and Chadd (1999). Aquatic invertebrate species and families have been given a rating relating to their flow requirements. Using these ratings and the abundance of the species/ families, a LIFE score is calculated using the equation: LIFE = fs/n where fs is the sum of the individual taxon flow scores for the whole sample and n is the number of taxa used to calculate sum fs. This is referred to as LIFE S (species). LIFE F (family) scores can also be calculated using the family level data. Higher flows typically result in higher LIFE scores.

Monitoring data collected between 1986 and 2008[3] have been analysed, although the surveys were not undertaken every year during this period (Table 7.2). Some sites have been monitored more frequently than others, including some that are monitored twice or three times during survey years. At long term monitoring sites invertebrate data are generally collected twice every year, in spring and autumn.

Table 7.2 Macroinvertebrate Monitoring Locations and their Proximity to SGS Discharges

Monitoring Location	Proximity to SGS Discharges	Monitoring Periods
RIVER TERN		
Buntingsdale Bridge (SJ 6580 3310)	US of discharges	Annually 1990 to 2010 (exc. 2002, 2003, 2005)
US Stoke on Tern Outfall (SJ 6368 2784)	DS of Helshaw Garage Grange (SJ 6309 2900).	Annually 1987 to 1997; and annually 2005 to 2010
DS Stoke on Tern Outfall (SJ 6375 2764)	DS of Helshaw Grange; and Stoke on Tern (SJ 6368 2781)	Annually 1985 to 2010 (exc. 1988; 1991 to 1994; 2001 to 2004).
Eaton on Tern GS (SJ 6492 2314)	DS of Helshaw Grange; and Stoke on Tern	Annually 1985 to 2010 (exc. 1988; 1991 to 1994; 2003 and 2006).
Cold Hatton Footbridge (SJ 6384 2084)	DS of Helshaw Grange; Stoke on Tern; Bolas Bridge (SJ 6466 2196).	Annual 1985 to 1990; 2005; 2007
US Waters Upton (SJ 6309 1947)	DS of Helshaw Grange; Stoke on Tern; Bolas Bridge.	Annual 1985 to 2007 (exc. 2003, 2004)
DS Waters Upton (SJ 6309 1932)	DS of Helshaw Grange; Stoke on Tern; Bolas Bridge.; Waters Upton (SJ 6301 1933)	1988, 1995, 1996, 2005, 2006, 2007

[3] Following completion of the analyses further monitoring data were received (2009 and 2010). This represents a limited extension to the data set. The analysis has not been repeated to include this limited additional data as it is unlikely to alter the conclusions presented in this report.

Table 7.2 (continued) Macroinvertebrate Monitoring Locations and their Proximity to SGS Discharges

Monitoring Location	Proximity to SGS Discharges	Monitoring Periods
Longdon on Tern (SJ 6170 1550)	DS of Helshaw Grange; Stoke on Tern; Bolas Bridge.; Waters Upton	Annual 1985 to 2007 (exc. 2005)
RIVER PERRY		
Platt Bridge (SJ 4030 2230)	US of discharges	Annual 1987 to 2007 (exc. 1988, 1991, 1992, 1999, 2001, 2002, 2004, 2005)
US Adcote outfall (SJ 4213 1976)	US of discharge	1992, 1995, 1996, 1997, 2005, 2006
DS Adcote outfall (SJ 4213 1974)	DS of Adcote (SJ 4213 1975)	Annual 1986 – 2006 (exc. 1991, 1993, 1994; exc 2000 - 2005)
US Grafton Outfall (SJ 4392 1851)	DS of Adcote	1986, 1988, 1995, 1997 2005 2006
DS Grafton Outfall (SJ 4392 1849)	DS of Adcote and Grafton (SJ 4392 1850)	1987, 1988, 1995, 1996, 1997, 2005, 2007
Mytton (SJ 4390 1700)	DS of Adcote and Grafton	1988 – 2007 (exc. 1999, 2002, 2004, 2005)
RIVER SEVERN		
Montford Bridge (SJ 4320 1530)	US of discharges	Annual 1985 to 2007 (exc. 2003)
Isle of Bicton (SJ 4677 1646)	DS of Montford Bridge (SJ 4370 1624) and Leaton (SJ 4612 1781)	Annual 1985 to 2007 (exc 2002 and 2003)
US Monkmoor (SJ 5250 1360)	DS of Montford Bridge and Leaton	1995, 2001, 2006, 2007

There is limited ecological monitoring data available for Potford and Platt Brooks, restricted to four years of macroinvertebrate monitoring data, collected annually at Radmoor (SJ 62389 24444) and Ellerdine (SJ 63000 22700) between 2005 and 2008.

7.1.3 Macrophytes and Riparian Taxa

An overview of the macrophyte fauna associated with the River Perry (Harper 1990[4]) was reviewed. Relevant internet-based information on regional distribution of otter (Environment Agency 2010[5]) and water vole (Shropshire BAP) were also reviewed. However for the reasons described in Section 1.3.1 these taxa were scoped-out of detailed assessment.

7.1.4 Designated Sites

Data on designated sites situated within the wider area surrounding the SGS catchment were collated by The Environment Agency. These data are also held by Natural England (www.naturalengland.org); the MAGIC website (www.magic.gov.uk) and the Local Biological Records Centre (Shropshire Biodiversity Partnership). A

[4] Harper, D. M. (1990). *The Ecology of a Lowland Sandstone River: The River Perry, Shropshire*. Field Studies 7, 451- 468
[5] Environment Agency (2010). *Fifth Otter Survey of England 2009 – 2010*. Technical Report. Environment Agency, Bristol

total of 43 sites were identified (Appendix L). A screening assessment of these sites identified those that are designated for groundwater-dependent features and also potentially within the zone of influence of SGS pumping.

7.2 Current Environment

7.2.1 Fish

Table 7.3 summarises the fish species recorded at monitoring sites on the watercourses to which the SGS discharges. The surveys were undertaken between 1992 and 2010. Monitoring data collected at Cold Hatton and Waters Upton on the River Tern are only available from 2010.

All three watercourses support similar mixed fisheries, comprising salmonid and cyprinid species. All three watercourses are characterised by widespread chub, dace, roach, gudgeon and brown trout. Other species have a more patchy distribution, for example grayling and perch. Notably Atlantic salmon were not recorded on the River Tern during the monitoring, reflecting the fact that within the Tern catchment this species is currently only recorded downstream of Attingham sluice gates (Environment Agency *pers comm*.).

Notable species recorded during the surveys include bullhead (*Cottus gobio*), lamprey (Lampetra sp.) including brook lamprey (*Lampetra planerii*), Atlantic salmon (*Salmo salar*), brown/ sea trout (*Salmo trutta*) and eel (*Anguilla anguilla*). Eel, Atlantic salmon and brown/ sea trout are UKBAP species and are included on the list of Species of Principal Importance for the Conservation of Biological Diversity in England. Brook lamprey is a Shropshire BAP species.

All three lamprey species, Atlantic salmon and bullhead are included on Annex 2 of the European Habitats Directive[6], which requires member states to designate Special Areas of Conservation (SAC) for the protection of notable populations of these species. Sea lamprey (*Petromyson marinus*), twaite shad (*Alosa fallax*) and river lamprey (*lampetra fluviatilus*) are species that are the primary reason for the designation of the River Severn SAC. These species were not recorded at any monitoring sites during the surveys, although river lamprey and brook lamprey are indistinguishable in their larval (ammocoete) form.

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[6] *European Union Directive on the Conservation of Natural Habitats and of Wild Fauna and Flora* 1992 (the Habitats Directive)

Table 7.3 Fish Species Recorded on Rivers to which the SGS Discharges

Species	River Severn			River Tern						Perry			
	Mo	LK	Uf	HF	SoT	Pe	CH	WU	Cr	Mi	FB	AM	F
Atlantic salmon	✓	✓	✓							✓	✓		✓
Barbel	✓	✓	✓										
Bleak	✓	✓	✓										
Brown/sea trout	✓	✓	✓	✓	✓	✓	✓	✓		✓	✓		✓
Bullhead			✓	✓	✓		✓	✓	✓	✓	✓		✓
Chub	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓		✓
Dace	✓	✓	✓	✓	✓	✓	✓	✓	✓		✓		✓
Eel	✓	✓	✓		✓	✓			✓	✓	✓		✓
Grayling			✓		✓	✓				✓	✓		✓
Gudgeon	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓			
Lamprey			✓	✓			✓		✓	✓			
Minnow			✓	✓	✓		✓	✓	✓	✓	✓		✓
Perch			✓		✓	✓			✓		✓		
Pike	✓	✓	✓			✓			✓	✓	✓		
Rainbow Trout				✓									
Roach	✓	✓	✓	✓	✓	✓		✓	✓				✓
Rudd				✓									
Ruffe			✓						✓				
Stickleback				✓	✓		✓		✓	✓	✓		✓
Stone loach			✓	✓			✓	✓	✓		✓		✓

Key: Montford (Mo); Leaton Knowles (LK); Uffinton (Uf); Hall Farm (HF); Stoke on Tern (SoT); Peplow (Pe); Cold Hatton (CH); Waters Upton (WU); Crudgington (Cr); Milford (Mi); Frankbrook (Fb); Adcote Mill (AM); Fitz (F).

Figures 7.1 to 7.4 illustrate variations in fish density estimates on the River Tern at the monitoring sites, throughout the monitoring period, expressed as numbers of fish per 100m^2. Fish density at monitoring sites fluctuates across years. Total fish densities continue to be generally comparable with those previously reported (Peter Bottomley, Proof of Evidence, 1979) based on surveys in 1970 (0.7 to 4.5 fish/100m^2) and 1978 (1 to 9 fish/100m^2).

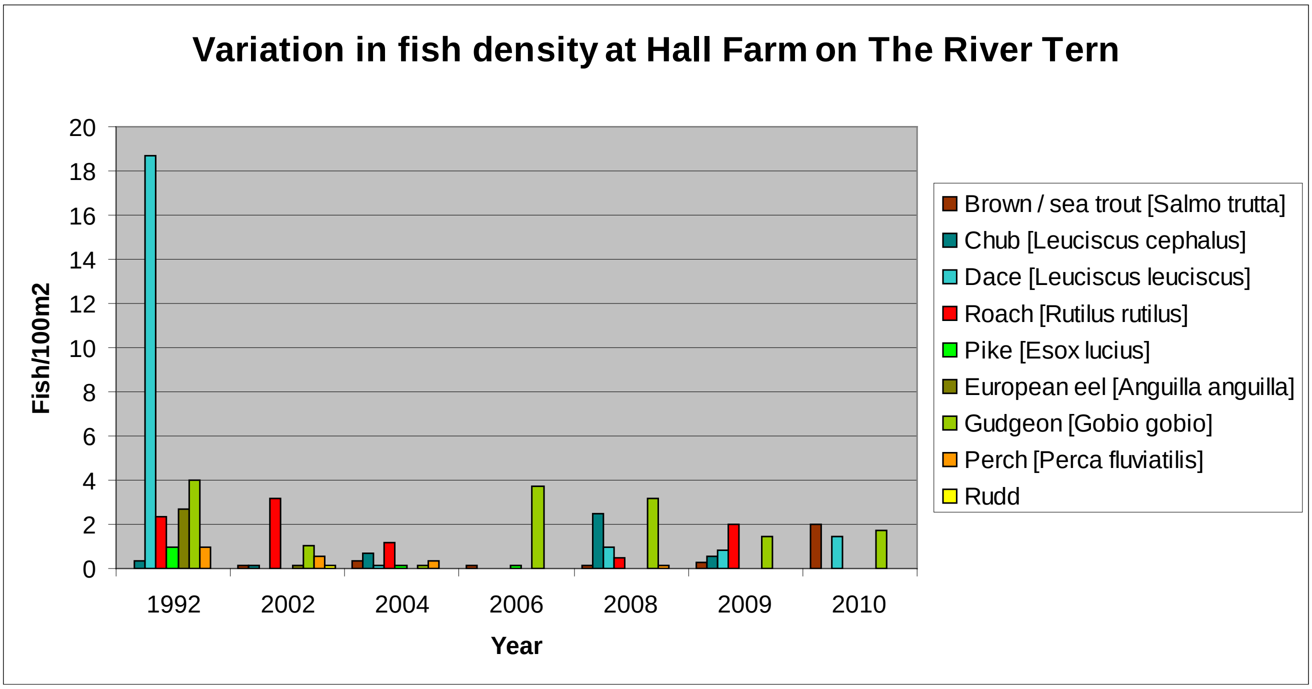
There are no apparent trends in fish density over the monitoring period that could be attributed to the effects of discharges from the SGS downstream from Hall Farm to Crudgington. The apparent absence of trends could be attributable at least in part to the limited number of survey events and numbers of fish caught and used in the population/ density calculations especially as fish are mobile and populations/ assemblages recorded at monitoring locations will vary in response to a range of environmental factors and in some cases isolated events. Fish populations/ assemblages at a given site are like to vary temporally and spatially on the River Tern in particular due to its limited habitat variability (Environment Agency pers comm.).

One notable aspect of the monitoring data is the comparatively high numbers of some species recorded in 1992. This includes Dace densities (c.19/100m2) at Hall Farm and Gudgeon densities (c.57/100m^2) at Stoke on Tern. The latter has been removed from the charts to aid interpretation of the data. These isolated high numbers could be related to shoaling/ spawning behaviour. There are little monitoring data available during the 10 year period 1992 to 2002, which would have put the high 1992 numbers into context.

Trout have recently been recorded at the upper survey sites on the Tern in low numbers, following a period when they were not recorded. Atlantic salmon were not recorded on the River Tern during the monitoring. The record of a rainbow trout (*Oncorhynchus mykiss*) on the River Tern is likely to be an escapee from a fish farm situated upstream on the outskirts of Market Drayton.

Fish growth rates on The River Tern have historically been average to fast for some species, notably brown trout, roach, dace and chub (Bottomly 1979; Voyce 2008[7]). However these growth rate studies have not been repeated recently.

Figure 7 1 Variation in Fish Density at Hall Farm on the River Tern



[7] Voyce, K. (2008). Presentation to Geological Society – Hydrogeology Group on Groundwater Management – Shropshire Ground Water Scheme

Figure 7.2 Variation in Fish Density on the River Tern at Stoke on Tern

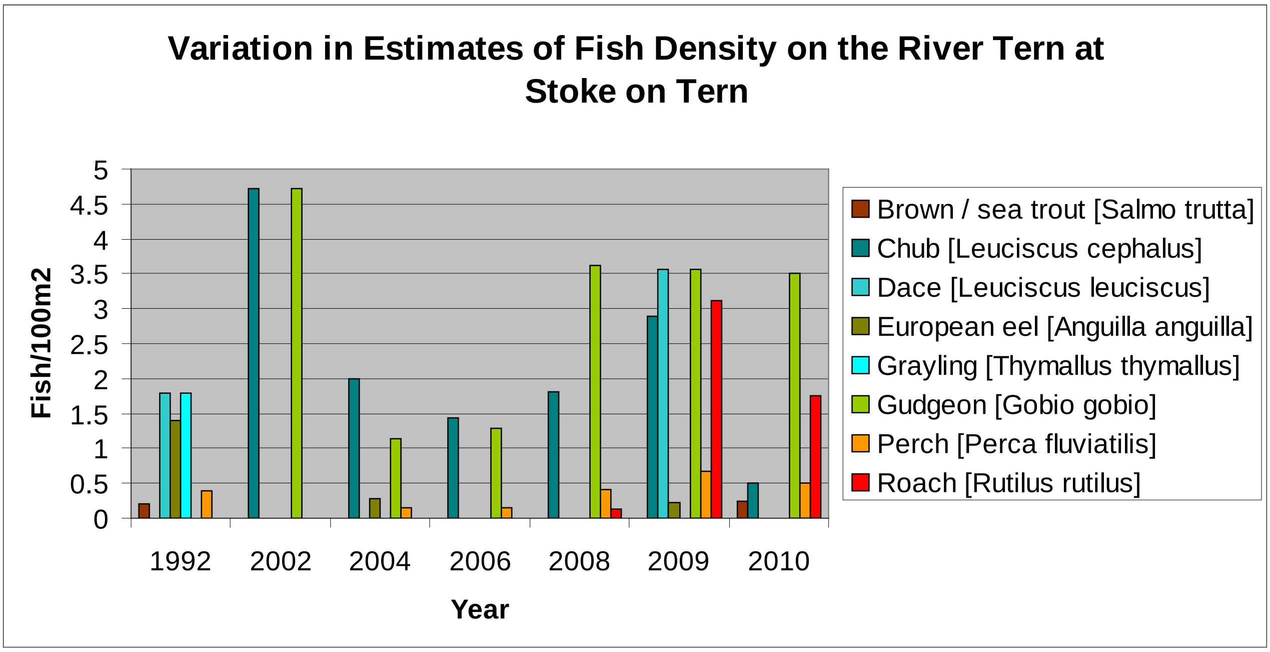


Figure 7.3 Variation in Fish Density on the River Tern at Peplow

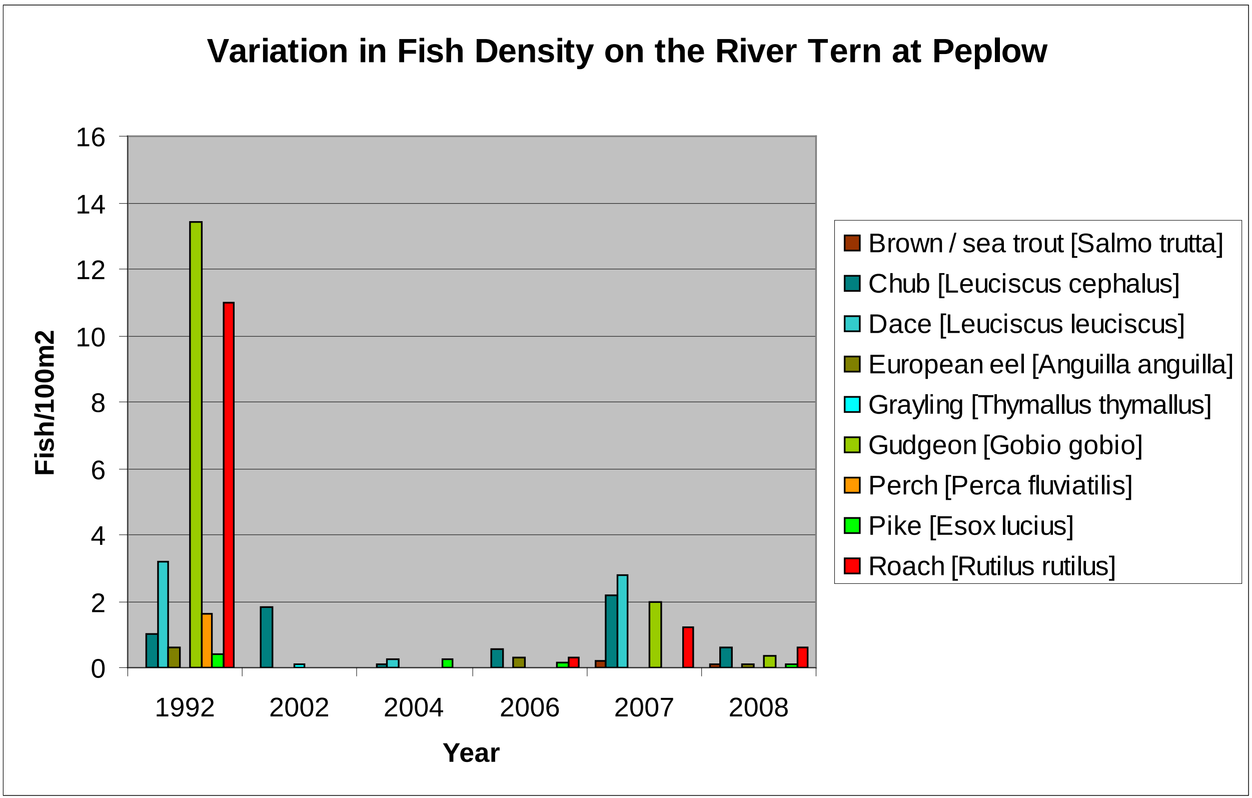
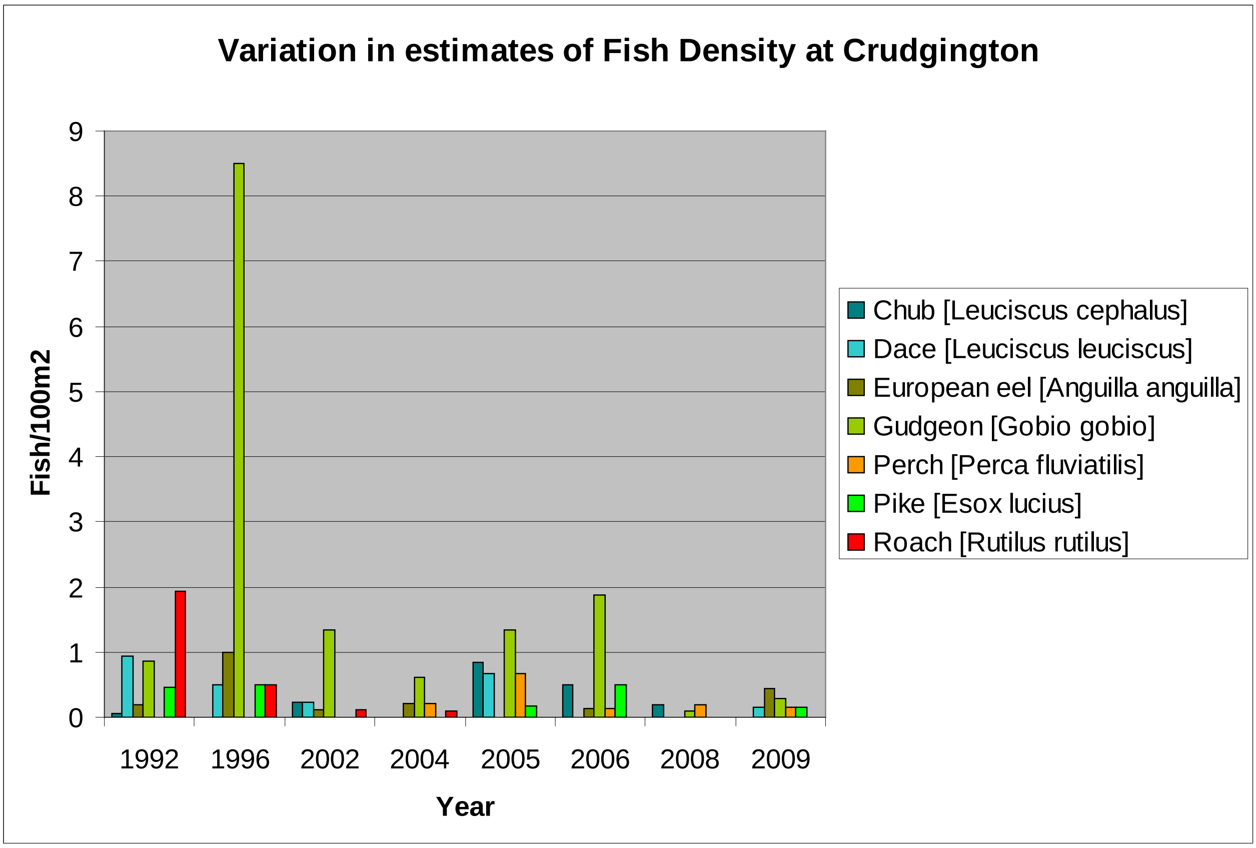


Figure 7.4 Variation in Fish Density on the River Tern at Crudgington



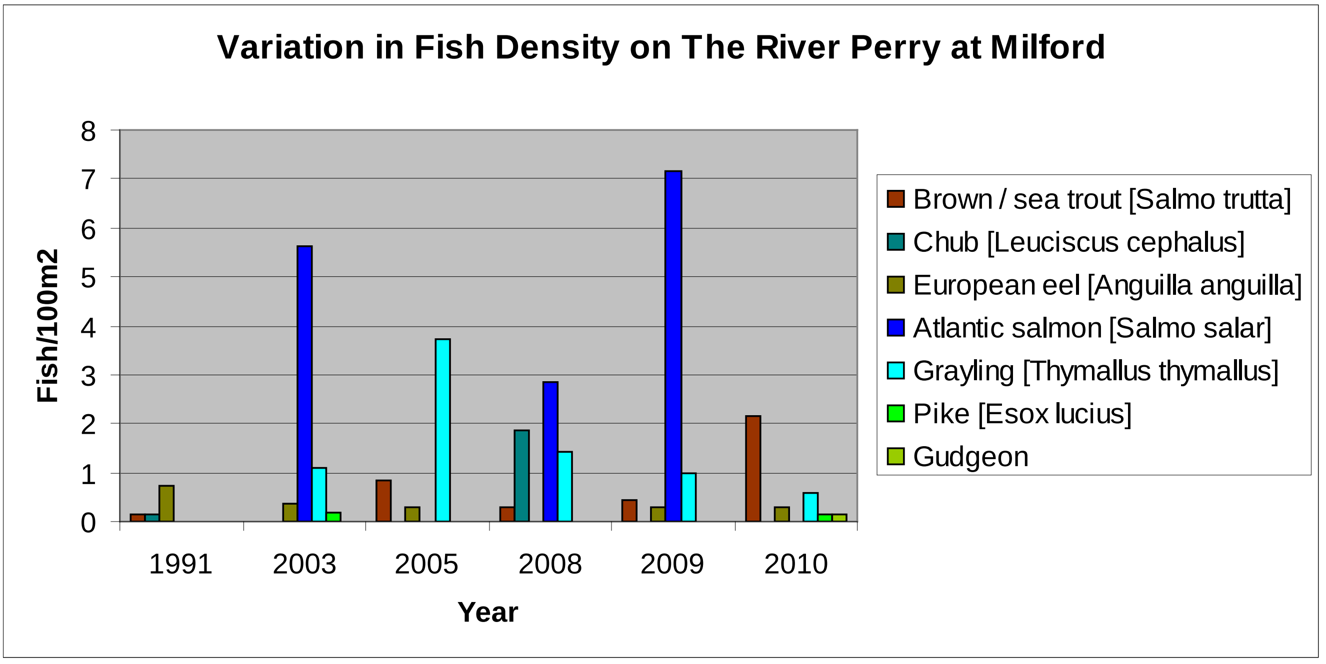
Figures 7.5 to 7.7 illustrate patterns of fish density estimates on the River Perry. The overall fish densities are comparable to those reported by Peter Bottomley (Proof of Evidence, 1979). They are lower than the combined fish density (11 to 105 fish/m^2) estimates reported on the Perry in 1978, however these high densities were potentially attributable to spawning dace (Peter Bottomley 1979).

Trout densities exhibit a slight upward trend, albeit not reaching levels recorded on the River Tern in 1978. The presence/ numbers of trout may be influenced by stocking. Atlantic salmon densities are relatively low, reaching a maximum of 7/100m^2 at Milford in 2009. The apparently low numbers of trout and salmon appear consistent with the Rivers and Streams Habitat Action Plan (Shropshire Biodiversity Action Plan) which comments that salmon spawning habitats on the River Tern (Attingham Park) and River Perry (Mytton Mill) have in places deteriorated due to compaction, and changes in composition, of gravels.

There are no apparent trends in fish density that could be attributed to the effects of previous discharges from the SGS downstream from Milford to Fitz. The apparent absence of trends could be attributable at least in part to the limited number of survey events and the numbers of fish caught and used in the population/ density calculations, especially as fish are mobile and populations/ assemblages recorded at monitoring locations will vary in response to a range of environmental factors and in some cases isolated events.

Fish growth rates on The River Perry have also historically been average to fast for some species, notably brown trout, roach, dace and chub (Bottomly 1979; Voyce 2008[8]). However these growth rate studies have not been repeated recently.

Figure 7.5 Variation in Fish Density on the River Perry at Milford



[8] Voyce, K. (2008). Presentation to Geological Society – Hydrogeology Group on Groundwater Management – Shropshire Ground Water Scheme

Figure 7.6 Variation in Fish Density on the River Perry at Frank Brook

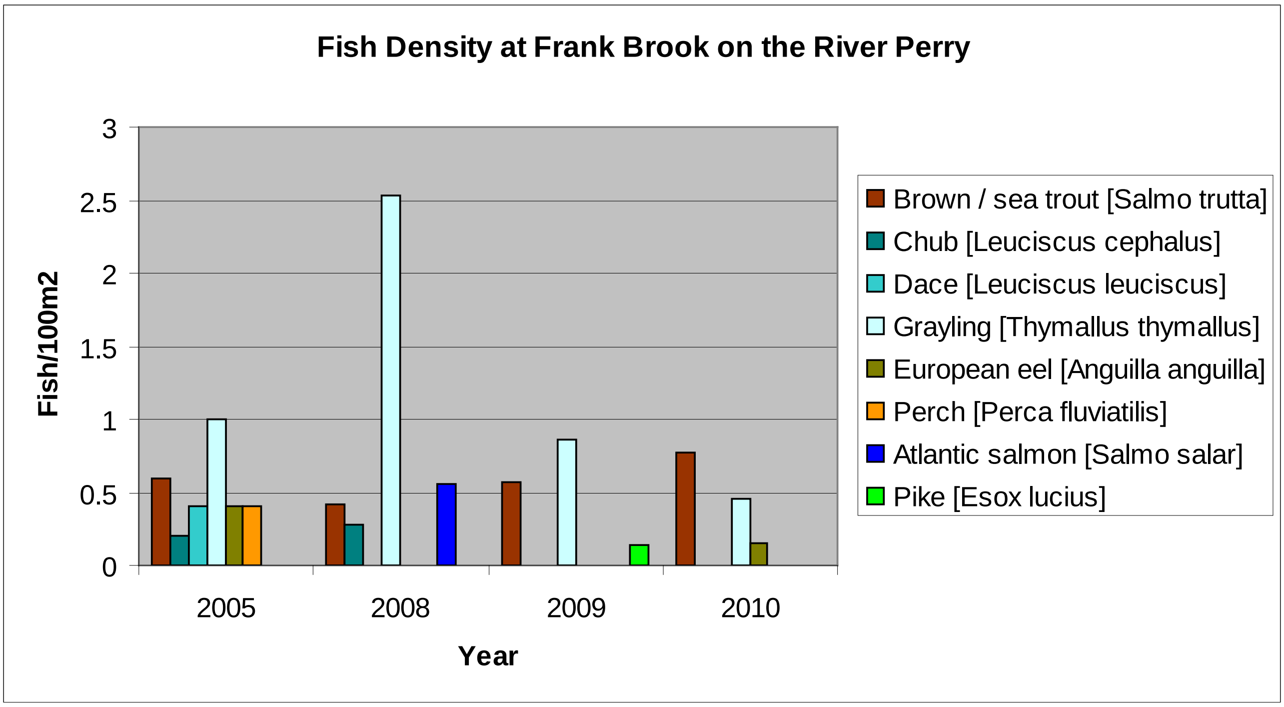
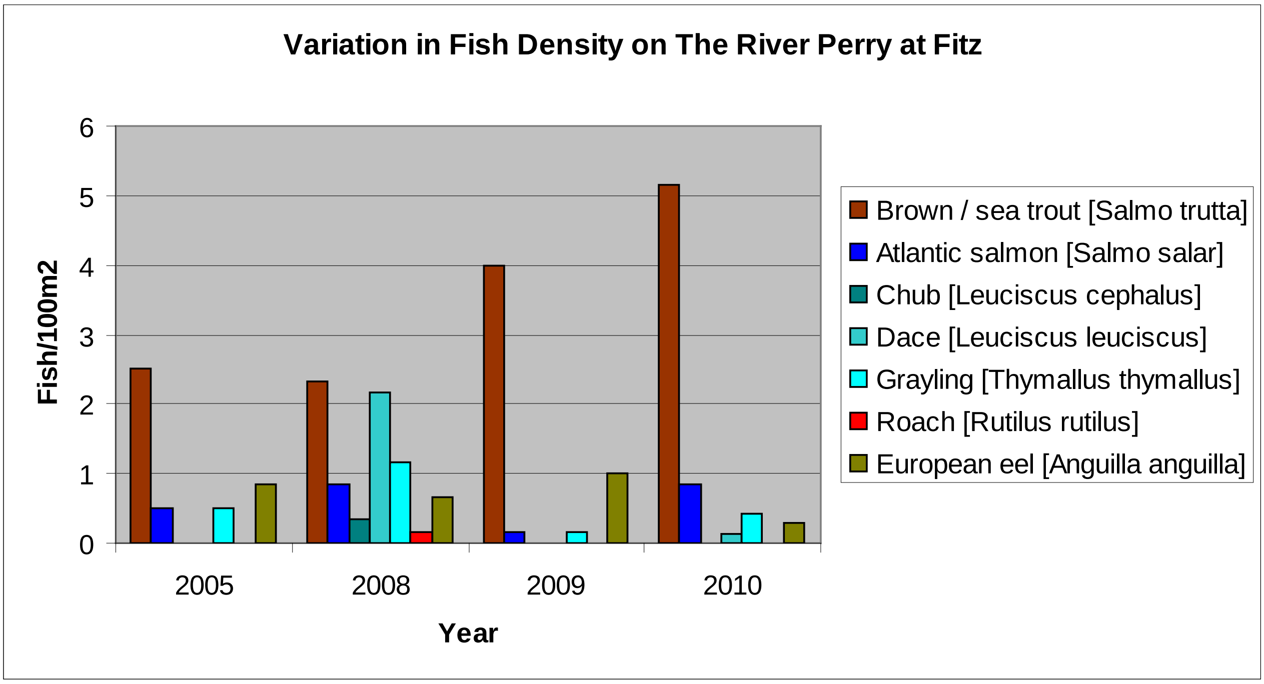


Figure 7.7 Variation in Fish Density on the River Perry at Fitz



7.2.2 Macroinvertebrates

The River Severn and its tributaries support a diverse range of macroinvertebrate species. Mayfly species recorded most frequently in the upstream monitoring sites include numerous *Baetis rhodani*, *Heptagenia sulphurea*, *Ephemera danica* and *Seratella ignita.* Stoneflies appear to be less abundant, including occasional *Isoperla grammatica.* Prominant caddisfly species recorded include numerous *Hydropsyche pellucidula*, frequent *Sericostoma personatum* and *Agapetus fuscipes*. The upper reaches also support numerous river limpet (*Ancyllus fluviatilus*). Frequently recorded water snails include *Lynea peregra*, *L. Stagnalis* and *Gyraulus albus*. Pea mussels (Sphaeridae), freshwater shrimps (*Gammarus pulex*), water hoglice (*Asellus aquaticus*), water beetles (such as *Limnius volckmari* and *Elmis aenea)* and a leech species (*Glossiphonia complanata*) were also frequently recorded throughout the watercourses. Sphaeriidae, Oligochaeta, water mites (*Hydracarina* sp.), chironomids and simulids are also abundant.

The River Tern and Perry support a similar assemblage of invertebrates. The most recent (2009/2010) survey samples taken on the Perry appear to have included comparatively fewer mayflies of the species *Baetis rhodani*, *Ephemera danica* and *Seratella ignita*. *Lymnaea peregra*, Sphaeridae and Pisidium appear to be more abundant, as did the water beetles *Limnius volckmari*, *Elmis aenea* and *Oulimnius* sp. The Perry samples also appear to support more of the caddis species *Hydroptila* sp. and *Brachycentrus subnubilus* and fewer *Sericostoma personatum and Hydropsyche contubernalis.*

7.2.3 Macrophytes

The macrophyte fauna associated with the River Perry (Harper 1990[9]) is characterised by abundant *Elodea Canadensis*, *Myriophyllum spicatum*, *Ranuculus fluitans* and *Potomogetan pectinatus* in the faster flowing riffles and runs; and *Callitriche stagnalis*, *Sparganium emersum* and *Potamogeton perfoliatus* in slower flowing runs and pools. There is also abundant filamentous alga (*Cladophora glomerata).* The river margins support *Myosotis scorpiodes*, *Veronica beccabunga*, *Phalaris arundinacea* and *Nasturtium officinale*. Stillwater areas support *Lemna minor*. This assemblage is typical of relatively Eutrophic reaches of the middle to lower catchment. Based on limited internet-based information (Harvey 2006[10]), it appears likely that the River Tern would support similar macrophyte species.

7.2.4 Other Riparian Taxa

The number of sites occupied by otters is continuing to steadily increase as this species spreads throughout the Severn catchment (Environment Agency 2010). Water voles have a much more localised distribution in Shropshire (Shropshire BAP), although the River Perry is known to be a stronghold for this species within the County.

[9] Harper, D. M. (1990). *The Ecology of a Lowland Sandstone River: The River Perry, Shropshire*. Field Studies 7, 451- 468
[10] Harvey, G. (2006). *Characterising physical habitat at the reach scale: River Tern, Shropshire*. PhD thesis, University of Nottingham.

7.2.5 WFD Status

The EC Water Framework Directive (Directive 2000/60/EC) is the main legislation relating to the protection of water quality and the ecological status of freshwaters and coastal waters. As part of the process of implementing WFD in the UK the Environment Agency has divided surface waters into discrete units termed ‘water bodies’, which have been assigned into different categories (typologies) based on their physical and ecological characteristics. Each WFD water body has also been assigned an ‘ecological status’ class based on its ecology and water quality. The status assigned to a water body is the lowest status assigned to any single parameter, for example a waterbody would be assigned ‘Moderate’ status where its invertebrate assemblage is at ‘Moderate’ status, even where all other ecological and water quality parameters are at ‘Good’ status.

The WFD requires that all water bodies must reach ‘Good’ overall status by 2015 and that the status of all surface water bodies must not deteriorate. Where it is deemed by the Environment Agency that it is not technically or economically feasible for a waterbody to achieve ‘Good’ Status by 2015, the attainment of this target has in most cases been put back to 2027.

The Environment Agency’s River Basin Management Plans provide the framework for implementing and monitoring ‘Programmes of Measures’ intended to work towards achieving Good Ecological Status. The Ecological Status and objectives for the River Severn and its tributaries is set out in *River Basin Management Plan – Severn River Basin District* (Environment Agency 2009, updated in 2011).

The current Ecological Status of waterbodies on the River Tern and River Perry is summarised in Table 7.4. The reasons for any failure by these waterbodies to achieve ‘Good’ Status are also identified. The predicted status of the waterbodies by 2015 is also stated and where this deviates from the generic WFD target of ‘Good’ status the justification is identified. The current Status of the three main biological elements (fish, invertebrates and phytobenthos) are also specified.

Table 7.4 Ecological Status of receiving Watercourses (Environment Agency 2009, updated 2011)

Waterbody	Overall Status	Reason (<'Good')	Justification (<Good 2015)	Fish		Invertebrates		Phytobenthos	
				Status	Predicted (2015)	Status	Predicted (2015)	Status	Predicted (2015)
RIVER TERN									
Source to conf Loggerheads Brook	Moderate (Uncertain)	Phosphate	Disproportionately Expensive	Good	Good	-	-	-	-
Conf. Loggerheads Brook to conf Coal Brook	Moderate (Uncertain)	Phytobenthos	Disproportionately Expensive	-	-	Good	Good	Moderate (Q. Certain)	Moderate
Conf. Coal Brook to conf. Bailey Brook	Poor (Quite Certain)	Phytobenthos	Disproportionately Expensive	Good	Good	Good	Good	Poor (V. Certain)	Poor
Conf. Bailey Brook to conf. R. Meese	Poor (Quite Certain)	Fish; Phytobenthos	Technically infeasible Disproportionately Expensive	Moderate (Uncertain)	Moderate	Good	Good	Poor (V. Certain)	Poor
Conf. R. Meese to conf R. Roden	Moderate (Uncertain)	Phytobenthos	NA	Good	Good	Good	Good	Moderate (Uncertain)	Moderate
Conf. R. Roden to conf R. Severn.	Moderate (Very Certain)	Fish; Invertebrtaes	NA	Moderate (Uncertain)	Good	Moderate (Uncertain)	Good	-	-

Table 7.4 (continued) Ecological Status of receiving Watercourses (Environment Agency 2009, updated 2011)

Waterbody	Overall Status	Reason (<'Good')	Justification (<Good 2015)	Fish		Invertebrates		Phytobenthos	
				Status	Predicted (2015)	Status	Predicted (2015)	Status	Predicted (2015)
RIVER PERRY									
Source to conf. Common Brook	Moderate (Uncertain)	Fish	Technically infeasible	Moderate (Uncertain)	Moderate	Good	Good	-	-
Conf. Common Brook to conf Tetchill Brook	Poor (Very Certain)	Fish	Technically infeasible	Poor (V. Certain)	Poor	Good	Good	-	-
Conf. Tetchill Brook to conf. R. Severn	Moderate (Very Certain)	Fish	Technically infeasible	Moderate (Q. Certain	Moderate	High	High	-	-
PLATT BROOK									
Source To conf River Tern	Moderate (Uncertain)	Phosphate	-	-	-	-	-		

7.2.6 Designated Sites

The Environment Agency's Biodiversity team identified a total of 43 sites designated for either nature conservation or geology/geomorphology situated within the operational area of the SGS. This includes eight notified as Sites of Special Scientific Interest (SSSI), two of which are wetlands of international importance (Ramsar sites); and one Local Nature Reserve (LNR). This list also includes 34 non-statutory sites, designated as Sites of Importance for Nature Conservation (SINC). These sites support a variety of habitat types, including watercourses, wetlands, marsh, open grassland, mixed scrub and woodlands. A small number of sites are designated for geomorphological and geological features. The details of these sites are summarised in Appendix L.

7.3 Assessment of Impacts on Current Environment

7.3.1 Scope of Assessment

The effects of a Drought Order on river hydrology have been informed by predictive simulations of the different Phases of the SGS[11]. The predicted effects of the Drought Order and increased operation of the SGS on the hydrology of the receiving watercourses were modelled for different drought scenarios. Specifically the effects of SGS releases have been predicted for a severe drought similar to 1976 (1976 drought scenario). This scenario has also been compared with the predicted effects of a modelled, more extreme drought scenario (extreme drought scenario) i.e. a peak demand sequence (1993 to 1996) followed by a severe drought (1976).

The assessment focuses on the River Tern and River Perry. These smaller tributaries receive multiple discharges from the SGS; are likely to have an ecology that is comparable to the middle reaches of the River Severn; and are likely to have generally more limited capacity than the Severn to buffer changes in, for example, water quality or temperature.

The assessment of the effects of the Drought Order focuses on ecological receptors (water dependent designated sites; fish; and aquatic macroinvertebrates) that are likely to be sensitive to the changes in hydrology that the scheme is predicted to bring about. These receptors are also likely to be the most sensitive indicators of any long-term changes in the ecology of the receiving watercourses that have occurred as a result of the operation of SGS. Riparian species such as otter, water voles, bats and birds are unlikely to be affected by the magnitude of temporal/ transient changes in flow that the scheme is predicted to bring about and therefore have been scoped-out of further assessment.

There is a degree of inherent uncertainty associated with this assessment because it is difficult to predict the precise hydrological conditions that will occur at the time the Drought Order is sought. The effects of the operation of the SGS and hence a Drought Order are also difficult to predict because its operation varies from year-to-year in terms of volume, frequency, duration and timing of releases, although releases predominantly take place between May

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[11] ESI Ltd (2011). *East Shropshire Permo-Triassic Sandstone Model: Predictive Simulations for Shropshire Groundwater Scheme Phases 1-4 Drought Order*. Technical Report prepared for the Environment Agency.

and September. There is also a lack detailed, long-term pre-scheme baseline monitoring data that is comparable to, and would have put into context, the recent monitoring data.

The assessment is based on the infrequent application of a Drought Order and the operation of SGS releases for discrete periods of limited duration. It is also on the basis that it is unlikely that repeated application of a Drought Order and/or prolonged periods of SGS pumping will occur in consecutive years. If this did become necessary it would need to be subject to further assessment.

7.3.2 Fish

The Drought Order could have a number of potential effects on fish populations. The changes predicted to occur as a result of the Drought Order are an increase in the proportion of groundwater contributing to river flow and an associated reduction in temperature; increased flow compared to what would otherwise be the case during drought periods; and localised changes in concentrations of dissolved chemicals, where concentrations in groundwater and the receiving watercourse differ. These changes could potentially influence fish population size and structure; migration and dispersal; spawning behaviour and recruitment; and the growth and survival of individuals. The following, although not exhaustive, describes the likely effects on fish populations.

Hydrology

The Drought Order and associated operational augmentation releases by the SGS is predicted to increase summer flow within the receiving watercourses above what would otherwise be expected during drought conditions. This increase is predicted to be within the range 42% to 76% on the River Tern and Perry during periods of drought similar to those in 1976; increasing up to approximately 95% during a modelled more extreme drought scenario. These increases are likely to occur over discrete periods (upto 12 weeks) during the period May to September, affecting discrete lengths of watercourse. Although the predicted increases attributable to the Drought Order are substantial as a proportion of low summer flows, the resulting overall flow is expected to remain within normal summer limits (see Table 5.10). Therefore this increase is likely to alleviate, to a limited extent, the effects of summer drought conditions on fish, which may occur in surrounding watercourses that do not receive SGS discharges:

- Reductions in river width during a drought can expose spawning substrates and nursery habitats;
- Reductions in flow and velocity can lead to silt accumulation in gravels, rendering them less suitable as spawning substrate for salmonids, lamprey and cyprinid lithophils;
- Reductions in water depth (and associated flows and velocity) at low flows during summer can reduce the available juvenile habitat for fish and increase intra-specific competition for food resources, resulting in reduced growth and survival of individual fish, with implications for population size and structure;
- Adult salmonids and cyprinids often reside in deeper pools and around undercut banks, with salmonids in particular often being associated with deeper, fast flowing glides (Cowx et al., 2004). Reductions in water depth (and associated flows and velocity) at low flows can reduce the available habitat for adult fish and increase intra-specific competition for food resources;

- Elevated water temperatures experienced during drought conditions can potentially affect the fish communities. Fish species have well defined physiological thermal tolerances, and these are sometimes exceeded in drought conditions (Cowx et al. 1984), potentially leading to temperature-induced mortality;

- Marginal areas with accumulations of silt provide suitable habitat for lamprey ammocoetes, whereas adult lamprey require clean spawning gravels for successful reproduction. Reductions in river width at low flows can expose areas of marginal silt utilised by ammocoetes;

- Reductions in depth and velocity at low flows can reduce connectivity within the river system restricting fish movements. The effects on fish of barriers to both upstream and downstream migration, including natural and man-made obstacles, can be exacerbated by drought conditions.

Not withstanding temperature effects summarised below, by increasing river flows and alleviating some of the effects listed above during drought conditions, the SGS is likely to have a limited positive effect on fish.

Temperature

The temperature of groundwater released to the surface watercourses is typically at approximately 10°C. The temperature of the receiving watercourse varies however in summer on the Tern and Perry it is frequently around 22°C. The resulting river temperatures downstream of discharges are therefore within the natural temperature variation experienced by fish. The effects of the release of cold water on the receiving watercourse broadly include (Cowx 2000): suppression of diurnal variation in temperature; reduced mean summer temperature; and increased autumn/ spring temperature. Reduced spring/ summer temperatures in particular can affect juvenile fish by reducing invertebrate food availability and fry survival and impeding the development of strong year classes.

Previous studies (Cowx 2000[12]) demonstrated that augmentation of surface watercourses via release of cooler groundwater have the potential to have deleterious effects on Cyprinid recruitment and growth, potentially leading to a decline in fish stocks. Although temperature changes observed downstream of discharges can be limited, the change in the overall cumulative degree-days over the course of a given year can be more notable. This previous study (Cowx 2000) on the River Ouse indicated that although water temperatures where typically predicted to be reduced by c.0.6°C as a result of augmentation, the number of cumulative degree days was reduced by 200 by prolonged augmentation during the summer months of a warm year. This study identified a significant correlation between cumulative number of degree days above 12°C and the length of roach, dace and chub fry. A significant correlation was also reported between cumulative number of degree days above 12°C and year class strength[13] in roach and gudgeon.

The operation of SGS reduces temperatures by up to 5.6°C at the point of first discharge to the watercourse during short periods of pumping at maximum licensed output. The cooler water appears to exhibit a streaming effect, remaining cooler close to the bank on the inside of meander bends (Appendices I, J, K). It is also possible that the coolest, denser water remains close to the river bed. Any prolonged changes in temperature of this magnitude

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[12] Cowx, I. G. (2000). *Potential impact of groundwater augmentation of river flows on fisheries: a case study from the River Ouse, Yorkshire, UK*. Fisheries Management and Ecology, 2000, 7, 85-96. University of Hull, Hull, UK.
[13] A measure of the number of fish surviving their first year

could be expected to have significant effects on fish growth and survival/recruitment, potentially turning a strong year class into a weak one. However this temperature change appears to be localised and appears to dissipate quickly, with temperatures being restored to upstream temperature within approximately 100m downstream of the outfall (Appendices I, J, K). In-channel structures that extend into the channel downstream at one outfall, perpendicular to the bank, also appear to enhance mixing and restore temperatures quickly. Therefore the current operation of the scheme and an associated temperature reduction, occurring infrequently and limited to a short length of river, appears likely to have no significant effects on fish populations.

During an extreme drought scenario, the Drought Order is predicted to lead to a small increase in the proportion of SGS groundwater making up total river flow at the point of discharge by 1% to 5% in addition to the benchmark 1976 river flows. This is expected to lead to a further temperature reduction at the point of discharge, after mixing, of 0.1 to 0.6°C. Based on the findings of the initial study (Appendices I, J, K) into temperature change downstream of the outfall, a change of this magnitude is unlikely to extend the cooling effect a substantial distance downstream beyond that anticipated in Section 6.5.2, and is therefore also unlikely to have significant effects on fish populations. However further work is required to verify the results of these temperature investigations.

Water Quality

Concentrations of metals and other determinands within groundwater and surface water have been compared (Section 6) at each discharge location. These concentrations have also been compared with water quality standards (Water Framework Directive 2000 and Freshwater Fish Directive 2006). The majority of determinands are at lower (or similar) concentrations in groundwater than those measured in the receiving rivers, resulting in a diluting effect of the discharge and a localised improvement in water quality.

A limited number of determinands (cadmium, nickel and orthophosphate) regularly occur at concentrations in groundwater that are higher than both the surface water concentrations and the corresponding Environmental Quality Standards (EQS). This is often the case with respect to Orthophosphate in particular. However after mixing and within a short distance downstream of the discharge location these concentrations are likely to be below the required water quality standards. The effects of these exceedances of water quality standards are therefore likely to be extremely localised and dissipate within a short distance downstream of the discharge. These localised changes in water quality in proximity to the discharge locations are unlikely to have significant effects on fish populations.

Groundwater typically has significantly lower levels of dissolved oxygen than surface water. This typically equilibrates within a short distance downstream of the discharge location or via agitation (Cowx 2000). Furthermore the main SGS discharges exceed 75% oxygen saturation and are therefore unlikely to have an effect on Dissolved Oxygen in the receiving watercourses. Therefore changes in oxygen concentration are likely to be limited, localised and are unlikely to have significant effect on fish populations.

7.3.3 Macroinvertebrates

Hydrology

Changes in flow regime can impact macroinvertebrate communities by for example changes in wetted width, flow, sediment dynamics and water quality. These changes can result in reductions in individual populations or shifts in community structure i.e. from a predominance of species which favour fast flowing environments, to a predominance of those species which are adapted to slower flowing environments.

As described above (Box 1.2), LIFE score (Extence, Balbi and Chadd, 1999) is a biotic indices that 'describes' the flow preference of invertebrate assemblages, recognising that different invertebrate families and species and hence assemblages exhibit clear preferences for particular ranges of flow/ velocity. Therefore by examining trends in LIFE score (in this case LIFE-family) it is possible to investigate any apparent flow-related effects on invertebrates, with higher LIFE(f) score indicating assemblages with preference for higher flow velocities.

Initially it is necessary to identify any apparent link between flow and LIFE score in the study river, before considering any perturbating effects of the operation of the SGS on this relationship, recognising that it is impractical to assess effects of flow regulation/ alteration on a macroinvertebrte community where no such relationship can be detected. It should also be noted that the relationship between flow and LIFE can be steeper for more heavily modified reaches of watercourses i.e. modifications to watercourses can mean invertebrate assemblages are more susceptible to shifts in composition in response to flow.

LIFE scores recorded upstream and downstream of two discharges on the River Tern and Perry were plotted against a range of antecedent flow parameters. The objective was to assess the 'strength' of any predictive relationships between these different flow parameters and LIFE(f) score. The statistic used to measure the strength of this relationship is R^2, where $R^2 = 1$ indicates that flow predicts 100% of the variation in LIFE score; and $R^2 = 0$ means flow does not predict LIFE score at all.

Figure 7.8 to 7.11 illustrate the relationship between different antecedent mean monthly flow parameters and LIFE score at four invertebrate monitoring locations. The best correlation between mean monthly flow and LIFE(f) occurs at sites downstream of discharges at Stoke on Tern on the River Tern and Grafton on the River Perry. In both these cases flow measured between approximately 9 to 18 months in advance of invertebrate sampling appear to have the best correlation with LIFE(f). Conversely there appears to be a poor correlation between LIFE(f) and antecedent flows downstream of the Waters Upton discharge on the Tern and the Adcote discharge on the River Perry.

Figure 7.12 indicates that LIFE scores recorded on the River Tern upstream of all SGS discharges at Buntingsdale Bridge are comparable with those recorded downstream of the discharges at Longdon-on-Tern. This suggests there are no notable cumulative downstream effects of SGS discharges on the Terns macroinvertebrates in terms of the flow preference of the assemblage recorded. Figure 7.13 also appears to indicate LIFE scores on the River Perry do not vary notably between the upstream and downstream sample sites, the latter being under greater influence of SGS discharges. However caution is necessary in drawing conclusions regarding this relationship as no detailed statistical analyses have been undertaken. Similarly, given the different locations of the sample sites, variables other than SGS could influence flow and LIFE score, for example river habitat structure and other water inputs.

Figures 7.14 to 7.16 (below) also indicates that LIFE(f) values remain comparable above and below specific discharge locations on both the River Tern and Perry. LIFE(f) recorded on Potford and Platt Brooks are comparable with those recorded elsewhere on the River Tern. However these watercourses differ considerably and limited invertebrate monitoring data from Potford and Platt Brook were available to inform the assessment. Future monitoring and assessment will therefore include comparison of Observed versus Expected biotic indices using outputs from the Environment Agency's RIVPACS database.

Based on the available data set, there appears to be no clear correlation between antecedent flow and LIFE(f) recorded on the Tern and Perry. It is therefore likely that any flow-induced changes in invertebrate assemblages in response to the infrequent operation of the scheme for discrete periods will be temporary and undetectable. Furthermore, in lotic environments macroinvertebrates can quickly recolonise once suitable conditions are restored due to immigration from upstream habitats. Therefore based on the assessment significant effects on invertebrates due to changes in flow do not appear likely.

Figure 7.8 Mean Flow Correlations to Family LIFE Scores for Stoke on Tern (River Tern)

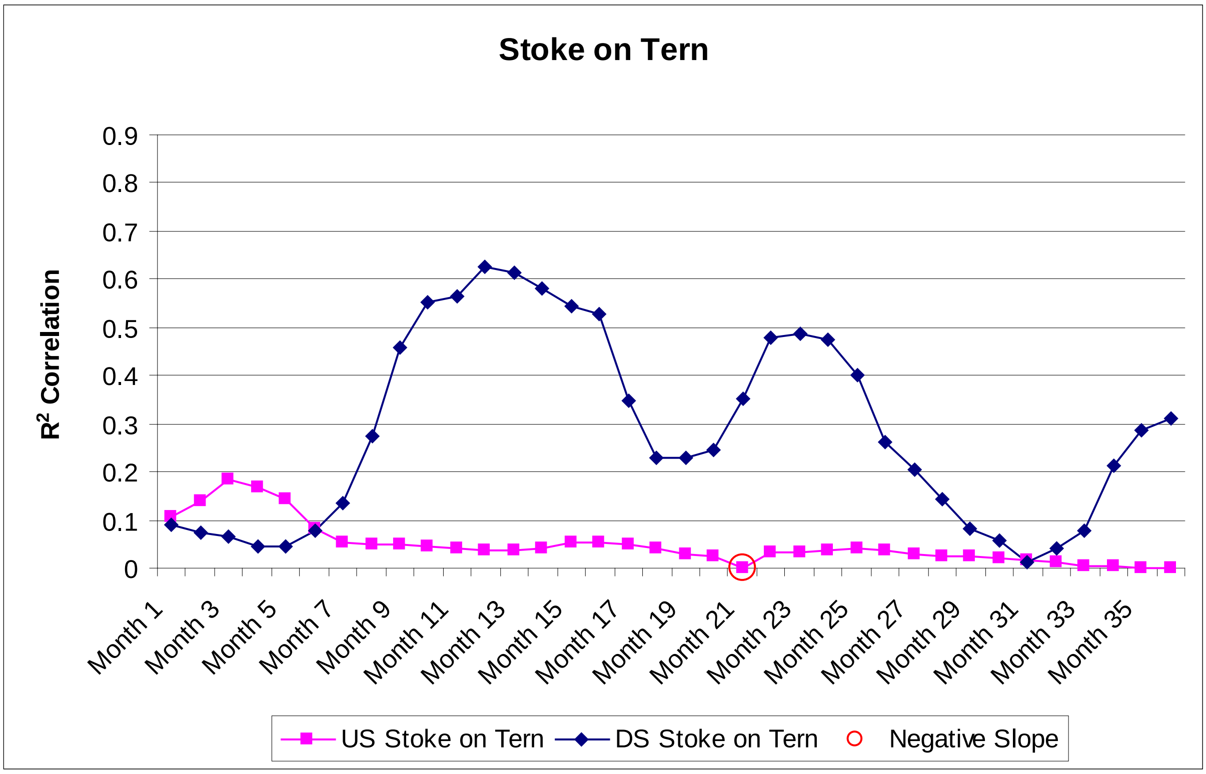


Figure 7.9 Mean Flow Correlations to Family LIFE Scores for Grafton (River Perry)

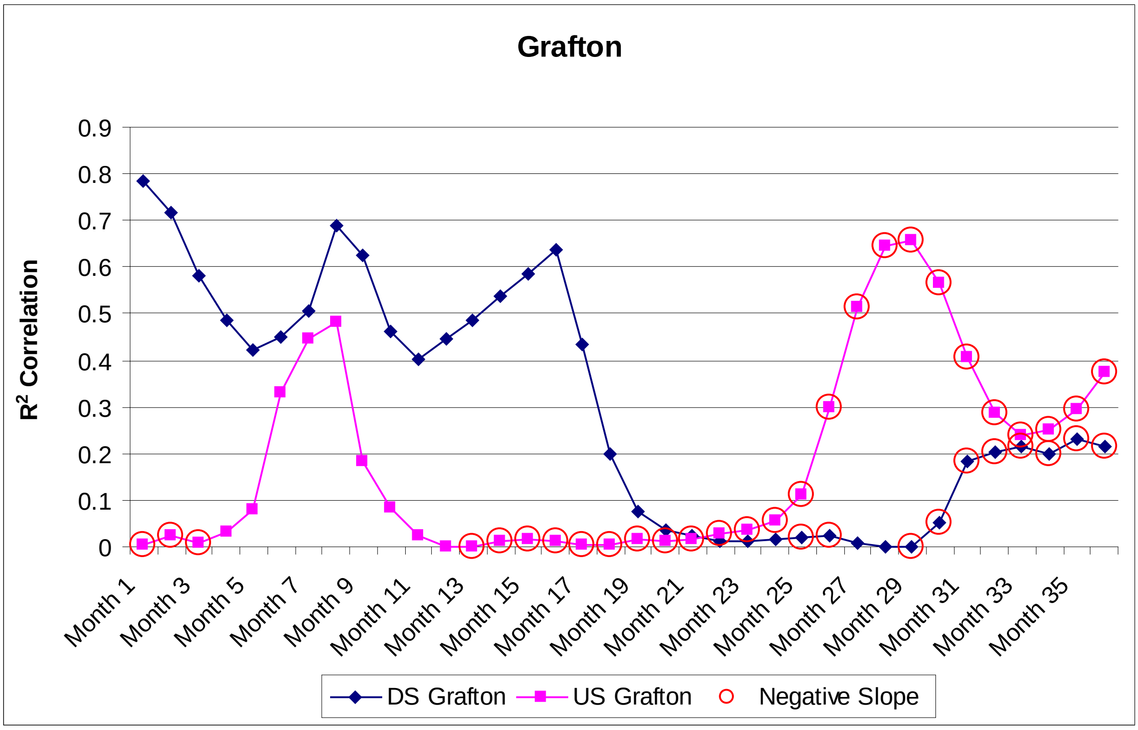


Figure 7.10 Mean Flow Correlations to Family LIFE Scores for Adcote (River Perry)

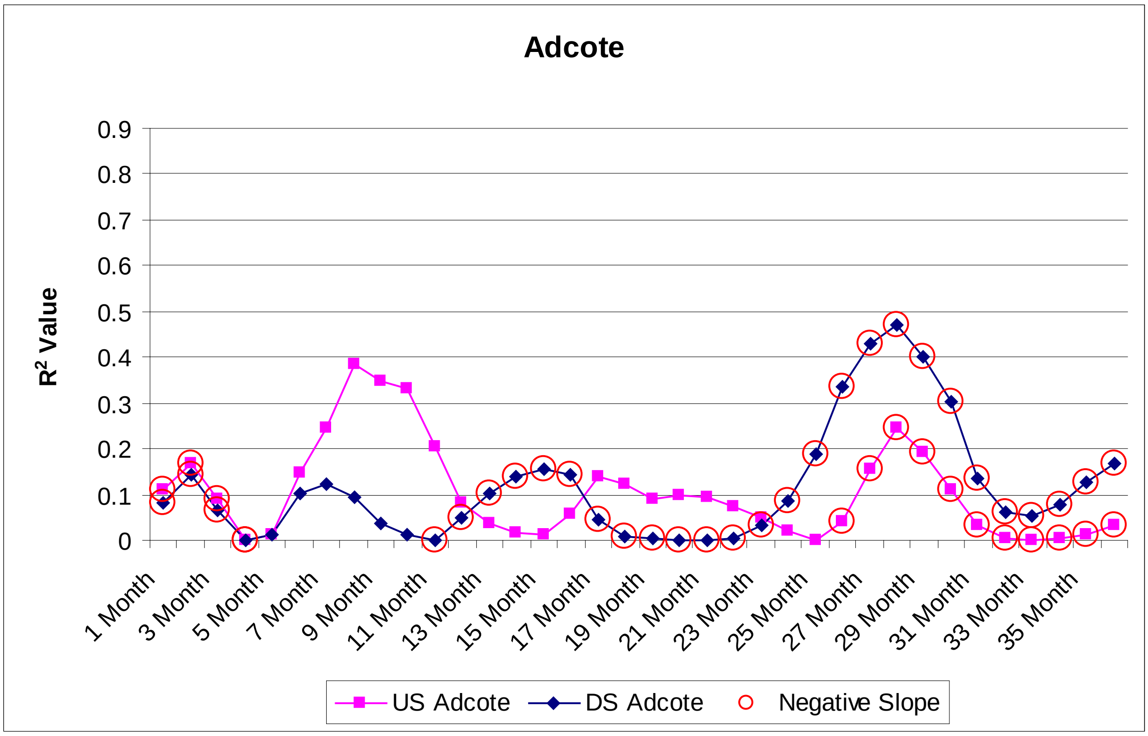


Figure 7.11 Mean Flow Correlations to Family LIFE Scores - Waters Upton (River Tern)

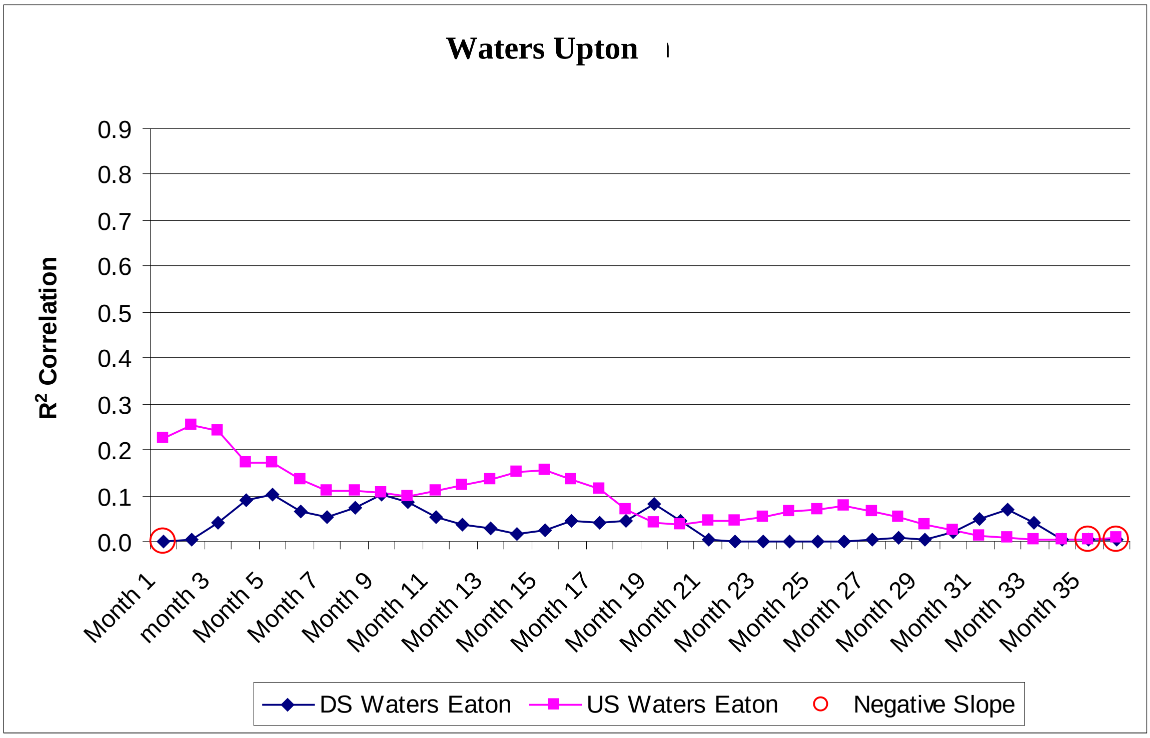


Figure 7.12 Comparison of LIFE Scores: River Tern

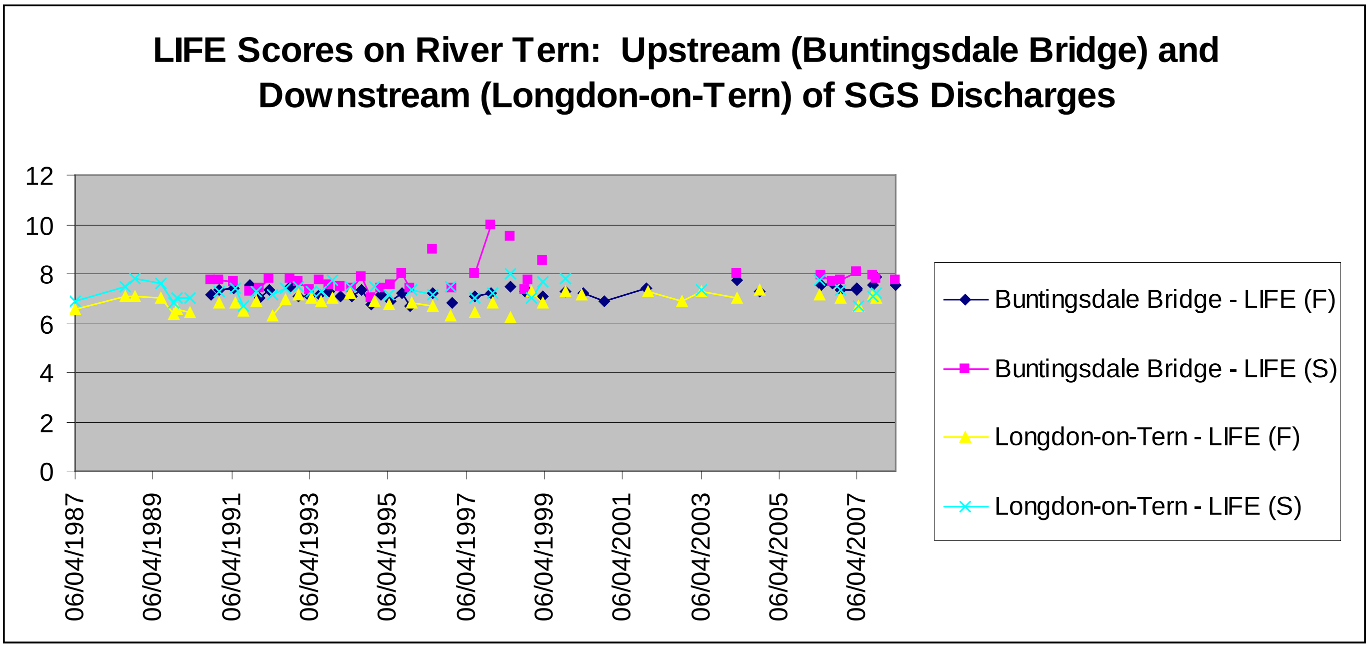
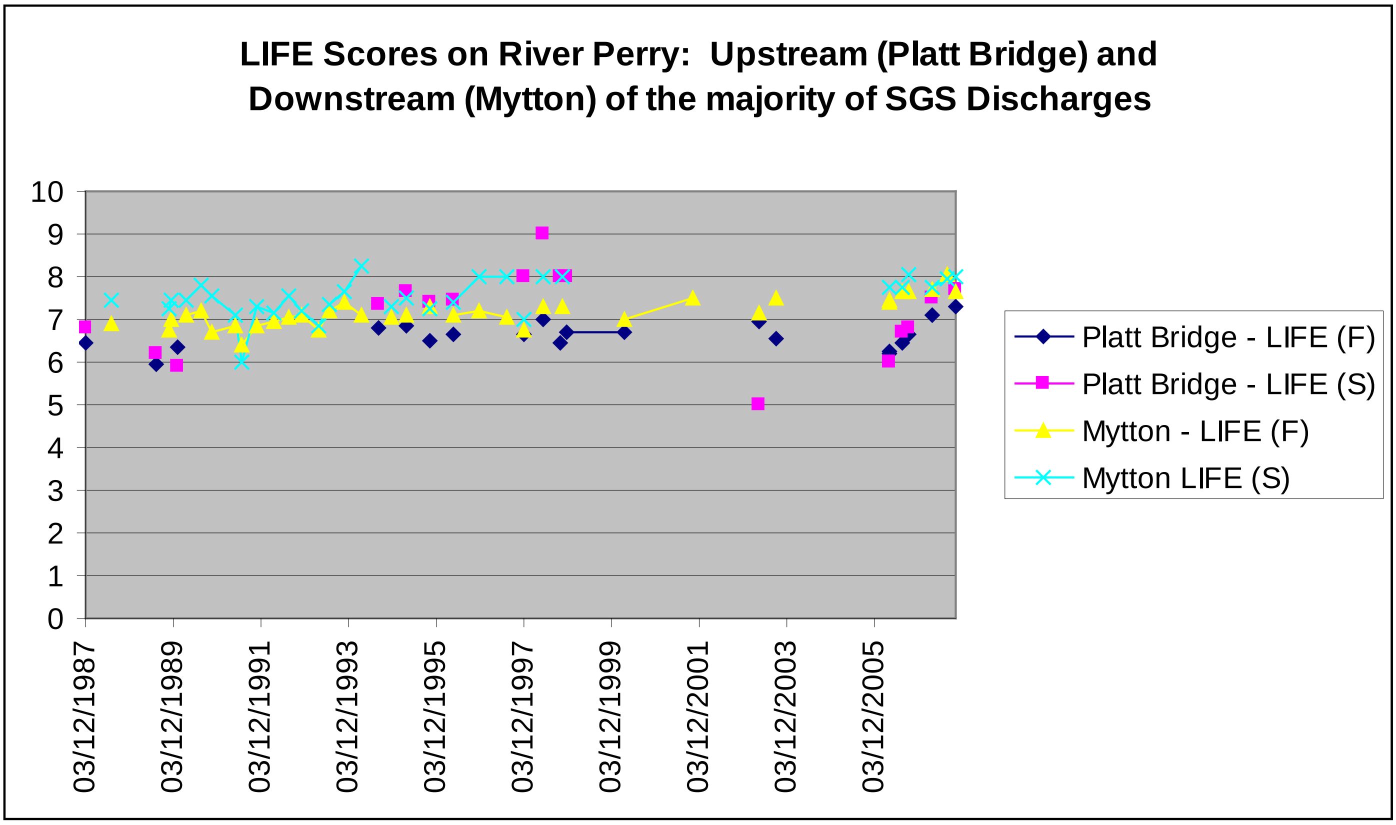


Figure 7.13 Comparison of LIFE Scores: River Perry



Water Quality

ASPT is a biotic index (Box 1.2) that uses aquatic macro-invertebrates as an indicator of the biological quality of running waters. It is primarily used to assess the tolerance to organic pollution of a river's invertebrate assemblage, with higher values indicating relatively pollution intolerant assemblages associated with rivers of good water quality. It can also be a useful indicator more generally of any long-term trends in invertebrate assemblages, having the potential for example to indicate environmental perturbation.

Figures 7.14 to 7.16 illustrate trends in ASPT score (as well as LIFE(f) – see above) assigned to invertebrate assemblages recorded up and downstream of SGS discharges on the River Tern and River Perry. The similar ASPT recorded across years and with limited variation above and below the discharge locations is consistent with the SGS being likely to have no significant effects on aquatic invertebrate assemblages. Therefore the previous operation of the SGS does not appear to have had long term effects on invertebrate assemblages.

The ASPT scores recorded on Potford and Platt Brooks were between 4.2 to 5.3, slightly lower than, but comparable with, those recorded on the River Tern. However these watercourses differ considerably and limited invertebrate monitoring data from Potford and Platt Brook were available to inform the assessment. Future monitoring and assessment will therefore include comparison of Observed versus Expected biotic indices using outputs from the Environment Agency's RIVPACS database.

Figure 7.14 Upstream and Downstream of Waters Upton ASPT and Family LIFE Score

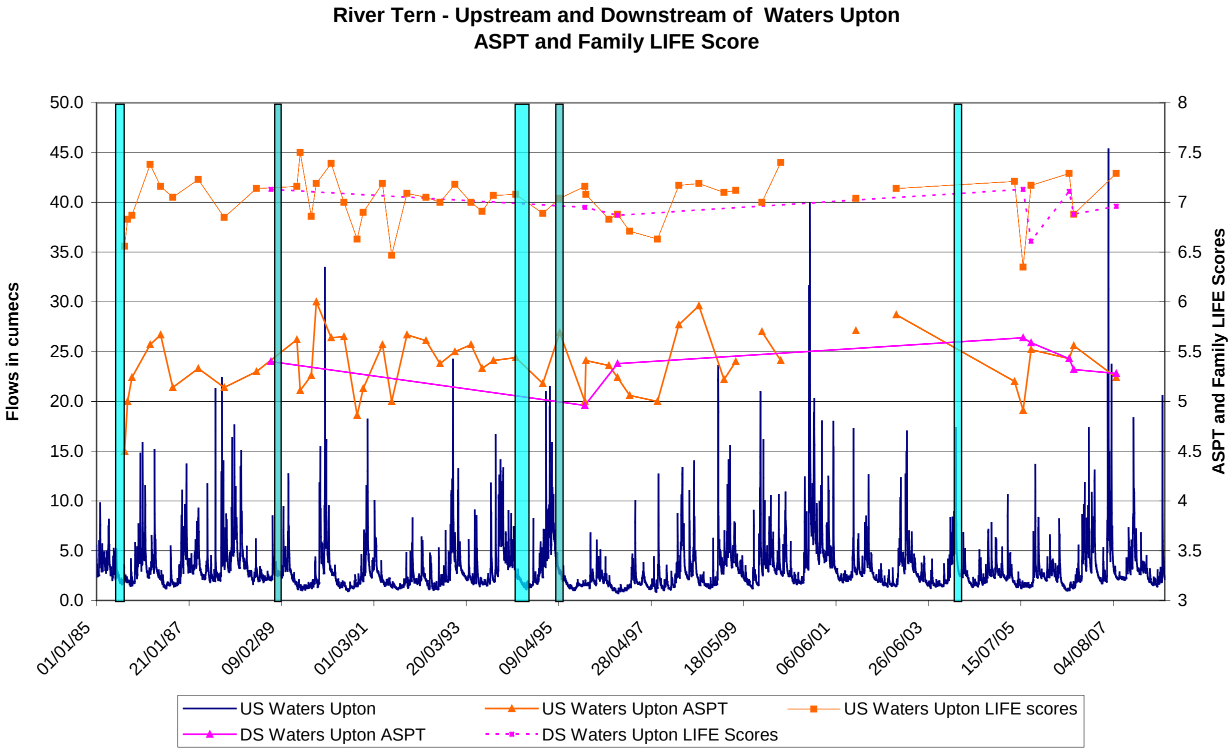


Figure 7.15 Upstream and Downstream of Adcote Outfall ASPT and Family LIFE Score

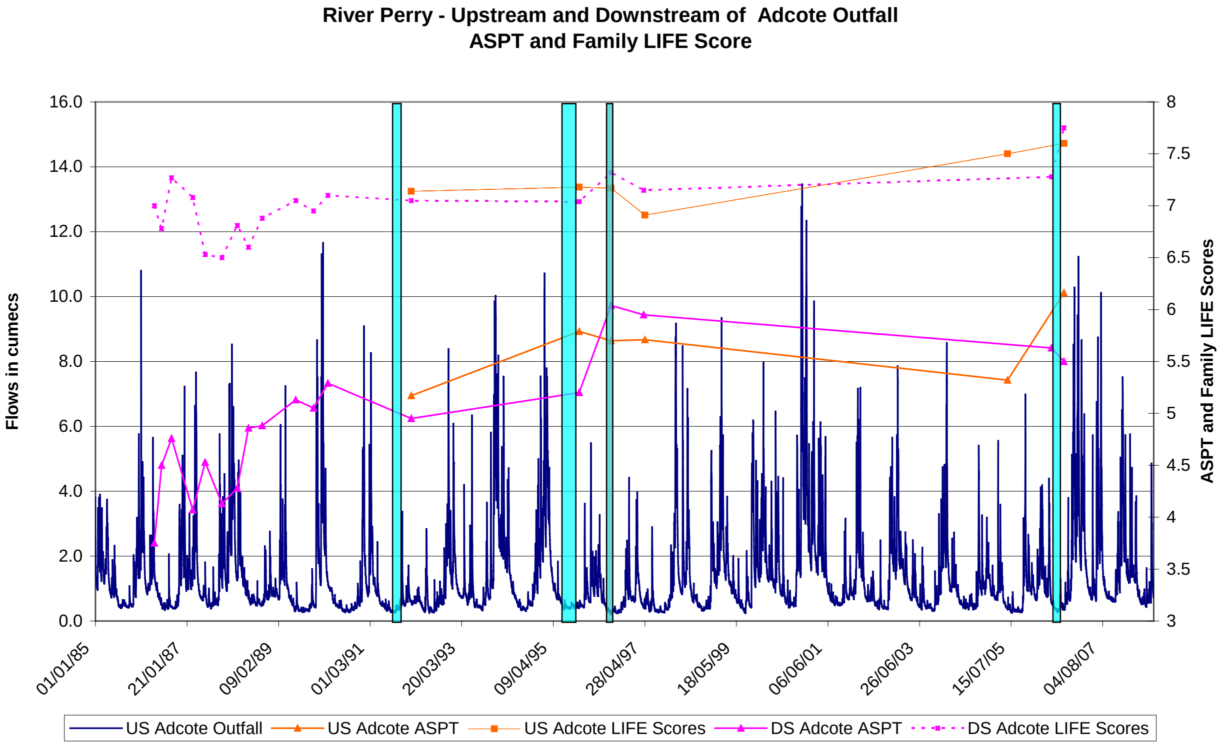
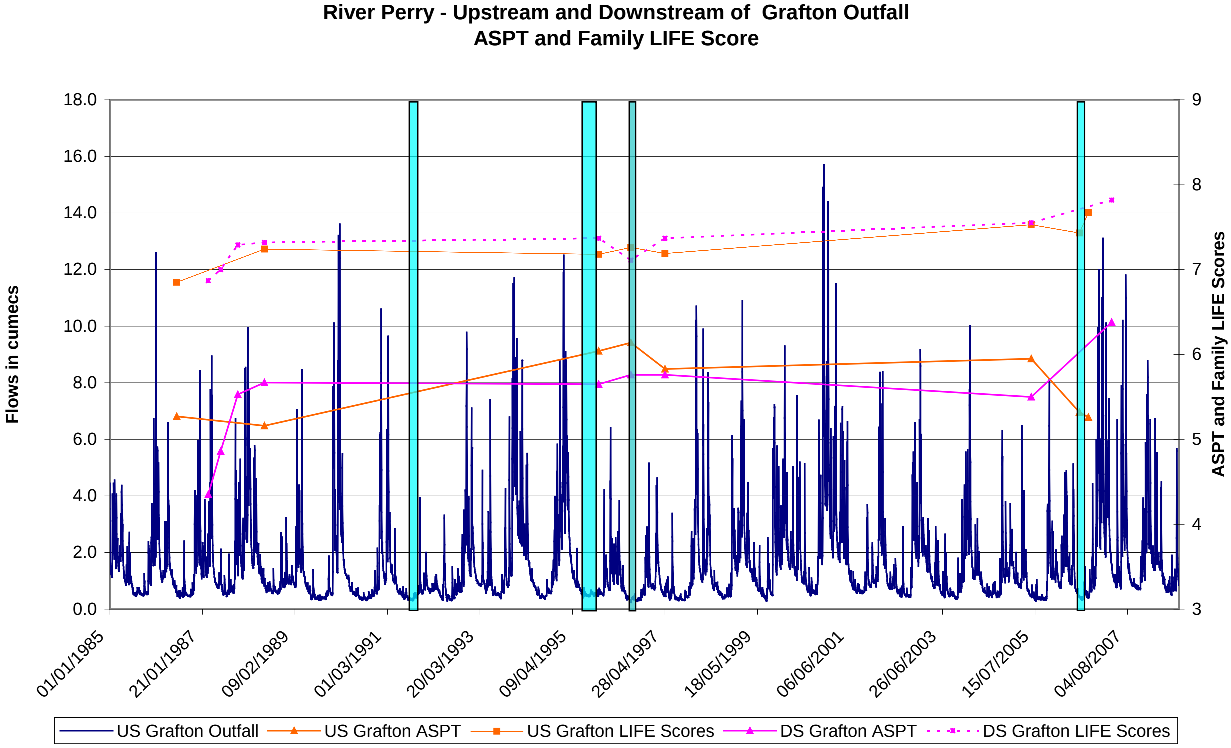


Figure 7.16 Upstream and Downstream of Grafton Outfall ASPT and Family LIFE Score



As stated above in relation to fish populations, concentrations of metals and other determinands within groundwater and surface water are comparable. After mixing these determinands are unlikely to exceed EQS. Any exceedances of water quality standards are likely to be extremely localised and dissipate within a short distance downstream of the discharge. This mixing will be enhanced by agitation. Localised changes in water quality in proximity to the discharge locations are unlikely to have significant effects on aquatic macroinvertebrates.

Groundwater typically has significantly lower levels of dissolved oxygen than surface water. However this quickly equilibrates within a short distance downstream of the discharge location or via agitation (Cowx 2000). Furthermore the main SGS discharges exceed 75% oxygen saturation and are therefore unlikely to have an effect on Dissolved Oxygen in the receiving watercourses. Therefore changes in oxygen concentration are likely to be limited, localised and are unlikely to have significant effect on fish populations.

Temperature

A reduction in temperature, attributable to the increase in proportion of cooler groundwater within the river, has the potential to affect macroinvertebrates. Like fish, invertebrate development can be influenced by a change in cumulative degree days, for example emergence of some mayfly species is correlated with cumulative degree days during the period late June to late August (Watanabe et al 1999[14]). Reduced temperatures and slower invertebrate development can lead to smaller size classes within age groups. This may also lead to delayed metamorphosis and emergence. The effect of this is that invertebrates complete fewer life cycles in any given year.

The operation of SGS is likely to reduce temperatures by up to 5.6°C at the first point of discharge to the water course during short periods of pumping at maximum licensed output. Prolonged changes in temperature of this magnitude could be expected to have significant effects on aquatic invertebrates, potentially reducing the number of life cycles completed each year. However based on the trends in biotic indices presented above, there are no apparent changes in invertebrate assemblage linked to the previous operation the SGS. Furthermore the temperature change associated with the outfall appears to be localised and dissipate quickly, with temperatures being restored to upstream temperature within approximately 100m downstream of the outfall (Appendices I, J, K). Therefore the current operation of the scheme and an associated temperature reduction, occurring infrequently and over a short length of river, appears likely to have no significant effects on aquatic invertebrate assemblages.

Under an extreme drought scenario, the Drought Order is predicted to lead to a further small increase in the proportion of SGS groundwater making up total river flow at the point of discharge by 1% to 5% in addition to the benchmark 1976 river flows. This 1 to 5% increase is in addition to the proportion of groundwater already assessed as making up between 9 to 52% of the total augmented river flows under drought conditions. This is expected to lead to a further temperature reduction at the point of discharge, after mixing, of 0.1 to 0.6°C. Based on the findings of the initial study (Appendices I, J, K) into temperature change downstream of the outfall, a change of this magnitude is unlikely to extend the cooling effect a substantial distance downstream and is therefore also unlikely to have significant effects on aquatic macroinvertebrate assemblages. However further work is required to verify the results of these temperature investigations.

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[14] Watanabe, N. C., Mori, I., Yoshitaka, I. (1999). *Effects of temperature on the mass emergence of the mayfly Ephoron shigae in a Japanese river*. Freshwater Biology (1999), **41**, 537-541. Blackwell Science Limited.

7.3.4 Macrophytes

Short, temporary changes in the operation of the SGS, affecting discrete reaches of watercourse are unlikely to have significant effects on macrophytes. In infrequent cases when the scheme is operated for prolonged periods e.g. 12 weeks during a drought, macrophytes are likely to respond by localised alterations in distribution/ productivity. However the operation of the SGS in drought years is also expected to mitigate to some extent the effects of drought on macrophytes, potentially keeping algal growth in check and restricting the extent to which river width is reduced, exposing marginal species. The scheme is therefore unlikely to have significant effects on macrophytes.

7.3.5 Designated Sites

Hydrogeological Screening

The 43 designated sites were subject to a screening study to determine the level of risk posed to each one as a result of SGS abstractions from the Permo-Triassic Sandstone. The screening process used available hydrogeological data to develop a conceptual model of each site. The degree to which the site interacted with groundwater in the sandstone was established and sites assigned to one of four categories.

- **Sandstone Head Dependant Feature**: a high groundwater table exists at the site because the groundwater head in the sandstone is perennially elevated above the drift groundwater head or the surface of the site. The intervening drift deposits are relatively thin and/or predominantly permeable allowing a good hydraulic connection between the sandstone groundwater and the groundwater in the near surface deposits. The conceptual understanding is that the water balance for this designated feature is dependant upon groundwater flow in the form of lateral or upward vertical discharge from the sandstone. The water balance for the site is therefore considered to be vulnerable to the effects of groundwater abstraction from the surrounding sandstone;

- **Non-Sandstone Head Dependant Feature:** the groundwater head in the sandstone lies below the elevation of the designated site. A downward head gradient exists between the drift deposits and the sandstone. A permanent unsaturated zone exists beneath the site, irrespective of temporal natural head fluctuations in the sandstone. The conceptual understanding is that the water balance for this designated feature is not dependant upon the sandstone groundwater for its source of water. This site is therefore considered not to be vulnerable to the effects of groundwater abstraction from the sandstone beneath the site;

- **Complex Sandstone Head Feature**: the groundwater head in the sandstone lies close to or occasionally above the elevation of the designated site. The intervening drift sequence beneath the site is complex with significant lateral and vertical lithological variation. This influences and supports both a semi-permanent saturated and or unsaturated zone determined by natural groundwater level fluctuations on a seasonal basis. The vulnerability of the water balance to the effects of groundwater abstraction from the sandstone is dependant upon the influence of the intervening drift's hydraulic properties;

- **Insufficient Data:** There is insufficient evidence on groundwater heads in the sandstone beneath the site, or the composition and thickness of the intervening drift and its hydraulic properties, to draw any conclusive conceptual understanding of the groundwater surface water exchange. No firm conclusion can be made to the dependence of this site on groundwater heads in the sandstone or the hydraulic influence of the intervening drift. In the absence of a conclusive conceptual understanding no statement can be made to assess the site's vulnerability to the effects of groundwater abstraction from the sandstone beneath the site.

Having characterised the sites, the risk of SGS impact on them was further assessed as likely, possible or no impact based on:

- possibility (relative relationship to SGS wellfields; and
- likelihood (observed historic or projected impact).

Of the 43 sites reviewed, 32 were deemed to have no connection with and therefore no dependency on groundwater in the sandstone aquifer. Therefore the SGS is will not have an impact at these sites. One site was underlain by complex sandstone head relationships, but was not considered to be at risk, and two had insufficient data on which to base a conclusive assessment. The results of the screening process are summarised in Appendix L. Eight sites were considered to be connected to, or interact with, groundwater from the sandstone. Of the eight sites categorised as being sandstone head dependant, the following four sites were assessed as not being at risk from SGS pumping:

- **River Severn at Montford (SSSI):** notified because of its geomorphological feature and is therefore not dependant on river flow. While baseflow to the River Severn may be reduced by SGS pumping along this stretch, no impact would be expected on this feature as a result of the operation of the scheme;

- **Peplow Hall Heronry (SINC):** designated because of a bird nesting site. The woodland sits within soil moisture vulnerability class 1, indicating potential sensitivity to groundwater fluctuations. It is likely that the root systems are predominantly developed within unsaturated soil zone, which offers favourable oxygen and nutrient conditions. The trees are more likely to suffer from drought stress due to lack of rainfall rather than reliance on groundwater levels;

- **Stoke Heath (SINC):** designated for mixed scrub, birch woodland and artificially impounded pond(s) features. Based on the limited available data the water features at the Stoke Heath SINC appear to be in good hydraulic connection with sandstone heads, and therefore potentially sensitive to localised groundwater abstraction from the sandstone. The effects of the SGS pumping to the east of the River Tern will be significantly reduced with the removal from operational use of Helshaw Grange. The residual effects of the main Phase 1 & 4 wellfield operating to the west of the River Tern are therefore unlikely to impact on groundwater levels beneath this site;

- **River Tern at Market Drayton:** Designated for watercourse and river corridor, this part of the River Tern is situated upstream and just beyond the northern-limit of the projected effects of the Phase 1&4 wellfield. Again the removal of Helshaw Grange is likely to reduce this northern limit/margin. No reduction in baseflow to the river at Market Drayton is expected, therefore no impacts on this site are predicted.

The effects of the scheme on the remaining four sites are described in Section 7.4.

7.4 Predicted Impacts

7.4.1 General

The main predicted effects of the Drought Order focus on the increase, by between 9 to 52% (up to 100% on certain stretches of the part of the Potford and Platt Brook system) in total river flow by relative proportion of augmented groundwater releases during the extreme drought scenario; a reduction in temperature by up to a further 0.6°C; and changes in concentration of some determinands where concentrations in groundwater differ from the receiving watercourses. The tributaries (River Tern and Perry) are likely to be most susceptible to these changes as they are likely to have a lower capacity than the larger River Severn to buffer changes in physico-chemical parameters.

The effects of the Drought Order must be considered within the context of the infrequent operation of the scheme for discrete periods, typically less than 8 weeks within any given year. This operation is unlikely to change significantly within the short to medium term. The Drought Order will however provide the capacity for discrete, longer periods of SGS releases in response to drought conditions.

There is a degree of uncertainty associated with this assessment because it is difficult to predict the precise hydrological conditions that will occur at the time the Drought Order is sought and because its operation varies from year-to-year in terms of volume, frequency, duration and timing of releases. The assessment is based on the infrequent application of a Drought Order and the ongoing operation of SGS releases for discrete periods of limited duration i.e. it is unlikely that repeated application of a Drought Order and/or prolonged periods of SGS pumping will occur in consecutive years. If this did become necessary it would need to be subject to further assessment.

7.4.2 Flow

The Drought Order is predicted to lead to an increase in total augmented flows in the River Tern and River Perry during drought conditions and is likely to have a positive effect on fish by, for example, reducing the risk of exposure of spawning substrates and ammocoete habitats; limiting silt deposition; maintaining river connectivity and limiting the reduction in available fish habitat. However this is likely to take place relatively infrequently and for short periods and therefore this is unlikely to have a significant positive effect on fish populations. Similarly, the Drought Order is likely to have positive effects on aquatic invertebrate assemblages by alleviating the effects of low flows and these are also unlikely to be significant.

7.4.3 Temperature

The effects of temperature reduction on cold water adapted species, such as salmonids, are likely to be of lower magnitude than effects on cyprinids, although growth rates of both salmonids and cyprinids can be suppressed by cooler water. Cyprinids have the capacity to bolster their populations following periods of lower population growth, through enhanced recruitment at irregular intervals and every several/ few years. As fish survival can be influenced by growth in the first summer, warm summers can lead to these stronger year classes. As SGS pumping is more likely in warm years, it has the potential to suppress these higher recruitment events.

SGS pumping typically takes place for a limited number of weeks per year. However under a severe drought scenario the SGS could begin to cause localised effects on fish growth and recruitment in parts of the Tern and Perry. The magnitude of this effect varies depending on ambient temperature – as described above during warmer drought years fish growth and recruitment may be expected to increase, compensating for weaker recruitment in other years. The operation of SGS could suppress this bolstering effect.

Notably the model scenario predicts three consecutive years when SGS pumping would occur between approximately three and four months in summer. The operation of SGS is predicted to reduce river temperatures at the point of discharge by up to 5.6°C and prolonged changes in temperature of this magnitude in consecutive summers could be expected to have effects on fish growth and survival/ recruitment. Similarly these temperature changes would be expected to slow invertebrate life cycles. This effect would be slightly greater under an extreme drought scenario, when the Drought Order is predicted to lead to a further small increase in the proportion of SGS groundwater making up total river flow at the point of discharge by 1% to 5% in addition to the benchmark 1976 river flows. This 1 to 5% increase is in addition to the proportion of groundwater already assessed as making up between 9 to 52% of the total augmented river flows under drought conditions. This is expected to lead to a further temperature reduction at the point of discharge, after mixing, of 0.1 to 0.6°C.

The above temperature changes appear likey to be localised and dissipate quickly, with temperatures being restored to upstream temperatures within approximately 100m downstream of the outfall (Appendices I, J, K). Therefore the temperature reduction associated with the SGS, occurring very infrequently under drought conditions; for short periods; and over a short length of river are, based on the data available, unlikely to have significant effects on fish populations, particularly within the context of wider catchment populations. Similarly any changes in invertebrate assemblages in response to the infrequent operation of the scheme for discrete periods are likely to be temporary and localised. Furthermore, in lotic environments macroinvertebrates can quickly recolonise once suitable conditions are restored due to immigration from upstream habitats. Although there is potential for localised temperature-related effects of SGS discharges, it is notable that the rivers receiving SGS discharges will not be subject to the same effects of low drought flows as other nearby watercourses that do not receive SGS inputs.

Based on the above, significant effects on fish populations and macroinvertebrate assemblages appear unlikely. This is supported by the fisheries and macroinvertebrate monitoring data collected to date, which do not appear to indicate a notable effect of previous SGS discharges on these receptors. However further work is required to verify the results of these temperature investigations.

7.4.4 Water Quality

Predicted effects on water quality include localised exceedances of water quality standards for a small number of determinands. However mixing/ agitation of water at discharge locations are likely to dilute these determinands. Localised, short term changes in concentrations of some determinands are unlikely to have significant effects on fish populations and invertebrate assemblages. Groundwater typically has significantly lower levels of dissolved oxygen than surface water. However the main SGS discharges exceed 75% oxygen saturation and are therefore unlikely to have an effect on Dissolved Oxygen in the receiving watercourses. Therefore changes in oxygen concentration are likely to be limited, localised and are unlikely to have significant effect on fish and invertebrates.

7.4.5 Potford and Platt Brooks

Platt Brook is a tributary of Potford Brook, which is a tributary of the River Tern. These small watercourses are affected by draw-down of groundwater when SGS is operational, due to reduced baseflow support. Increased reaches of these watercourses are predicted to be at risk of drying out during combined effects of drought and SGS pumping. Mitigation measures are in place, with Q95 flows triggering compensation releases. This will lead to periods when flow within these watercourses is sustained predominantly by groundwater compensation releases.

There are limited ecological monitoring data available for Potford and Platt Brooks, largely restricted to four years of macroinvertebrate monitoring data, collected annually at Radmoor (SJ-62389-24444) and Ellerdine (SJ-63000-22700) between 2005 and 2008. It is likely that the prolonged groundwater releases to this watercourse will maintain flows within normal summer limits. However the reduced summer temperatures downstream of compensation discharges are likely to slow invertebrate life cycles in these reaches and potentially slow growth rates of fish, with associated effects on populations. These effects are likely to be localised, restricted to the reaches downstream of discharges and are unlikely to have a significant effect on macroinvertebrates and fish within the context of the wider Tern catchment. These effects are also likely to be offset to some extent by the benefits of SGS providing enhanced flows on receiving watercourses during drought, compared with other watercourses. However, limited data are available on these smaller tributaries and further ecological monitoring is required to further inform future monitoring and assessment of these effects.

Further assessment work is required to refine the flow targets which trigger the need to make compensation releases to these streams. The current target of Q9 is considered to be too conservative making inefficient use for groundwater resources and therefore increasing the cost of maintaining the compensation flows. The compensation operating rules should be replaced by more site specific hydro-ecological flow criteria to more efficiently match flows to the betterment of the streams ecological systems.

7.4.6 Designated Sites

The screening of designated sites concluded that four sandstone head dependant sites are potentially at risk of impacts associated with SGS pumping. These are summarised below.

Old River Bed (SSSI)

Occupying the eastern arc of a cut-off meander of the River Severn, this site has been notified for its extensive sedge fen and marshy wetland inundation features. The SSSI is drained by a central drainage channel flowing initially eastwards and then south to form the Bagley Brook. The site is underlain at depth by Permian sandstone, with an intervening complex cover of heterogeneous glacial till, sands and gravels deposits. The corridor of the meander arc and the body of the SSSI (and SINC) is in turn underlain by more recent river terrace and alluvial deposits. Observation boreholes to the north (Crosshill Obs) and south (Old River Bed Obs) of the SSSI record groundwater heads in the Permian sandstone lying between 51.8 to 52.2mAOD (metres above Ordnance Datum) and 51.2 to 51.8mAOD respectively. Based on Lidar data the marshy surface elevation of the SSSI body has been surveyed to lie at an elevation of ~50.25 to ~50.50mAOD. The sandstone groundwater level is thus projected to be in the region of ~51.25 to ~51.75mAOD in relation to the SSSI. A borehole drilled in the middle of the site, through the drift and in to the underlying sandstone, would expect to record a groundwater level effectively ~0.75m to ~1.25m above the surface of the wetland body.

An inspection of the site in February 2012 did not reveal specific areas of point source springs or spring lines suggesting that groundwater seepage is largely diffuse across the body of the site. Water flow within the drainage ditch features within the body of the SSSI was observed to be largely sluggish. Flow from the site to the upper reaches of the Bagley Brook was not observed to be significant. However no gauged flow or level monitoring data are available.

The bulk of the groundwater flowing through the sandstone body is likely to be by-passing beneath the site to discharge to the current location of the River Severn to the south. However as groundwater levels in the sandstone are elevated above the surface of the SSSI, a proportion of the groundwater flow will be intercepted, upwell and seep through the intervening drift, supporting and maintaining the water balance for the SSSI. The rate of discharge will be controlled by; i) the difference in the elevation between the groundwater level in the sandstone and the surface topography of the SSSI body, ii) the hydraulic conductivity properties of the intervening glacial and alluvial drift deposits. Given the heterogeneous nature of the drift the flow paths through this body are likely to be complex.

The SSSI sits on the southern marginal edge of drawdown influence of the SGS Phase 3 wellfield. Historic hydraulic responses to operational pumping of the Phase 3 wellfield in summer 1999 and 2006 have recorded a 0.1 to 0.2m temporary reduction in groundwater head in the sandstone observation boreholes either side of the SSSI. No impact on level was observed during the shorter operational periods of Phase 3 in 2010 and 2011.

During SGS Phase 3 operational events the hydraulic response to pumping has not caused groundwater levels to deviate out side the normal historic actual long term annual seasonal trend (+/-0.25 to 0.5m). The natural hydrogeological flow regime has been maintained through out with groundwater continuing to up well and support the wetland water balance. Operational use of SGS Phase 3 has shown no deterioration in groundwater levels therefore abstraction to date is considered to be sustainable and in harmony with the natural groundwater resource balance.

Under the drought scenario the groundwater model predicts that the extended pumping from Phase 3 could generate drawdown in the range of ~0.4 to ~0.7m in the sandstone beneath the SSSI. Taking the higher end of the drawdown range from the groundwater head above the floor the SSSI, projected as +0.75m to +1.25m under non-pumping conditions, would reduce the head to between +0.05m to +0.55m. While this would result in temporary reduction in the groundwater head, the potentiometric head would still be maintained above the floor level of the SSSI. The natural hydraulic flow regime would be retained with groundwater still up welling into, and supporting the saturated body of the SSSI. However the rate of groundwater inflow through the site would reduce in-line with the temporary reduction in groundwater head. In the absence of any hydro-ecological characterisation of the site it is difficult to quantify any degree of impact on this site from this temporary reduction in diffuse seepage. Other than to conclude that the site will remain fully saturated throughout the projected pumping event.

Old River Bed (SINC)

Designated for its marshy grassland and carr, this site lies within the same cut off meander feature as the above SSSI, but lies on the western arc of the meander. The SINC is drained by a central drainage channel flowing initially westwards and then south towards the River Severn. The effect on the hydrogeology of this site will be similar to that described above.

Platt Brook (SINC)

Designated for its watercourse and stream corridor, the impact of SGS pumping on baseflow to, and therefore total flow in, the Potford and Platt Brooks has already been observed under commissioning of SGS Phase 4, the southern abstraction boreholes of which sit within the lower part of this catchment. The need for compensation releases to be made to the streams therefore already forms part of the mitigation measures for intermittent operation within current licence limits. The groundwater modelling for the in-combination drought scenario predicts that the magnitude of impact on flow in the streams will be more severe due to the extended duration of pumping required and impact on groundwater levels. This will require close stream management of compensation releases both during the pumping events and in following years as the groundwater heads recover in response to long-term recharge.

Sunderton Pool and Sundorne Pool (SINC)

This SINC site has been designated for its open waterbody and marshy ground bordering the edge of the pool. The pools have been artificially created by impounding the Astley Brook which, drains through the pools. The Sundorne Pool was drained a number of years ago due to fears over the structural integrity of the impounding dam. The poor condition of the Sunderton Pool dam structure is currently under review by the Environment Agency. Water levels in the pool may have to be lowered to reduce the risk posed by failure of the structure. The pool lies within the flooded floor of the Astley Brook corridor, lying directly on a narrow outcrop area of Permian sandstone, flanked by glacial till deposits that blanket the higher ground surrounding the valley. With the sandstone water table lying very close to the water level in the pool, and the absence of any intervening drift deposit (other than the sediment at the base of the pool) it is likely that there is good hydraulic connection between the two. The groundwater head is likely to support levels within the pool and provide a small component of baseflow to the Astley Brook inflowing to the pool. Under the drought scenario the eastern marginal edge of the Phase 3 wellfield is modelled to generate a drawdown influence in the region of 0.5 to 0.8m beneath the pool and brook. This may reduce the sandstone baseflow component possibility causing inflows to the pool to be impacted by the operation of the Phase 3 wellfield.

7.5 Mitigation and Monitoring

Based on the available data the Drought Order and associated modifications to the SGS licence appear unlikely to have significant effects on aquatic ecological receptors. However given the inherent uncertainties in terms of the timing, frequency and duration of pumping, the following is recommended on a precautionary basis:

- Agitation of discharge water at all outfalls should be undertaken to increase oxygen content to the maximum level practicably achievable, where this is not already the case;

- Wherever possible, slow continuous release of SGS water over the period of operation;

- Flexible SGS operation rules that cease in the event of natural flow increase;

- Avoid discharge to lengths of watercourse with dense over-hanging tree canopy, which may lead to water remaining cooler for longer.

There is inherent uncertainty in predicting hydrological changes in rivers and the response of biological communities, particularly as the timing, frequency and duration of SGS releases varies between years. Therefore a robust monitoring programme will be necessary to inform a further assessment of the scheme in the future. This is particularly important with respect to any operation of the scheme approaching its maximum licensed output in consecutive years. The monitoring programme would include the following:

- Fish surveys and intermittent review of patterns in fish numbers/density; standing crop and growth rates, focusing on roach, dace, chub, trout and gudgeon and comparing control sites with sites situated downstream of outfalls;

- Continued invertebrate monitoring and intermittent analyses of biotic indices, including LIFE and ASPT, comparing control sites with sites situated downstream of outfalls. This monitoring should include sites on Potford and Platt Brooks;

- More detailed investigations to verify the effects of the scheme on temperature profiles downstream of all outfalls, taking into account temperatures throughout the full water column and across the width of the channel and comparing upstream and downstream temperatures;

- Ongoing and frequent monitoring of water quality, comparing sites upstream and downstream of discharges.

The Mitigation and Monitoring in relation to designated sites is summarised separately as follows:

- **Old River Bed SSSI:** This wetland is predicted to fall within the marginal pumping effects of Phase 3. The degree of drawdown influence is not predicted to reverse the natural hydrogeological regime. Groundwater is predicted to continue to up well and support the wetland water balance. The diffuse seepage inflow will also be retained but at a reduced rate. Monitoring should focus on groundwater level observation in the two key boreholes at Crosshill Obs and Old River Bed Obs to ensure groundwater levels do not fall below the floor level of the SSSI body. Using the Old River Bed Obs as a key reference borehole the following relationship between groundwater level and the SSSI could be used to monitor and trigger management actions on the continued operational use of Phase 3.

  1. Groundwater levels between 50.25 and >51.75mAOD - Groundwater remains above the topographic surface of the SSSI. The hydraulic gradient causes groundwater to discharge to the SSSI, supporting and maintaining the water balance.
  2. Groundwater levels ~50.25mAOD - Groundwater sits at the same topographic level of the SSSI. The site will remain saturated however there is no driving pressure difference to push groundwater flow through the intervening drift and the body of the SSSI.

3. Groundwater levels <50.25mAOD - Groundwater sits below the topographic level of the SSSI. The hydraulic relationship will be reversed potentially causing the site to lose water to the underlying drift rather than receiving water from it.

Surface out flows from the site should also be gauged and the condition of the site monitored in close liaison with Natural England. In the event that groundwater levels adjacent to the site begin to approach levels of concern, in mitigation the Phase 3 pumping regime could be modified to see if the magnitude of drawdown could be reduced. This could be achieved by modifying the abstraction rate from the southern half of Phase 3 or switching off entirely the abstraction at Newton, which at 2.5km is the closet point of abstraction to the SSSI.

- **Sunderton and Sundorne Pools:** If the wider effects of operating the Phase 3 wellfield were to have detrimental effect on the baseflow contribution to flows on the Astley Brook, Sunderton Pool and Sundorne Pool, in mitigation it would be feasible to run the Phase 5 stream compensation borehole at Hadnall No2. This would require the establishment of operating rules under which flow compensation would be provided. This compensation regime would have to be agreed with the Panel Engineer responsible for the Reservoir Safety plan for the dam structure. It would be advisable to monitor flows in the Astley Brook and water levels in the Pools;

- **Platt Brook:** The impact on flows within the Potford and Platt Brook system from the operation of Phase 1&4 is well established. Mitigation measures are already in place, through the provision of permanent dedicated stream compensation boreholes at Heath House No2 and Greenfields. The trigger for making flow releases from these two sources should be controlled from the stream flow gauging station on Platt Brook at Sandyford Bridge. In the absence of any hydro-ecological flow based criteria, the Q95 value has been proposed to trigger the need to make and maintain stream compensation releases. However, it should be noted that historic actual flows have naturally reached this flow in the absence of SGS abstraction and Q95 may therefore be an overly conservative trigger. Ecological monitoring needs to be improved to characterise the ecology of the stream and to monitor the effects of augmented flow.

7.6 Summary and Conclusions

The assessment of the effects of the drought order focus on ecological receptors (groundwater dependent designated sites, fisheries and aquatic macroinvertebrates) that are likely to be sensitive to the changes in hydrology that the scheme is predicted to bring about. Riparian species such as otter, water voles, bats and birds are unlikely to affected by the temporal/ transient changes caused by the operation of the scheme and were therefore scoped-out of further assessment.

The assessment focused mainly on the River Tern, River Perry, Potford and Platt Brooks. These smaller tributaries receive multiple discharges from the SGS; are likely to have an ecology that is comparable to the middle and upper reaches of the River Severn; are regularly monitored; and are likely to have more limited capacity than the larger River Severn to buffer changes in, for example, water quality or temperature.

Based on the available historical data set, there appears to be no clear correlation between antecedent flow and LIFE(f) recorded on the River Tern and River Perry. It is therefore likely that any localised flow-induced changes in invertebrate assemblages in response to the infrequent operation of the scheme for discrete periods will be temporary and undetectable.

Long term trends in ASPT biotic index score assigned to invertebrate assemblages, recorded up and downstream of SGS discharges on the River Tern and River Perry, were analysed. Similar ASPT scores recorded across years and with limited variation above and below the discharge locations, is consistent with the SGS having no significant effects on aquatic invertebrate assemblages. Therefore the previous operation of the SGS does not appear to have had long term effects on invertebrate assemblages.

Modelling predicts that the effect of the extreme drought scenario will cause stream and river flows to fall lower than that observed in 1976. Approximately 41km of SGS augmented water courses will benefit from the scheme as total flows will be elevated to within normal summer flow ranges. This benefit will come as a consequence of an increase in the proportion of groundwater making up the total augmented river flow.

The operation of SGS is predicted to reduce river temperatures at the point of discharge by up to 6°C. Prolonged changes in temperature of this magnitude in consecutive summers could be expected to have significant effects on fish growth and survival/ recruitment. Similarly these temperature changes would be expected to slow invertebrate life cycles. However the SGS induced temperature change appears to be localised and to dissipate quickly, with river temperatures being restored to upstream ambient temperatures within short distances downstream of the outfalls. The length of water course affected by cooling water is therefore nominally small, relative to the length of river benefiting from augmented flow as a whole.

Predicted effects on river quality from discharge of groundwater include localised exceedances of water quality standards for a small number of determinands as well as, in a small number of cases, reduced oxygen concentrations immediately downstream of discharges. However mixing/ agitation of water at discharge locations are likely to dilute these determinands and increase oxygen concentrations. Localised, short term changes in concentrations of some determinands are unlikely to have significant effects on fish populations and invertebrate assemblages.

The Potford and Platt Brook stream systems already have dedicated stream augmentation boreholes designed to provide compensation flows to mitigate for impacts within normal licensed operation of Phase 1&4. It is likely that the Hadnall No2 (Phase 5) stream compensation borehole may be required to mitigate for the predicted Phase 3 impacts on flows to the lower Astley Brook and Sunderton Pool.

The drought order will require an extended reliance on these support mechanisms to maintain flows during operational pumping and intermittently thereafter while the aquifer recovers. Further assessment work is required to refine the flow targets which trigger the need to make compensation releases to these stream systems. The current target of Q95 is considered to be too conservative making inefficient use for groundwater resources and therefore increasing the cost of maintain the compensation flows. The compensation operating rules should be replaced by more site specific hydro-ecological flow criteria to more efficiently match flows to the betterment of the streams ecological systems. Further ecological monitoring is required to further inform an assessment of these effects.

A total of 43 designated biodiversity sites have been identified within the operational area of the SGS. This includes eight notified as Sites of Special Scientific Interest (SSSI), two of which are wetlands of international importance (Ramsar sites); and one Local Nature Reserve (LNR). This list also includes 34 non-statutory sites, designated as Sites of Importance for Nature Conservation (SINC). These sites underwent hydrogeological screening to identify whether they were groundwater-dependent or surface water-dependent. This screening process was then used to assess the potentially susceptibility of sites to the effects of SGS pumping.

Of the 43 sites reviewed, 32 were determined as having no connection with, and therefore no dependency upon, groundwater from the sandstone aquifer. Therefore no impact from SGS would be expected at these sites. One site was under lain by complex hydrogeology, but not considered to be at risk, and two had insufficient data with which to make any conclusive assessment. Of the eight sites considered to interact with groundwater from the sandstone, only four had some level of predicted impact from SGS. Two out these four already have established flow compensation schemes.

The Old River Bed SSSI wetland falls within the marginal pumping effects of Phase 3. The drought scenario is predicted to increase the magnitude of drawdown under the site compared with that seen to date when Phase 3 is operated within its licensed limits. To ensure the natural upward hydrogeological regime is maintained beneath the site trigger levels have been set on an observation borehole next to the site to prompt review and possible modification of the pumping regime to mitigate against the effects from Phase 3.

8. Archaeological and Cultural Heritage

8.1 Introduction

This section presents an appraisal of whether the predicted changes to groundwater levels, as a result of the operation of the Shropshire Groundwater Scheme (SGS), will have an effect on archaeological sites and monuments. A technical note detailing the appraisal and the methodology is included in Appendix M, summary details are reproduced below.

8.2 Data Availability and Assessment

8.2.1 Data Sources

Data was collected from within the SGS study area, as defined by the outer protection zone, in the first instance (Figure 1.1).

This appraisal uses three primary sources of data:

- A subset of the national data set on scheduled monuments, maintained by English Heritage;
- A subset of the national data set on listed buildings, maintained by English Heritage;
- Shropshire Historic Environment Record (HER), a county-based register of known archaeological and historical sites, maintained by Shropshire Council.

8.2.2 Assessment Methodology

A high-level appraisal of the potential for changes to groundwater levels beneath archaeological sites and monuments, predicted as a result of the operation of the SGS, has been undertaken. The technical note (Appendix M) includes an outline of the methodology used and the results of the appraisal, including a brief account of baseline conditions and an account of those sites identified which may be susceptible to change.

The appraisal attempts to categorise archaeological sites in terms of the potential sensitivity of the deposits within which they are contained to changes in water level. It identifies which sensitive sites lie within areas where groundwater is relatively close to the surface, defined as lying within 0 to 4m below ground level (mbgl). The combination of these two measures is used to identify archaeological sites and monuments which are likely to be susceptible to changes in water level and an attempt is made to grade the susceptibility of sites according to a defined scale.

A hydrogeological screening exercise has then been undertaken, using the data provided by the ADAS-EA soil moisture vulnerability mapping (Section 3.1.4) and the groundwater modelling contours (Section 5.4) to further screen out sites based on their location and the characterisation of the intervening drift deposits.

8.3 Current Environment

Scheduled Monuments

There are 27 scheduled monuments within the study area, the majority of which (19) are judged to be of high sensitivity. Four monuments lie outside the sandstone area and therefore there is no groundwater data for these. However, of these four, two lie above the 100mAOD topographic contour and are therefore unlikely to be affected. A further monument (32297 Round barrow cemetery and parts of a field system 500m west of Whitmore House) lies *c*. 20m above the nearest watercourse and has therefore also been judged as being unlikely to be affected. The fourth monument for which there was no data is nevertheless considered to be susceptible to changes in groundwater owing to its riverine position and the types of deposits which might be expected to be connected with the type of monument (a castle).

Twenty-two of the scheduled monuments within the study area are unlikely to be susceptible to changes in groundwater levels according to the methodology above (they lie in areas where groundwater is more than 4m bgl). The remaining five are shown in the table below.

Table 8.1 Scheduled Monuments

No.	Name	X	Y	Sensitivity	Groundwater Depth (m)	Comments
33835	Ringwork and bailey castle 390m west of Buntingsdale Hall	365087	332540	High	No data	No data available, although cannot be discounted owing to riverine position and the nature of the monument **Screened out following discussion with the EA**
34907	Wall Camp in the Weald Moors: A large low-lying multivallate hillfort	368088	317819	High	6.33 (P1)	This is somewhat of a special case –the monument is some distance above groundwater, although this type of monument can include substantial ditched **Screened out following discussion with the EA**
19217	Motte Castle 140m south east of Wilcot Hall	337963	318526	High	3.00 (P2)	**Screened out following discussion with the EA**
27557	Moreton Corbet Castle	356131	323162	High	3.91 (P1); 1.00 (P2)	Monument includes 3 scheduled areas
		355875	323093		5.04 (P1); 2.00 (P2)	
		356102	322996		4.11 (P1); 1.00 (P2)	
32315	Moated site 140m east of St Mary's Church	356057	321148	High	4.61 (P1); 2.00 (P2)	-

However, discussion with the EA has indicated that the first two sites are outside the projected area of influence from the SGS and should therefore be screened out. At the third site, more detailed analysis of topographic data and groundwater levels indicates that 4 to 6m of unsaturated zone exists at this location and the site should therefore be excluded on this basis.

Other Features Recorded on the Historic Environment Record

The Historic Environment Record (HER) search returned 1813 entries recorded within the study area. However, 1151 of these are recorded as monument record type 'building' (and not sub-type 'bridge') and have therefore been discounted. A further 62 entries relate to findspots, which were also discounted.

A further 75 HER entries were discounted as being of no sensitivity to changes in groundwater levels, owing to site/monument typology. Thirteen HER entries contained insufficient information on which to base a judgement as to their likely sensitivity (although two of these were outside the sandstone outcrop area and a further five were more than 4m above groundwater levels and are therefore unlikely to be affected).

112 HER entries fall outside the area mapped by the ADAS-EA project and therefore there is no groundwater data against which to assess any potential effect.

397 HER entries were therefore identified within the study area as being of either High, Medium or Low sensitivity to changes in groundwater levels and also within P1 and/or P2 areas. Of these 125 fall within areas where groundwater lies within 4m of the ground level and are therefore judged as being potentially susceptible to changes in groundwater levels. Eight of these 125 are bridges under monument record type 'building', which have not been scored as to their susceptibility as it is the structure, rather than archaeological deposits, which may be affected. These are shown on the Figure in Appendix M.

The potential susceptibility of the 117 sites is broken down as follows:

- 1 (most susceptible) = 39 archaeological sites;
- 2 = 24 sites;
- 3 = 33 sites;
- 4 = 16 sites; and
- 5 (least susceptible) = 5 sites.

A further 14 HER entries have been taken as 'special' cases, according to the stated methodology, which if affected would warrant further consideration. This has been decided purely on professional judgement and no scoring mechanism has been applied. These features are also shown on Figure 3.1. Eight bridges recorded as monument record type 'building' on the HER are also shown on Figure 3.1.

8.4 Assessment of Impact on Current Environment

The archaeological appraisal included all features within the SGS outer protected zone, not all of which will fall in areas where effects will occur as a result of abstraction from the wellfields either for current operation or under the modelled drought scenario. A further hydrogeological screening has been undertaken to take into account, at a high level, the results of predicted changes in water levels as part of SGS and the number of archaeological sites which will actually be affected.

43 of the 139 sites identified by the archaeological screening lie outside the areas identified as experiencing an effect from the drought scenario abstraction from SGS. This number is large than originally postulated in the archaeological note, which commented that up to two thirds of the susceptible archaeological sites may be outside the area affected. This difference is due to the extension of the ESM regional groundwater model to include the Phase 3 SGS area. This means that the wellfields from these three phases can merge, and the large number of sites that lie to the west of Phase 1 and 4 and east of Phase 3, close to the River Roden, are now included in an affected area not previously identified by the contours from the individual wellfields.

This screening brings the number of susceptible sites down to 88 HER entries (including 10 special cases), plus 8 bridges.

Based on the conclusions of the geology chapter, where no impact is anticipated to arise on the structural fabric of the solid geology from the extended pumping regime envisaged to provide addition groundwater support under drought conditions, the potential effect of the scheme on bridges has been deemed to be negligible. Additionally 2 of the bridges lie within channels where the rivers will be augmented and therefore effects will not be seen. The remaining features lie at the marginal edge of the wellfields where effects are likely to be small as well as being buffered by the presence of the river channels themselves.

This screening brings the number of susceptible sites down to 88 HER entries (including 10 special cases).

Furthermore, it is reasonable to assume that:

- the likelihood of an effect on most archaeological sites will decrease with the increasing depth of groundwater below ground level;
- The potential effect of drawdown in the sandstone on the archaeological sites identified will depend on the characteristics of the intervening soil/ drift type; and
- The potential for effects on those archaeological sites identified would depend on the degree of change in comparison to existing water levels.

The same risk methodology applied to the soil moisture vulnerability has been applied to the archaeology sites .i.e. where sites are underlain by/ within drift domains with A class deposits (High permeability, likely to free drain quickly) they are at higher risk than where C class deposits (Low permeability clays, unlikely to dry out during the couple of months of pumping drawdown). Of the 88 sites remaining in the assessment 35 lie within Class C deposits, these sites are therefore screened out on the basis that movement of water between the sandstone aquifer and the low permeability drift deposits will be limited.

A total of 50 sites lie within the Class B (medium permeability) and Class A (High permeability) deposits. Of these, 20 lie within the Class B and 30 within Class A. The final list of sites is presented in Appendix M.

8.5 Predicted Impacts

The archaeological assessment and the hydrogeological screening indicate that there are 50 sites within the area affected by abstraction from SGS that may be susceptible to changes in groundwater level. These sites vary in their susceptibility but, with the exception of 3 sites, sequential screening has resulted in a list of sites with a sensitivity score of less than 3 indicating high or medium sensitivity to changes in groundwater levels and depth to groundwater of less than 2 mbgl.

However, these results should be put into context with the existing operation of the scheme. The majority of the sites identified lie within the existing footprint of the scheme. If they were susceptible to the effects of pumping they would therefore also be affected by operation of the scheme under current full licensed conditions. To date there has been no reported or recorded detrimental impact to designated sites attributed to the effects of groundwater abstraction. Additionally, the drought scenario includes a dry climate change factor which reduces groundwater levels by up to 1.5 m across the area before any effects of the abstraction are also seen, this suggests that any additional effects of the scheme, beyond the natural climatic effects, may have reduced significance for the archaeological sites.

When assessing ground movement careful consideration should be taken to differentiate between the amplification of natural soil dessication under drought conditions and the effects of changes in groundwater levels beneath the site. From the available studies natural ground level fluctuations due to expansion and contraction of soils at surface, are more likely to have a greater influence on near surface soil conditions, and therefore structures supported within, than dewatering of unconsolidated drift deposits at depth.

Despite the best endeavours at developing a hydrogeological screening methodology, in the absence of site specific information on the hydrogeological conditions underlying each site, it is extremely difficult to draw any quantifiable conclusions as to the exact risk posed by any natural or induced fluctuation in groundwater levels.

8.6 Mitigation and Monitoring

The Environment Agency has already established and currently maintains an environmental monitoring network within each of the operational SGS Phase areas. This on-going programme has been specifically designed to collate and capture data to provide an evidence base against which the operation of the scheme on the surrounding environment can be qualitatively assessed. Without any quantifiable impact there are no plans to extend the current environmental network to include site specific monitoring of ground conditions at any archaeological or scheduled monument sites within the operational area of the SGS.

8.7 Summary and Conclusions

A high-level appraisal of the potential for changes to groundwater levels beneath archaeological sites and monuments, predicted as a result of the operation of the SGS, has been undertaken.

The appraisal attempts to categorise archaeological sites in terms of the potential sensitivity of the deposits within which they are contained to changes in water level. It identifies which sites lie within areas where groundwater is relatively close to the surface (0 to 4m below ground level).

The archaeological assessment and the hydrogeological screening methodology applied here indicate that of the 1840 sites identified, there are 50 sites within the area affected by abstraction from SGS that may be susceptible to changes in groundwater level. These sites vary in their susceptibility but, with the exception of 3 sites, sequential screening has resulted in a list of sites with a sensitivity score of less than 3 indicating high or medium sensitivity to changes in groundwater levels and depth to groundwater of less than 2 mbgl.

In the absence of site specific information on the hydrogeological conditions underlying each site, it is extremely difficult to draw any quantifiable conclusions as to the exact risk posed by any natural or induced fluctuation in groundwater levels. Without any quantifiable impact there are no plans to extend the current environmental network to include site specific monitoring of ground conditions at any archaeological or scheduled monument sites.

9. Implication of the Extended Operation of the Scheme on Water Framework Directive Classification Status

The European Water Framework Directive (WFD) came into force in December 2000 and became part of UK law in December 2003. WFD is a key piece of European legislation, rewriting existing water legislation into an overarching programme to deliver long-term protection of the water environment and improve the quality of all waters and associated wetlands. It takes an approach to managing water called River Basin Management Planning, looking at the water within the wider ecosystem and taking into account the movement of water through the water cycle.

The Environment Agency is designated by the Department for Environment, Food and Rural Affairs (Defra) as the 'Competent Authority' for implementing the Directive to the water environment in England and Natural Resources Wales for Wales. As the competent authority we need to ensure that the activities and duties we undertake are fully compliant. In pursuing a permit to modify the scheme beyond its current licence constraints consideration must be given to any potential impact this modification may have on the WFD status of the water body in which the scheme operates.

9.1 Description of the Current WFD Status

The Shropshire Groundwater Scheme sits within the Shropshire Middle Severn Permo-Triassic Sandstone groundwater body. The current WFD assessment considers that the groundwater body is already at poor quantitative status. The groundwater body fails for two out the four tests (elements) for groundwater namely; i) the resource balance (abstraction to recharge ratio), and ii) the impacts of groundwater abstraction on surface water body flows. It is good for the remaining two tests: i) impacts on dependent wetlands and ii) there are no saline or other intrusion associated quality problems.

9.2 Assessment of Impact

As part of the wider river basin management the impacts of the extreme drought event are proposed to be mitigated by additional groundwater pumping beyond the current licence limit to support river flows. In the short term the extended pumping will initially be met at the expense of water stored in the groundwater body. Thereafter in the medium term a temporary period of reduced groundwater baseflow to the surface water body has been modelled. The magnitude of this effect will diminish with time as the scenario modelled suggests that the groundwater levels would take over six years to fully recover based on mean annual recharge. Further assessment work is required to fully quantify whether any impact will be predicted in context to WFD.

During this recovery period depressed groundwater levels may impact on river flows. While no saline intrusion is foreseen, an appropriate assessment may be required on the projected influence on the wetland Habitat Directive site at the Old River Bed.

Given the extreme event envisaged by the drought scenario both the environment and the ability to maintain public water supply will be placed under severe stress. The drought permit would seek to provide mitigation to address a potential risk to human health and public safety and to provide clear and demonstrable direct environmental benefit. Under these circumstances there may be an over riding public interest to seek a modification under WFD to permit the additional support sought under this application.

9.3 Application for a Temporary New Modification under WFD

When assessing scheme impacts on WFD elements consideration needs to be made as to whether the impacts are temporary. Will conditions recover in an acceptable timescale or are the impacts non-recoverable?

Fluctuations in the condition of water bodies can sometimes occur as a result of short-duration activities.

If the water body:

- is only impacted for a short period of time ;
- recovers within a short period of time;
- recovers without the need for any restoration measures.

Article 4.6 of the WFD allows for a temporary deterioration which is as a 'result of circumstances of natural cause which are exceptional or could not reasonably have been foreseen, in particular extreme floods and prolonged droughts. These give rise to situations which cause us to make use of the water environment in ways that results in its deterioration of status (e.g. by taking emergency action to save life and property during floods; by supplying the public with drinking water during prolonged drought; by having pollutants to be washed into the water environment by floods). It is essential for proper river basin management planning and the application of Article 4.6 to make a distinction between the natural cause itself and the effects of management practices.

The scenario modelled suggests that the groundwater levels would take over six years to fully recover. As this extends beyond the length of the natural cause (i.e. the effective drought period) it is therefore considered that Article 4.6 cannot be applied in this case.

There is an underlying long term commitment to manage the water body to attain good status and thus be compliant with WFD. The severity of the drought event considered under this scenario is recognised as being extreme with an expected low frequency of return. Any impact from the extended operation of SGS is likely to be relatively short term, but as stated longer that that foreseen under ‘natural causes’. Therefore exemption to cause deterioration or failure to meet good status/ potential objectives may need to be sought under a defence in the form of a new modification under Article 4.7 of the WFD.

The conditions laid out in Article 4.7 of the WFD are reproduced below in italics:

Member States will not be in breach of this Directive when:

-failure to achieve good groundwater status, good ecological status or, where relevant, good ecological potential or to prevent deterioration in the status of a body of surface water or groundwater is the result of new modifications to the physical characteristics of a surface water body or alterations to the level of bodies of groundwater, or

-failure to prevent deterioration from high status to good status of a body of surface water is the result of new sustainable human development activities

and all the following conditions are met:

(a) all practicable steps are taken to mitigate the adverse impact on the status of the body of water;

(b) the reasons for those modifications or alterations are specifically set out and explained in the river basin management plan required under Article 13 and the objectives are reviewed every six years;

(c) the reasons for those modifications or alterations are of overriding public interest and/or the benefits to the environment and to society of achieving the objectives set out in paragraph 1 are outweighed by the benefits of the new modifications or alterations to human health, to the maintenance of human safety or to sustainable development, and

(d) the beneficial objectives served by those modifications or alterations of the water body cannot for reasons of technical feasibility or disproportionate cost be achieved by other means, which are a significantly better environmental option

Any application for a new modification under Article 4.7 would require a number of tests to be reviewed and met. At the element test level the impact on the groundwater body would have to be reviewed against;

- the resource balance (abstraction to recharge ratio); and
- the impacts of groundwater abstraction on surface water body flows.

Two further tests look at;

- impacts on dependent wetlands; and
- presence/ absence of saline or other intrusions.

Any application for a drought permit would require preparation and presentation of evidence at inquiry. As part of this process the implication for consequences of this drought permit on WFD will also have to be assessed. Where it is anticipated that the Article 4.7 defence might be needed, reference should be made to the following documents (or the latest revised versions) and specific guidance and support sought to assess the process outlined in these documents.

- ‘Assessing new modifications for compliance with WFD’ – Operational instruction 488_10 issued 09/11/10;
- ‘Assessing new modifications for compliance with WFD – detailed supplementary guidance’ – Operational instruction 488_10_SD01 issued 09/11/10.

Sufficient time should be allowed to trigger this process and therefore the need to consider any such application should be identified early on within the environmental action plan.

The East Shropshire Groundwater Model is a well calibrated and trusted numerical groundwater model. The out puts from this model in conjunction with the Water Resources ArcGIS should be used as tools to provide predicted impacts of operating SGS, and any implications for WFD status of the groundwater body in context to the prevailing drought conditions that have triggered the necessity to apply for this drought order.

10. Environmental Action Plan

10.1 General

The Environment Agency has already established and currently maintains an environmental monitoring network within each of the operational SGS Phase areas. This on-going programme has been specifically designed to collate and capture data to provide an evidence base against which the operation of the scheme on the surrounding environment can be qualitatively assessed.

Under this Drought Order it is considered that the current core environmental network is sufficiently robust to meet the requirement of the action plan. The established monitoring points and long term baseline data trends will provide a basis with which to monitor and report upon the effects of any extended operational use of the scheme beyond it licensed limits. Implementation of this programme will present a significant draw on resources given the duration operations predicted under this scenario.

10.2 Groundwater Scheme Abstraction Licence Usage

Abstraction of groundwater from the sandstone aquifer by SGS is governed by abstraction licence 18/54/04/1118/G. The licence is sub-divided by Phase, which have each been allocated maximum annual one year and five year rolling licence gross aggregate volumes.

At the end of each year abstraction returns (total volume of water pumped) are submitted for each individual point of abstraction. These are grouped by Phase and the percentage of the licence used calculated against both an annual and five year rolling volume limits. Each Phase licence usage should be carefully monitored and projections made as to how much licence resource is available on the one year licence with cut off dates set, for the following operational year. These figures should be communicated to the Area Drought Management team.

10.3 Water Resources

- Hydrogeology – the current network of observation boreholes provide a comprehensive and sufficiently dense spatial coverage without the need to expand further. The current number of boreholes equipped with data loggers should be maintained and increased. This will significantly improve the data captured and reduce the resource and mileage incurred to maintain weekly manual groundwater dipping activities;

- Hydrology – the river network is currently well served with a good spatial distribution of strategically located permanent gauging stations capturing flow data at 15 minute intervals with remote telemetry access to daily data. No expansion of the network is considered necessary. Spot low flow gauging should be considered to monitor any effects of pumping on flows in the Astley Brook feeding Sundorne Pool SINC, and outflows in the Bagley Brook from the Old River Bed SSSI;

- Stream Compensation Flow Management – The need for stream compensation support for the streams have already been recognised as part of the normal mitigation activity within the current licence limits (i.e. Potford & Platt Brooks, Sundorne Brook). Modelling for the in-combination drought scenario predicts that the magnitude of impact upon flow in the streams will be more severe due to the extended duration of pumping required and impact on groundwater levels. A review of the current Q95 value trigger needs to undertaken, using more hydro-ecological flow based criteria with which to refine the stream compensation management to ensure the stream system is not over compensated as the volume support is accounted within the SGS licence allocation;

- Soil Moisture – soil moisture measurements employing capacitance probe technology will already be in place at established sites determined by the ADAS risk mapping. The frequency of measurement should remain weekly;

- Abstractors - The onset of drought conditions and more frequent operational use of the Scheme should trigger the need to carry out more frequent periodic reviews of the spatial and temporal derogation risk posed to private sources. The register of private sources should reviewed, maintained and periodically updated to retain a good working knowledge of the presence and existence of other groundwater users within each of the wellfields. Groundwater levels and trends should be monitored, both under non-operational and operational conditions, via the established groundwater network. The need to intensify focus on the likelihood of derogation risk should be triggered when groundwater levels begin to approach or fall beyond historic low levels. The register of sources and groundwater level data should be used to predict sources at likely risk of derogation through the extended operation of the scheme. Wherever practicable, derogation risk should identified before the impact is actually realised to avoid the need to implement emergency temporary supplies. Any projected or known derogation attributed to the Scheme should be mitigated for through the application of permanent alternative remedial solutions available under the model terms and conditions agreement;

- Model Terms & Conditions Agreement - Any detrimental impacts on third parties arsing from the operation of the scheme should be dealt with by reference to the formal agreement adopted by the Environment Agency and the National Farmers Union (NFU) and Country Landowners Association (CLA). The details of this formal agreement are presented in a booklet entitled "Shropshire Groundwater Scheme Safeguards and Assurances" setting out the policies and principles when developing and operating the Scheme.

10.4 Water Quality

Other than additional sampling of the Potford and Platt brooks, no major modification is considered necessary to the number of sites in the existing water quality monitoring network. The current practice of sampling boreholes, outfall and rivers on the same day should still be applied. This should be scheduled on a Phase by Phase basis to stagger the sampling programme and spread the work load.

- Water Quality Sampling –Under normal operating conditions the sampling frequency normally comprises two or three rounds of water quality sampling. It is recommended that at least 5 rounds of samples are taken to provide a better groundwater evidence base on which to assess potential impacts. A site-specific, risk-based determinand suite should be analysed for first monitoring round. Then for successive monitoring rounds (3-4 samples) analyses should be limited to an operational suite (comprising major ions, minor ions and nutrients) and occasional Gas Chromatography Mass Spectrometry (GCMS) analysis to provide detailed analysis results for volatile and semi-volatile organic compounds;

- Dissolved Oxygen - The Shropshire Groundwater Scheme outfalls already contain a variety of mitigation measures, designed to ensure that groundwater discharged from wellheads has sufficient dissolved oxygen prior to entering the receiving water. With the exception of Bolas Bridge out fall to the River Tern, this dissolved oxygen target has been achieved on all main operational outfalls to date. Low frequency operation of the stream flow compensation boreholes at Greenfields (Potford Brook) and Heath House No2 (Platt Brook) mean that dissolved oxygen levels in these discharges have not been fully quantified. These stream systems will become highly modified and dependant upon the groundwater discharge. These sites will require further characterisation and mitigation measures introduced if dissolved oxygen falls below the minimum threshold;

- Frankbrook - It is well established that the Frankbrook borehole is affected by elevated chloride concentrations. At present, this is monitored by periodic electrical conductivity (EC) measurements that are taken during visits to the abstraction. Currently this relies on infrequent measurement. We recommend that this discharge is fitted with an EC data logger, set to record EC at 15 minute intervals, with telemetry to allow frequent comparison against the EC threshold from the office. Based on work undertaken by the Environment Agency, the conductivity triggers for the raw groundwater discharge to the River Perry at Adcote would be 2000 μS/cm (Amber - start more intensive monitoring) and 2300 μS/cm (Red - stop if chloride concentrations in river exceed 250 mg/l). These are based on regression analysis and modelling of the historic actual data in the River Perry downstream of the outfall;

- Temperature Effects - As the effect of discharging groundwater on the temperature of the receiving watercourse is potentially the most important impact of the scheme, additional temperature profiling exercises (as in Appendices F-H) should be carried out to characterise the effect of each discharge upon the receiving watercourse. Measurements should be taken in the channel upstream, at the point of discharge and extending downstream until the ambient temperature returns to upstream values.

10.5 Ecology

Based on the available data the Drought Order and associated modifications to the SGS licence appear unlikely to have significant effects on aquatic ecological receptors. However given the inherent uncertainties in terms of the timing, frequency and duration of pumping, the following is recommended on a precautionary basis:

- Agitation of discharge water at all outfalls should be undertaken to increase oxygen content to the maximum level practicably achievable, where this is not already the case;

- Wherever possible, slow continuous release of SGS water over the period of operation;

- Wherever possible delay or reduced release of SGS water until late summer to maximise fish recruitment and fry growth;

- Flexible SGS operation rules that cease in the event of natural flow increase;

- Avoid discharge to lengths of watercourse with dense over-hanging tree canopy, which may lead to water remaining cooler for longer.

There is inherent uncertainty in predicting hydrological changes in rivers and the response of biological communities, particularly as the timing, frequency and duration of SGS releases varies between years. Therefore a robust monitoring programme will be necessary to inform a further assessment of the scheme in the future. This is particularly important with respect to any operation of the scheme approaching its maximum licensed output in consecutive years. The monitoring programme would include the following:

- Fish surveys and intermittent review of patterns in fish numbers/density; standing crop and growth rates, focusing on roach, dace, chub, trout and gudgeon and comparing control sites with sites situated downstream of outfalls;

- Invertebrate monitoring and intermittent analyses of biotic indices, including LIFE and ASPT, comparing control sites with sites situated downstream of outfalls. This monitoring should include sites on Potford and Platt Brooks;

- More detailed investigations to verify the effects of the scheme on temperature profiles downstream of all outfalls, taking into account temperatures throughout the full water column and across the width of the channel and comparing upstream and downstream temperatures;

- Ongoing and frequent monitoring of water quality, comparing sites upstream and downstream of discharges.

The Mitigation and Monitoring in relation to designated sites is summarised separately as follows:

- Old River Bed SSSI & SINC: This wetland is predicted to fall within the marginal pumping effects of Phase 3. The degree of drawdown influence is not predicted to reverse the natural hydrogeological regime. Monitoring should focus on groundwater level observation in the two key boreholes at Crosshill Obs and Old River Bed Obs to ensure groundwater levels do not fall below the floor level of the SSSI body. Surface out flows from the site should also be gauged and the condition of the site monitored in close liaison with Natural England. In the event that groundwater levels adjacent to the site begin to approach levels of concern, in mitigation the Phase 3 pumping regime could be modified to test if the magnitude of drawdown could be reduced. This could be achieved by reducing the abstraction rate or switching off entirely the Phase 3 abstraction at Newton which at 2.5km is the closet point of abstraction to the SSSI & SINC;

- Platt Brook: see stream flow compensation management action;

- Sundorne Brook: This stream system has no permanent flow gauging structures. Spot gauging should be undertaken to assess the nett gain effect of the augmented flow and a water level monitoring should be established on the Sundorne Pool. Operating rules to maintain flows should be established in consultation with EA Bio-diversity team and the Panel Engineer responsible for the Sundorne dam structure.

10.6 Application for a Temporary New Modification under WFD

Any application for a drought permit would require preparation and presentation of evidence at inquiry. As part of this process the implication for consequences of this drought permit on WFD will also have to be assessed. Sufficient time should be allowed to trigger this process and therefore the need to consider any such application should be identified early on within the environmental action plan.

Where it is anticipated that the Article 4.7 defence might be needed, reference should be made to the following documents (or the latest revised versions) and specific guidance and support sought to assess the process outlined in these documents.

- ‘Assessing new modifications for compliance with WFD’ – Operational instruction 488_10 issued 09/11/10;
- ‘Assessing new modifications for compliance with WFD – detailed supplementary guidance’ – Operational instruction 488_10_SD01 issued 09/11/10.

Sufficient time should be allowed to trigger this process and therefore the need to consider any such application should be identified early on within the environmental action plan.

The East Shropshire Groundwater Model is a well calibrated and trusted numerical groundwater model. The out puts from this model in conjunction with the Water Resources ArcGIS should be used as tools to provide predicted impacts of operating SGS, and any implications for WFD status of the groundwater body.

10.7 Summary and Conclusions

There is an underlying long term commitment to manage the water body to attain good status and thus be compliant with WFD. The severity of the drought event considered under this scenario is recognised as being extreme with an expected low frequency of return. Any impact from the extended operation of SGS is likely to be relatively short term, but as stated longer that that foreseen under ‘natural causes’.

In pursuing a permit to modify SGS beyond its current licence constraints consideration must be given to any potential impact this modification may have on the WFD status of the water body in which the scheme operates. SGS sits within the Shropshire Middle Severn Permo-Triassic Sandstone groundwater body. The current WFD assessment considers that the groundwater body is already at poor quantitative status failing for two out the four tests.

Further assessment work is required to fully quantify whether any impact will be predicted in context to WFD. The level of any impact will diminish exponentially with time as groundwater levels recover. However this process may exacerbate the current resource balance and impacts of abstraction on surface flow failures. This may cause to delay the on set of improving conditions and the desired recovery of the body from poor to good status under WFD.

11. Summary and Conclusions

11.1 Section 2 Shropshire Groundwater Scheme Drought Order Rationale and Proposal

The River Severn is a regulated river, which forms part of a large water supply and management system. The Environment Agency is the lead organisation with responsibility for regulation of the River Severn in consultation with Natural Resources Wales. This is statutory controlled through provisions under the Clywedog Reservoir Joint Authority Act 1963, and the Operating Rules for the River Severn Resource/ Supply System.

These rules govern how much water is released to the river system from both surface water and groundwater storage sources to balance the ecological needs of the river against the demands of abstraction for; public water supply, spray irrigation, industry, and navigation.

SGS sits within and draws upon the significant resource potential offered by the North Shropshire Permo-Triassic Sandstone aquifer. The Permo-Triassic Sandstone is one of most important principal aquifers in the United Kingdom, second only to the Chalk. The properties of the sandstone mean that it has an excellent capacity to store large volumes of groundwater, making it the biggest strategic store of potable water in the UK. This favours its use for large scale strategic resource development.

The purpose of SGS is to provide a large strategic volume of groundwater to supplement and conserve the remaining storage in Clywedog reservoir to sustain regulation support for the River Severn.

Before a River Severn Drought Order application is made, all necessary water saving measures and strategies identified in the Midlands Drought Plan should have been implemented. The Environment Agency will also have been working closely with water companies to ensure they follow their own Drought Plans and manage water resources in a sustainable manner as the drought develops.

In the absence of alternative strategic water resources of equivalent volume within the Severn basin, no alternative action or resources would be available to the Environment Agency other than to apply for the River Severn Drought Order.

This order aims to ration out the remaining resources in Llyn Clywedog by seeking to extend pumping of SGS beyond its current abstraction licence constraints to counter the effects of an extreme drought event.

11.2 Section 3 Methods and Modelling

Bespoke numerical water resource and groundwater models have been used to provide an assessment of how much additional water beyond the annual or five year SGS abstraction licence limit would be required to support River Severn regulation under simulated extreme severe drought conditions. Standard climate change scenarios have been applied to assess the potential impact on the storage components of the system.

The modelled scenario looked at a five year period emulating the back to back drought years experienced in the UK in the early to mid 1990's. To provide a robust challenge modelling used a dry climate change sequence incorporating a prolonged three year drought similar to that seen in 1995 and 1996. This culminated in a "1976" extreme drought event in the last year of the sequence. Under the scenario modelled here an additional 3,680 Ml of groundwater support would be required, in excess of the current 55,500 Ml five year abstraction licence limit. Equivalent to 107% of the SGS 5 year licence allocation. This approximates to 21 days of additional pumping support at 190 Ml/d, beyond that permitted by the current abstraction licence.

The impact of this level of groundwater SGS abstraction on the surrounding hydrogeology, hydrology and ecological environment in North Shropshire was assessed through the application of the East Shropshire Groundwater Model and a crop vulnerability methodology developed by ADAS and the Environment Agency. The outputs from these models were used as the basis of the environmental assessments in this report.

The prolonged back to back drought sequence modelled by this drought order draws parallels with the "chronic drought scenario" modelled by the River Severn Drought Order. These predictive scenarios represent very extreme climate events not observed within the last 100 years. Although given the uncertainty posed by the impacts of climate change, it should not necessarily be regarded as unlikely.

11.3 Section 4 Geology and Soils

The SGS has been developed in the extensive low-lying area occupied by the North Shropshire Plain. These plains mark the subcrop and out-crop area of the Permo-Triassic aged sedimentary rock in-fill sequence. These sedimentary rock formations include the Sherwood Sandstone Group, forming the present day principal groundwater bearing aquifer in which the wellfields of the SGS have been developed.

The rock formations of North Shropshire are blanketed by a variable thickness of unconsolidated sediments. These deposits owe their origin to glacial, periglacial and post-glacial temperate climatic conditions related to the Late Devensian glaciation and Holocene period.

Based on the nature of the geology in which the groundwater scheme has been developed, no impact on the structural fabric of the local geology due to pumping has been observed to date due to the historic operation of the scheme. No impact is anticipated to arise from the extended pumping regime envisaged to provide additional groundwater support under drought conditions.

11.4 Section 5 Water Resources

The Permo-Triassic Sandstone in which SGS has been developed, is one of the most important principal aquifers in the United Kingdom, second only to the Chalk. Despite its much smaller outcrop, the sandstone's properties means that it has an excellent capacity to store and slowly discharge large volumes of groundwater, making it the biggest strategic store of potable water in the UK. These properties favour its use for large scale strategic resource development, as the effects of seasonal abstraction and recharge patterns are more evenly distributed over longer periods within the environment.

Much of the Permo-Triassic Sandstone aquifer in the area of interest is covered by complex drift with significant vertical, lateral and lithological variation, giving rise to both confined and unconfined conditions across the aquifer. This combined with a variable depth to groundwater means that environmental sensitivity also varies spatially across the scheme.

The hydrogeological setting of the Phase 1 and 4 wellfields, is such that there is good interaction between the groundwater and surface water systems, with relatively shallow groundwater levels present across much of the catchment. This catchment is recognised as being more sensitive to the effects of pumping with stream compensation measures for the Potford and Platt Brooks and soil moisture monitoring already in place as part of the normal operating regime for SGS. The extensive drought pumping will culminate in more extended use of these stream compensation schemes.

In direct contrast, the hydrogeology of the Phase 2 & 3 wellfields are predominantly underlain by deep groundwater. Other than the River Severn itself and the lower reaches of the Sundorne Brook and Bagley Brook, on the whole support from the sandstone is not considered to be an important mechanism to maintain stream flows. These phase areas are therefore considered to be less sensitive to the effects of pumping.

The effects of groundwater abstraction by SGS in the short term are supported by taking groundwater stored in the aquifer. In the medium term this will be at the expense of a reduction in the proportion of groundwater supporting stream and river flows. Given the intermittent operational nature of the scheme over the long term this impact will diminish as recharge naturally replaces the water pumped out by the scheme and therefore replenishes groundwater levels.

Under normal demand conditions SGS was designed to be operated in two out of every five years, allowing a period of recovery between operational periods. Monitoring indicates that groundwater levels have recovered to pre-pumping levels between historic operational periods. This indicates that SGS is operating in harmony with the natural groundwater resource balance when used within its licence limits.

The magnitude of pumping sought under the drought conditions will however be greater than that observed to date, as will the impact on groundwater levels in the aquifer. The drought order scenario does not allow for the recovery of groundwater levels between the three year back to back operational periods. The consequence of this being that impacts on stream and river flows will be greater as the recovery period for aquifer recharge may be in excess of 6 years.

Excluding the River Severn, approximately 41km of tributary carrier rivers and streams will benefit from artificially enhanced SGS augmented flows. Under drought conditions these augmented stretches of watercourse will be in a more favourable flow condition than surrounding water courses which will be experiencing low flow stress conditions.

Under the extended use of SGS additional stress may be placed on less resilient private water supply sources. Small volume domestic sources, drilled to a shallower depth within the aquifer will be more sensitive to pumping operations. Larger volume commercial sources, such as public water supply and spray irrigation boreholes, tend to be more resilient and therefore less sensitive to groundwater level fluctuations. Wherever practicable, derogation risk should identified before the impact is actually realised to avoid the need to implement emergency temporary supplies. Any projected or known derogation attributed to the Scheme should be mitigated for through the application of permanent alternative remedial solutions available under the model terms and conditions agreement.

11.5 Section 6 Groundwater and Surface Water Quality

The aim of this Groundwater and Surface Water Quality section was to characterise the current quality of the groundwater and surface water courses, to assess the chemical and temperature effects of augmenting river flow with groundwater and to predict the effect of pumping groundwater beyond the current licence constraints.

All historical groundwater quality analysis data gathered from the scheme to date was reviewed. These data were compared against Environmental Quality Standards (EQSs) set out within the Water Framework Directive (WFD) and Freshwater Fish Directive.

This study concluded that groundwater quality is, on the whole, better than the receiving surface water courses and exceeded fewer EQSs. Water quality effects in rivers from groundwater augmentation are therefore considered to be largely neutral or beneficial.

A limited number of determinands regularly occur at concentrations in groundwater that are higher than both the surface water concentrations and the corresponding EQSs. Additional water quality modelling should be undertaken to determine whether these pose a threat to quality standards under low flow conditions. Any effects are likely to be extremely localised and dissipate within a short distance downstream of the discharge.

No deterioration in groundwater quality has been observed with the duration of pumping seen to date, with the exception of Frankbrook (Phase 2) where rising chloride concentrations need to be monitored closely, and Helshaw Grange (Phase 1) which has been taken out of operational use due to localised solvent contamination. No significant deterioration in groundwater quality is foreseen given the extended pumping required to support the drought order.

The SGS outfalls already contain a variety of mitigation measures, designed to ensure that groundwater discharge has sufficient levels of dissolved oxygen prior to entering the receiving watercourse. With the exception of one marginal site, this dissolved oxygen target has been achieved on all main operational outfalls to date. Low frequency operation of the stream flow compensation boreholes at Childs Ercall, Greenfields (Potford Brook) and Heath House No. 2 (Platt Brook) mean that dissolved oxygen levels in these discharges require further evaluation.

The effect of discharging groundwater on the temperature of the receiving watercourse is to reduce river temperature on a localised scale. Any effects are likely to be extremely localised and dissipate within a short distance downstream of the discharge. Additional temperature profiling exercises should be carried out to better quantify the effect of each discharge upon the receiving watercourse.

11.6 Section 7 Ecology

The assessment of the effects of the drought order focus on ecological receptors (groundwater dependent designated sites, fisheries and aquatic macroinvertebrates) that are likely to be sensitive to the changes in hydrology that the scheme is predicted to bring about. Riparian species such as otter, water voles, bats and birds are unlikely to affected by the temporal/ transient changes caused by the operation of the scheme and were therefore scoped-out of further assessment.

The assessment focused mainly on the River Tern, River Perry, Potford and Platt Brooks. These smaller tributaries receive multiple discharges from the SGS; are likely to have an ecology that is comparable to the middle and upper reaches of the River Severn; are regularly monitored; and are likely to have more limited capacity than the larger River Severn to buffer changes in, for example, water quality or temperature.

Based on the available historical data set, there appears to be no clear correlation between antecedent flow and LIFE(f) recorded on the River Tern and River Perry. It is therefore likely that any localised flow-induced changes in invertebrate assemblages in response to the infrequent operation of the scheme for discrete periods will be temporary and undetectable.

Long term trends in ASPT biotic index score assigned to invertebrate assemblages, recorded up and downstream of SGS discharges on the River Tern and River Perry, were analysed. Similar ASPT scores recorded across years and with limited variation above and below the discharge locations is consistent with the SGS having no significant effects on aquatic invertebrate assemblages. Therefore the previous operation of the SGS does not appear to have had long term effects on invertebrate assemblages.

Modelling predicts that the effect of the extreme drought scenario will cause stream and river flows to fall lower than that observed in 1976. Approximately 41km of SGS augmented water courses will benefit from the scheme as total flows will be elevated to within normal summer flow ranges. This benefit will come as a consequence of an increase in the proportion of groundwater making up the total augmented river flow.

The operation of SGS is predicted to reduce river temperatures at the point of discharge by up to 6°C. Prolonged changes in temperature of this magnitude in consecutive summers could be expected to have significant effects on fish growth and survival/ recruitment. Similarly these temperature changes would be expected to slow invertebrate life cycles. However the SGS induced temperature change appears to be localised and to dissipate quickly, with river temperatures being restored to upstream ambient temperatures within short distances downstream of the outfalls. The length of water course affected by cooling water is therefore nominally small, relative to the length of river benefiting from augmented flow as a whole.

Predicted effects on river quality from discharge of groundwater include localised exceedances of water quality standards for a small number of determinands as well as, in a small number of cases, reduced oxygen concentrations immediately downstream of discharges. However mixing/ agitation of water at discharge locations are likely to dilute these determinands and increase oxygen concentrations. Localised, short term changes in concentrations of some determinands are unlikely to have significant effects on fish populations and invertebrate assemblages.

The Potford and Platt Brook stream systems already have dedicated stream augmentation boreholes designed to provide compensation flows to mitigate for impacts within normal licensed operation of Phase 1&4. It is likely that the Hadnall No2 (Phase 5) stream compensation borehole may be required to mitigate for the predicted Phase 3 impacts on flows to the lower Astley Brook and Sunderton Pool.

The drought order will require an extended reliance on these support mechanisms to maintain flows during operational pumping and intermittently thereafter while the aquifer recovers. Further assessment work is required to refine the flow targets which trigger the need to make compensation releases to these stream systems. The current target of Q95 is considered to be too conservative making inefficient use for groundwater resources and therefore increasing the cost of maintain the compensation flows. The compensation operating rules should be replaced by more site specific hydro-ecological flow criteria to more efficiently match flows to the betterment of the streams ecological systems. Further ecological monitoring is required to further inform an assessment of these effects.

A total of 43 designated biodiversity sites have been identified within the operational area of the SGS. This includes eight notified as Sites of Special Scientific Interest (SSSI), two of which are wetlands of international importance (Ramsar sites); and one Local Nature Reserve (LNR). This list also includes 34 non-statutory sites, designated as Sites of Importance for Nature Conservation (SINC). These sites underwent hydrogeological screening to identify whether they were groundwater-dependent or surface water-dependent. This screening process was then used to assess the potentially susceptibility of sites to the effects of SGS pumping.

Of the 43 sites reviewed, 32 were determined as having no connection with, and therefore no dependency upon, groundwater from the sandstone aquifer. Therefore no impact from SGS would be expected at these sites. One site was under lain by complex hydrogeology, but not considered to be at risk, and two had insufficient data with which to make any conclusive assessment. Of the eight sites considered to interact with groundwater from the sandstone, only four had some level of predicted impact from SGS. Two out these four already have established flow compensation schemes.

The Old River Bed SSSI wetland falls within the marginal pumping effects of Phase 3. The drought scenario is predicted to increase the magnitude of drawdown under the site compared with that seen to date when Phase 3 is operated within its licensed limits. To ensure the natural upward hydrogeological regime is maintained beneath the site trigger levels have been set on an observation borehole next to the site to prompt review and possible modification of the pumping regime to mitigate against the effects from Phase 3.

11.7 Section 8 Archaeology and Cultural Heritage

A high-level appraisal of the potential for changes to groundwater levels beneath archaeological sites and monuments, predicted as a result of the operation of the SGS, has been undertaken.

The appraisal attempts to categorise archaeological sites in terms of the potential sensitivity of the deposits within which they are contained to changes in water level. It identifies which sites lie within areas where groundwater is relatively close to the surface (0 to 4m below ground level).

The archaeological assessment and the hydrogeological screening methodology applied here indicate that of the 1840 sites identified, there are 50 sites within the area affected by abstraction from SGS that may be susceptible to changes in groundwater level. These sites vary in their susceptibility but, with the exception of 3 sites, sequential screening has resulted in a list of sites with a sensitivity score of less than 3 indicating high or medium sensitivity to changes in groundwater levels and depth to groundwater of less than 2 mbgl.

In the absence of site specific information on the hydrogeological conditions underlying each site, it is extremely difficult to draw any quantifiable conclusions as to the exact risk posed by any natural or induced fluctuation in groundwater levels. Without any quantifiable impact there are no plans to extend the current environmental network to include site specific monitoring of ground conditions at any archaeological or scheduled monument sites.

11.8 Section 9 Water Framework Directive Implications

There is an underlying long term commitment to manage the water body to attain good status and thus be compliant with WFD. The severity of the drought event considered under this scenario is recognised as being extreme with an expected low frequency of return. Any impact from the extended operation of SGS is likely to be relatively short term, but as stated longer that that foreseen under 'natural causes'.

In pursuing a permit to modify SGS beyond its current licence constraints consideration must be given to any potential impact this modification may have on the WFD status of the water body in which the scheme operates. SGS sits within the Shropshire Middle Severn Permo-Triassic Sandstone groundwater body. The current WFD assessment considers that the groundwater body is already at poor quantitative status failing for two out the four tests.

Further assessment work is required to fully quantify whether any impact will be predicted in context to WFD. The level of any impact will diminish exponentially with time as groundwater levels recover. However this process may exacerbate the current resource balance and impacts of abstraction on surface flow failures. This may cause to delay the on set of improving conditions and the desired recovery of the body from poor to good status under WFD.

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Appendix A
Aquator Modelling Report

SGS Drought Order Environmental Report

Further update on additional modelling work 14-10-08

The results update from 29th August suggested that further work could be done by looking at a scenario which covered the 5 years from 1993 – 1997 but replaced 1997 data with that from 1976 in order to create an extreme long duration drought (ie 1995+1996+1976). A meeting was held at Hafren on 26th September attended by Kevin Voyce, Claire Walker, Sarah Hainie and Ellie Creer of Entec where this issue was discussed and we felt that it would be sensible to model a more extreme version of an actual multi year event in order to fully test the 5 year licence limits. The scenario of using the actual 1995, 1996 drought with 1976 added on instead of 1997 was agreed to be the best way to do this.

Methods

The same methods as before were used to create a 1970 -1997 time series with the 1997 data replaced by that from 1976. Due to time constraints this time series was only created and the model run for the dry climate change scenario flow sequences.

Results

For the dry climate change scenario the annual limit is only exceeded for phases 2b and 3 (Montford and Leadon) in “1997” but the total annual licence limit is not exceeded. The five year licence limit is exceeded for phases 2b, 3 & 4 (Montford, Leadon and Tern 2) and also for the overall licence limit.

Table 1 – Percentage of annual licence used for each phase during the modelled 1993-1997 period for the dry scenario

Phase	1993	1994	1995	1996	“1997”
Tern I	0.2	10.06	48.93	64.5	81.91
South Perry	1.8	9.23	42.09	52.6	65.05
Montford	0.0	13.27	60.72	76.4	101.48
Leaton	0.0	12.70	58.10	73.9	100.89
Tern II	0.0	11.46	51.92	67.4	90.01
Total	**0.2**	**11.52**	**53.35**	**68.6**	**90.48**

Table 2 – Percentage 5 year licence total used for each phase during the modelled 1993-1997 period for the dry scenario

Phase	Proportion of SGS used
Tern I	95 %
South Perry	79 %
Montford	115 %
Leaton	113 %
Tern II	101%
Total	**103%**

Shropshire Groundwater Scheme Drought Order
Aquator Modelling Work

Sarah Hainie/ Claire Walker (November 2008)

1. Introduction

The Environment Agency oversees regulation of the River Severn to maintain the prescribed flow conditions at Bewdley via release of water from reservoirs and the Shropshire Groundwater Scheme (SGS). Our drought plans identify that in an extreme drought additional measures may be required to ensure public water supplies and protect the environment. The River Severn drought order includes a series of actions to preserve supplies and reduce demand during an extreme drought to maintain flows. This includes the potential to extend the annual and five-year licence for the SGS. The aim of this project was to analyse the use of SGS within a range of climate scenarios to assess whether these licence limits may be exceeded and how much extra water would be required to maintain flows on the River Severn. This information will then be used in the production of an environmental assessment of the potential impacts of extra pumping from the SGS. Further background on the SGS and the River Severn drought order are included within the scoping report (Environment Agency, 2008).

The aquator water resources model for the Severn and Wye system was used to model regulation of the River Severn and the use of SGS. Standard climate change scenarios currently used for water resources planning were applied to assess the potential use of SGS under altered patterns of rainfall frequency. Scenarios of different seasonal patterns were also simulated to investigate the impact on the licence of more prolonged droughts than have been observed previously, as well as more severe drought conditions.

1.1 Overview of the model

Severn Trent Water's aquator model of the River Severn and Wye system was used to assess the potential requirement of SGS under different climate scenarios. The model uses a 77 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. This includes regulation of the River Severn and appropriate releases from Clywedog reservoir, Vyrnwy reservoir and SGS are modelled when the flows require it. A series of demand centres are present within the model (representing major urban areas) and these have demand profiles allocated to them based on patterns of demand for water supply in 1995, a dry year of high demand. Demand was assumed to be the same as the dry year demand which Severn Trent plan to for their baseline deployable output. This is effectively the demand profile of the 1995 dry year multiplied by a factor of 1.025. This demand factor was obtained from estimation of the deployable output: The model was run repeatedly for the period of run-off data (currently 1920-1996) at variable levels of demand, converging on the optimum factor at which demand is maximised and all demand centres can still be supplied. The amount of water which can be supplied is termed the deployable output of the system.

The model version used was that produced by Severn Trent for the 2008 draft water resources management plan. It is worth noting that an extensive review and update of the model has been undertaken for the final water resources management plan.

The new version, produced in October 2008, includes updated inflow sequences to 2007 and the parameter sets have been revised. The planning process also required Severn Trent to consider a series of climate change scenarios to look at the impact on surface water availability. The flow factors approach was used for the draft plan although the climate change scenarios have now also been updated in the new version of the model using the more sophisticated rainfall-runoff methodology (see section below).

1.2 Climate change scenarios

The climate change methodology used by water companies for water resources planning have been developed based on scenarios from 6 different global climate models assuming a medium emissions scenario. These estimate monthly rainfall and potential evapotranspiration factors for the 2020s at the catchment scale (Vidal and Wade, 2006). The factors can be applied directly to long-term records of precipitation and PET for the rainfall-runoff approach to then generate a climate change flow sequence. The methodology has also developed a tool to estimate flow factors which can be applied directly to catchment inflow sequences using the catchment Base Flow Index and catchment specific precipitation and PET factors.

For the purposes of the draft plan Severn Trent opted to use the flow factors approach. For each subcatchment, monthly flow factors were estimated and applied to the inflow sequence feeding into the aquator model. Flow factors for a mid-range climate change scenario were derived from the mean of the 6 different model forecasts. For a more extreme dry scenario flow factors were also derived from the range of results from the 6 GCM models (the 95 percentile) and wet scenario (the 5 percentile). For the purposes of this assessment only the mid-range and the dry scenario were used in addition to the baseline.

1.3 Severn Regulation and the Drought Order

When River Severn flows at Bewdley are falling towards the maintained flow condition (850 Ml/d) regulation is switched on which uses Clywedog Reservoir in preference, then Vyrnwy and finally SGS. There are two different methods available within the aquator model to switch on SGS. The first switches SGS on in response to crossing a single control curve on Clywedog Reservoir. The second method involves the use of five separate control curves (designed for use on all eight phases so only three are currently used) and these switch on phases more gradually initially preserving the more expensive SGS resource in favour of the cheaper water available from Clywedog (EA, 1999). These control curves would also be used in reality for regulation of the River Severn.

A drought order is instigated by the crossing of separate control lines on Clywedog for initially the application and then instigation. The curve which switches on the drought order is labelled the level 2 demand saving curve within aquator. During regulation conditions releases can be made from Clywedog up to a maximum of 500 Ml/d. Under a drought order these are capped at 300 Ml/d. The drought order will also reduce the prescribed flow at Bewdley to 730 Ml/d and result in a 5% reduction in demand on non-spray irrigation licences. Once Clywedog reservoir falls to below 17.8% storage maximum releases are then capped at 1.5% of remaining storage.

2. Methods

2.1 SGS parameters

The model was set-up so that only phases 1-4 were available with the efficiencies for each phase taken from the Skinner proof of evidence (table 1). The licence amounts set in the parameters reflected the actual licence amounts used for the daily, annual and five year licence (Environment Agency, 2008). Initial runs used the single SGS line to control switching on and off (original method). This was replaced with the updated method (EA October 99 method) which uses multiple control curves for the later runs (July/August runs). Following comparison of the two methods it was agreed that using the multiple control curves is a more accurate representation of how the SGS scheme would be operated in reality. However, the model runs in Severn Trent's draft 2008 Water Resources Management Plan used the original method. The method is selected within the model using the Setup regulation dialogue box under the macros.

Table 1 – SGS efficiencies

Phase	Efficiency (%)
1 Tern I	64
2a South Perry	71
2b Montford	71
3 Leaton	89
4 Tern II	64

The control curve at Draycote Reservoir was also switched off from controlling the onset of Level 2 demand savings, which are effectively drought order conditions and thus how Clywedog was being used. It was found that this was switching on a drought order much earlier in the season than would be expected in real life. Additionally, levels on this reservoir would not specifically control regulation on the River Severn so it was decided it was more appropriate to switch this off. The level 2 demand savings (drought order conditions) are also switched on in the model by the control curve at the Elan valley reservoir.

2.2 Scenarios

Three scenarios were initially run to test the potential use of the annual and five year scenario all using the inflow sequences from 1920-1996:

- Baseline
- Mid-range climate change factor
- Dry climate change factor

From each of these two notably dry 5 year periods were selected for further investigation:

- 1972-76
- 1992-96

Further scenarios were then looked at to extend the drought period for each of the climate change scenarios:

- Double 1976 (1973-76 +1976 then repeated)
- 1990's + 76 (1993-96 +1976)

Where the licence was completely used up the model run was then repeated but with the licence limits increased by initially 10% and then for the most extreme scenario 20% was required for some phases.

Double 1976 scenario
To further investigate the potential impact of climate change on the need for a drought order for SGS a scenario was considered which increased the frequency of an extreme drought on the River Severn. The inflow sequences for each subcatchment in the model were exported for the baseline, mid-range and dry climate change scenarios. A time series was created where 1976 occurred twice in a five year period – double 76. This was achieved by repeating the 76 flow sequence two years in a row. The new time series created for every catchment in the model included the 1970-76 time series, as it occurred, with 1976 then repeated. This was also reproduced for the climate change flow sequences for the mid-range and dry scenarios. The sequences were then re-imported back into the model and new scenarios/sequence sets were created for each of the baseline, mid-range and dry climate change scenarios. The model was then run again for each. The aim of this work was to test the 5 year licence limits to see whether they would be exceeded if an extreme 2-year drought occurred.

1990's+ 76 scenario
A similar process was followed as above but this time the sequence from 1970-1996 was used with 1976 repeated again at the end. This was selected as 1976 was shown to be the critical year within the sequence. However, 1995-96 was shown to be a more prolonged drought with an increased pressure on the 5 year licence so the two periods were combined to create a worst case scenario.

3. Results/conclusions

The section below presents a brief summary of the results from the model runs. For further analysis and charts see the analysis files produced for each of the modelling runs (Section 4 lists file locations).

3.1 EA October 99 methodology

Considerably less water was used from the SGS in the period 1973-77 when the EA October 99 method was used as opposed to the original method. However, during the peak period August – September 1976, flows at Bewdley still dropped below the 850 or 730 Ml/d (during a drought order) target flow. During this period regulation releases were maximised so additional annual licence for the SGS would not have been of benefit. As indicated in table 1, the amounts of water required were below the licence limits. Closer examination of the results for each phase showed that sources were approaching their annual licence limits only during the dry scenario (see separate results files).

Table 1 – Use of SGS in the updated analysis using the EA October 99 methodology

Scenario	1976 annual licence use	1973-77 5-yr licence use	1992-96 5-yr licence use
Baseline	63.7%	30.8%	21%
Mid	71.1%	35.2%	38.7%
Dry	86.9%	43.1%	64.1%

In the dry scenario 100% of the annual licence was used in 1976 for the Montford phase 2b. The results indicate total outputs from SGS drop off at the end of the summer in response to this. Re-running the model with 10% added to all the annual licences resulted in more water being pumped from 2b, although all the others remained the same. This confirmed only this source was limited by the licence. This provided additional support when the outputs had dropped at the end of the 1976 drought and slightly raised Bewdley flows. An additional licence amount of 460 Ml was added for Phase 2b. The results show that 328.6 Ml extra were used from this source for regulation to maintain the maximum output from SGS until regulation ceased.

Results from the original methodology (June runs) suggested that both the annual licence and the five year licences would be exceeded under the dry climate change scenario. However, the contrasting results from the EA Oct 99 rule method suggest that managing the quantities released from the SGS preserve stocks sufficiently to meet the five year licence conditions even in a fairly extreme scenario of climate change.

Analysis was also done to look at the 92-96 period for each of the scenarios. The dry scenario does use a high proportion of the licence amounts in 1995 and 1996 and also for the five year period overall.

3.2 Double 1976 scenario

The results, presented in Table 2, show that for the baseline and medium climate change scenarios there was still sufficient water within the annual and 5-year licence to meet the requirements of the River (although as noted previously the daily limits on phases 1-4 prevented flow at Bewdley being maintained once outputs from Clywedog were capped due to the drought order).

Table 2 – Total SGS use within 5 year licence limits.

Scenario	1973-77	Double76
Baseline	30.8%	61.0%
Mid	35.2%	69.6%
Dry	43.1%	88.3%

In the dry climate change scenario the 5 year licence limits were approached for several of the phases and completely used up by Phases 2b and 3. The 5 year licence was therefore increased by 10% to allow additional water to be pumped from the restricted Phase 2b (Table 3).

Table 3 – SGS use within the 5 year period for the dry year scenario with 10% added to the annual and 5-year licence limits.

Phase	Proportion of SGS used
1 Tern I	80.1%
2a South Perry	65.0%
2b Montford	105.8%
3 Leaton	99.6%
4 Tern II	87.3%

3.3 1990s + 1976 scenario

4. File locations

File locations (saved on both the aquator computer and on the Sapphire G drive under the Modelling folder):

SGS drought order

1. Planning
2. Model runs
3. Data analysis
    - August (double 76)
    - August (single SGS curve)
    - July runs (multiple SGS curves)
    - June runs (single SGS curves but Draycote curve switching on drought order early)
    - STW runs (from the draft WRMP)
4. Results
    Aquator results_28-07-08
    Aquator results_29-08-08

Technical reports

Within the folders listed above are the files. For each of the data analysis files these are labelled with the scenario name, time period and date when work done.

References

Environment Agency 1999 Design of operating rules for the Shropshire Groundwater Scheme.

Environment Agency 2008 SGS Scoping document for the production of an Environmental Report in Support of a drought order.

Severn Trent Water/Oxford Scientific 2005 VBA Customisation Severn Trent Components.

Vidal, J and Wade S 2006 Effects of climate change on river flows and groundwater recharge: guidelines for resource assessment and UKWIR06 scenarios, UKWIR.

Other useful reports

Environment Agency 2006 Operating rules for the River Severn Resource/Supply System (Blue Book) FINAL.

Hydro-logic 2008 Updating of aquator models.

Mott Macdonald 2008 Review of Severn Trent Aquator Models.

Mott Macdonald 2008 Extension of aquator flow database.

Skinner, A.C 1979 SGS Public local inquiry – Proof of evidence.

STW 1999 Simulation of flows of River Severn.

STW's 2004 water resources plan – the DO appendix contains a well written summary of the ResSim models from which the aquator ones were assembled so it's useful background.

STW 2007 Draft Water Resources Management Plan.

Appendix B
ESI ESM Predictive Simulations Report, 2009

East Shropshire Permo-Triassic Sandstone Model: Predictive Simulations for Shropshire Groundwater Scheme Phases 1-4 Drought Order

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East Shropshire Permo-Triassic Sandstone Model: Predictive Simulations for Shropshire Groundwater Scheme Phases 1-4 Drought Order

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FIGURES

TABLES

1 INTRODUCTION

1.1 Background

The Environment Agency wishes to obtain a drought order to enable increased abstraction from Phases 1, 2, 3 & 4 of the Shropshire Groundwater Scheme (SGS), exceeding the licensed rates, in times of drought. The East Shropshire Permo-Triassic Sandstone Model (ESM) has been developed to enable the assessment of the impacts on groundwater levels and surface water flows from the SGS (Streetly and Shepley, 2005, ESI, 2008). Further predictive simulations have been carried out to assess the impacts of increased abstractions from the SGS in response to climate change.

1.2 Scope of Work

Three new predictive simulations have been carried out using the ESM as updated in 2008:

1. Normal climate with recent actual abstraction rates and no SGS abstractions (baseline simulation).

2. ‘Dry’ climate change with recent actual abstraction rates and no SGS abstractions (‘dry’ simulation) ‘

3. ‘Dry’ climate change with recent actual abstraction rates plus SGS abstractions (‘dry plus SGS’ simulation) ‘

All three simulations use a climate sequence which includes an extreme three year drought, which is represented by the climatic data from the years 1995 and 1996, followed by 1976. The full climate sequence for the models is discussed in detail in Section 2.1. For the dry climate change scenario, used in predictive simulations 2 and 3 above, the rainfall and potential evapotranspiration (PE) rates have been modified using monthly factors according to the UKWIR methodology (UKWIR, 2007).

1.3 This Report

This report contains a concise description of the predictive simulations (Section 2) and discusses the results in terms of the impacts on groundwater levels and surface water flows (Section 3).

This report will form an appendix to the environmental report by being prepared Entec UK.

2 DEFINITION OF PREDICTIVE SIMULATIONS

2.1 Time Period for Predictive Simulations

The climate sequence for the combined recharge and groundwater model (combined model) predictive simulations is summarised in Table 2.1.

Table 2.1 Summary of time periods for predictive simulations

Model period	Climate data from:	Notes on predictive simulation with SGS operational
April 2007 – December 2033	April 1970 – - December 1996	SGS operational
January 2034 to December 2034	January 1976 to December 1976	SGS operational
January 2035 - March 2041	January 1997- March 2003	SGS not operational (recovery period)

The combined model time period starts in April 2007, to be consistent with the existing ESM predictive simulations, which follow on from the end of the calibrated and updated ESM. The recharge model has a warm up period (starting with climate data from January 1969) which is necessary due to the unsaturated zone attenuation function which delays the arrival of recharge at the water table by up to 7 months (ESI, 2008). The groundwater model has 408 monthly stress periods.

2.2 Recharge Model

For the baseline predictive simulation, the recharge model was run using the normal climate sequence of the years 1970 – 1996, 1976, then 1997-2003, using calendar years.

The ‘dry’ climate change scenario uses the same climate sequence, but the rainfall and potential evapotranspiration data have been modified using monthly factors defined by the UKWIR methodology (UKWIR, 2007).

Six climate models are discussed in the UKWIR report and for each model a set of monthly factors for precipitation and potential evapotranspiration are provided. A preliminary assessment of the six UKWIR scenarios was carried out using the WFD spreadsheet calculator (Environment Agency, 2007) to assess which would produce the driest climate. The ECHAM4/OPYC3 scenario was clearly the driest of the six scenarios, so this was adopted for the purposes of simulating ‘dry’ conditions[1].

Each monthly factor for precipitation and potential evapotranspiration was applied to the rainfall and PE input sequences within the recharge model. The factors applied are summarised in Table 2.2.

[1] Note that it is not appropriate to use a statistical approach on the results from the six climate models (i.e. take a mean or percentile of the factors for each month), since the factors for each model are based on an annual climate cycle.

Table 2.2 Summary of recharge model climate factors for 'dry' conditions

Month	Precipitation	Potential evapotranspiration
	Percentage change	
Jan	26.44	29.99
Feb	11.82	34.74
Mar	-5.42	15.82
Apr	3.35	8.65
May	-9.58	9.71
Jun	-13.59	7.94
Jul	-7.90	6.23
Aug	-24.06	11.63
Sep	-32.88	13.44
Oct	7.69	14.99
Nov	9.93	14.79
Dec	1.55	16.94

2.3 Groundwater Model

2.3.1 Abstractions

The SGS abstraction rates for Phases 1 to 4 are defined by the Aquator model results for the dry predictive simulation described in Hainie and Walker, 2008. Note that 'pumping rates' not 'supply' rates have been used. The total abstraction rate for each phase has been split among the SGS boreholes in proportion to their estimated yield, as in previous predictive simulations (Streetly and Streetly, 2008). The abstraction rates are applied for the period 2007 to 2034 (equivalent climate years 1970 - 1996 and 1976, see Table 2.2). After 2034 there are 6 years of no SGS abstraction in order to simulate the recovery of the aquifer.

Spray irrigation abstractions were factored depending on climatic year as for previous predictive scenarios (ESI, 2008). No changes to spray irrigation uptake factors have been made. Whilst spray irrigation uptakes are likely to increase in the dry climate change scenarios, for the impacts of the SGS to be evaluated, it is preferable to be able to separate the impact of the SGS from that of increases in other abstractions.

For the Newport compensation abstraction (which is related to flows at Crudgington), the periods of operation were defined by each climatic year, based on the rates used in the recent actual (non SGS) predictive scenario.

The total abstraction rates for each phase used in the predictive simulations are shown in Figure 2.1 and the SGS total abstraction in the model is shown in Table 2.3. Table 2.4 shows the total abstraction per borehole for the SGS scheme for the drought years 2032-2034 (equivalent to 1995, 1996 and 1976).

Table 2.3 SGS abstraction rates in the predictive groundwater model (total abstraction in Ml per year)

Year	Phase 1	Phase 2*	Phase 3	Phase 4	Total
2007	0	2	0	0	2
2008	0	0	0	0	0
2009	0	0	0	0	0
2010	0	4	0	0	4
2011	141	19	192	195	547
2012	210	26	235	239	710
2013	5170	608	5551	5728	17058
2014	0	0	0	0	0
2015	21	2	0	0	23
2016	86	2	0	24	112
2017	104	3	0	17	124
2018	0	1	0	0	1
2019	0	9	22	54	85
2020	0	0	0	0	0
2021	1826	204	1890	2029	5949
2022	0	0	0	0	0
2023	44	3	0	18	65
2024	0	1	0	2	3
2025	4	1	0	17	22
2026	3427	377	3571	3762	11136
2027	3729	381	3377	3805	11293
2028	2151	167	1367	1929	5614
2029	173	19	100	254	546
2030	13	3	0	0	16
2031	674	79	711	768	2231
2032	3278	359	3254	3478	10369
2033	4319	451	4138	4518	13427
2034	5488	590	5650	6031	17759
2035 to 2041	No SGS abstraction				

- Note that only 10% of the Phase 2 abstraction is applied at the flux boundary on the western boundary of the Merrington groundwater management unit.

Table 2.4 Summary of abstractions from SGS boreholes from 2032 to 2034

Borehole	Phase	Yield (m3/d)	Total abstracted (Ml)
Greenfields	1	0	0
Hopton	1	6270	1847
Lodgebank 1	1	5030	1482
Green Lane	1	6999	2062
Ellerdine Heath	1	4050	1193
Heath House 1	1	3790	1117
Childs Ercall	1	0	0
Helshaw Grange 1	1	6550	1930
Hodnet 2	1	6690	1971
Heath House 2	1	0	0
Lodgebank 2	1	5030	1482
Phase 2 total	2	57087	14009
Albrighton	3	5846	1278
Great Wollascott	3	6996	1530
Merrington Lane	3	6944	1518
Newton	3	7150	1563
Pim Hill	3	5906	1291
Plex	3	6454	1411
Preston Gubbals	3	6220	1360
Shawell Cottage	3	6748	1476
Smethcote	3	7380	1614
Espley Farm(E)	4	5556	1559
Espley Farm(W)	4	5556	1559
Hodnet 1	4	6019	1688
Cotton Farm	4	4630	1299
High Hatton (E)	4	6019	1688
High Hatton (W)	4	3704	1039
Ellerdine Station	4	3704	1039
Windy Oak 1	4	3704	1039
Woodmill Farm	4	4630	1299
Bolas House	4	6481	1818

2.3.2 Starting heads

The starting heads for all three predictive simulations are the final heads from the calibrated groundwater model (ESI, 2008), as for the previous predictive scenarios.

2.3.3 Stream flows

The runoff inputs for the MODFLOW Stream Cells on the Potford, Platt and Astley Brooks have been imported to the groundwater model using the output from the relevant recharge model.

3 RESULTS

3.1 Groundwater Levels

Hydrographs for the observation boreholes in the Phase 1 and 4 and Phase 3 areas are shown in Figures 3.1 and 3.2. These hydrographs illustrate the times of maximum impact at each observation point. The maximum impact occurs later for observation points further from the SGS abstraction sites.

Figures 3.3 and 3.4 show drawdown[2] contours due to SGS abstraction at two different time periods, 2 months and 24 months after SGS abstraction ceases. The time at which maximum drawdown occurs varies with proximity to the abstractions wells, as can be seen from close inspection of the groundwater level hydrographs at the monitoring locations. Close to the abstraction wells, drawdown is greatest immediately following the abstraction period, whilst further away, the maximum drawdown may occur up to 2 years after abstraction ceases. Therefore these two time periods have been selected for the drawdown plots in order to illustrate the range of impacts across the whole aquifer. The simulated groundwater levels used for these calculations are from Layer 2 of the model, which is representative of the Permo-Triassic Sandstone aquifer.

Figure 3.3 shows that 2 months after SGS abstraction ceases, there is a maximum drawdown of 10 m in the Phase 1 and 4 area, whilst, in the Phase 3 area, there is a maximum drawdown of 5 m centred on the abstraction at Shawell Cottage. Figure 3.4 shows that after 24 months, the maximum drawdown has reduced to 5 m for Phases 1 and 4 and 2.5 m for Phase 3.

Drawdown at the same time periods due to reduction in recharge in simulations 1 and 2 (i.e. the difference in groundwater levels between the normal and dry climate predictive simulations without SGS abstraction) has also been calculated. With the ‘dry’ simulation recharge applied, there is a simulated reduction in groundwater levels of 0.5 to 1.5 m over the Phase 1 and 4 area, whilst over most of the Phase 3 area the simulated groundwater levels are about 1 m lower.

The combined maximum effect on groundwater levels as a result of the combined effects of climate change and will be up to 11 m in the Phase 1 and 4 area and up to 6 m in the Phase 3 area for the period two months after abstraction.

3.2 Surface Water Flows

The surface water flow factors implied by the results of the combined ESM with the ‘dry’ recharge model have been compared with the flow factors used by Hainie and Walker (2008). It is important that these flow factors are similar since the SGS abstraction rates used in the ESM are derived from Hainie and Walker (2008) Aquator model.

The monthly flow factors used by Hainie and Walker (2008) for the Tern at Walcot have been compared with the average monthly flow factors for the Tern at Walcot from the combined ESM (Table 3.1 and Figure 3.5). These were calculated as the average percentage difference in flows between the normal and dry climate predictive simulations for each month over the simulated time period. Anthropogenic factors were ignored when calculating the flow factors.

[2] i.e. the difference in groundwater levels between dry climate models with and without SGS abstraction

Table 3.1 Comparison of flow factors from Aquator and ESM predictive models

Month	ESM predictive model flow factors	Aquator model flow factors
Jan	3.4%	-14.5%
Feb	-0.1%	-10.4%
Mar	-16.4%	-11.4%
Apr	-15.4%	-14.1%
May	-17.5%	-22.4%
Jun	-19.3%	-21.6%
Jul	-16.2%	-21.5%
Aug	-24.2%	-32.2%
Sep	-32.2%	-30.6%
Oct	-24.9%	-22.3%
Nov	-19.5%	-10.4%
Dec	-18.2%	-14.1%

The flow factors are negative[3] for all months except in January. This is because, whilst the ECHAM4 model has higher PE for all months of the year, the precipitation is also higher in several months and is particularly high in January (Table 2.2). Whilst there are some differences between the Hainie and Walker (2008) and ESM flow factors, there is an overall general agreement in the seasonality and magnitude of the flow factors.

The impacts on baseflow to the Potford/Platt Brook and the Tern at Walcot are illustrated in Figures 3.6 and Figure 3.7. Note that the model has been run with no SGS abstractions from either Greenfields or Heath House No 2 which are compensation boreholes. The Potford/Platt Brook is modelled as MODFLOW 'Stream Cells' and, as a result, the groundwater model simulates a total flow rather than just 'baseflow' for these cells. Therefore the 'baseflow'[4] to the stream for Figure 3.6 has been estimated by subtracting the runoff component that was input to the streams.

Figures 3.8 and 3.9 show the total stream flows for the Tern at Walcot and the Potford/Platt Brook at Sandyford Bridge. The flows for the Tern at Walcot do not include surface water anthropogenic influences such as surface water abstractions and discharges. This means that the flows in Figure 3.8 do not include the SGS discharges from Phases 1 and 4 (which occur within the catchment of the Tern at Walcot), in order to make comparison of the three model runs easier. The impact from climate change alone is shown by the difference between predictive simulations 1 and 2. Initially the difference in flows is small, reflecting a small reduction in the runoff to the Brook for the dry climate predictive simulation. However as groundwater levels begin to fall, the difference in flows increases, reflecting a reduction in baseflow

There are times when the 'dry' climate predictive simulation produces higher winter flows than the normal climate predictive simulation; this not unexpected, as the precipitation factors for winter months (Table 2.2) indicate higher rainfall than the normal climate.

The changes in baseflows (surface water gain from groundwater) are summarised in Table 3.2.

[3] i.e. total simulated flow in the 'dry' climate predictive simulation is less than the normal climate simulation
[4] i.e. simulated discharge from groundwater into the stream

Table 3.2 Simulated baseflows for the Tern at Walcot and the Potford/Platt Brook at Sandyford Bridge

		Normal climate predictive simulation	Dry climate predictive simulation	Dry climate predictive simulation with SGS abstraction	
Time step	**Date**	**Tern at Walcot baseflow (Ml/d)** (Percentage change from Normal climate predictive simulation shown in brackets)			Estimated reduction in baseflow due to SGS abs. (Ml/d)**
1	January 2007	151.5	151.5	151.5	0
332	November 2034	109.9	86.4 (-21%)	75.2 (-32%)	11.2 (-11%)
354	September 2036	117.7	93.5 (-21%)	86.3 (-27%)	7.2 (-6%)
408	March 2041	175.2	147.1 (-16%)	143.8 (-18%)	3.3 (-2%)
		Potford/Platt Brook at Sandyford Bridge baseflow (Ml/d) (Percentage change from Normal climate predictive simulation shown in brackets)			Estimated reduction in baseflow due to SGS abs. (Ml/d)**
1	January 2007	2.31	2.30 (-0.3%)	2.30 (-0.3%)	0
332	November 2034	1.54	0.77 (-50%)	-1.63* (-206%)	2.4 (-155%)
354	September 2036	2.40	1.43 (-40%)	-0.65* (-127%)	2.1 (-87%)
408	March 2041	4.62	3.15 (-32%)	1.92 (-58%)	1.2 (-27%)

*net flow from stream to aquifer
**Numbers in brackets are the percentage of the baseflow of the Normal climate predictive simulation

Tern catchment at Walcot

For the predictive simulation with a dry climate, the reduction in baseflow to the Tern catchment at Walcot is about 20%. The impact from SGS abstraction is less than the impact of the dry climate; 2 months after abstraction ceases, an additional reduction in baseflows of 11% can be attributed to the SGS abstraction and after 24 months this has reduced to 6%.

Potford/Platt catchment at Sandyford Bridge

For the predictive simulation with a dry climate, the reduction in baseflow to the Potford/Platt catchment at Sandyford Bridge is predicted to be about 1.5 Ml/d (about 40%). The SGS abstraction causes a large reduction in baseflows: 2 months after abstraction ceases, there is a net flow of 1.6 Ml/d to the aquifer and after 24 months this has reduced to 0.6 Ml/d.

The areas where the MODFLOW Stream and River cells are gaining and losing flow from groundwater are shown in Figures 3.10 and 3.11. The areas where the SGS has most effect are the lower reaches of the Potford/Platt Brook, which are gaining flow in the lower reaches for both the normal and dry climate predictive simulations without SGS. The predictive simulation with SGS abstractions indicates that the streams are losing flow over the entire stream length 2 months after abstraction ceases. 24 months after abstraction ceases, the lower parts of the Potford/Platt Brooks have started to gain baseflow again, although much of the central part of the Brook is still losing flow.

Note that in Figure 3.11 some stream cells are not plotted as they have zero flux. This is because the stream has dried up (all flow has entered the aquifer) and no more leakage is occurring. The stream starts flowing again when there is an input to the MODFLOW Stream cell either from baseflow or from runoff. Runoff is represented in the model as flows entering at five discrete cells along the Potford/Platt stream. In reality, runoff will be entering the streams along its whole length. The model is therefore unable to simulate flows in some reaches of the Potford/Platt streams accurately when flows are very low. However, it is clear from the results that the impacts on flows in the Potford/Platt Brooks are likely to be large and may result in some reaches drying up during periods of low runoff, if groundwater levels are below the base of the streams.

There are two dedicated stream compensation boreholes at Greenfields and Heath House No 2, which may be used to augment flows in the Potford/Platt Brooks.

In previous reports (Streetly and Shepley, 2005) a flow trigger of Q95 at the Sandyford gauging point has been assumed in order to estimate the need for compensation releases. However, it should be noted that under natural conditions the flows would reach this trigger sometimes without any abstractions from the SGS. In the absence of any hydro-ecological flow based triggers, the Q95 value (3 Ml/d) has been used as a trigger level to estimate the amount of flow compensation required for the Potford/Platt Brooks, as shown in Figures 3.12 and 3.13. Figure 3.12 shows the compensation flows required as an annual total in Ml and as a percentage of the 5 year license for SGS Phase 1 (14,500 Ml). Figure 3.13 shows the monthly flows required to increase the flow at Sandyford Bridge to Q95 (3 Ml/d). The annual and 5 year volumes are also shown in Table 3.3.

The calculated compensation flows reach a maximum of 17% of the 5 year licence for SGS Phase 1. This occurs in 2036, two years after the extreme drought of 2032-2034.

Table 3.3 Flow compensation required for the Potford/Platt Brooks

	5 Year Total Flow below 95%ile (Ml)			Annual Total Flow below 95%ile (Ml)		
Year	ESMDO_01	ESMDO_02	ESMDO_03	ESMDO_01	ESMDO_02	ESMDO_03
2007				0.0	9.9	9.9
2008				0.0	0.0	0.0
2009				0.0	0.0	0.0
2010				0.0	0.0	0.0
2011	0.0	9.9	9.9	0.0	0.0	0.0
2012	16.5	117.3	143.3	16.5	117.3	143.3
2013	89.9	287.5	446.0	73.4	170.2	302.6
2014	89.9	298.3	711.4	0.0	10.8	265.4
2015	89.9	335.2	976.2	0.0	36.9	264.8
2016	89.9	336.7	1041.8	0.0	1.4	65.6
2017	73.4	219.4	898.5	0.0	0.0	0.0
2018	0.0	49.2	595.8	0.0	0.0	0.0
2019	0.0	38.4	330.4	0.0	0.0	0.0
2020	0.0	1.4	65.6	0.0	0.0	0.0
2021	0.0	1.2	133.9	0.0	1.2	133.9
2022	0.0	7.7	195.2	0.0	6.5	61.3
2023	0.0	29.4	265.8	0.0	21.6	70.6
2024	0.0	29.4	283.9	0.0	0.0	18.1
2025	0.0	29.4	283.9	0.0	0.0	0.0
2026	4.8	125.7	399.0	4.8	97.6	249.1
2027	4.8	197.3	877.2	0.0	78.1	539.5
2028	5.8	250.1	1318.8	1.1	74.5	512.1
2029	5.8	298.6	1618.0	0.0	48.5	317.3
2030	20.1	415.5	1978.9	14.3	116.9	360.9
2031	15.3	350.2	1992.6	0.0	32.2	262.7
2032	15.3	330.4	1903.8	0.0	58.3	450.7
2033	52.7	413.1	1916.7	38.5	157.2	525.1
2034	109.7	517.9	2031.6	56.9	153.3	432.2
2035	96.5	505.5	2241.1	1.1	104.5	570.4
2036	96.5	563.7	2441.2	0.0	90.4	462.8
2037	96.5	518.9	2193.2	0.0	13.5	202.8
2038	58.0	361.7	1840.7	0.0	0.0	172.6
2039	1.1	208.4	1479.4	0.0	0.0	70.9
2040	0.0	105.4	1006.8	0.0	1.5	97.9
2041	0.0	14.9	544.1	0.0	0.0	0.0

3.3 Groundwater Model Water Budget

The difference in flows in and out of the groundwater model between the dry climate predictive simulations with and without SGS are shown on Figure 3.14. This figure illustrates the time periods required for recovery of the Permo-Triassic Sandstone aquifer following SGS abstraction. Following the initial SGS abstraction period in 2013, the aquifer makes an almost complete recovery before the next SGS abstraction period in 2021. After the final SGS abstraction period (which represents severe drought conditions) the aquifer does not make a full recovery by the end of the modelled time period 6 years later. It is estimated that full recovery might take another six years, based on similar rates of recovery to those occurring from 2015-2021.

4 CONCLUSIONS

The ESM has been used to carry out three predictive simulations in order to investigate the impact of SGS abstraction in a dry climate. The impact of the dry climate is large and causes a reduction in groundwater levels across the model of up to 1.5 m after 27 years with the dry climate.

The predicted impacts of SGS abstraction on flows in the Potford/Platt Brooks are substantial and may result in some reaches drying up during periods of low runoff, if groundwater levels are below the base of the streams. Recovery of baseflows in these streams after the final period of abstraction (representing an extreme three year drought) is slow: the model results indicate that the aquifer has not made a full recovery by the end of the predictive simulations, 6 years after the end of SGS abstraction.

Compensation flows for the Potford/Platt Brook have been calculated based on a trigger level set at 3 Ml/d (the Q95) at Sandyford Bridge. The calculated compensation flows reach a maximum of 17% of the 5 year licence for SGS Phase 1. This occurs in 2036, two years after the extreme drought of 2032-2034.

The baseflow to the Tern catchment at Walcot is about 20% less for the dry climate model compared with the normal climate model. The additional impact from SGS abstraction on the baseflow to the Tern catchment at Walcot is less than the impact of the dry climate.

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FIGURES

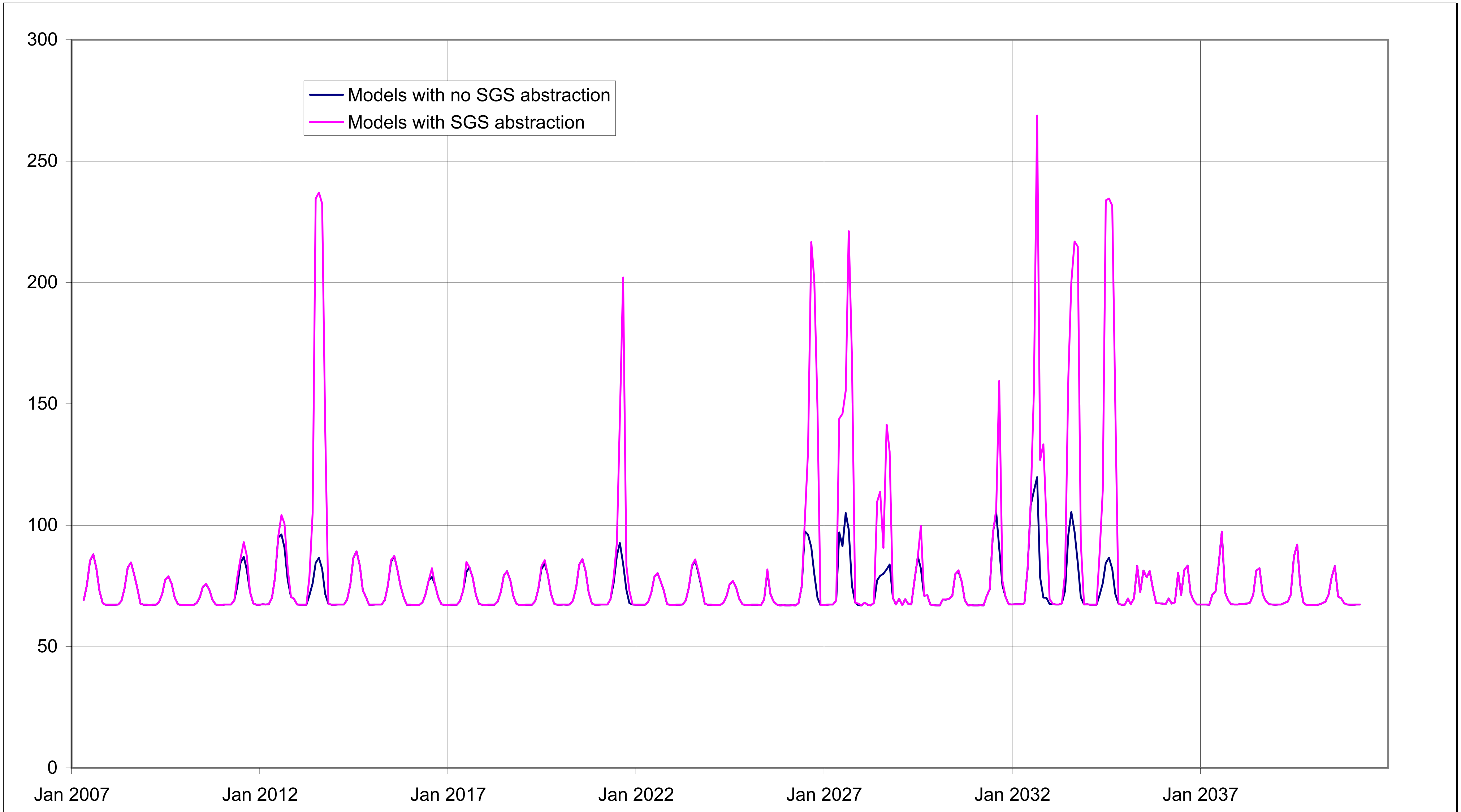

Figure 2.1
Total abstraction rates used in the groundwater model

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Original: A4	Revision: 1

File Reference
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esi soil & groundwater

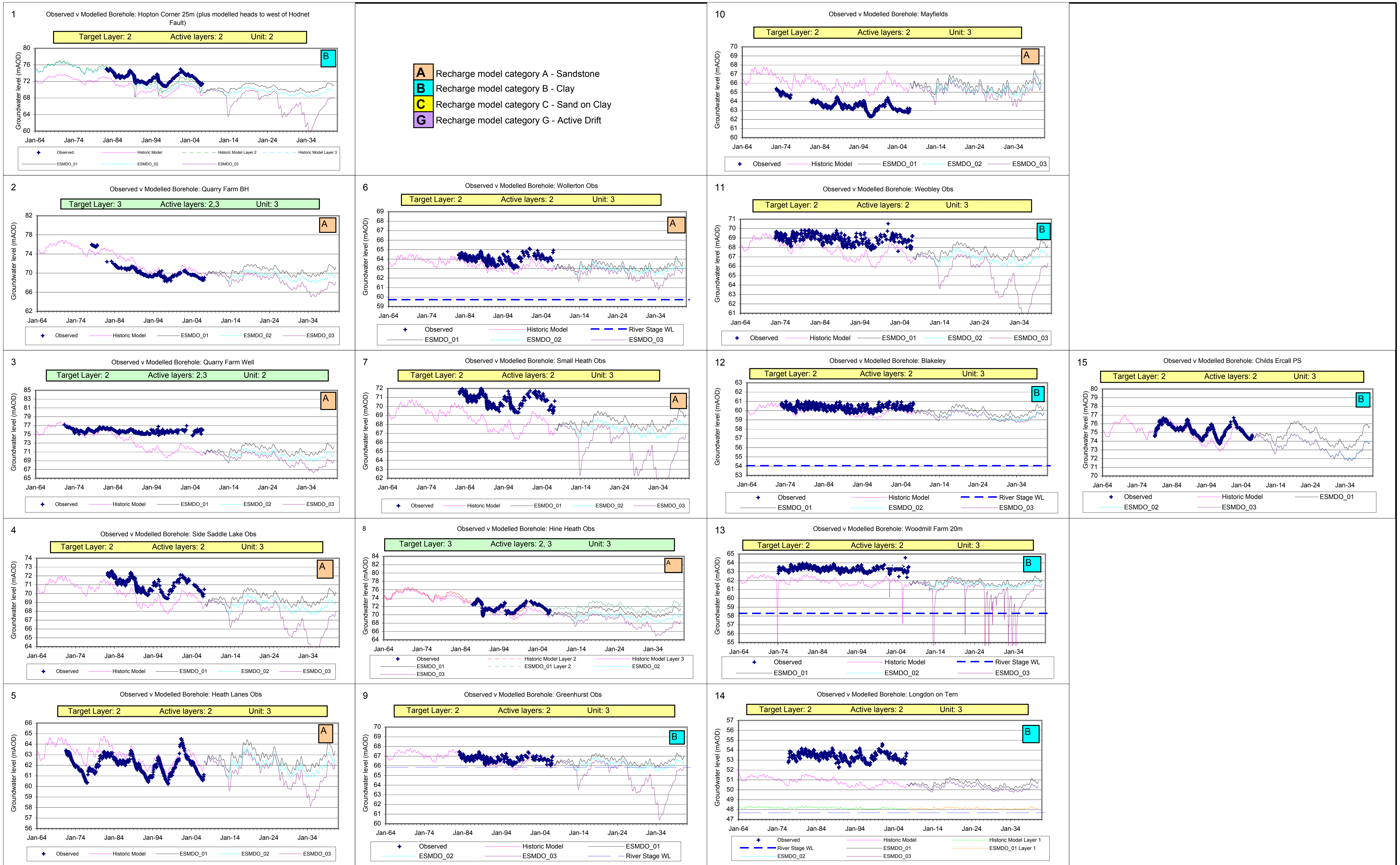

Figure 3.1

Time series groundwater hydrographs: Phase 1 and 4 areas

ESMDO_01 - Baseline
ESMDO_02 - Dry
ESMDO_03 - Dry plus SGS

Date	Drawn
Feb 09	ERF
Scale	Checked
dns	HRS
Original	Revision
A3	1

File Reference

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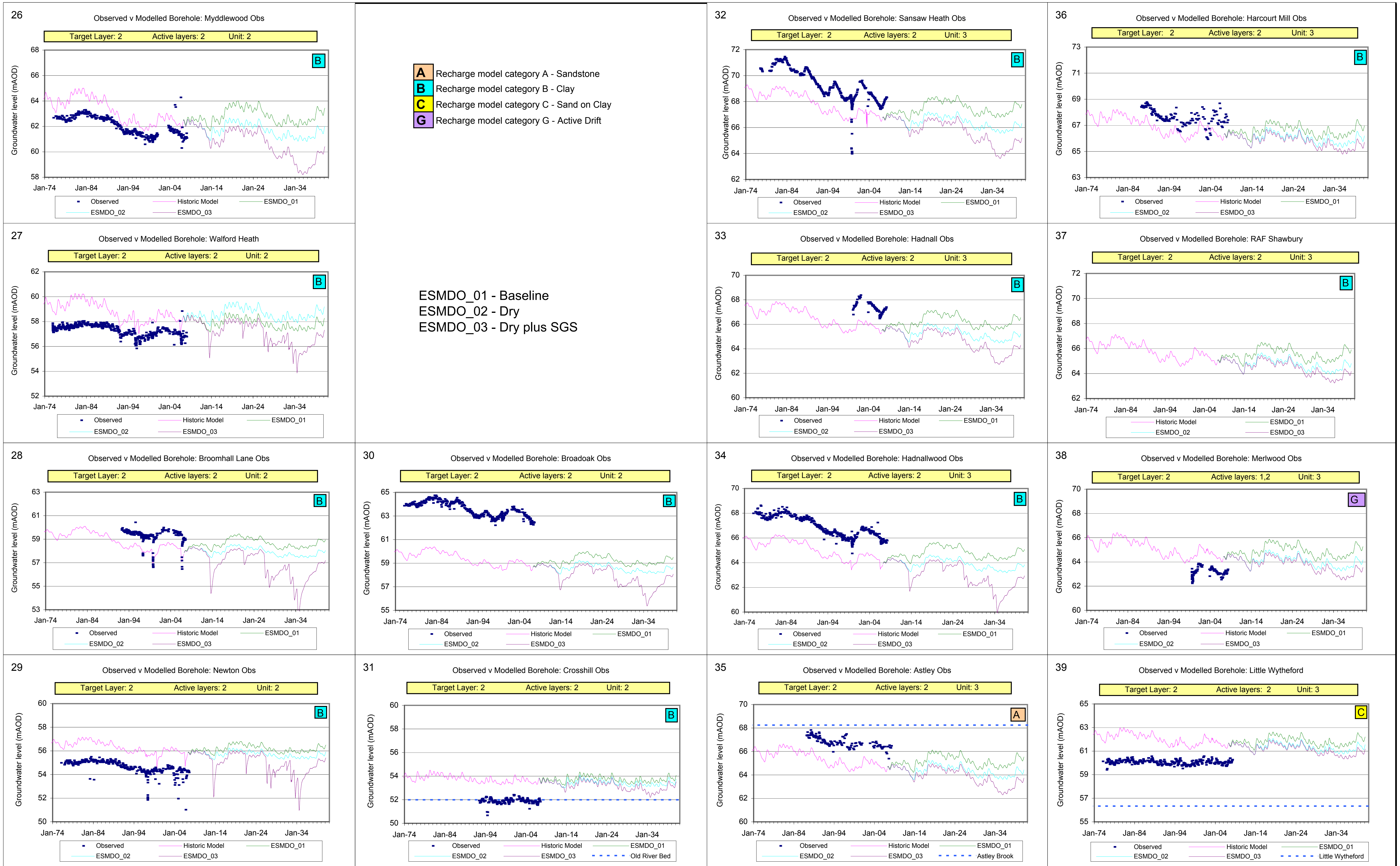

Figure 3.2

Time series groundwater hydrographs Phase 3 area

Note that 10% of the Phase 2 abstraction is applied at the flux boundary on the western boundary of the Merrington groundwater management unit

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Original: A3	Revision: 1

File Reference

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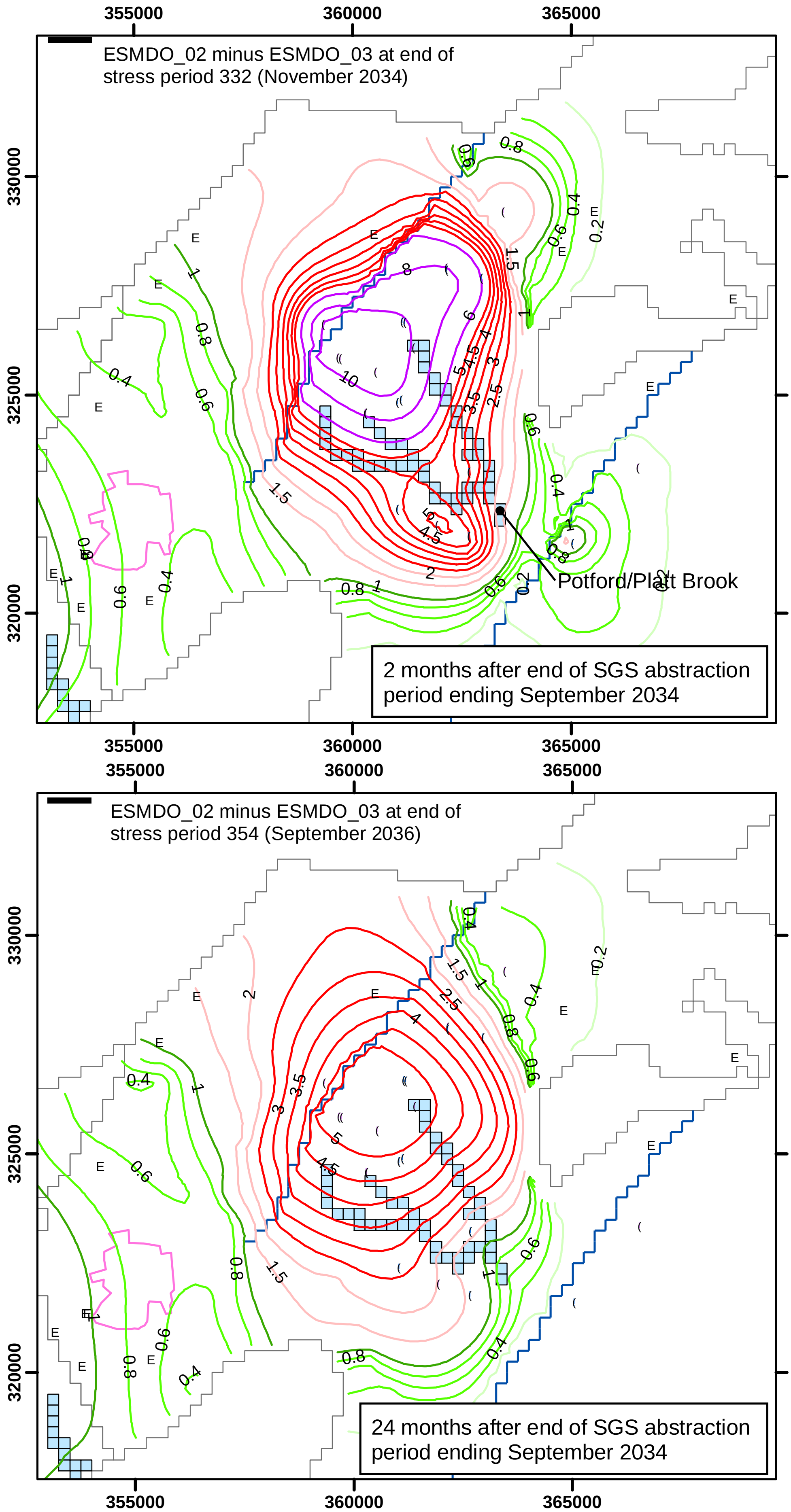

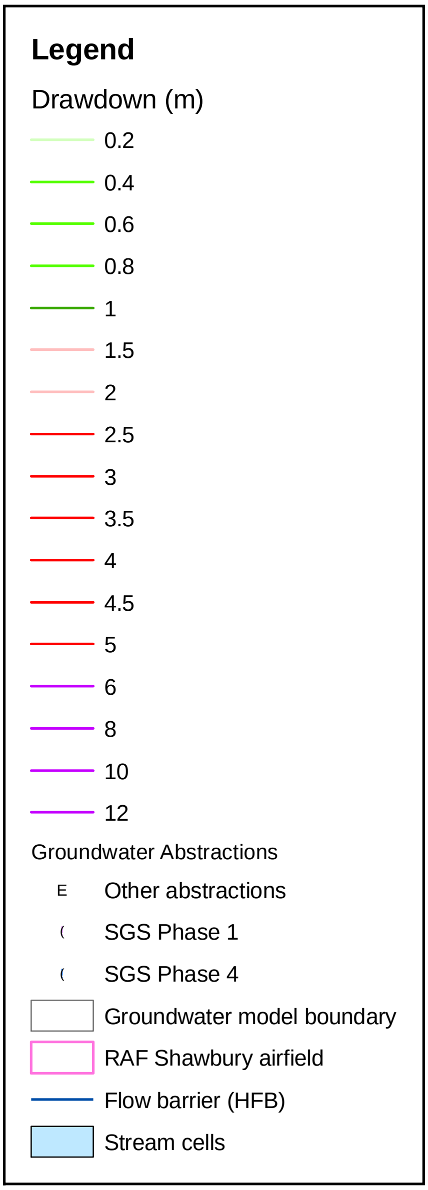

Figure 3.3 Impact from SGS pumping in a dry climate in Phase 1 and 4 area: Drawdown (difference in heads) between predictive model runs with and without SGS abstraction.	Date: Feb 2009	Drawn: ERF
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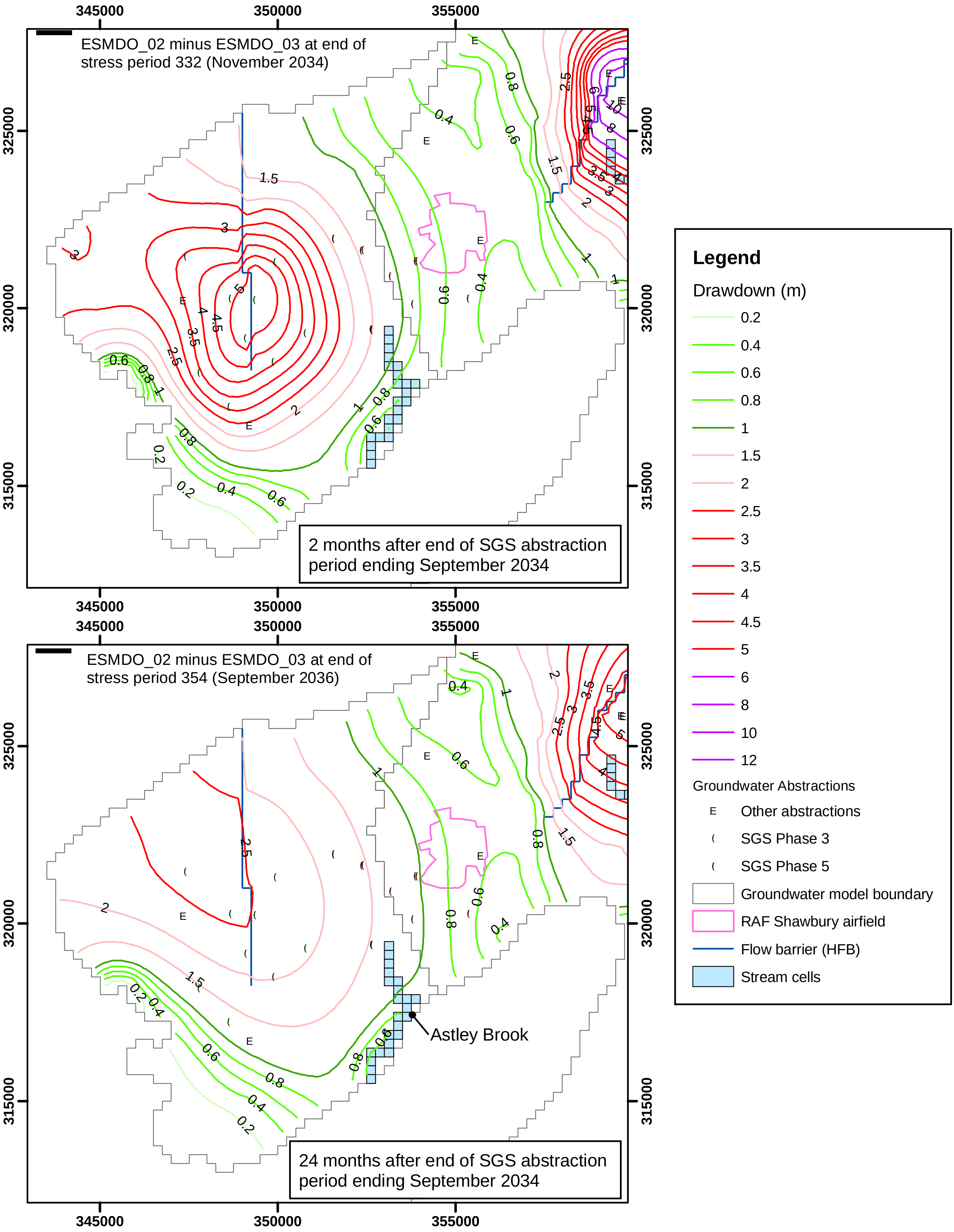

Figure 3.4
Impact from SGS pumping in a dry climate in Phase 3 area: Drawdown (difference in heads) between predictive model runs with and without SGS abstraction.

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Original: A4	Revision: 1
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esi

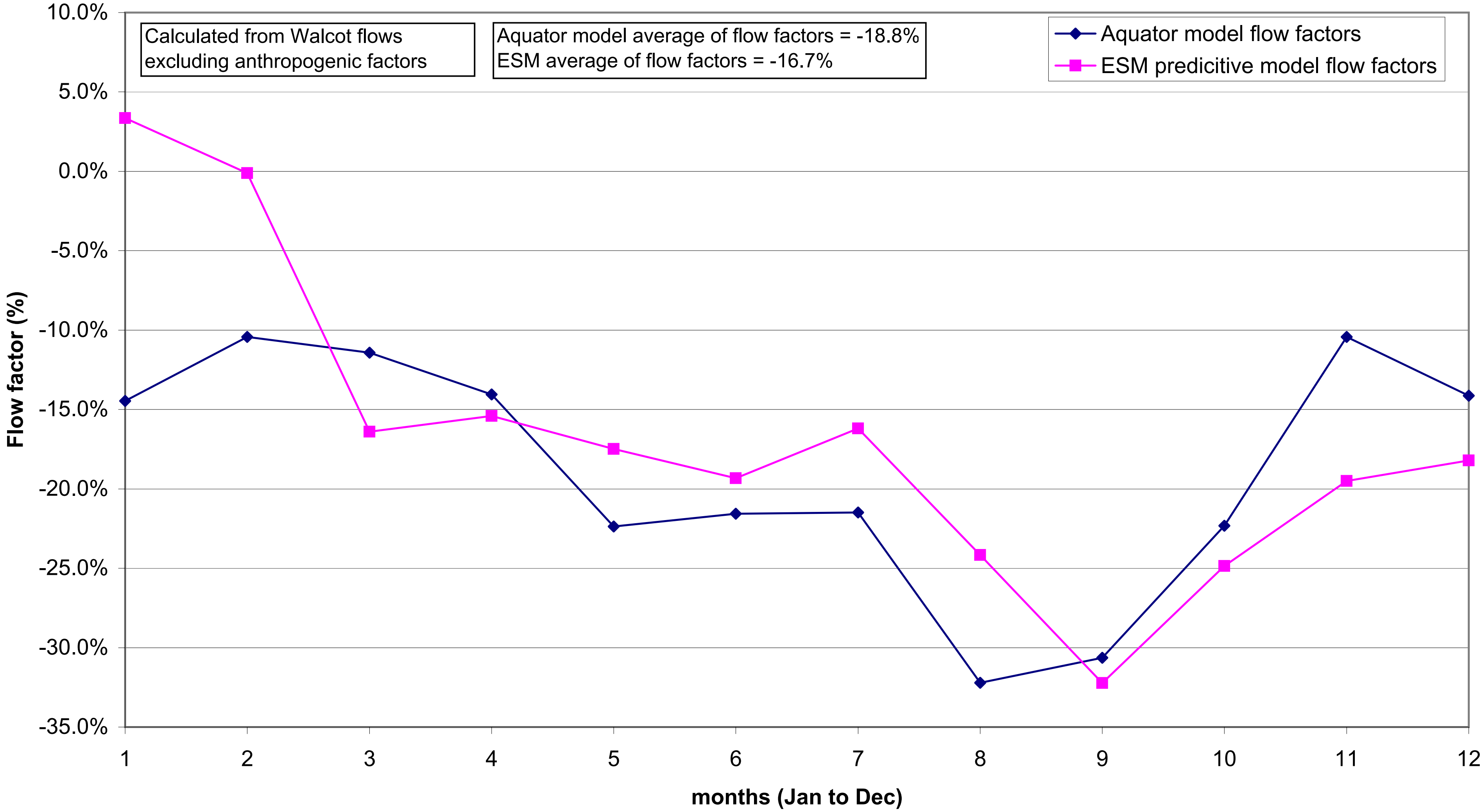

Figure 3.5

Comparison of Aquator model dry climate flow factors with flow factors calculated from ESM dry climate model runs for the Tern at Walcot

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Mar 09	HRS
Scale	Checked
dns	MJS
Original	Revision
A4	1

File Reference
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soil & groundwater

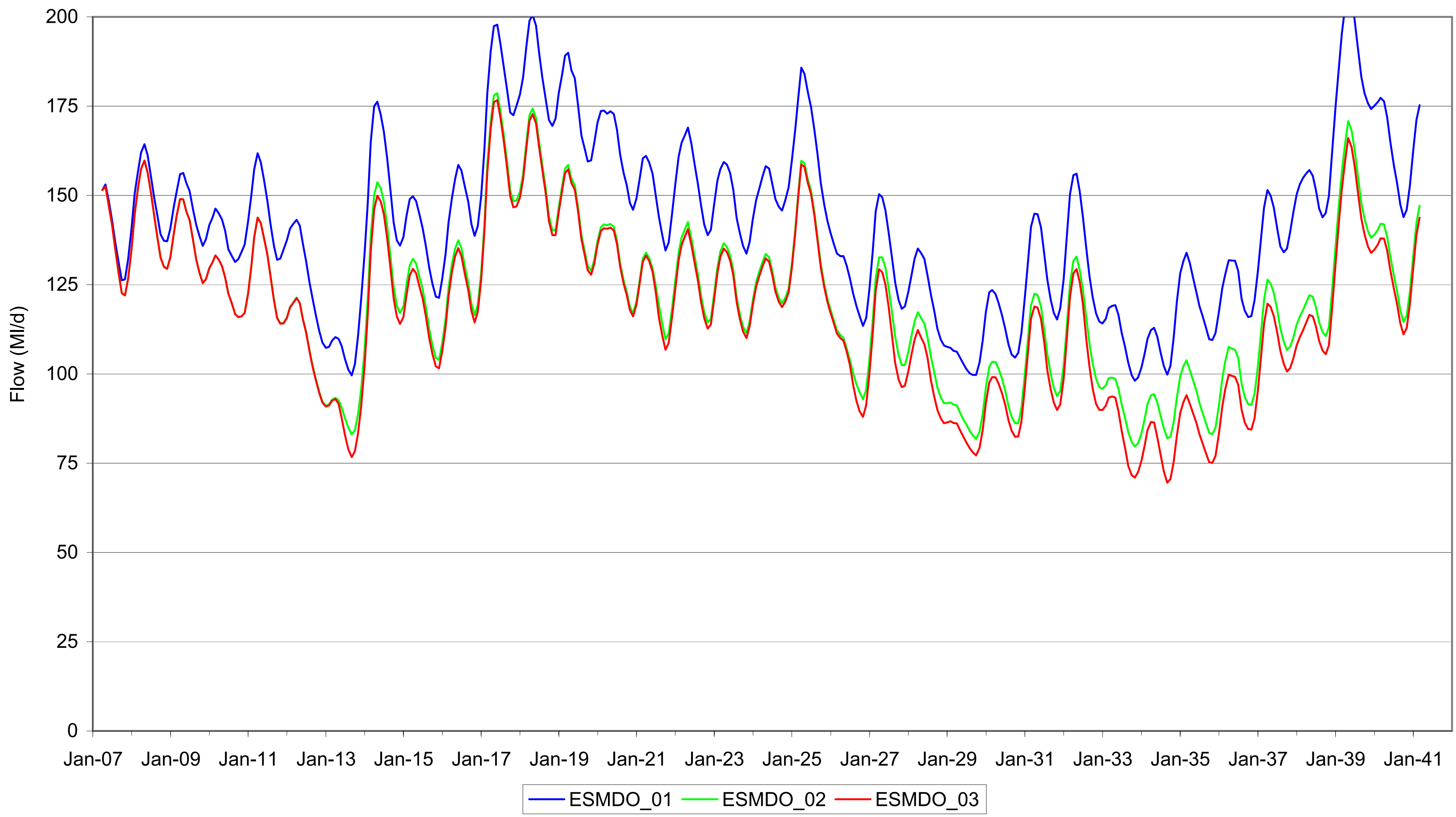


Figure 3.6

Simulated baseflow for the Tern catchment at Walcot

ESMDO_01 (Normal climate, recent actual abstractions, excluding SGS)
ESMDO_02 (Dry climate, recent actual abstractions, excluding SGS)
ESMDO_03 (Dry climate, recent actual abstractions, SGS Phases 1 to 4 operational)

Date	Drawn
Mar 09	HRS
Scale: dns	Checked: MJS
Original: A4	Revision: 1

File Reference
O:\6492AE ESM Update\models\drought order\model output\ESMDO_01_rivers_Mlperday.xls

soil & groundwater

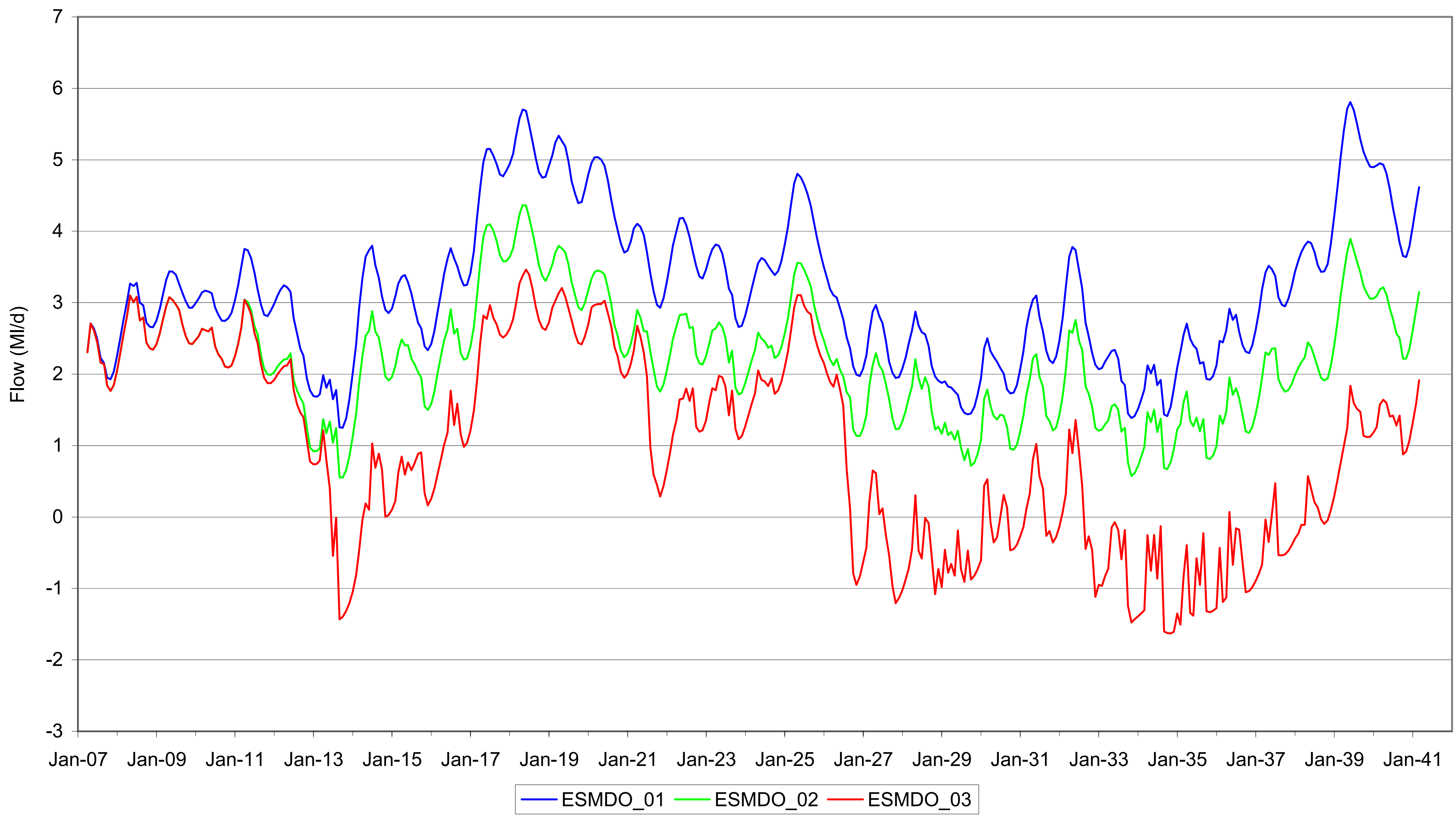


Figure 3.7

Simulated baseflow for the Potford/Platt catchment at Sandyford Bridge

ESMDO_01 (Normal climate, recent actual abstractions, excluding SGS)
ESMDO_02 (Dry climate, recent actual abstractions, excluding SGS)
ESMDO_03 (Dry climate, recent actual abstractions, SGS Phases 1 to 4 operational)

Date Mar 09	Drawn HRS
Scale dns	Checked MJS
Original A4	Revision 1
File Reference O:\6492AE ESM Update\models\drought order\model output\ESMDO_01_rivers_Mlperday.xls	

esi soil & groundwater

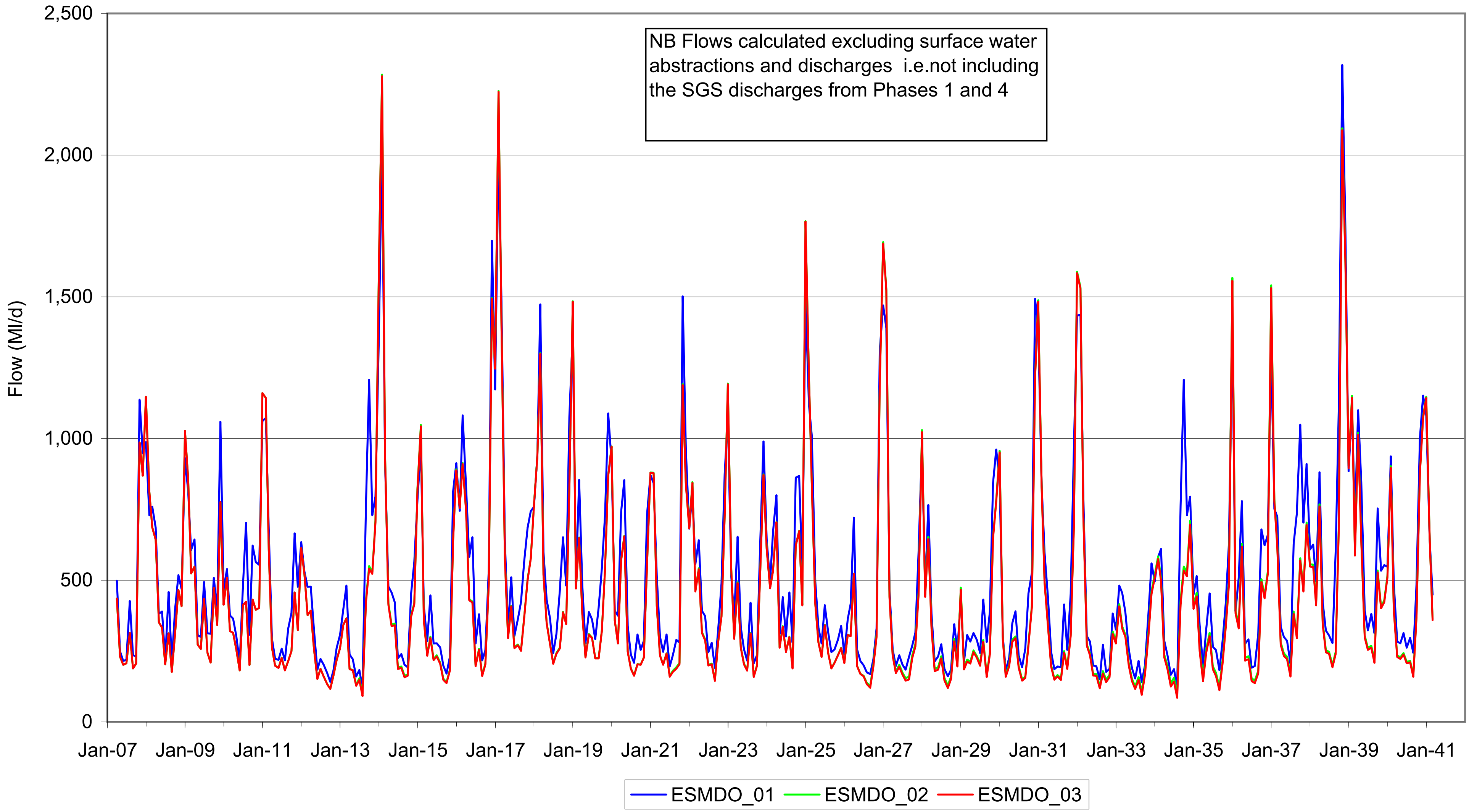


Figure 3.8

Simulated total river flow for the Tern catchment at Walcot

ESMDO_01 (Normal climate, recent actual abstractions, excluding SGS)
ESMDO_02 (Dry climate, recent actual abstractions, excluding SGS)
ESMDO_03 (Dry climate, recent actual abstractions, SGS Phases 1 to 4 operational)

Date	Drawn
Mar 09	HRS
Scale: dns	Checked: MJS
Original: A4	Revision: 1

File Reference
O:\6492AE ESM Update\models\drought order\model output\ESMDO_01_rivers_Mlperday.xls

esi soil & groundwater

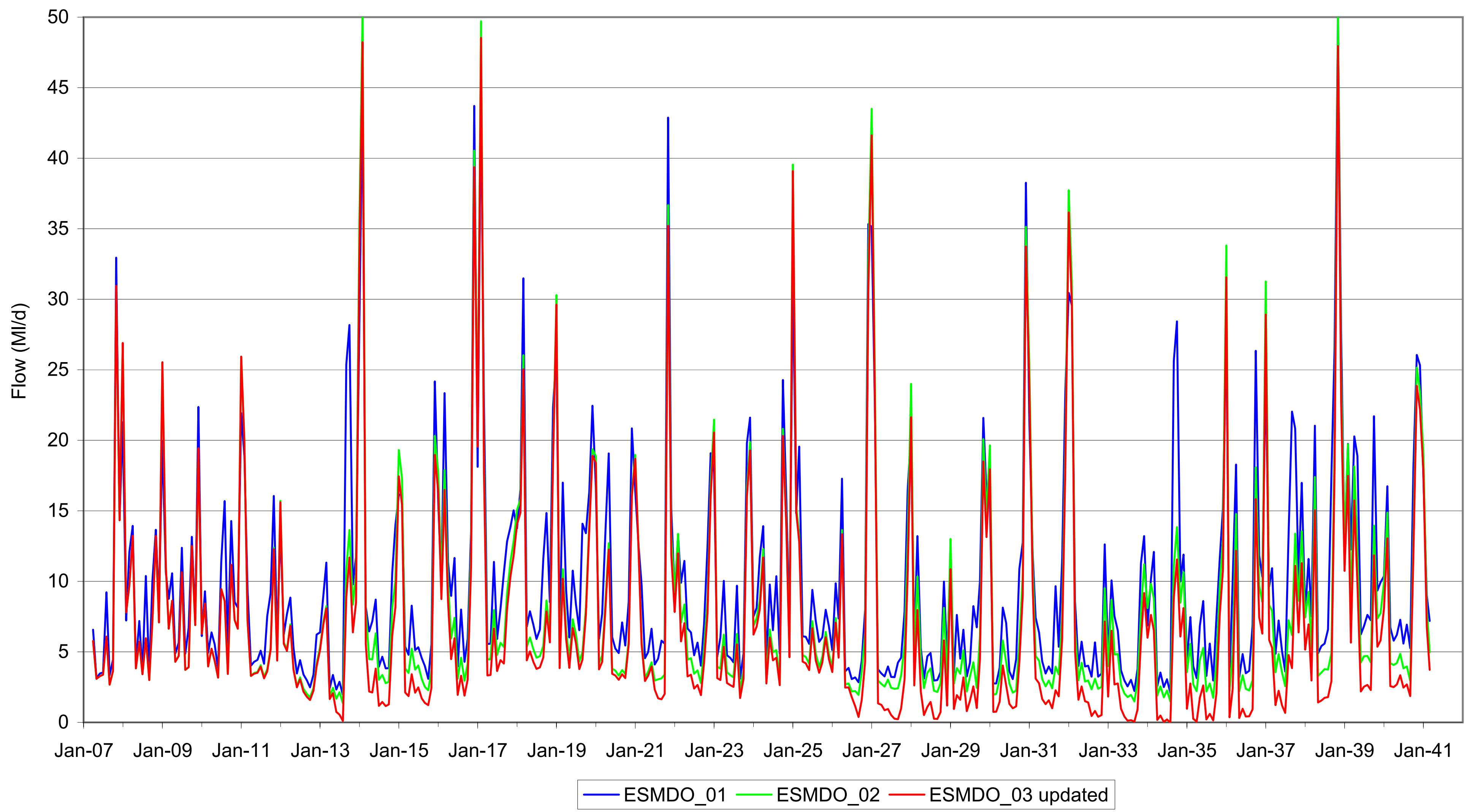


Figure 3.9

Simulated total stream flow for the Potford/Platt catchment at Sandyford Bridge

ESMDO_01 (Normal climate, recent actual abstractions, excluding SGS)
ESMDO_02 (Dry climate, recent actual abstractions, excluding SGS)
ESMDO_03 (Dry climate, recent actual abstractions, SGS Phases 1 to 4 operational)

Date	Drawn
Mar 09	HRS
Scale	Checked
dns	MJS
Original	Revision
A4	1

File Reference
O:\6492AE ESM Update\models\drought order\model output\ESMDO_01_rivers_Mlperday.xls

esi soil & groundwater

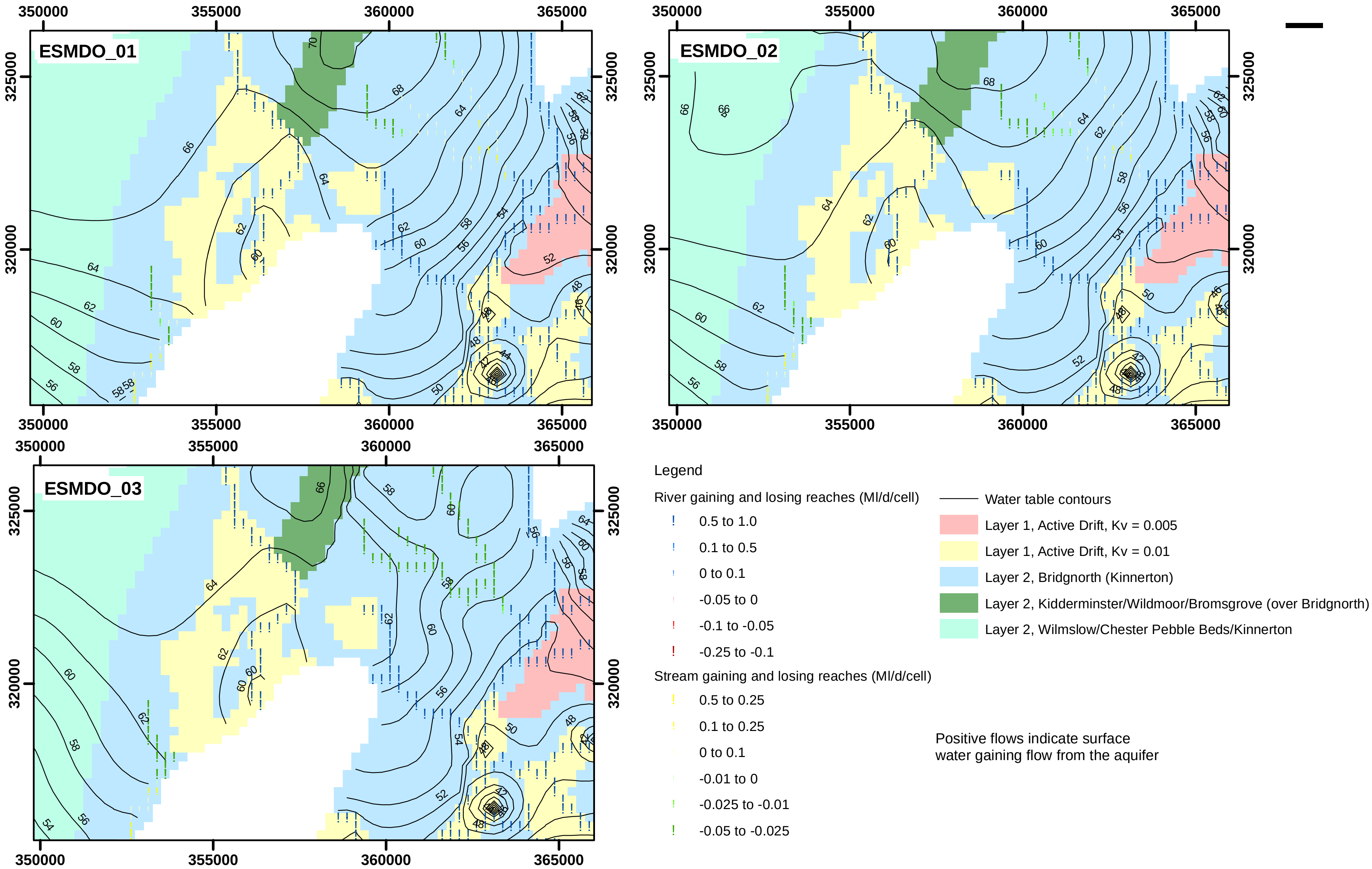


Figure 3.10
Gaining and losing reaches for modelled rivers and streams:
November 2034 - 2 months after end of SGS abstraction (stress period 332)

Date	Drawn
March 2009	ERF
Scale 1:150,000	Checked HRS
Original A4	Revision 1

File Reference
O:\6492AE ESM Update\GIS\modeloutput\gainlose
\ESMDO_01\ESMDO_332_gainlose.mxd

esi soil & groundwater

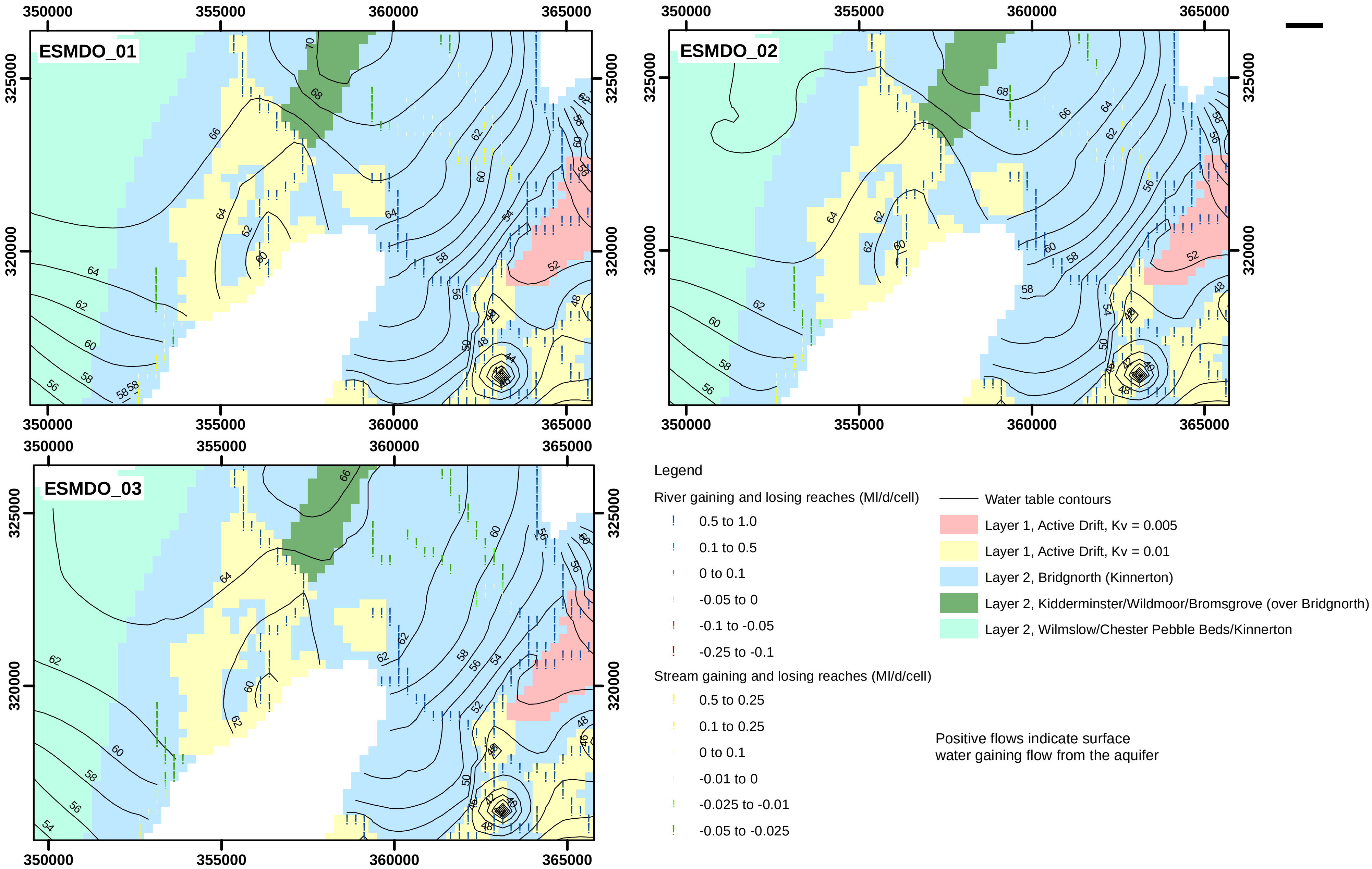


Figure 3.11
Gaining and losing reaches for modelled rivers and streams :
September 2036 - 24 months after end of SGS abstraction (stress period 354)

Date: March 2009	Drawn: ERF
Scale: 1:150,000	Checked: HRS
Original: A4	Revision: 1

File Reference
O:\6492AE ESM Update\GIS\modeloutput\gainlose\ESMDO_01\ESMDO_354_gainlose.mxd

soil & groundwater

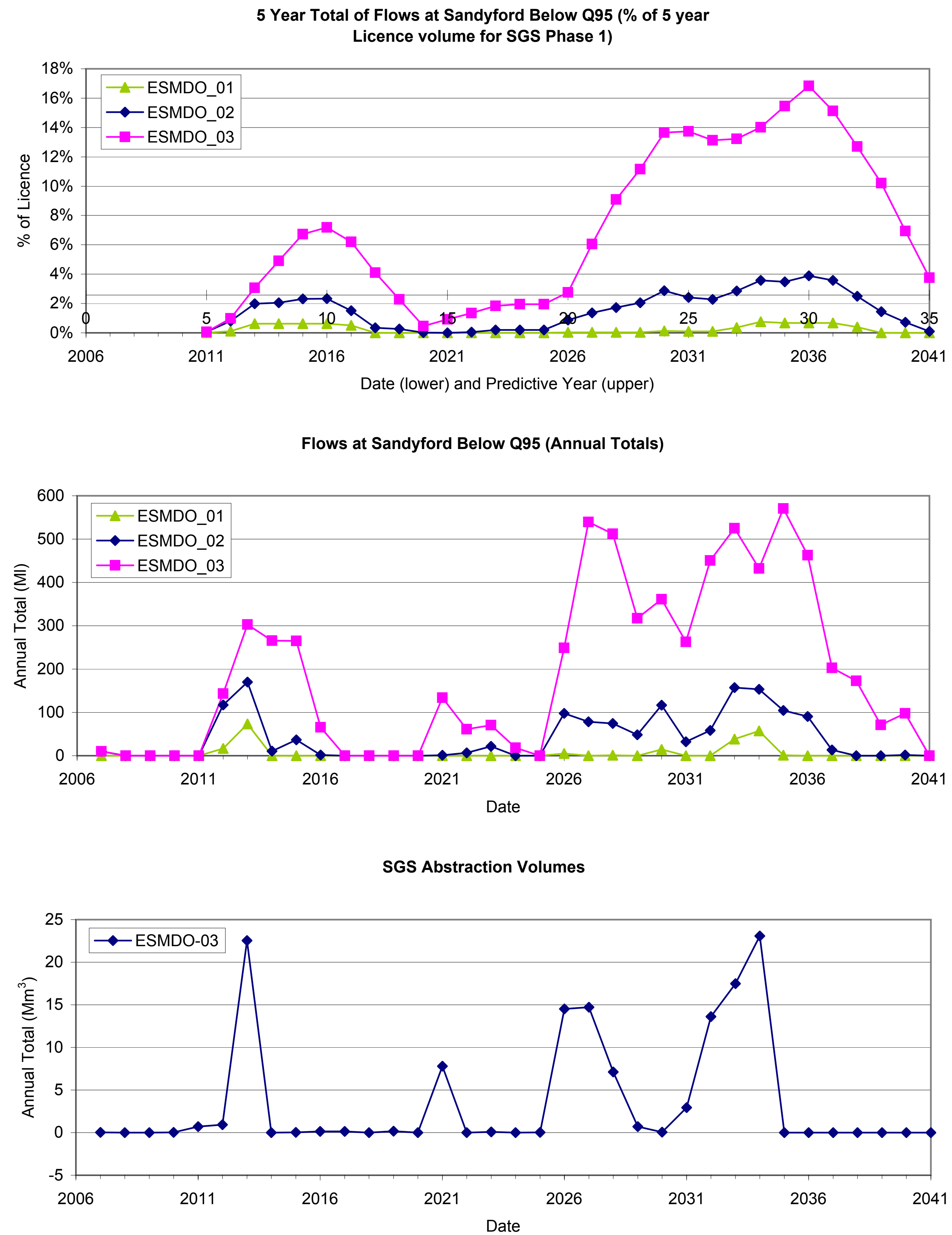


Figure 3.12

Compensation flows required to the Platt/Potford Brooks upstream of Sandyford Bridge

Date	Drawn
Mar 2009	HRS
Scale: dns	Checked: MJS
Original: A4	Revision: 2

File Reference

O:\6492AE ESM Update\models\drought order models\model output\Sandyford flows below 95percentile.xls

esi

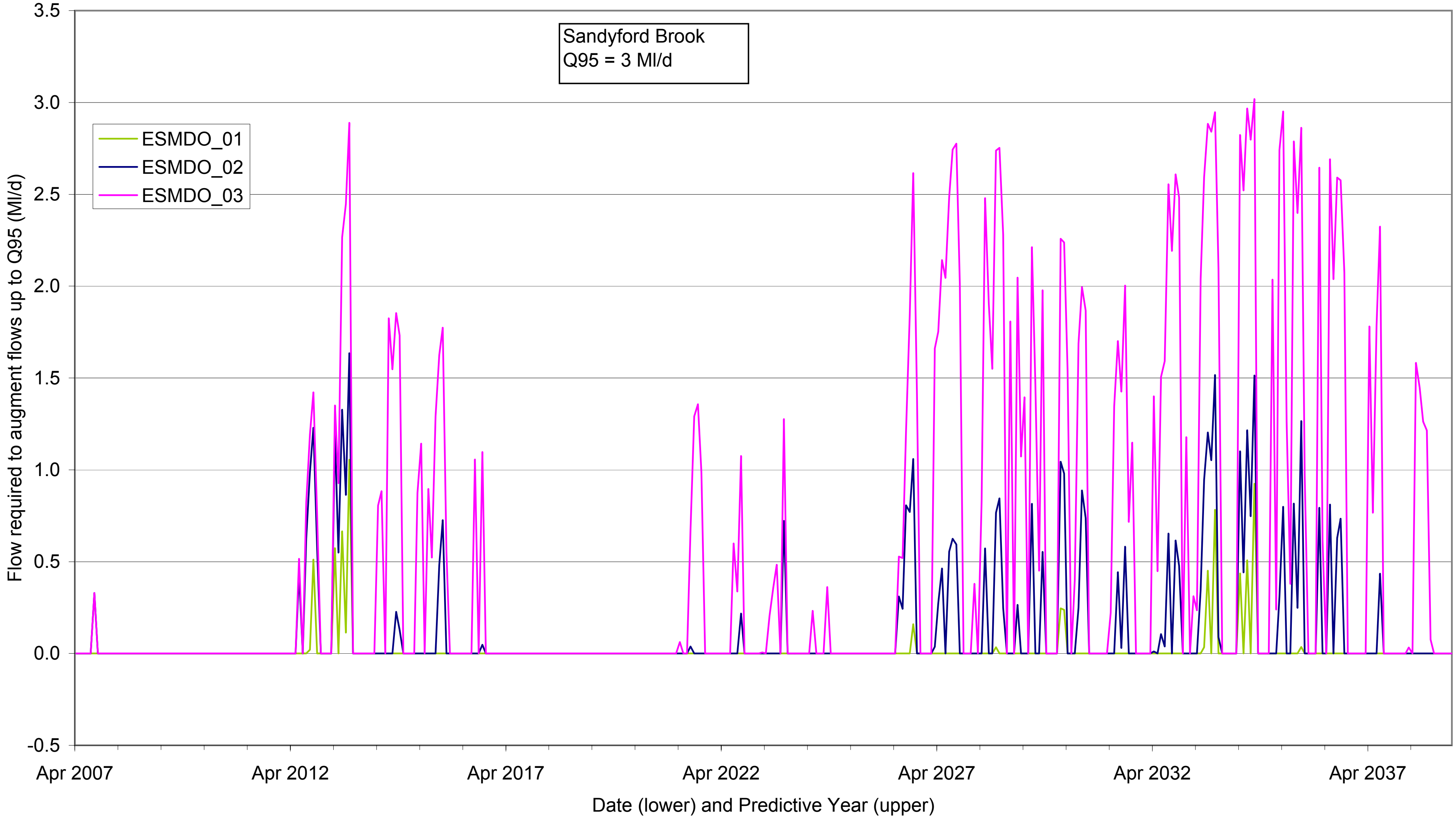


Figure 3.13

Monthly Potford/Platt Brook Flows at Sandyford Bridge below Q95

Date Mar 2009	Drawn HRS
Scale dns	Checked MJS
Original A4	Revision 2
File Reference O:\6492AE ESM Update\models\drought order models\model output\Sandyford flows below 95percentile.xls	

esi

Figure 3.14

Total groundwater model water balance difference between dry climate model runs with and without SGS operation

Date	Drawn
Mar 09	ERF
Scale dns	Checked HRS
Original A4	Revision 1

File Reference

O:\6492AE ESM Update\models\predictive scenarios\model output\ESMpr09AC\ESMpr09AC_budget.xls

esi soil & groundwater

Appendix C
Water Quality Standards

General Environmental Quality Standards (EQSs)

Worksheet:

a. WFD EQSs (Damon)

Catchment Specific Environmental Quality Standards (EQSs)

Worksheet:

b. Catchment Specific EQSs (Dawn)

DETE_DESC	MEAS_DETERMINAND_CODE	CountOf MEAS_RESULT	Select For Timeseries Work?	Determinand Group	WFD Freshwater EQS (µgl)	EQS Type	Comments	Class (where appropriate)
ALKALINITY PH 4.5 - as CACO3	0162	983	Yes	Field	No EQS			
ALUMINIUM - AS AL	6057	216	Yes	Metals	1000	MAC Total	Draft EQS used when modelling Al dosing	
AMMONIA - AS N	0111	1035	Yes	Nutrients	See Catchment Specific EQS			
ARSENIC - AS AS	6046	169	Yes	Non-metals	50	AA Dissolved		
BOD ATU as O2	0085	595	Yes	Redox	See Catchment Specific EQSs			
CADMIUM - AS CD	0108	992	Yes	Metals	0.09	AA Dissolved	Hardness 50 - 100 mg/l	Class 3
					0.15	AA Dissolved	Hardness 100 - 200mg/l	Class 4
	0106	429	Yes	Metals	0.25	AA Dissolved	Hardness > 200mg/l	Class 5
					0.6	MAC Dissolved	Hardness 50 - 100 mg/l	Class 3
					0.9	MAC Dissolved	Hardness 100 - 200mg/l	Class 4
					1.5	MAC Dissolved	Hardness > 200mg/l	Class 5
CADMIUM DISSOLVED - AS CD					No EQS			
CONDUCTIVITY @20C	0062	941	Yes	Field	1000 uS/cm at 20°C		Repealed SWAD Directive - Guideline Value	
COPPER - AS CU	6452	996	Yes	Metals	No EQS			
COPPER DISSOLVED - AS CU	6450	357	Yes	Metals	10	AA Dissolved	Hardness 100 - 250mg/l	
					28	AA Dissolved	Hardness > 250mg/l	
FLUORIDE - AS F	0177	141	Yes	Non-metals	5	AA Dissolved	List 2 Dangerous Substances	
					15	MAC Dissolved	List 2 Dangerous Substances	
IRON - AS FE	6051	1015	Yes	Redox	No EQS			
IRON DISSOLVED - AS FE	6460	450	Yes	Redox	1000	AA Dissolved		
LEAD - AS PB	0050	992	Yes	Metals	No EQS			
LEAD DISSOLVED - AS PB	0052	409	Yes	Metals	7.2	AA Dissolved		
MAGNESIUM - AS MG	0237	1032	Yes	Metals	No EQS			
MAGNESIUM DISSOLVED - AS MG	0235	22	Yes	Metals	No EQS			
MANGANESE - AS MN	6050	1015	Yes	Redox	No EQS			
MANGANESE DISSOLVED - AS MN	6458	434	Yes	Redox	30	AA Dissolved		
					300	MAC Dissolved		
MERCURY - AS HG	0105	121	Yes	Metals	0.05	AA Dissolved		
					0.07	MAC Dissolved		
NICKEL - AS NI	6462	992	Yes	Metals	No EQS			
NICKEL DISSOLVED - AS NI	3410	440	Yes	Metals	20	AA Dissolved		
NITRATE - as N	0117	434	Yes	Nutrients	No EQS			
NITRITE - as N	0118	469	Yes	Nutrients	No EQS			
ORTHOPHOSPHATE - as P	0180	998	Yes	Nutrients	See Catchment Specific EQS			
OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O	9924	403	Yes	Field	See Catchment Specific EQS			
OXYGEN DISSOLVED (INSTRUMENTAL) - AS % SATN	9901	860	Yes	Field	See Catchment Specific EQS			
PH - AS PH UNITS	0061	1027	Yes	Field	6 - 9	95% of samples	Freshwater Fish Directive	
PH IN SITU MEASUREMENT	3169	94	Yes	Field	No EQS			
SODIUM - AS NA	0207	993	Yes	Metals	No EQS			
SULPHATE - AS SO4	0183	1008	Yes	Non-metals	400	AA	List 2 Dangerous Substances	
					250	AA	As Total Anions (Cl, NO3, SO4)	
TEMPERATURE WATER	0076	865	Yes	Field	</= 1.5 Increase	95% of samples	Salmonid Designation	
					</= 3 Increase	95% of samples	Cyprinid Designation	
					21.5	95% of samples	Salmonid Designation	
					28	95% of samples	Cyprinid Designation	
ZINC - AS ZN	6455	990	Yes	Metals	75	AA Total	Hardness 100 - 250mg/l	
					125	AA Total	Hardness > 250mg/l	
ZINC DISSOLVED - AS ZN	3408	337	Yes	Metals	No EQS			

SCHEDULED_	WIMS_SAMPL	NGR	EASTINGS	NORTHINGS	RECEIVING_	PHASE	MONITORING	Physico-Chemical Element	WFD Standard for Good		Freshwater Fish Directive
Waters Upton	26949560	SJ 63060	363060	319360	R.Tern	PHASE 1	Outfalls	Ammonia	0.6	mg/l (90%ile)	
								BOD	5	mg/l (90%ile)	
								DO	60	%sat (10%ile)	(cyprinid) ≥7 mg/l (50% of samples), ≥ 4 mg/l(absolute)
								pHlower	6	pH (5 & 95%ile for Good)	
								Phosphate	0.12	mg/l AA	
								pHupper	9	pH (5 & 95%ile for Good)	
								Temperature	28		
Stoke on Tern	26951780	SJ 63640	363640	327760	R.Tern	PHASE 1	Outfalls	Ammonia	0.6		
								BOD	5		
								DO	60		(cyprinid) ≥7 mg/l (50% of samples), ≥ 4 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	28		
Adcote	29992310	SJ 42130	342130	319750	R. Perry; R. Severn	PHASE 2	Outfalls	Ammonia	0.6		
								BOD	4		
								DO	75		(Salmonid) ≥9 mg/l (50% of samples), ≥ 6 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	23		
Grafton	29991920	SJ 43900	343900	318450	R. Perry; R. Severn	PHASE 2	Outfalls	Ammonia	0.6		
								BOD	4		
								DO	75		(Salmonid) ≥9 mg/l (50% of samples), ≥ 6 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	23		
Forton	56310	SJ 43700	343700	316240	R. Severn	PHASE 2	Outfalls	Ammonia	0.6		
								BOD	5		
								DO	60		(cyprinid) ≥7 mg/l (50% of samples), ≥ 4 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	28		
Leaton	55140		346120	317810	R. Severn	PHASE 3	Outfalls	Ammonia	0.6		
								BOD	5		
								DO	60		(cyprinid) ≥7 mg/l (50% of samples), ≥ 4 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	28		
Waters Upton	26949560	SJ 63060	363060	319360	R. Tern	PHASE 4	Outfalls	Ammonia	0.6		
								BOD	5		
								DO	60		(cyprinid) ≥7 mg/l (50% of samples), ≥ 4 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	28		
Stoke on Tern	26951780	SJ 63640	363640	327760	R. Tern	PHASE 4	Outfalls	Ammonia	0.6		
								BOD	5		
								DO	60		(cyprinid) ≥7 mg/l (50% of samples), ≥ 4 mg/l(absolute)
								pHlower	6		
								Phosphate	0.12		
								pHupper	9		
								Temperature	28		

Appendix D
Groups of Water Quality Monitoring Points

Phase	Sample Point Code (WIMS Code)	Sites	Receiving Watercourses	Monitoring Point	Group	Group Name
1	28396540	Lodgebank No 1	R. Tern	Wellhead	5	Waters Upton
1	26949580	Upstream Waters Upton Outfall	R. Tern	River	5	Waters Upton
1	28396300	Ellerdine Heath	R. Tern	Wellhead	5	Waters Upton
1	28388940	Green Lane	R. Tern	Wellhead	5	Waters Upton
1	28403760	Hopton	R. Tern	Wellhead	5	Waters Upton
1	26949560	Waters Upton	R.Tern	Outfall	5	Waters Upton
1	28396560	Lodgebank No 2	R. Tern	Wellhead	5	Waters Upton
1	26949540	Downstream Waters Upton Outfall	R. Tern	River	5	Waters Upton
1	28396520	Heath House No 1	R. Tern	Wellhead	5	Waters Upton
1	28632445	Childs Ercall	Allford Brook; R. Tern	Wellhead	6	Childs Ercall
1	28388880	Hodnet No 1	R. Tern	Wellhead	8	Stoke on Tern
1	26951780	Stoke on Tern	R.Tern	Outfall	8	Stoke on Tern
1	26951760	Downstream of Stoke on Tern Outfall	R. Tern	River	8	Stoke on Tern
1	26952660	Helshaw Grange	R. Tern	Wellhead	9	Helshaw Grange
1	28388980	Greenfields	Potford Brook; R. Tern	Wellhead	10	Potford Brook
1	28396518	Heath House No 2	Platt Brook, R. Tern	Wellhead	11	Platt Brook
1	26953100	Wollerton Corn Mill (Extreme Upstream River Monitoring Point)	R. Tern	River	5,6,7,8, 9,10,11	Phase 1 & 4
1	26948480	Longdon on Tern Bridge (Extreme Downstream River Monitoring Point)	R. Tern	River	5,6,7,8, 9,10,11	Phase 1 & 4
1	26951900	Upstream Stoke on Tern Outfall	R. Tern	River	8,9	Stoke on Tern
2	29992280	Adcote Mill downstream Adcote Outfall	R. Perry; R. Severn	River	1	Adcote
2	30015170	Frankbrook	R. Perry; R. Severn	Wellhead	1	Adcote
2	29992310	Adcote	R. Perry; R. Severn	Outfall	1	Adcote
2	30008180	Grafton	R. Perry; R. Severn	Wellhead	2	Grafton
2	29991920	Grafton	R. Perry; R. Severn	Outfall	2	Grafton
2	29991910	Downstream Grafton Outfall	R. Perry; R. Severn	River	2	Grafton

Phase	Sample Point Code (WIMS Code)	Sites	Receiving Watercourses	Monitoring Point	Group	Group Name
2	29991945	Upstream Grafton Outfall	R. Perry; R. Severn	River	2	Grafton
2	30448200	Nib Heath	R. Severn	Wellhead	3	Forton
2	56310	Forton	R. Severn	Outfall	3	Forton
2		Upstream Forton Outfall - RIVER SEVERN AT MONTFORD BRIDGE	R. Severn	River	3	Forton
2	30447310	Knolls No 2	R. Severn	Wellhead	3	Forton
2	30447300	Knolls No 1	R. Severn	Wellhead	3	Forton
2	29991620	Forton Heath	R. Severn	Wellhead	3	Forton
2	30433490	Forton	R. Severn	Wellhead	3	Forton
2	30447450	Ensdon	R. Severn	Wellhead	3	Forton
2	30008400	Bank House	R. Severn	Wellhead	3	Forton
2	30447760	Rodefern	R. Severn	Wellhead	3	Forton
2	29992315	Upstream Adcote Outfall	R. Perry; R. Severn	River	1, 2	Adcote
2	29991100	Mytton Bridge	R. Perry; R. Severn	River	1, 2	Adcote; Grafton
3	29956500	Great Wollascott	R. Severn	Wellhead	4	Leaton
3	30030950	Merrington Lane	R. Severn	Wellhead	4	Leaton
3	29210500	Albrighton	R. Severn	Wellhead	4	Leaton
3		RIVER SEVERN AT ISLE OF BICTON	R. Severn	River	4	Leaton
3	29920860	Newton	R. Severn	Wellhead	4	Leaton
3	29188940	Preston Gubbals	R. Severn	Wellhead	4	Leaton
3	29245380	Plex	R. Severn	Wellhead	4	Leaton
3	27631950	Shawell Cottage	R. Severn	Wellhead	4	Leaton
3	29245880	Smethcote	R. Severn	Wellhead	4	Leaton
3	55140	Leaton	R. Severn	Outfalls	4	Leaton
3	55610	Upstream Leaton Outfall	R. Severn	River	4	Leaton
3	27631900	Pim Hill	R. Severn	Wellhead	4	Leaton
3	55570	Downstream Leaton Outfall	R. Severn	River	4	Leaton
4	28396280	Woodmill	R. Tern	Wellhead	5	Waters Upton
4	26949580	Upstream Waters Upton Outfall	R. Tern	River	5	Waters Upton
4	26949540	Downstream Waters Upton Outfall	R. Tern	River	5	Waters Upton
4	28396500	High Hatton No 2	R. Tern	Wellhead	5	Waters Upton
4	28396505	High Hatton No 1	R. Tern	Wellhead	5	Waters Upton

Phase	Sample Point Code (WIMS Code)	Sites	Receiving Watercourses	Monitoring Point	Group	Group Name
4	28410360	Windy Oak	R. Tern	Wellhead	5	Waters Upton
4	28394800	Ellerdine Station	R. Tern	Wellhead	5	Waters Upton
4	26949560	Waters Upton	R. Tern	Outfall	5	Waters Upton
4	28628400	Great Bolas	R. Tern	Wellhead	7	Great Bolas
4	26951900	Upstream Stoke on Tern Outfall	R. Tern	River	8	Stoke on Tern
4	26951780	Stoke on Tern	R. Tern	Outfall	8	Stoke on Tern
4	28675850	Cotton Farm	R. Tern	Wellhead	8	Stoke on Tern
4	28389240	Espley No 1	R. Tern	Wellhead	8	Stoke on Tern
4	28389245	Espley No 2	R. Tern	Wellhead	8	Stoke on Tern
4	28675900	Hodnet No 2	R. Tern	Wellhead	8	Stoke on Tern
4	26951760	Downstream Stoke on Tern Outfall	R. Tern	River	8	Stoke on Tern
4	26953100	Wollerton Corn Mill	R. Tern	River	5,6,7,8, 9,10,11	Phase 1 & 4
4	26948480	Longdon on Tern Bridge	R. Tern	River	5,6,7,8, 9,10,11	Phase 1 & 4

Appendix E
Determinands selected for Time Series Investigation

Chemical Substance	Number of Analysis Results	Chemical Group	Select For Timeseries Work?
ALKALINITY PH 4.5 - as CACO3	983	Field	Yes
ALUMINIUM - AS AL	216	Metals	Yes
AMMONIA - AS N	1035	Nutrients	Yes
ARSENIC - AS AS	169	Non-metals	Yes
BOD ATU as O2	595	Redox	Yes
CADMIUM - AS CD	992	Metals	Yes
CADMIUM DISSOLVED - AS CD	429	Metals	Yes
CONDUCTIVITY @20C	941	Field	Yes
COPPER - AS CU	996	Metals	Yes
COPPER DISSOLVED - AS CU	357	Metals	Yes
FLUORIDE - AS F	141	Non-metals	Yes
IRON - AS FE	1015	Redox	Yes
IRON DISSOLVED - AS FE	450	Redox	Yes
LEAD - AS PB	992	Metals	Yes
LEAD DISSOLVED - AS PB	409	Metals	Yes
MAGNESIUM - AS MG	1032	Metals	Yes
MAGNESIUM DISSOLVED - AS MG	22	Metals	Yes
MANGANESE - AS MN	1015	Redox	Yes
MANGANESE DISSOLVED - AS MN	434	Redox	Yes
MERCURY - AS HG	121	Metals	Yes
NICKEL - AS NI	992	Metals	Yes
NICKEL DISSOLVED - AS NI	440	Metals	Yes
NITRATE - as N	434	Nutrients	Yes
NITRITE - as N	469	Nutrients	Yes
ORTHOPHOSPHATE - as P	998	Nutrients	Yes
OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O	403	Field	Yes
OXYGEN DISSOLVED (INSTRUMENTAL) - AS % SATN	860	Field	Yes

Chemical Substance	Number of Analysis Results	Chemical Group	Select For Timeseries Work?
PH - AS PH UNITS	1027	Field	Yes
PH IN SITU MEASUREMENT	94	Field	Yes
SODIUM - AS NA	993	Metals	Yes
SULPHATE - AS SO4	1008	Non-metals	Yes
TEMPERATURE WATER	865	Field	Yes
ZINC - AS ZN	990	Metals	Yes
ZINC DISSOLVED - AS ZN	337	Metals	Yes

Appendix F
Studies of the Frankbrook Wellhead

National Rivers Authority Phase 2 Initial Feasibility Testing (1975) Report and Phase 2 Commissioning Report (1991/92)

Piper Diagrams from SGS Well Yield MSc (supplied by K. Voyce)

SGS Phase 2 – Frank Brook Abstraction Borehole Water Quality Analysis

Chloride concentration at Frankbrook abstraction site, group pumping test, 1975

FIGURE 5.1

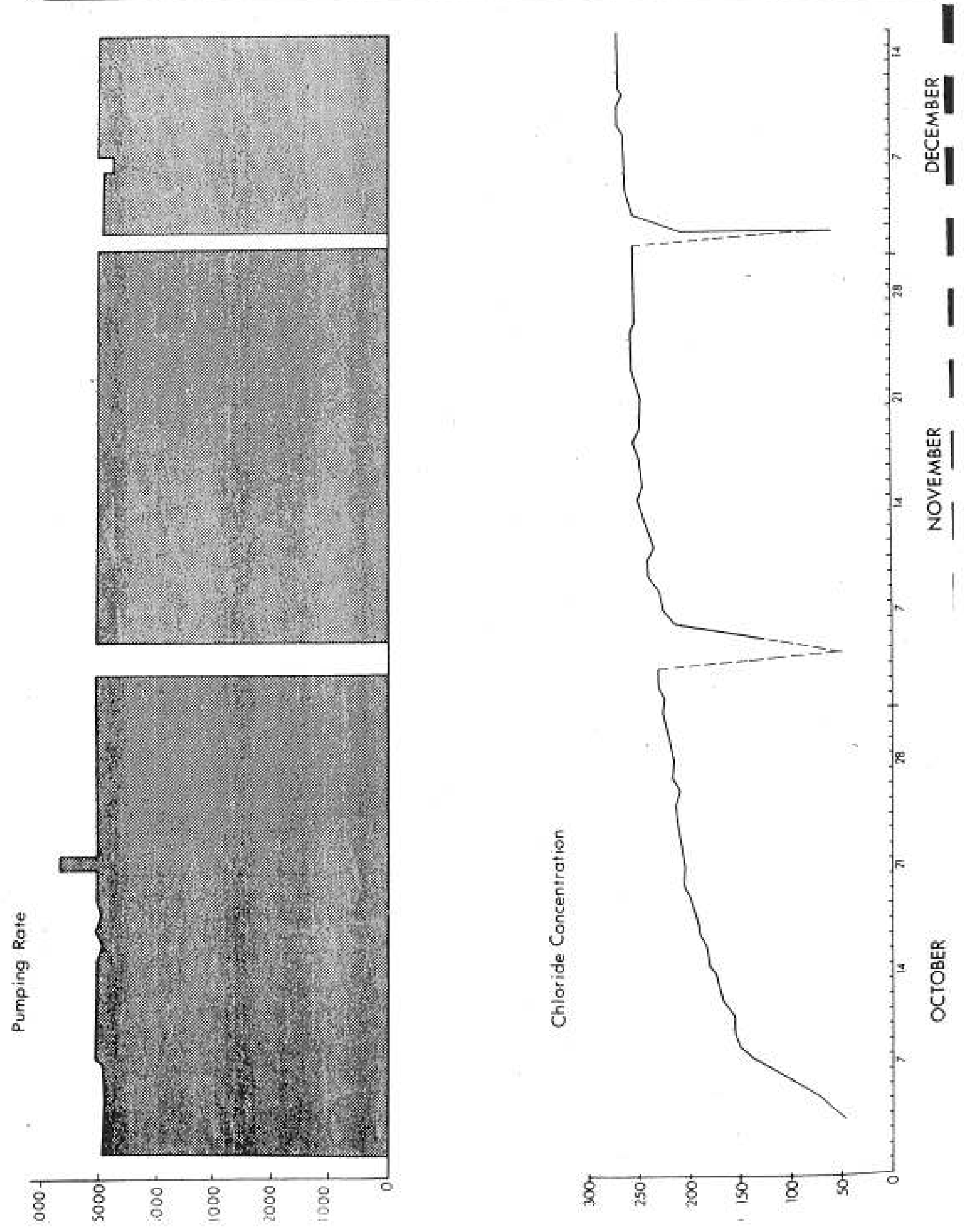


FIGURE 5.2 FRANKBROOK CHLORIDE TREND INDIVIDUAL AND GROUP TEST

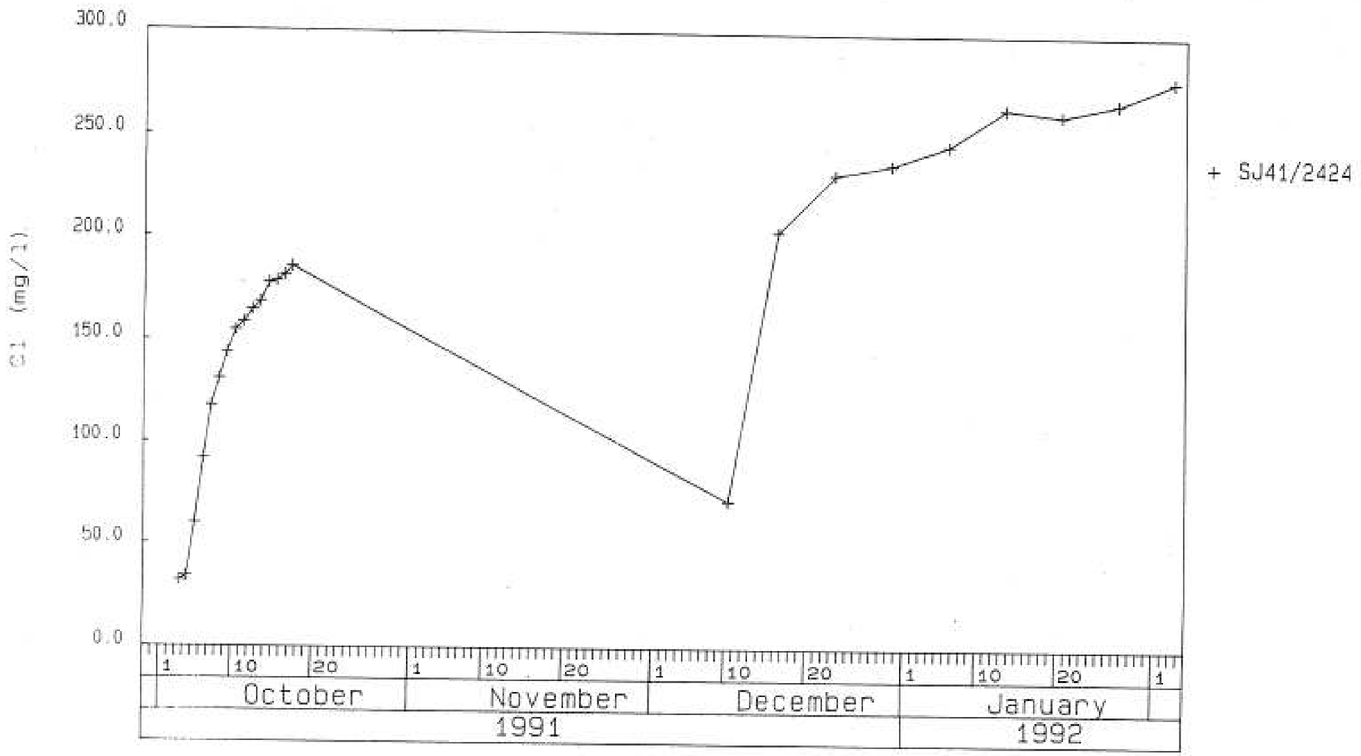


FIGURE 5.3 FRANKBROOK SAMPLES TAKEN DURING THE INDIVIDUAL TEST

DUROV Hydrochemical Plots

+	03.10.91	⊕	08.10.91
●	04.10.91	○	10.10.91
■	05.10.91	□	12.10.91
⊗	06.10.91	×	14.10.91
▸	07.10.91	▹	17.10.91

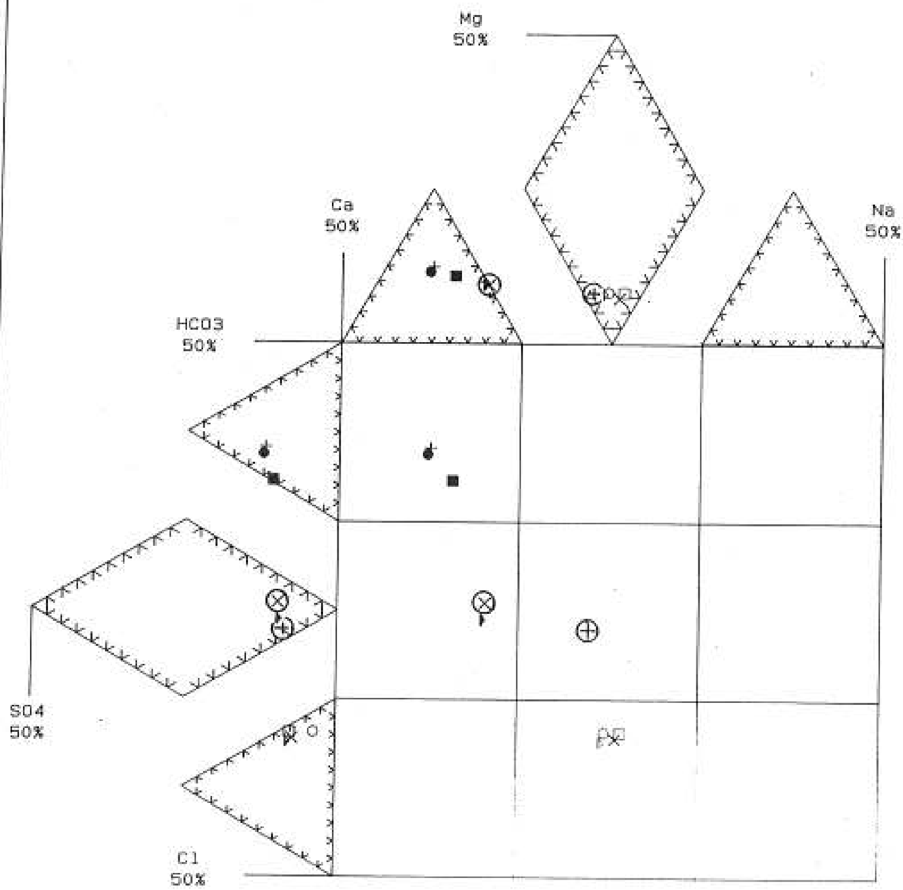


FIGURE 5.4 FRANKBROOK SAMPLES TAKEN DURING THE GROUP PUMPING TEST

DUROV Hydrochemical Plots

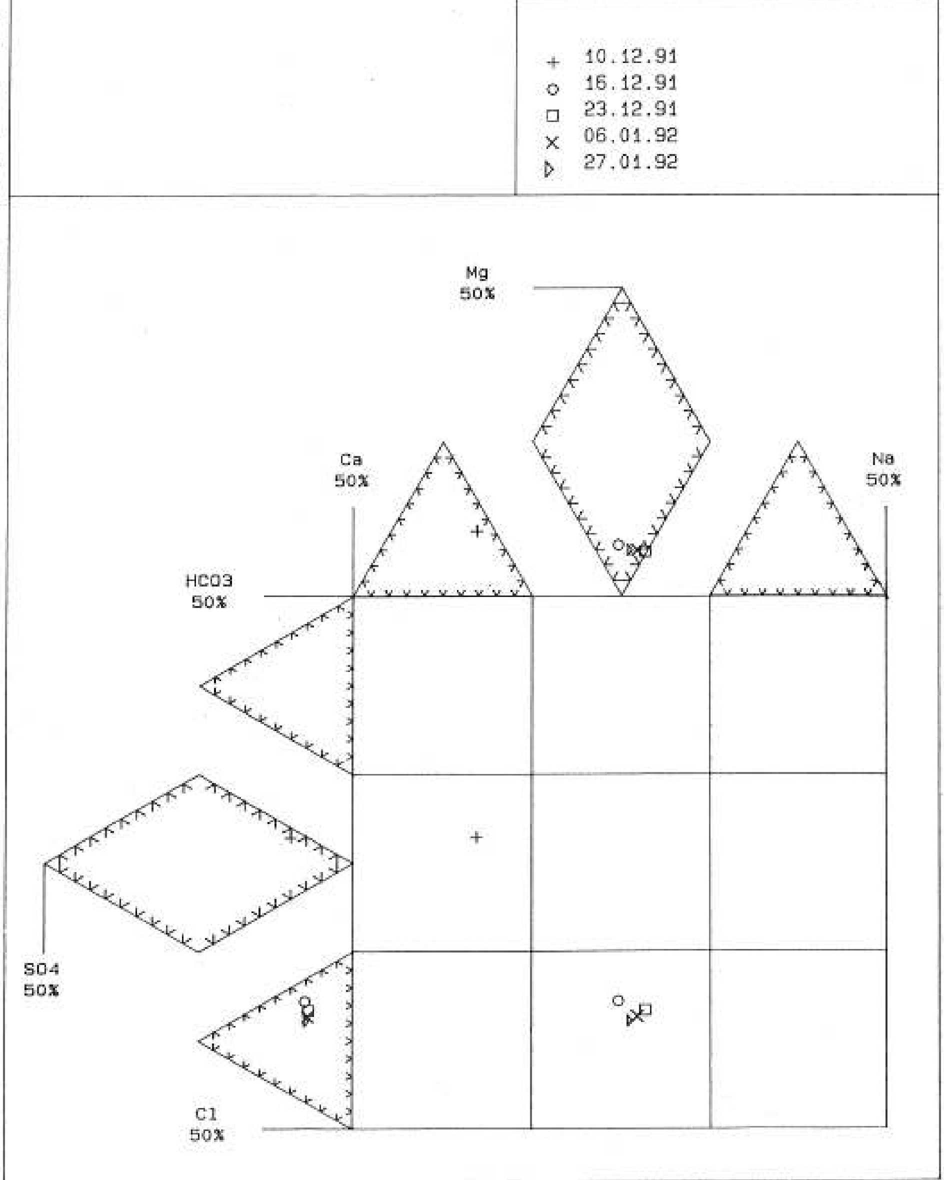
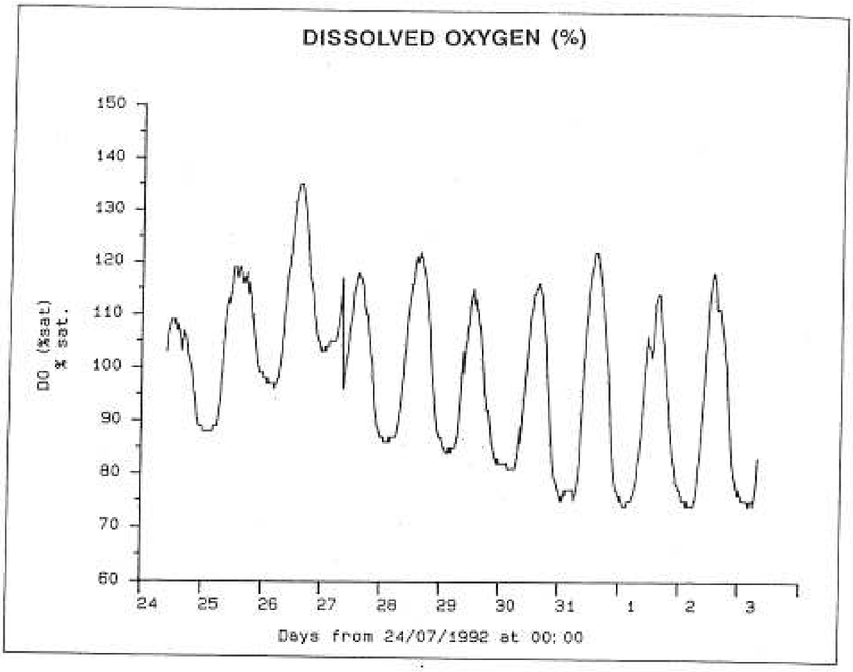


FIGURE 5.6 GRAFTON VENTURI TEST UPSTREAM DO/TEMPERATURE PROFILES



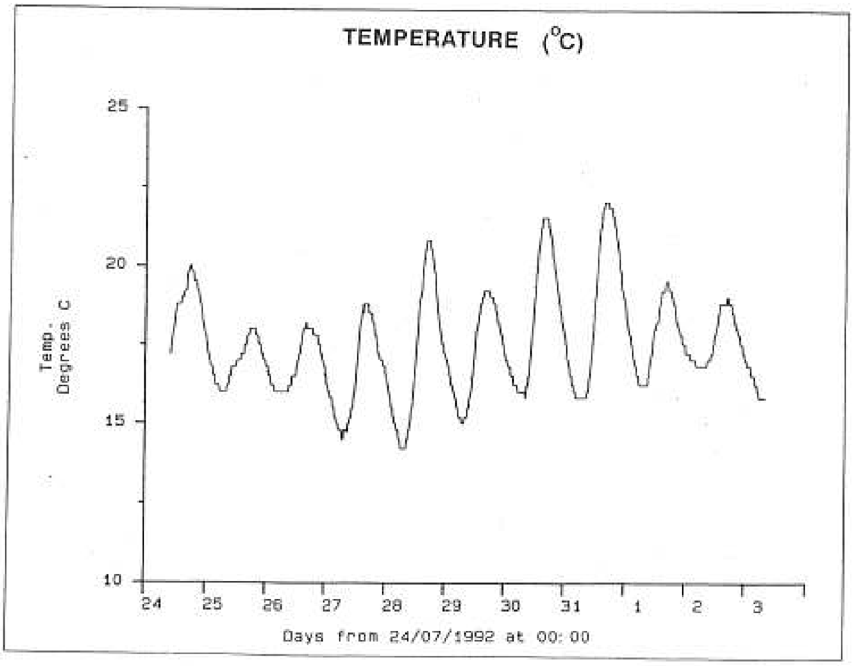
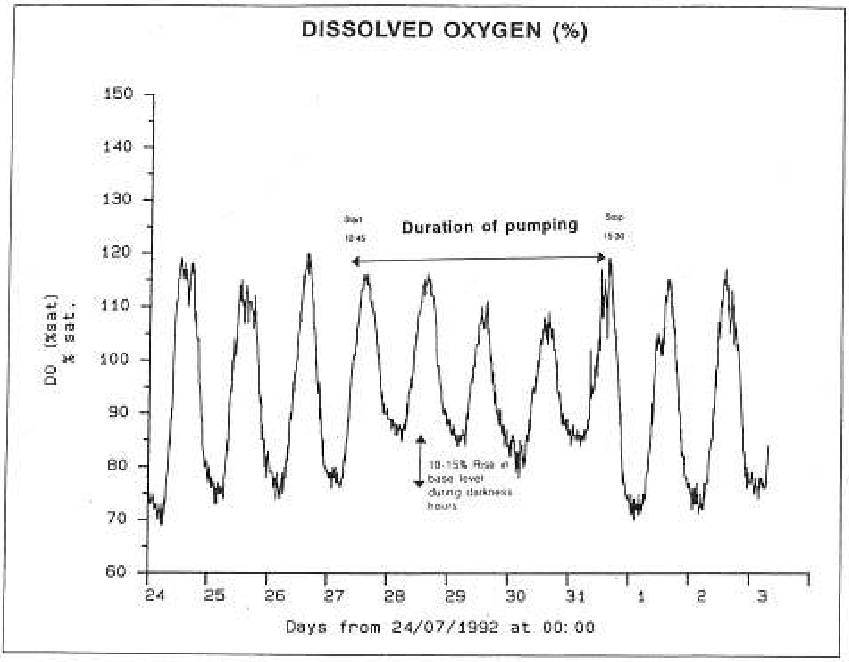


FIGURE 5.7 GRAFTON VENTURI TEST DOWNSTREAM DO/TEMPERATURE PROFILES



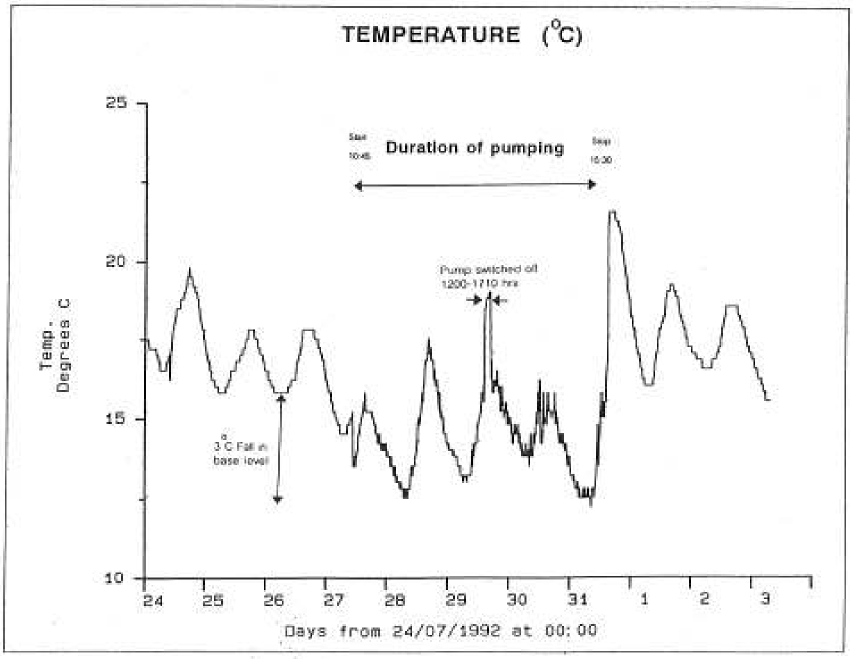


Figure 34: Piper Plot showing the bulk hydrochemistry of waters pumped by the scheme

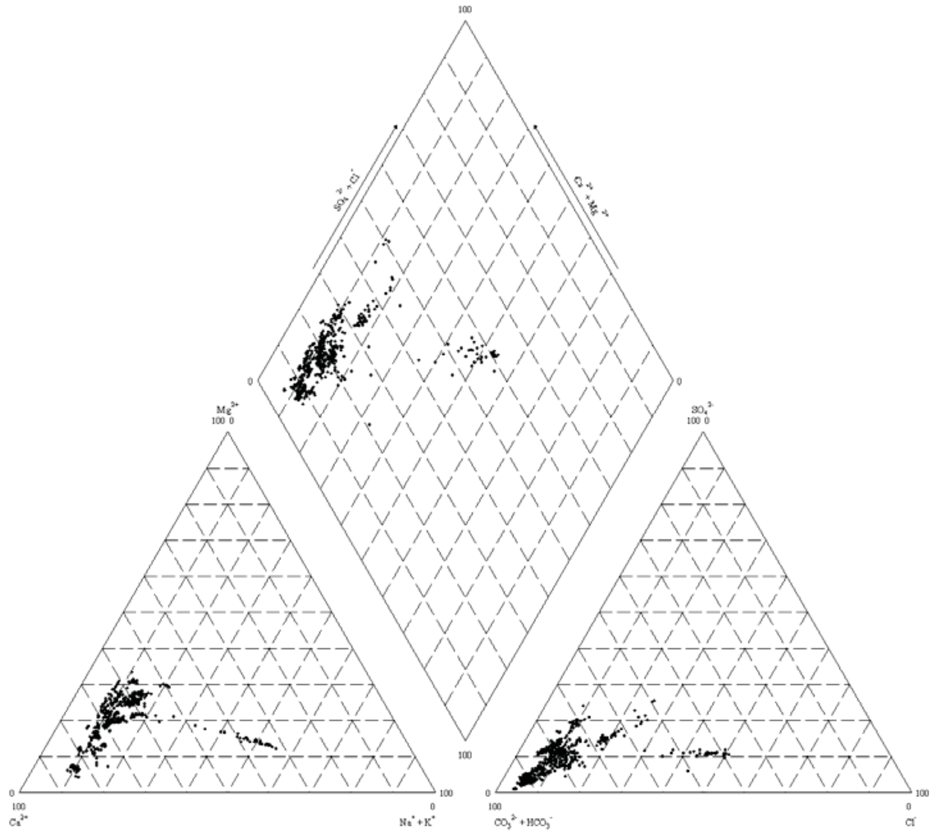
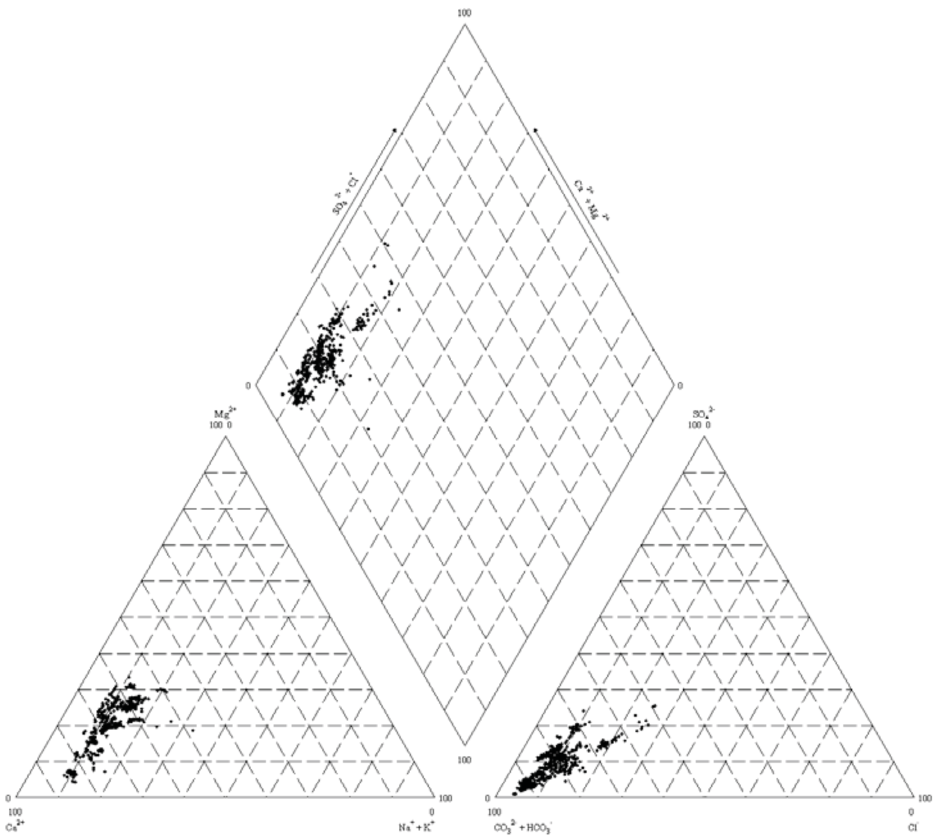


Figure 35: Piper plot of water analysis results for samples obtained from the scheme, excluding Frankbrook



Appendix G
Relationship between Water Quality and Groundwater Pumping

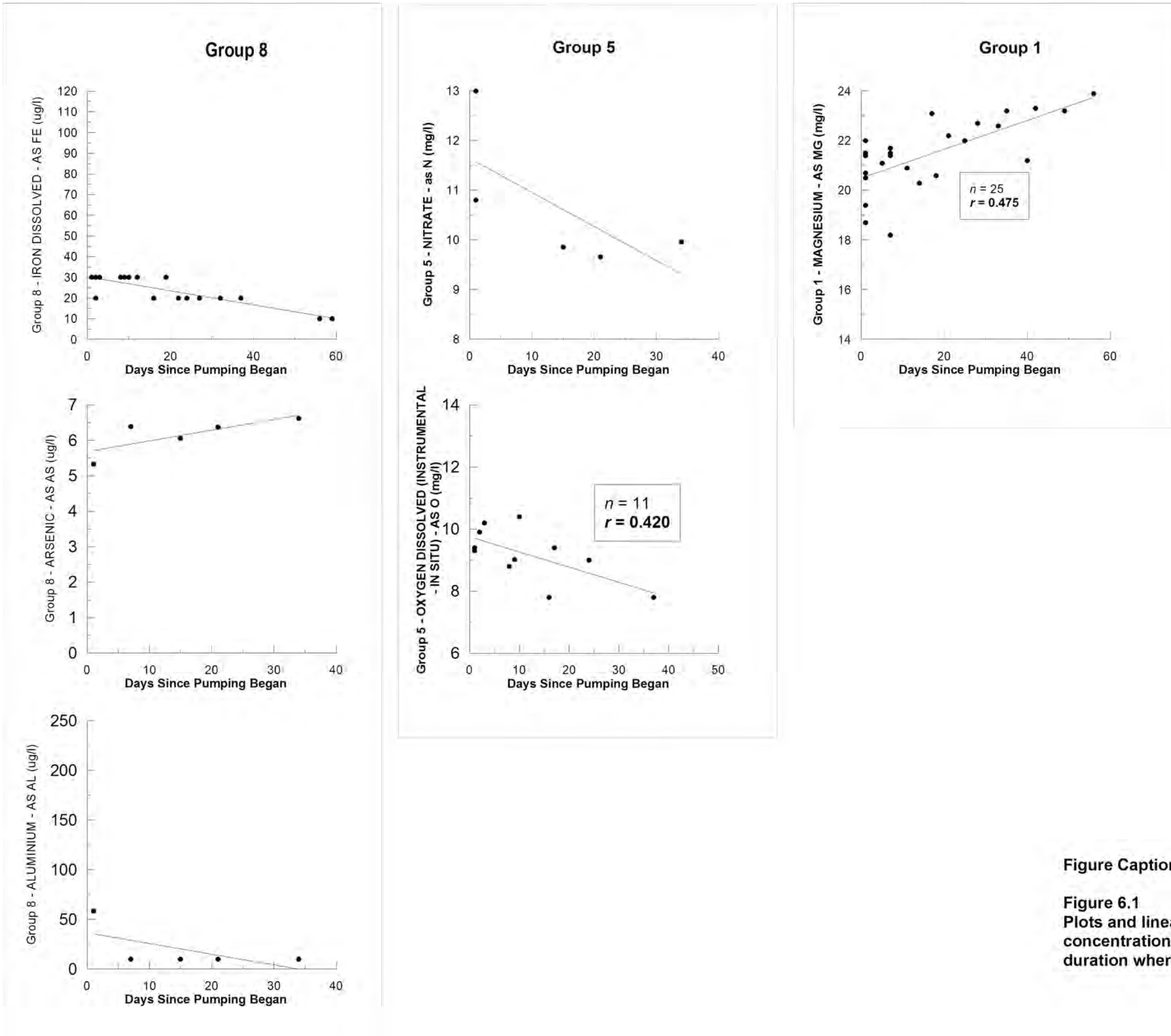
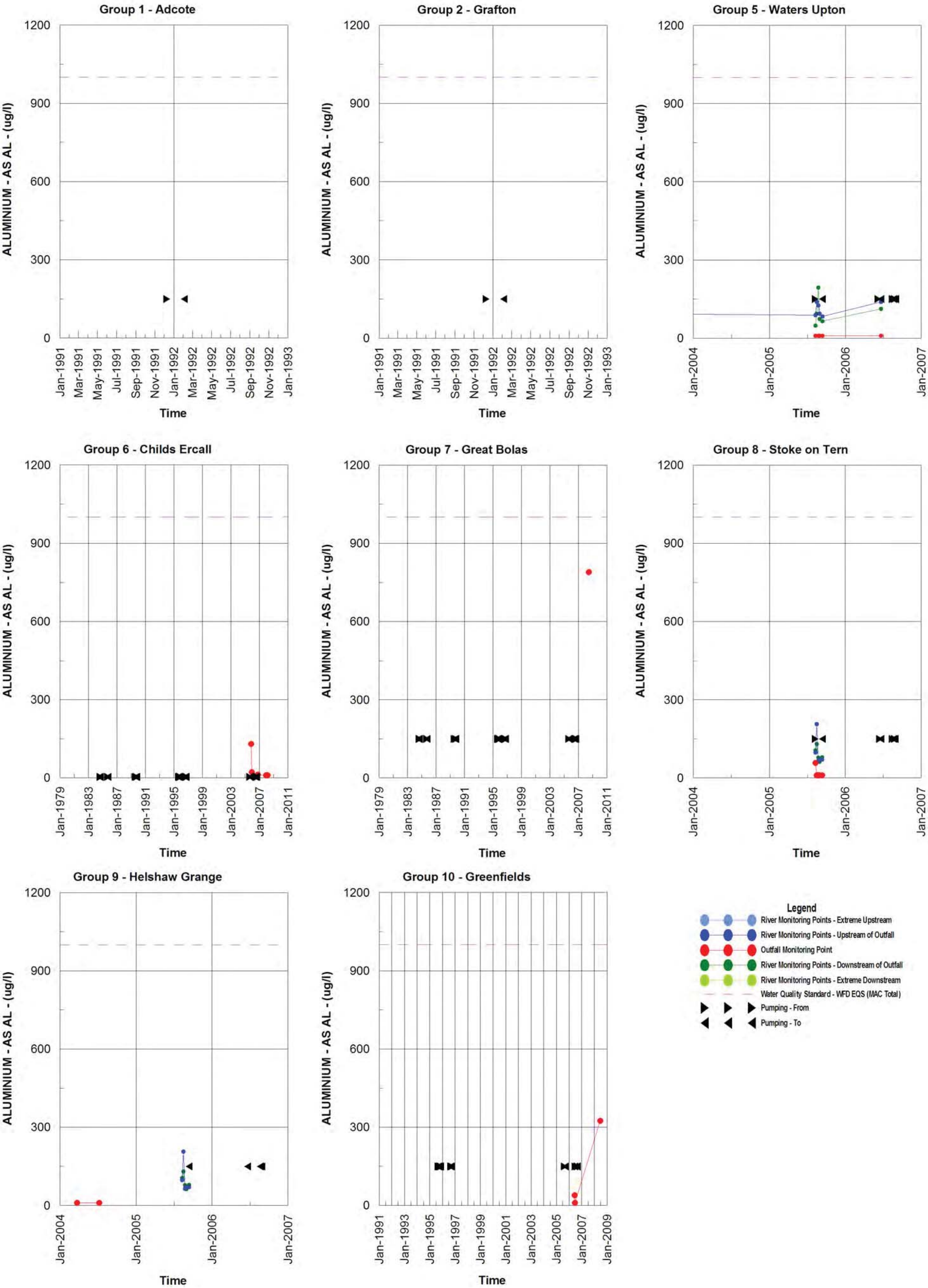
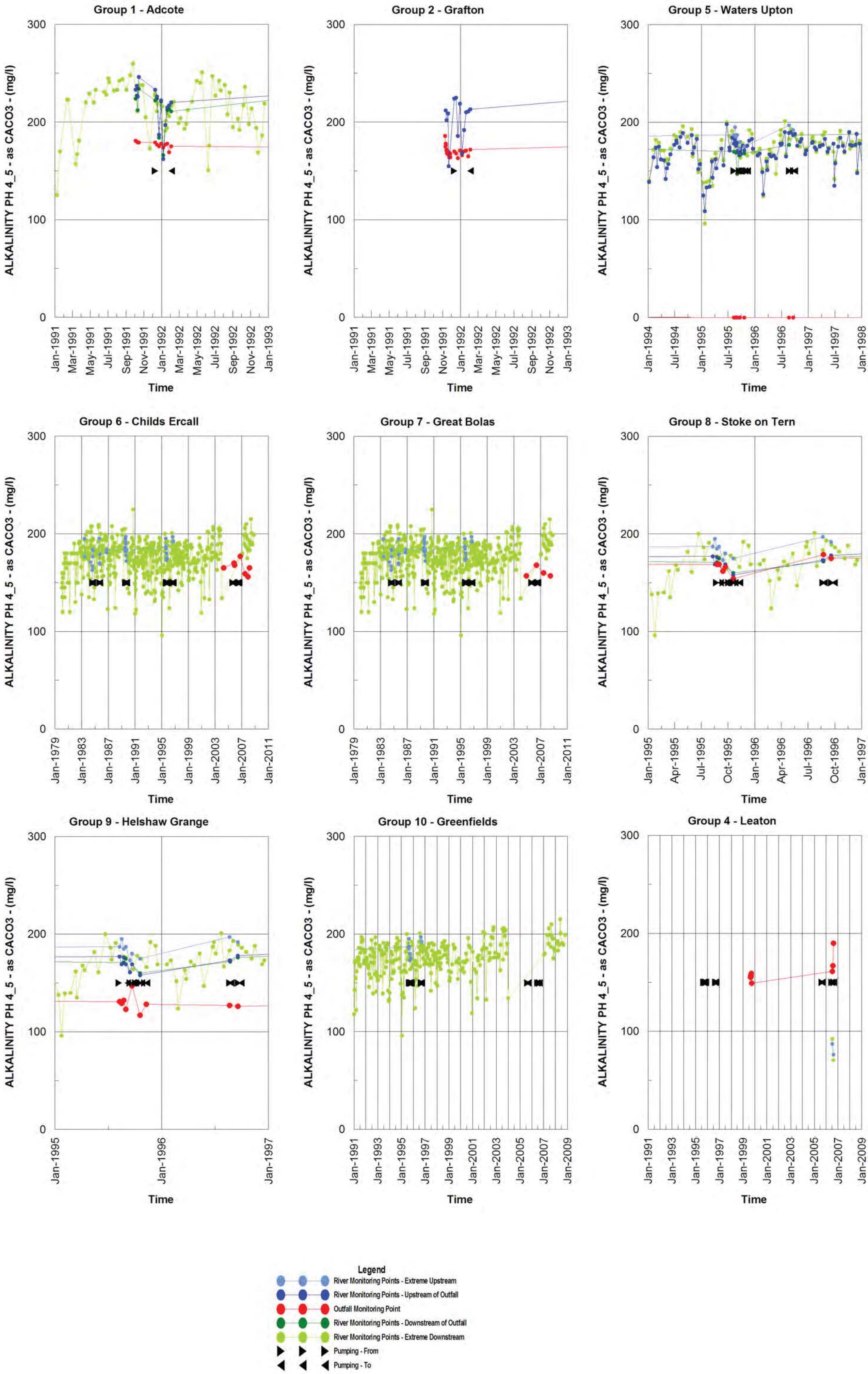


Figure Caption:

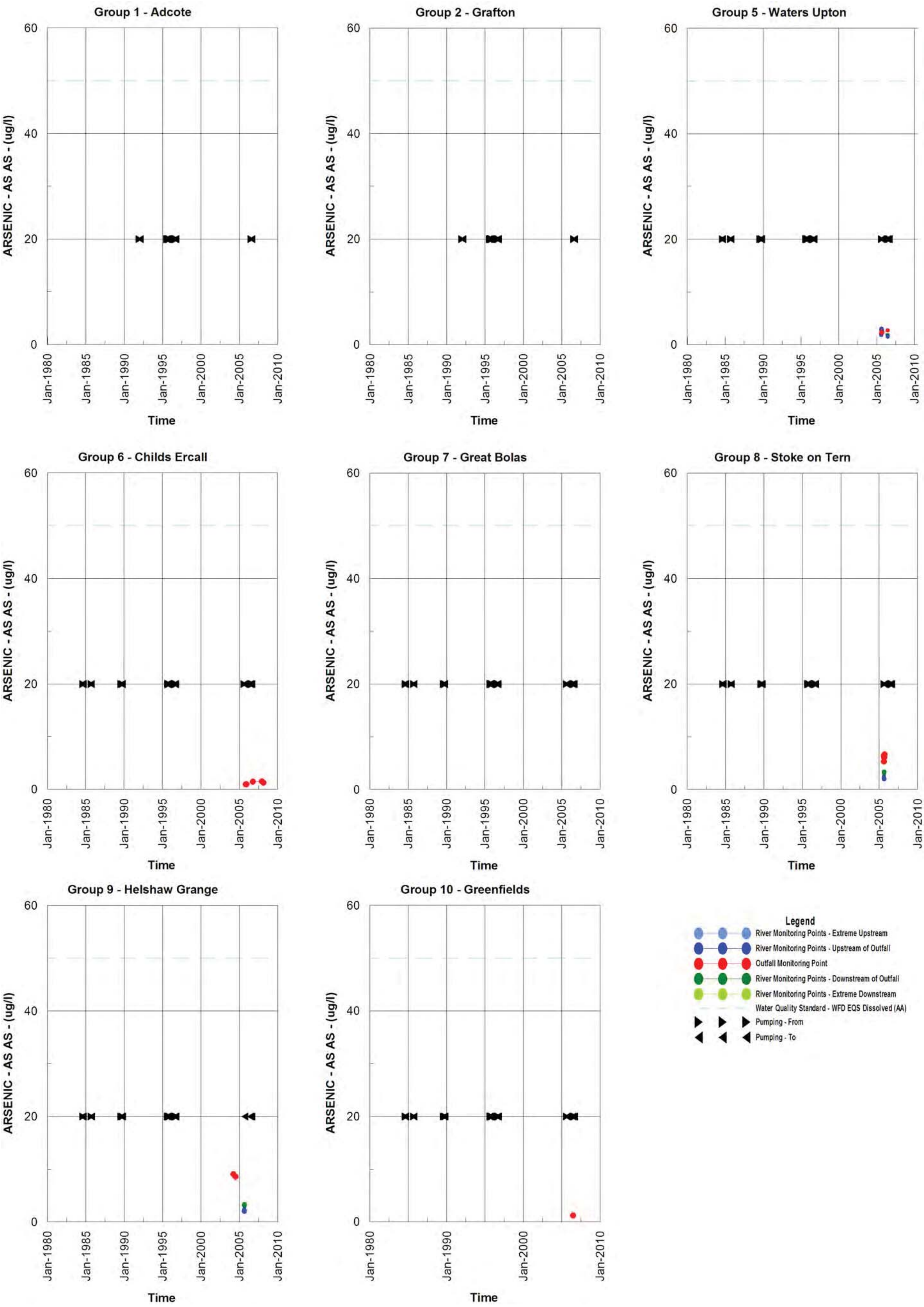
Figure 6.1
Plots and linear fits of determinand concentration at outfall vs pumping duration where *r*>0.4

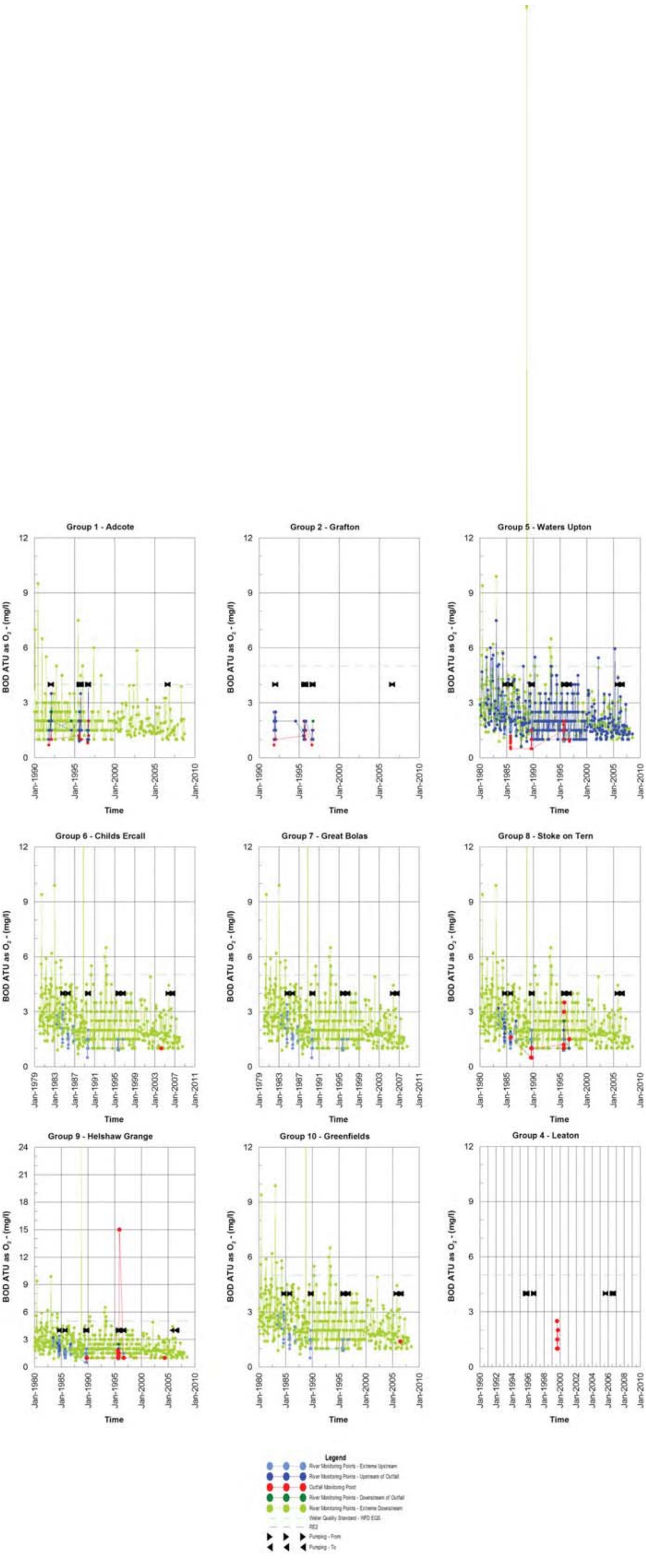
Appendix H
Time Series of Determinand Concentrations

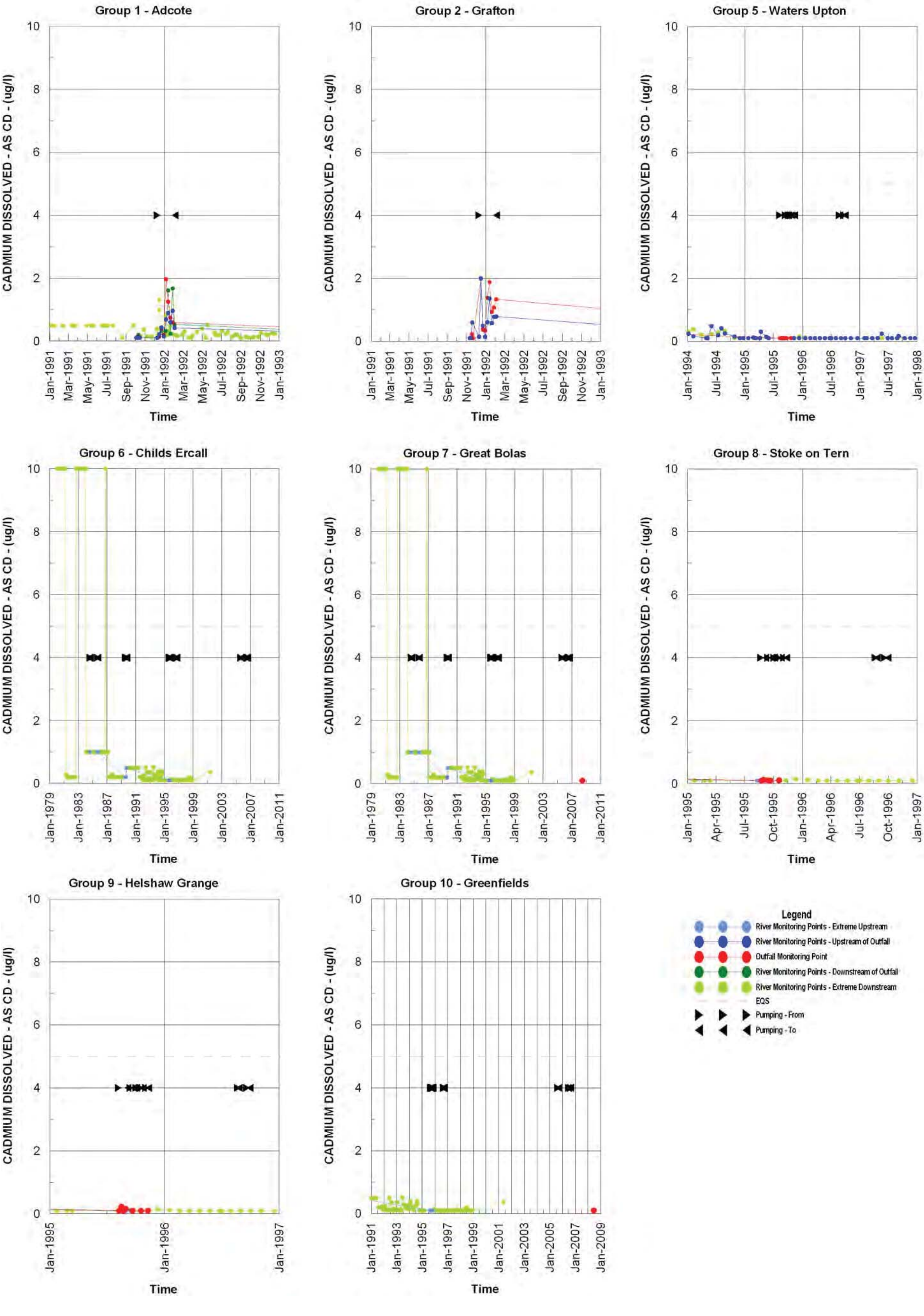

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
ALUMINIUM - AS AL - (ug/l)
Time
1200
900
600
300
0
Jan-1991
Mar-1991
May-1991
Jul-1991
Sep-1991
Nov-1991
Jan-1992
Mar-1992
May-1992
Jul-1992
Sep-1992
Nov-1992
Jan-1993
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-1979
Jan-1983
Jan-1987
Jan-1991
Jan-1995
Jan-1999
Jan-2003
Jan-2007
Jan-2011
Jan-1993
Jan-1995
Jan-1997
Jan-1999
Jan-2001
Jan-2003
Jan-2005
Jan-2007
Jan-2009
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS (MAC Total)
Pumping - From
Pumping - To



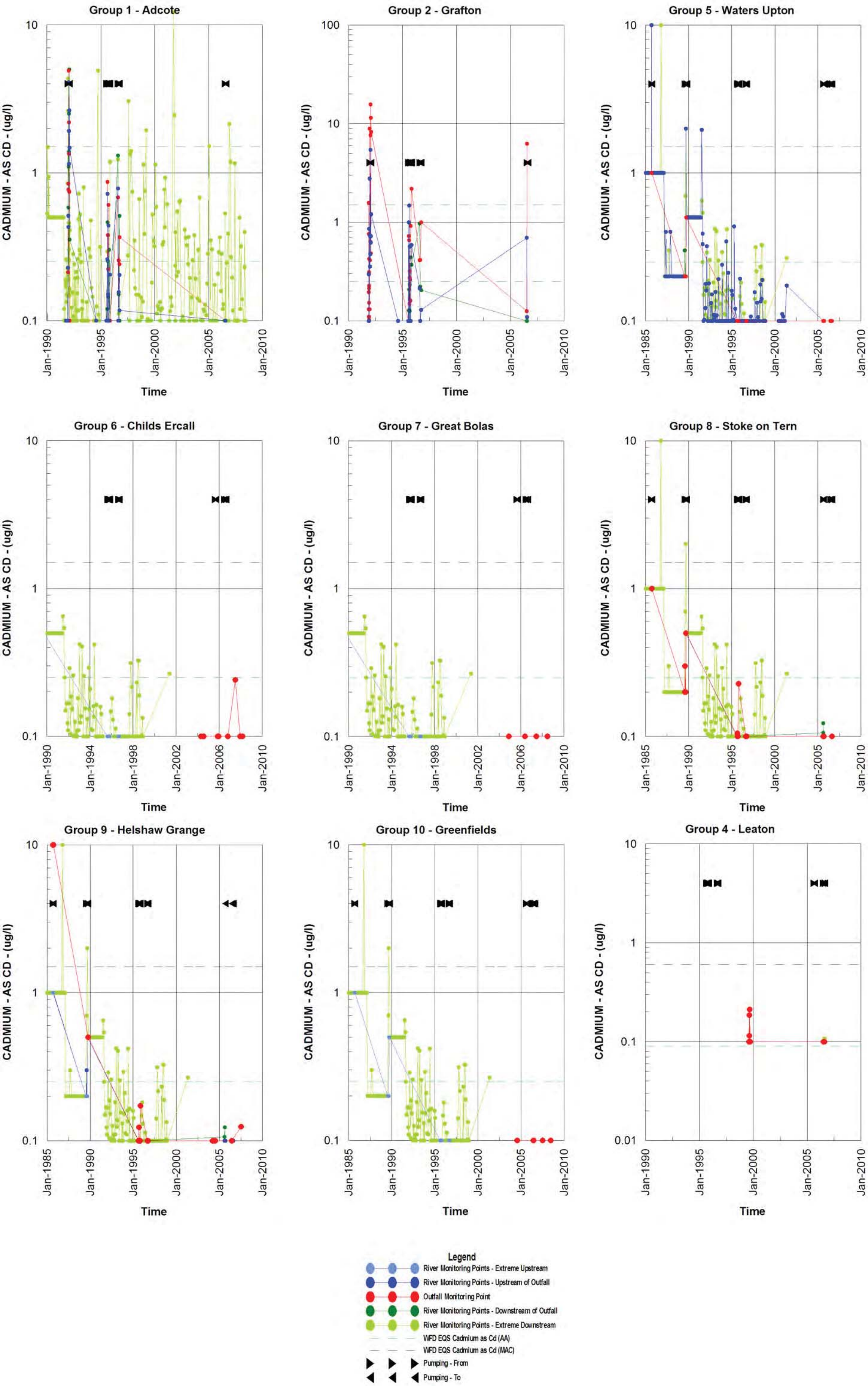
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
ALKALINITY PH 4_5 - as CACO3 - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To


Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
ARSENIC - AS AS - (ug/l)
Time
0
20
40
60
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS Dissolved (AA)
Pumping - From
Pumping - To

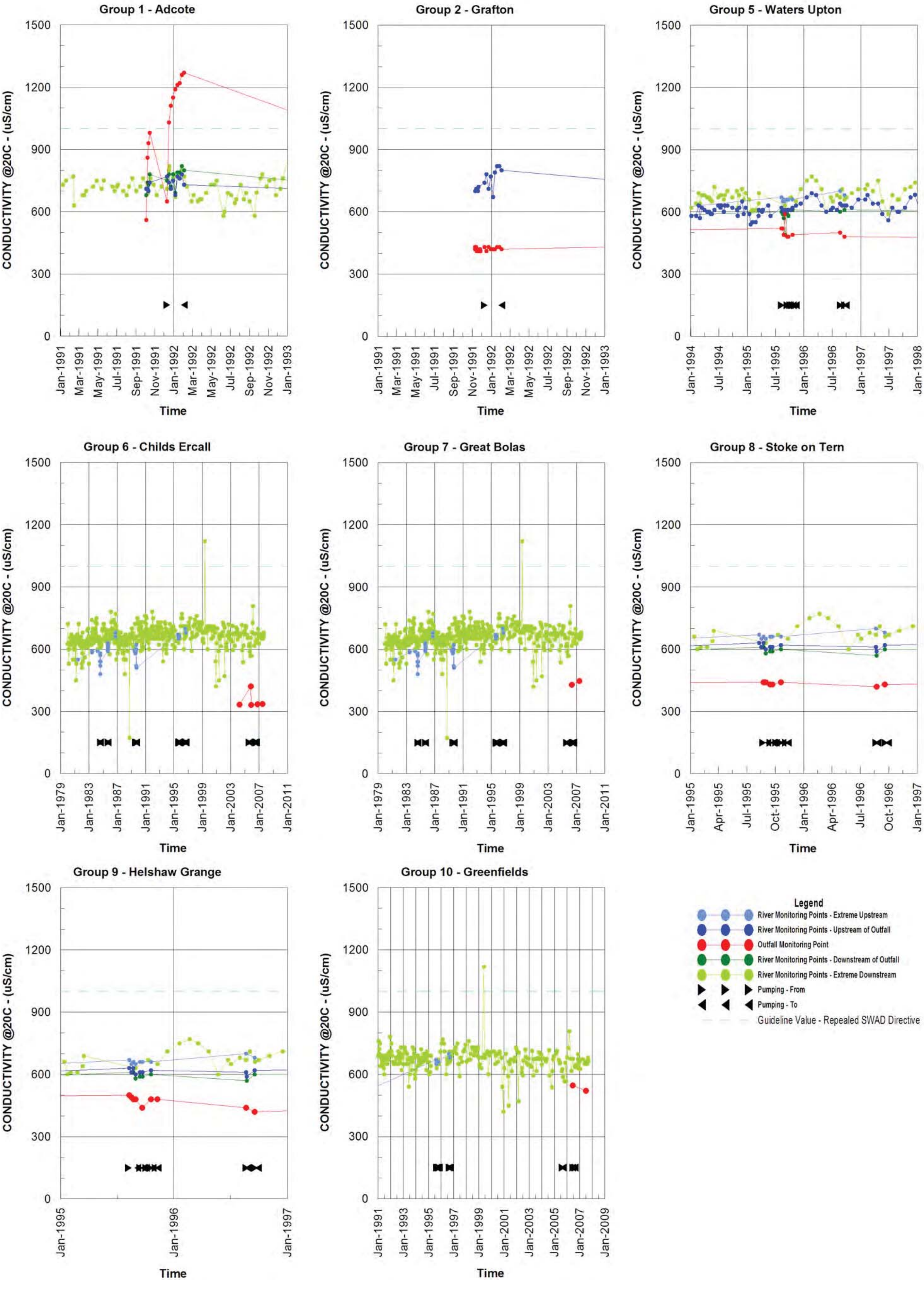

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
BOD ATU as O_2 - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS
RE2
Pumping - From
Pumping - To



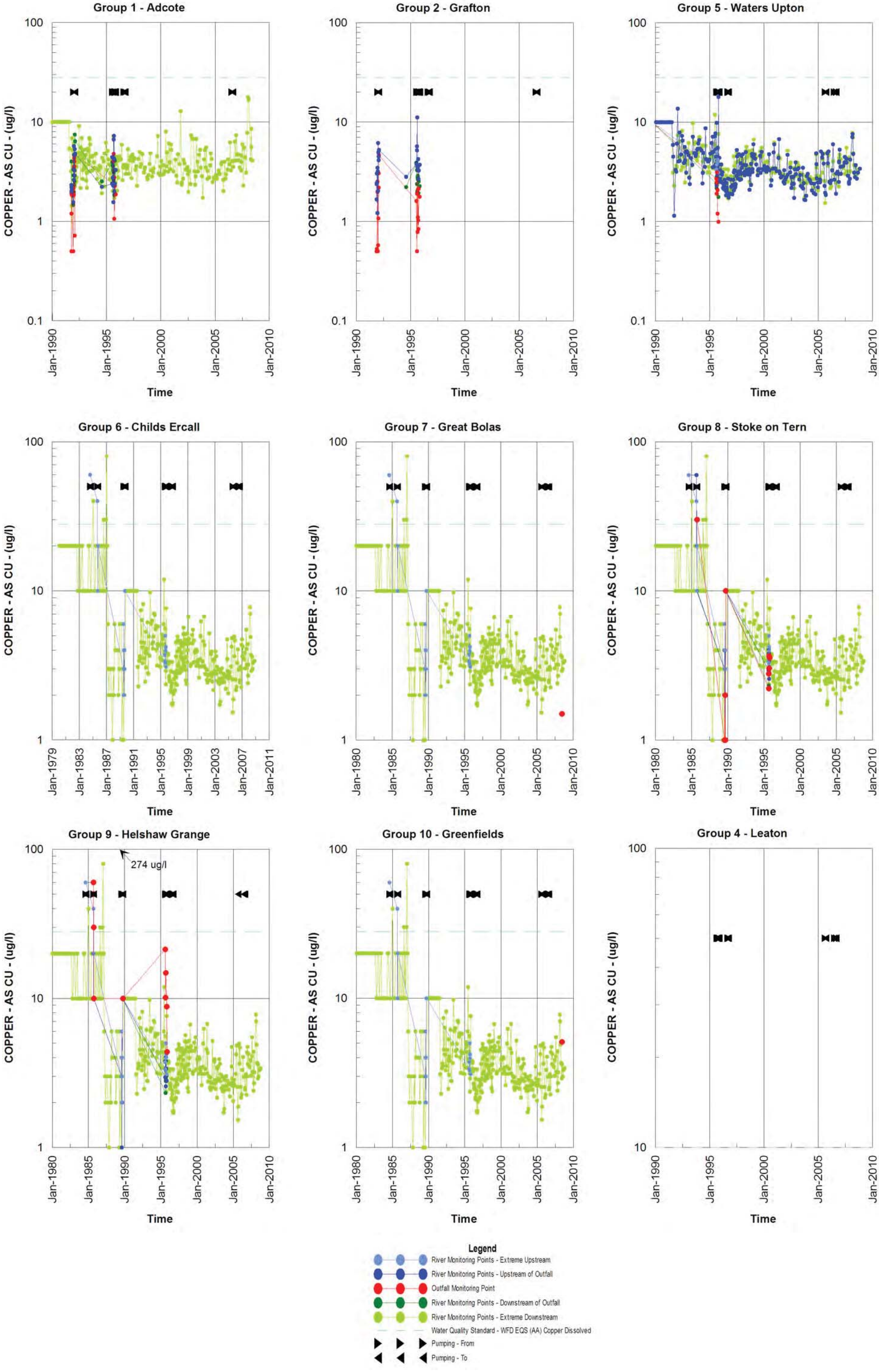
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
CADMIUM DISSOLVED - AS CD - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
Pumping - From
Pumping - To



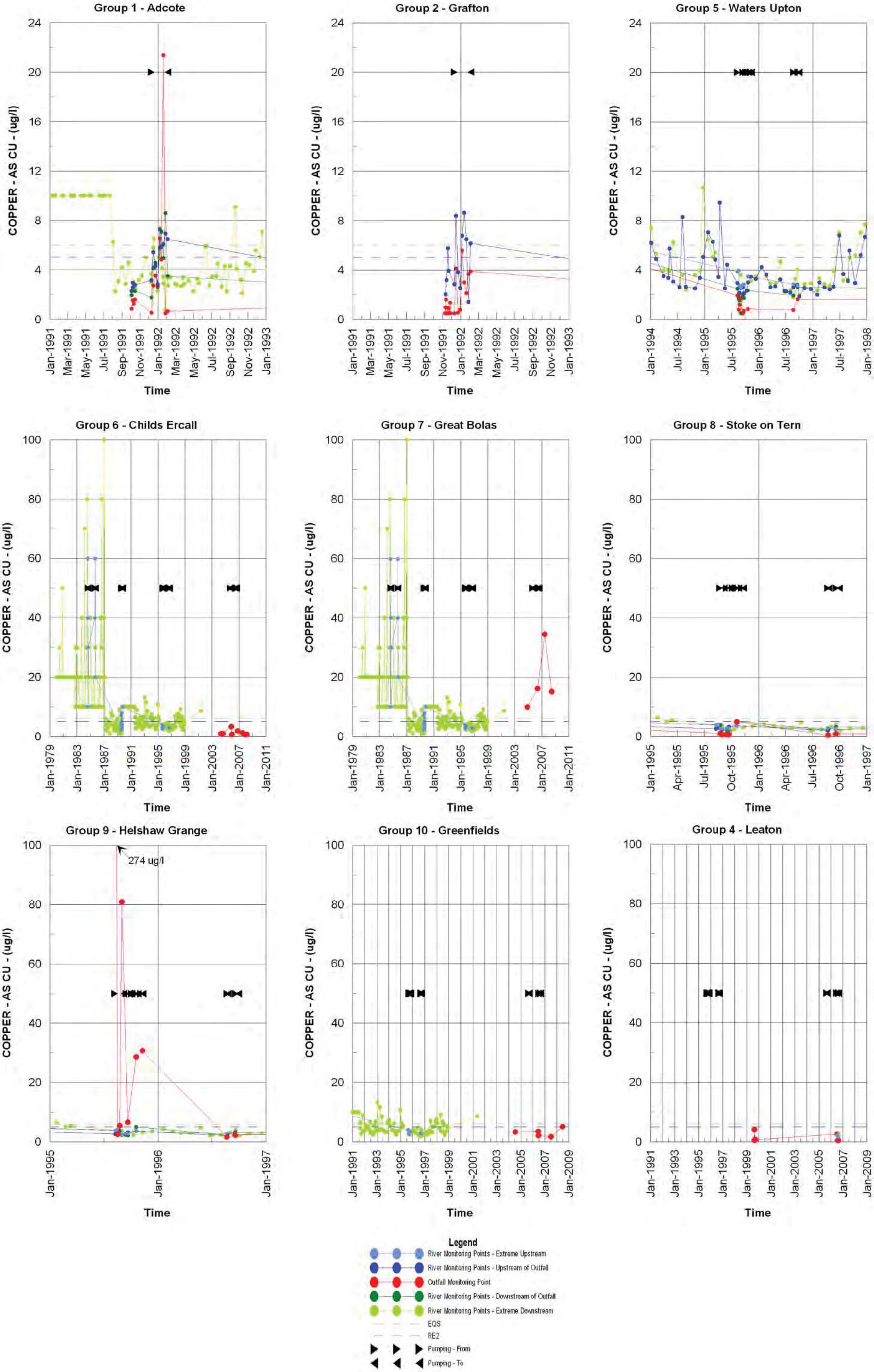
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
CADMIUM - AS CD - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
WFD EQS Cadmium as Cd (AA)
WFD EQS Cadmium as Cd (MAC)
Pumping - From
Pumping - To



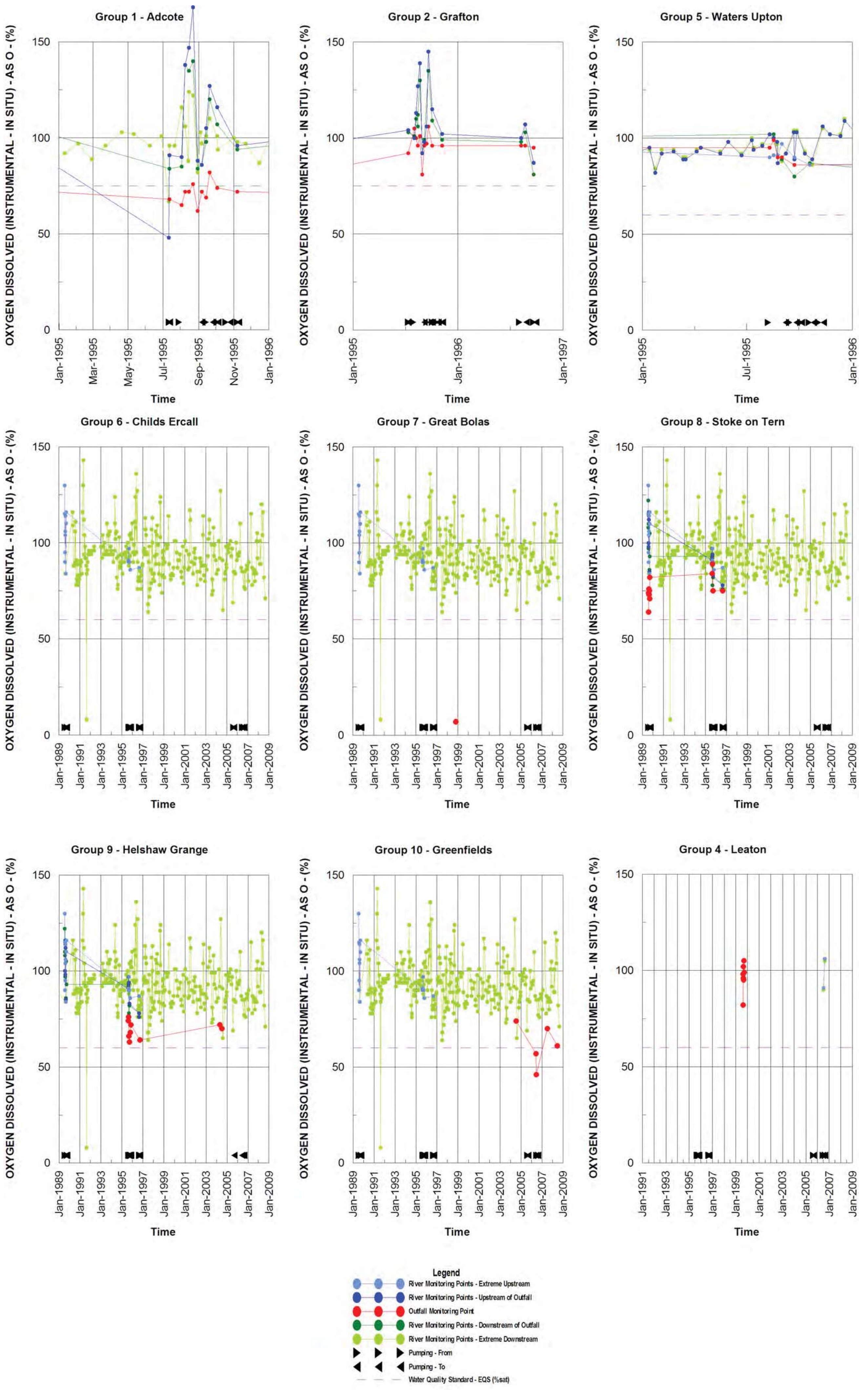
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
CONDUCTIVITY @20C - (uS/cm)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
Guideline Value - Repealed SWAD Directive



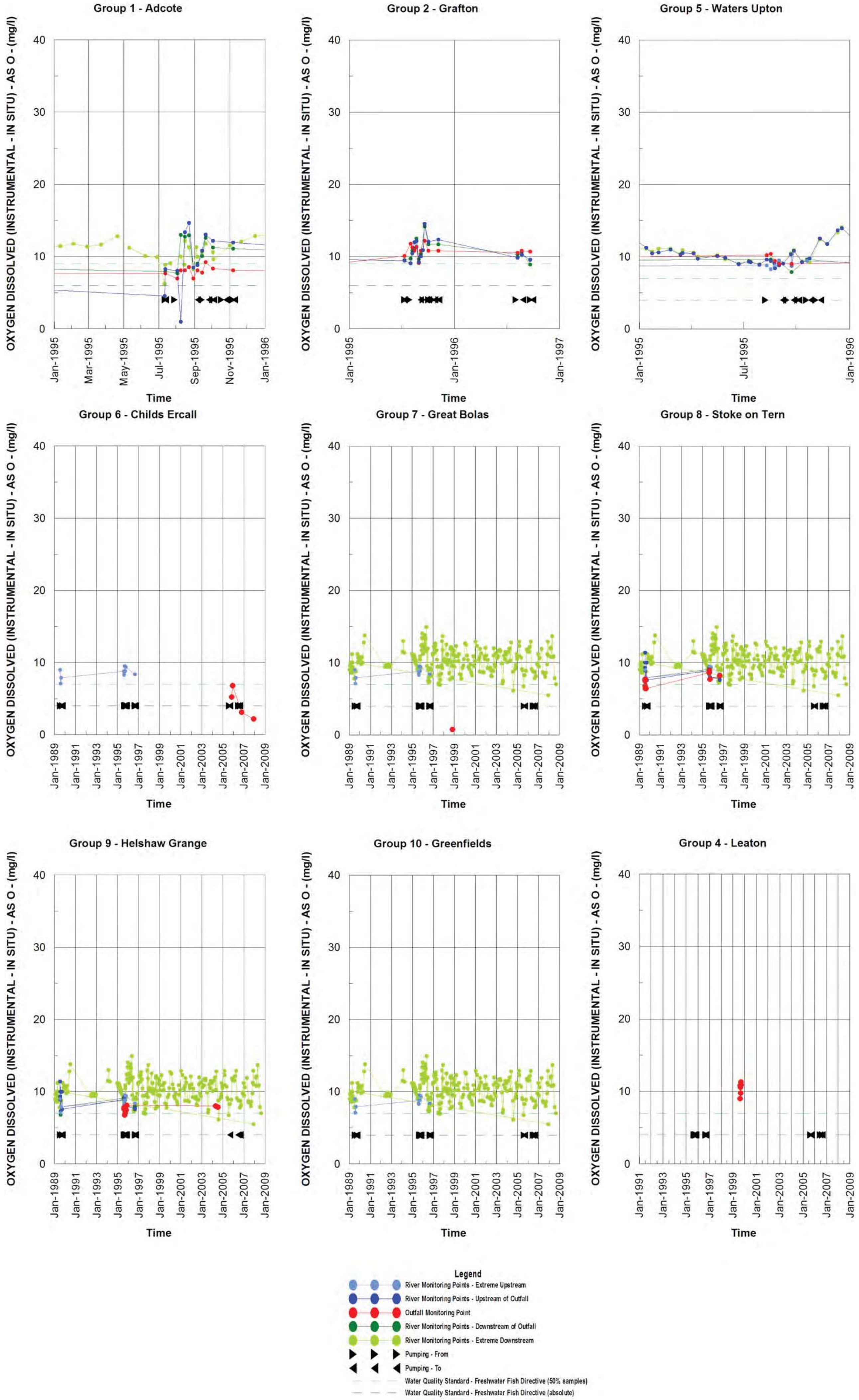
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
274 ug/l
Group 10 - Greenfields
Group 4 - Leaton
COPPER - AS CU - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS (AA) Copper Dissolved
Pumping - From
Pumping - To



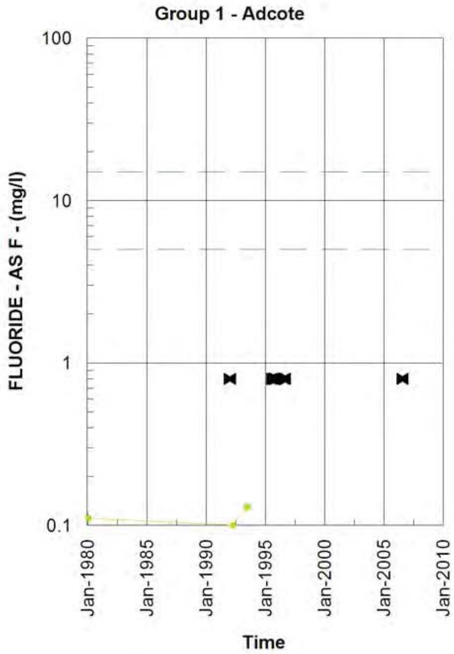
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
COPPER - AS CU - (ug/l)
Time
274 ug/l
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
RE2
Pumping - From
Pumping - To

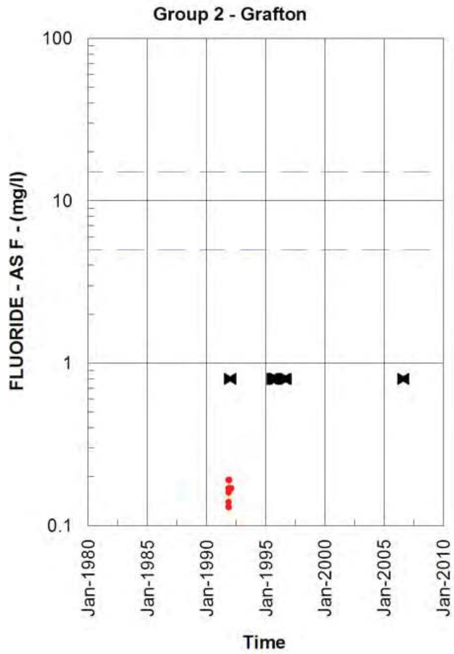


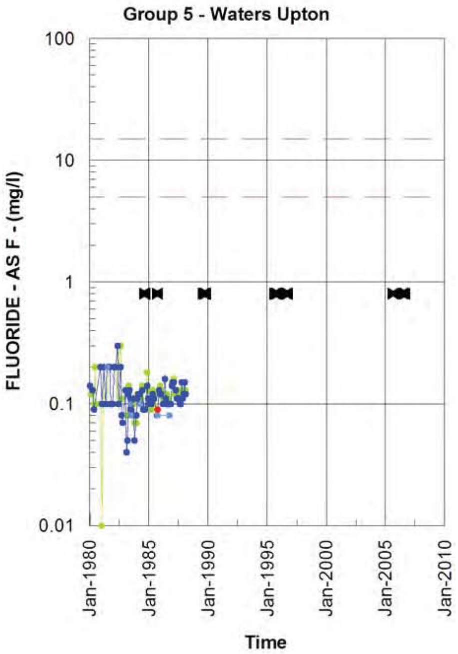
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - (%)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
Water Quality Standard - EQS (%sat)

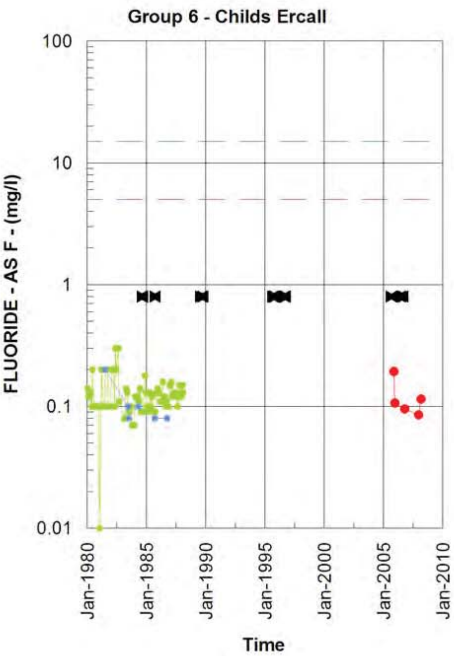


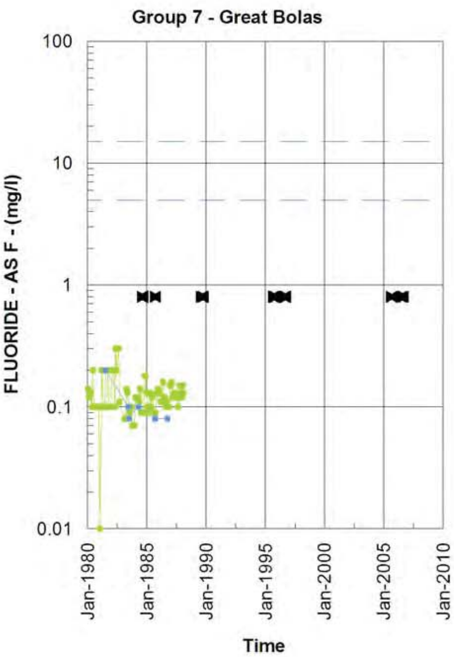
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
OXYGEN DISSOLVED (INSTRUMENTAL - IN SITU) - AS O - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
Water Quality Standard - Freshwater Fish Directive (50% samples)
Water Quality Standard - Freshwater Fish Directive (absolute)

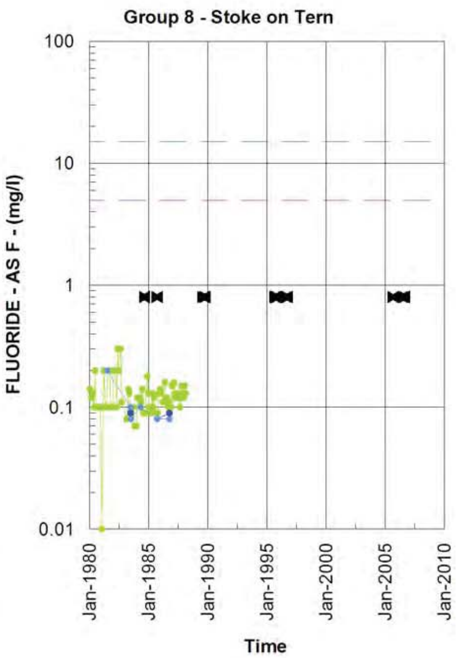

Group 1 - Adcote
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

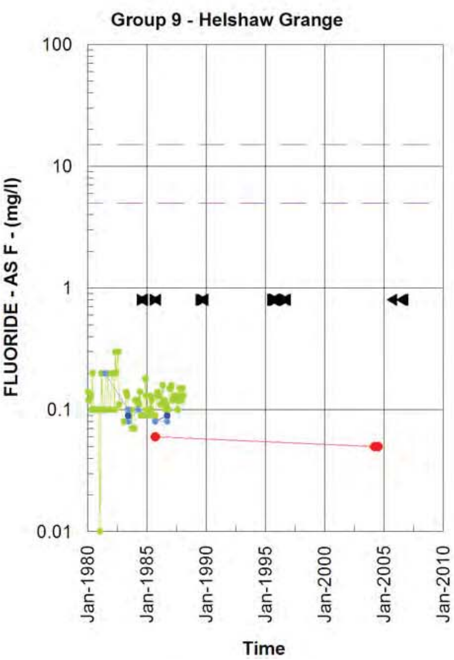

Group 2 - Grafton
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

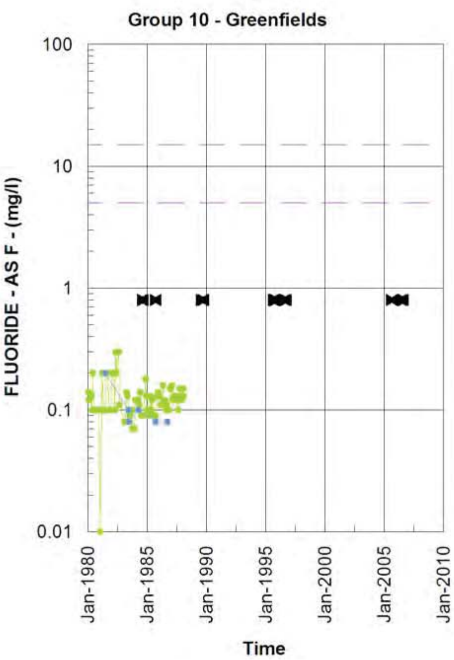

Group 5 - Waters Upton
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
0.01
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time


Group 6 - Childs Ercall
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
0.01
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

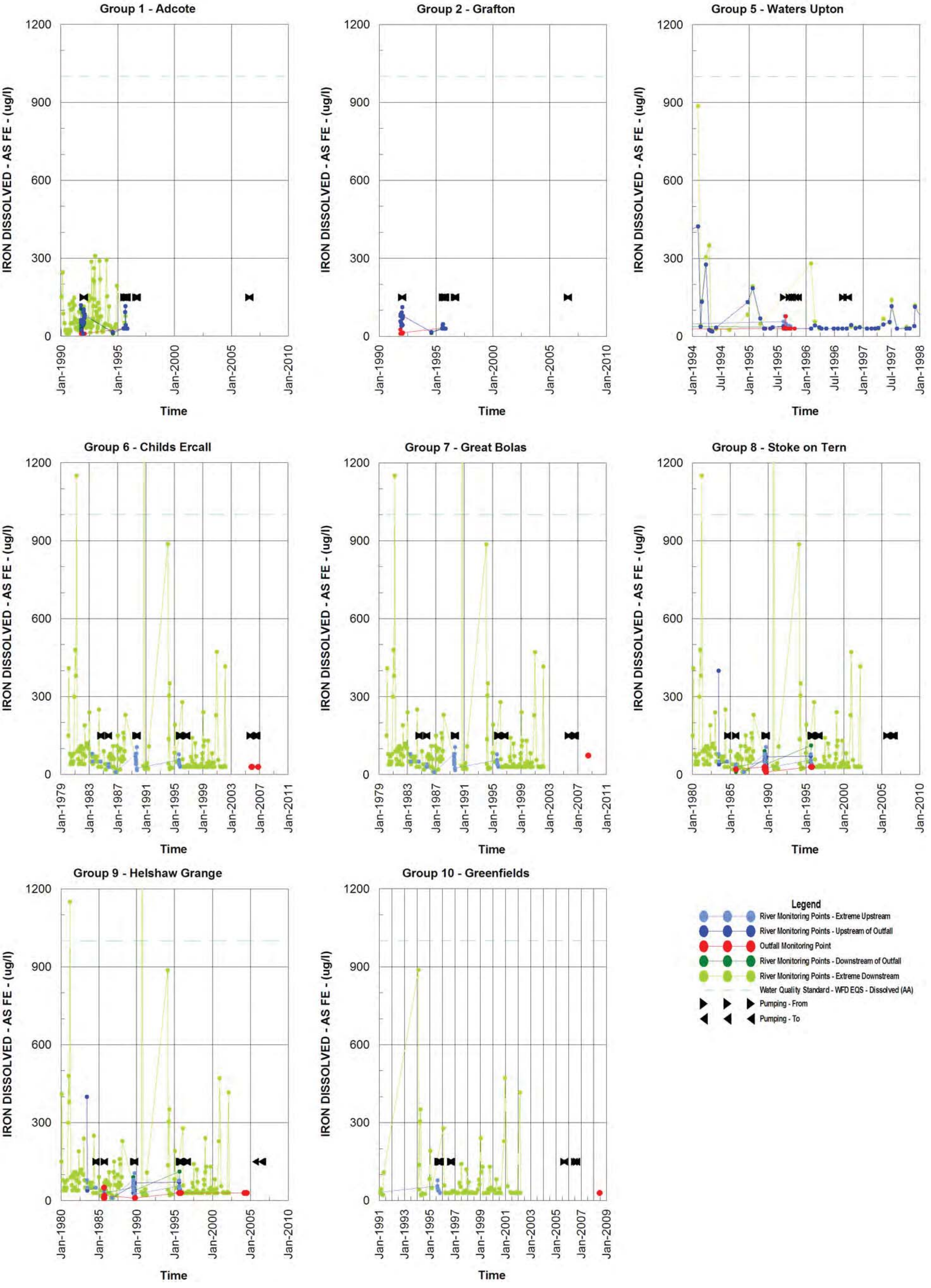

Group 7 - Great Bolas
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
0.01
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

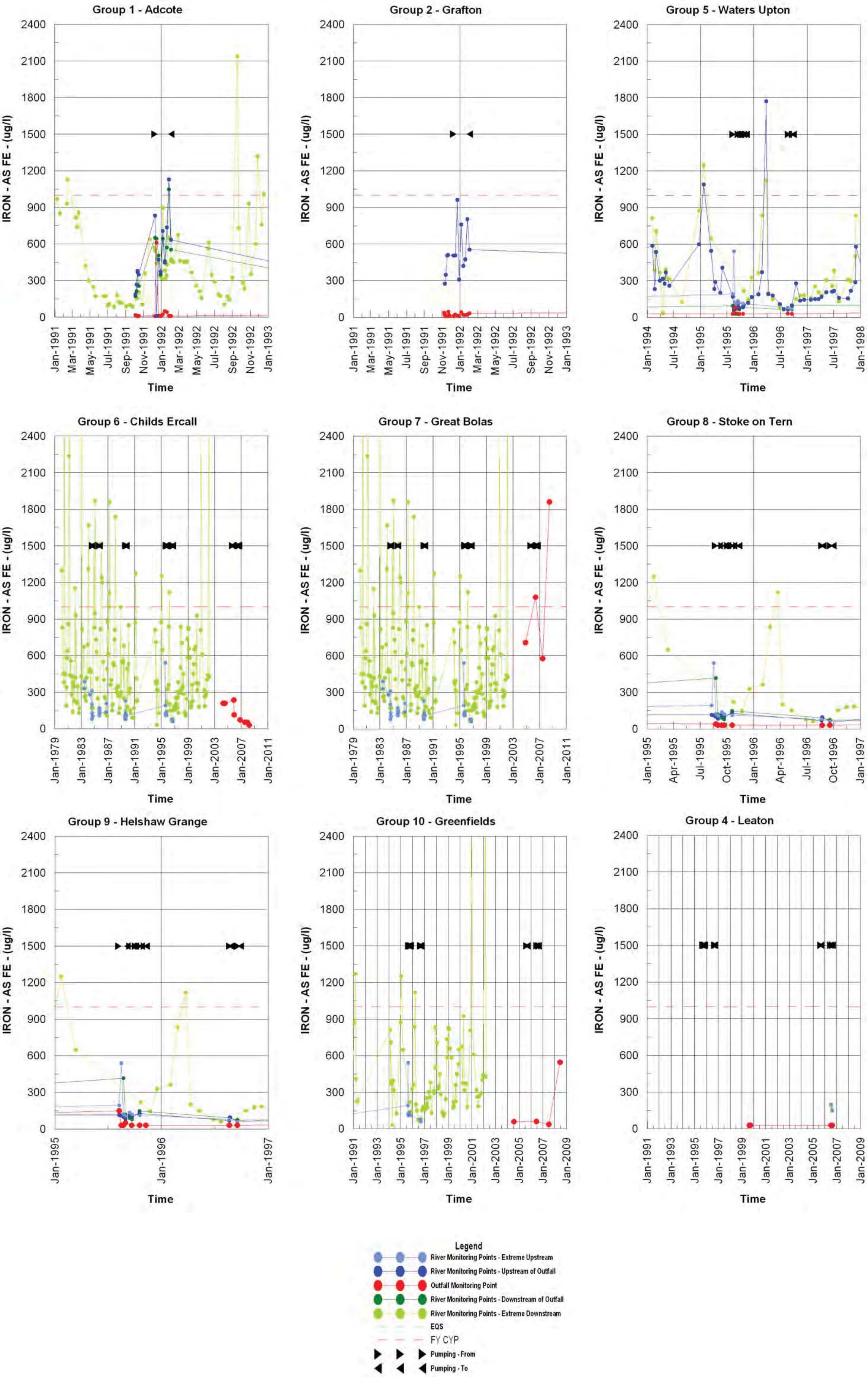

Group 8 - Stoke on Tern
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
0.01
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

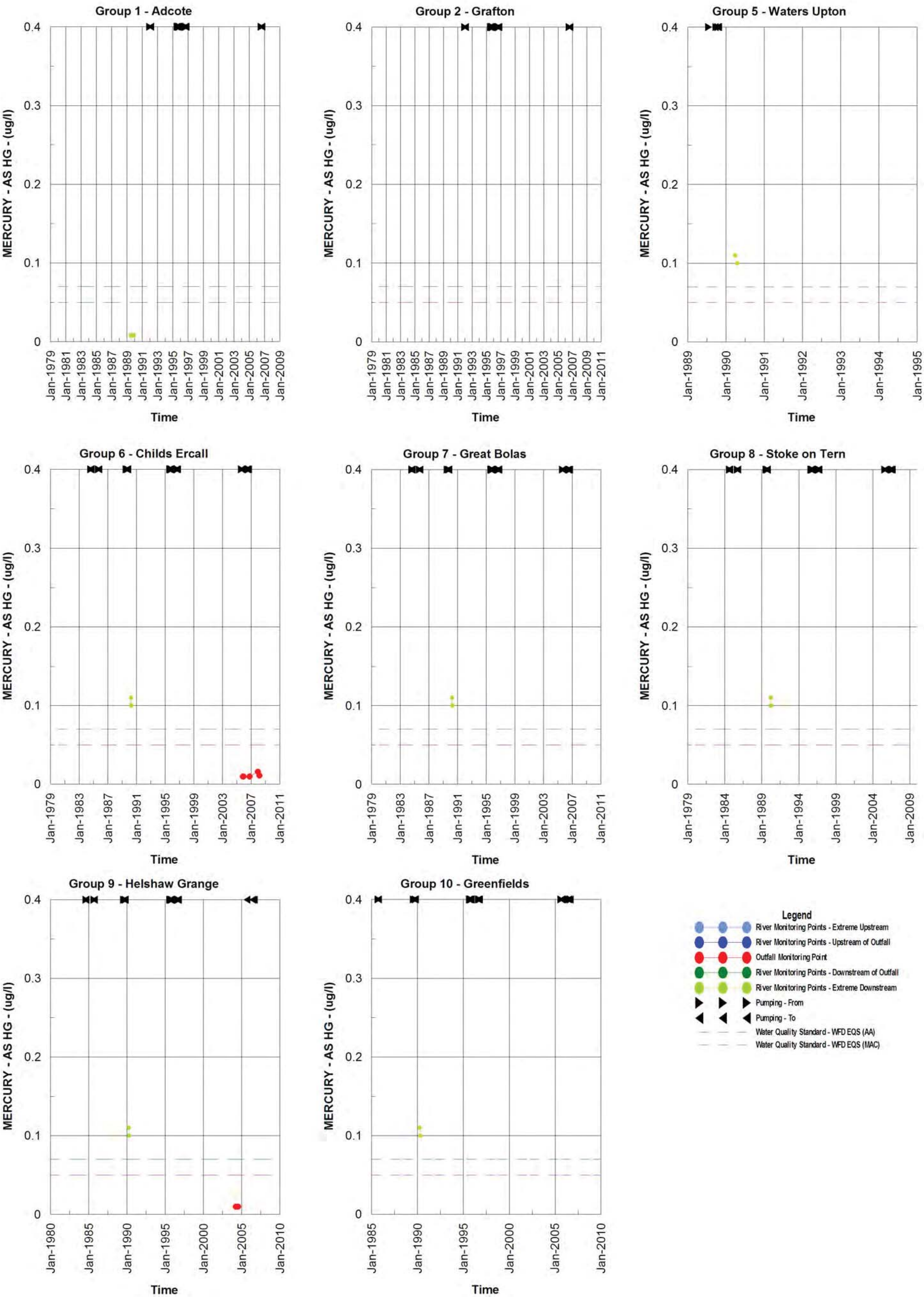

Group 9 - Helshaw Grange
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
0.01
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

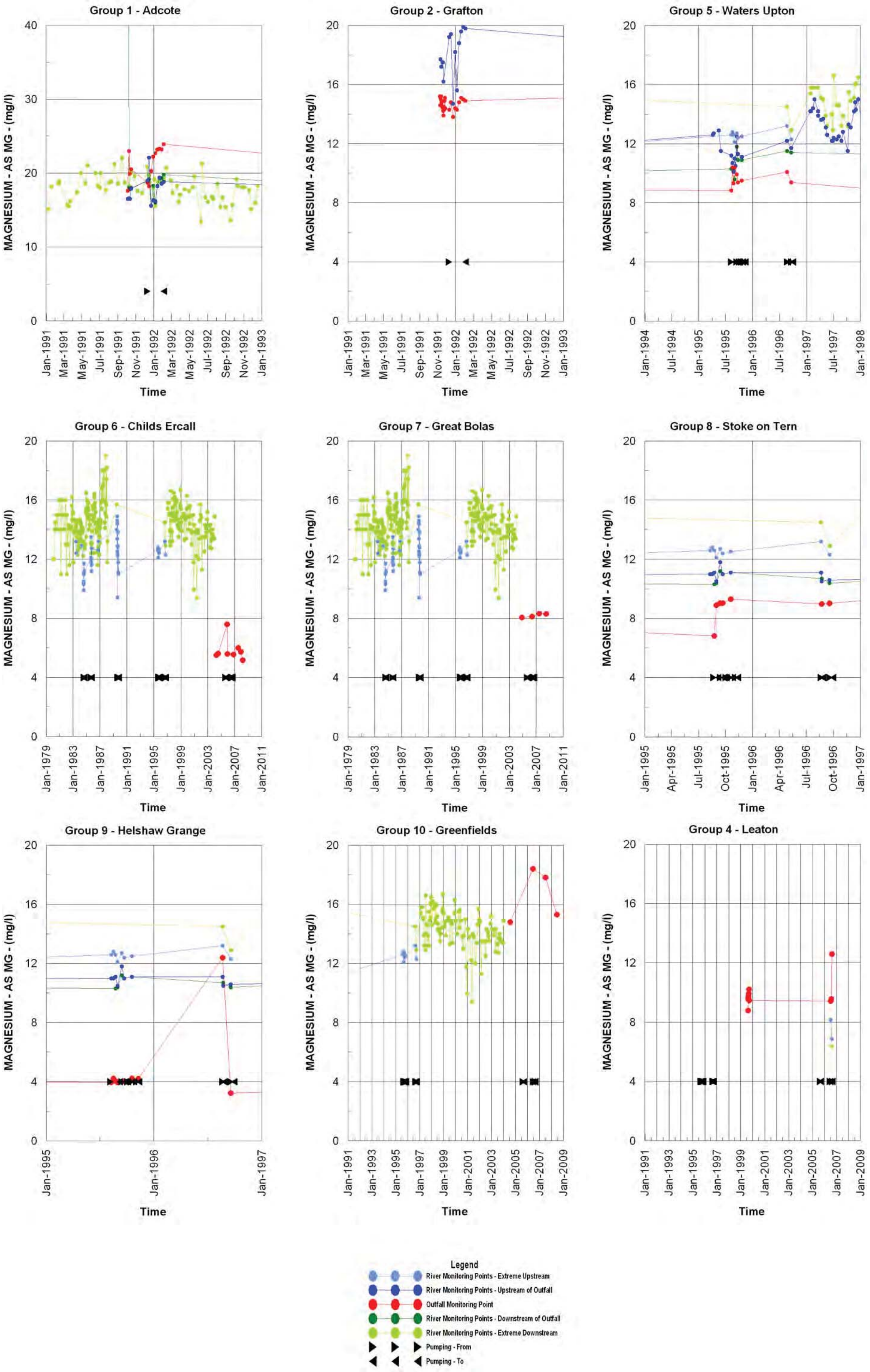

Group 10 - Greenfields
FLUORIDE - AS F - (mg/l)
100
10
1
0.1
0.01
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Time

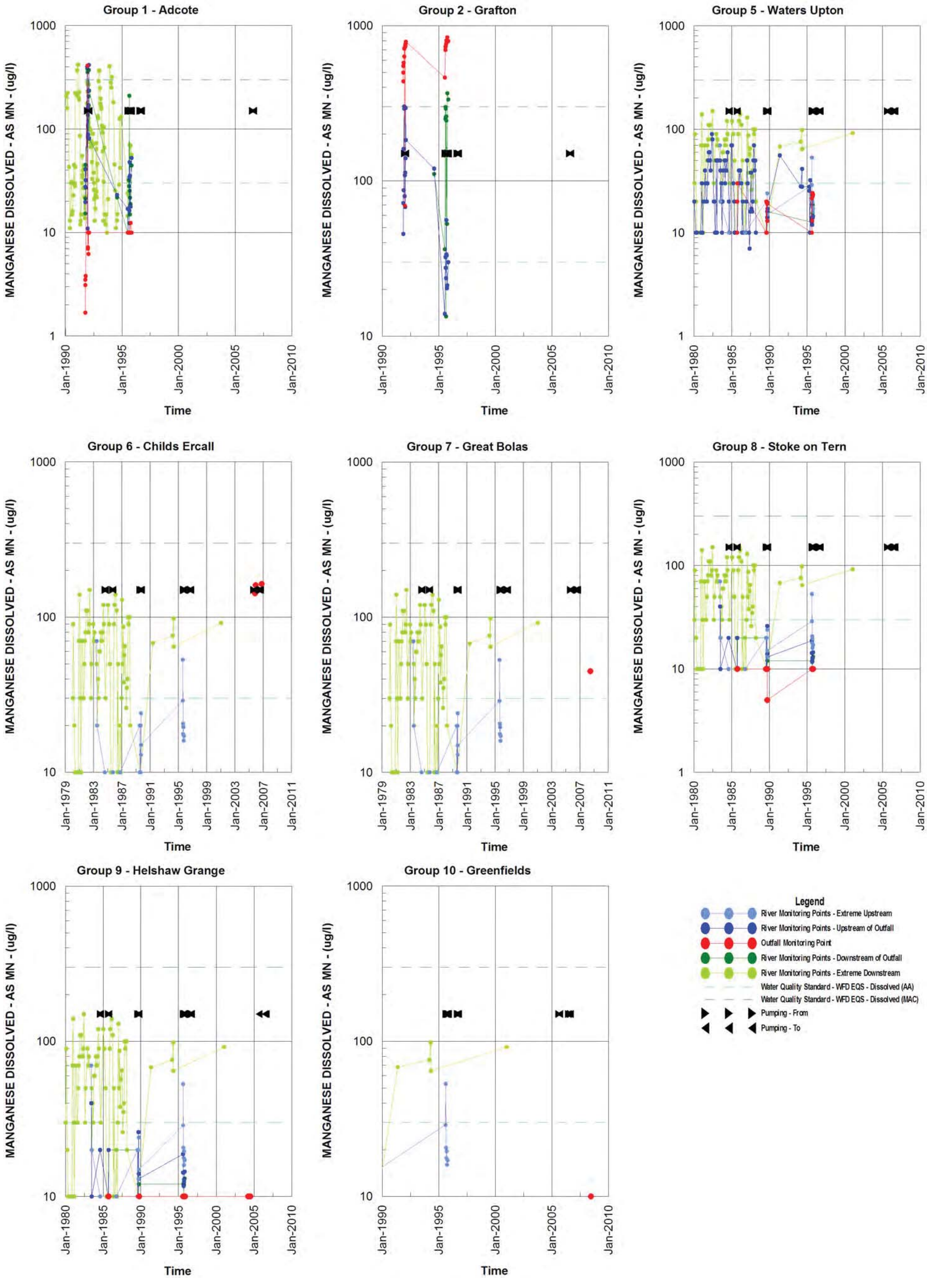

Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
Water Quality Standard - WFD EQS (AA)
Water Quality Standard - WFD EQS (MAC)


Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
IRON DISSOLVED - AS FE - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS - Dissolved (AA)
Pumping - From
Pumping - To

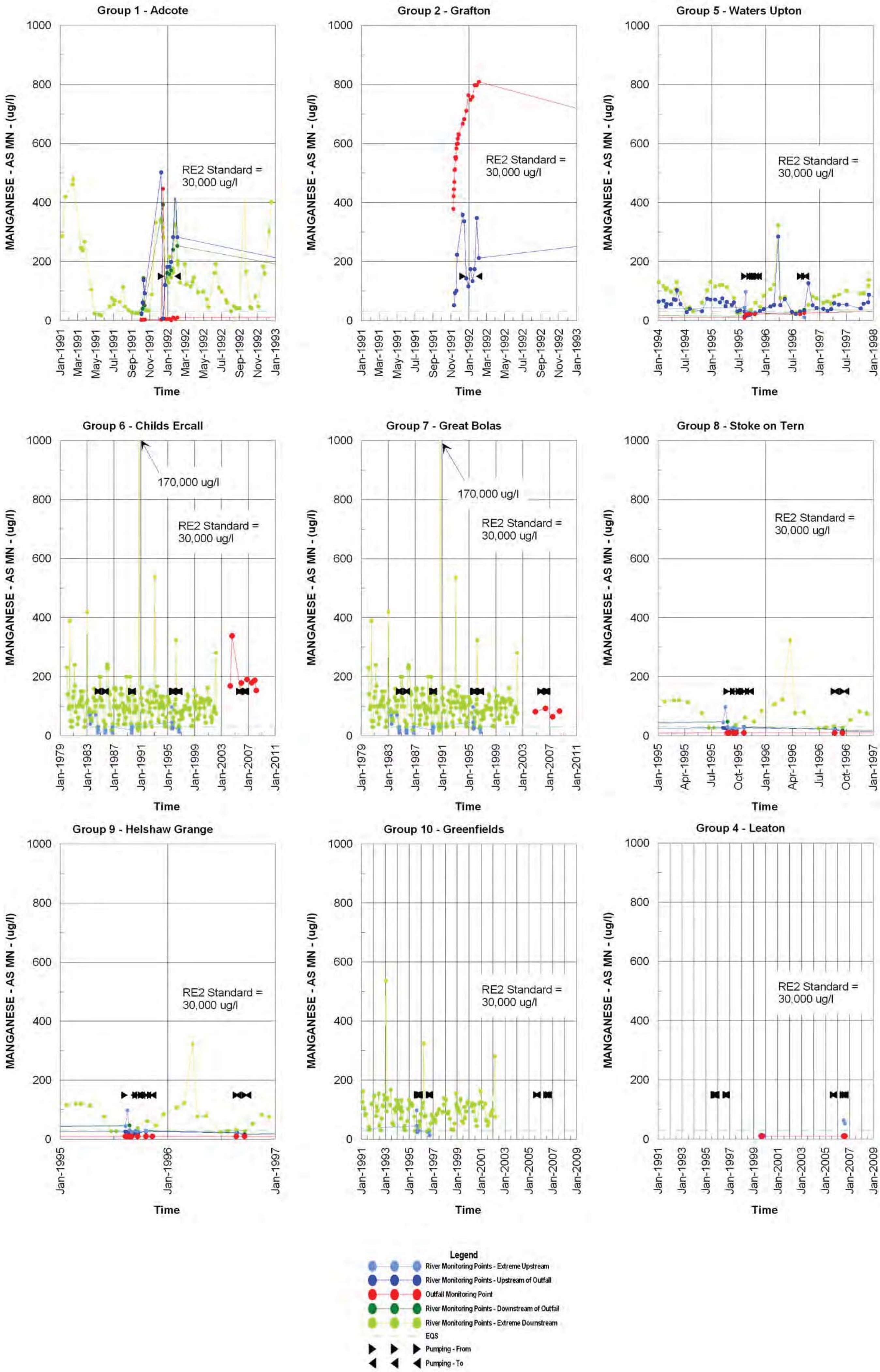

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
IRON - AS FE - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
FY CYP
Pumping - From
Pumping - To

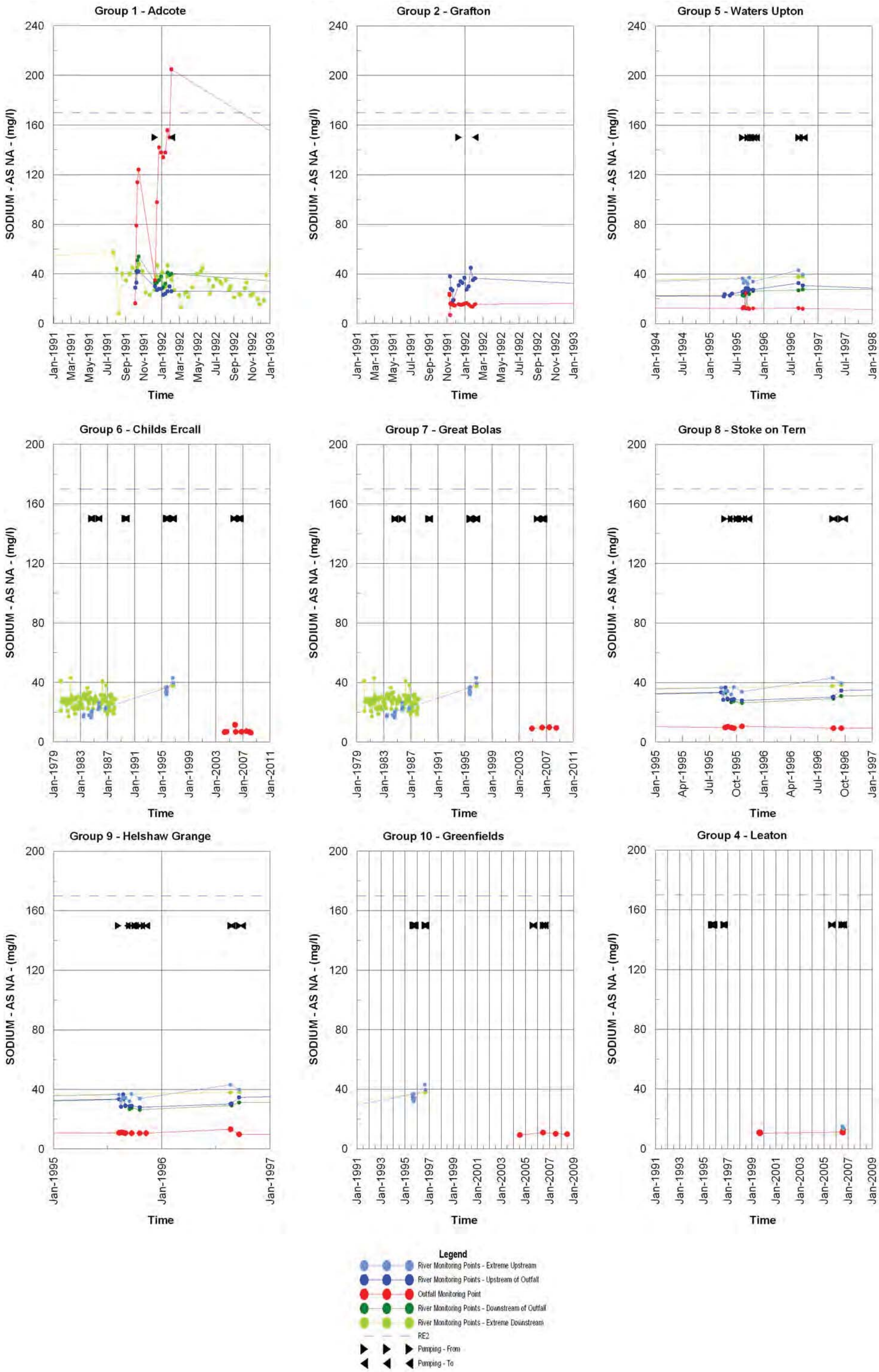

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
MERCURY - AS HG - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
Water Quality Standard - WFD EQS (AA)
Water Quality Standard - WFD EQS (MAC)

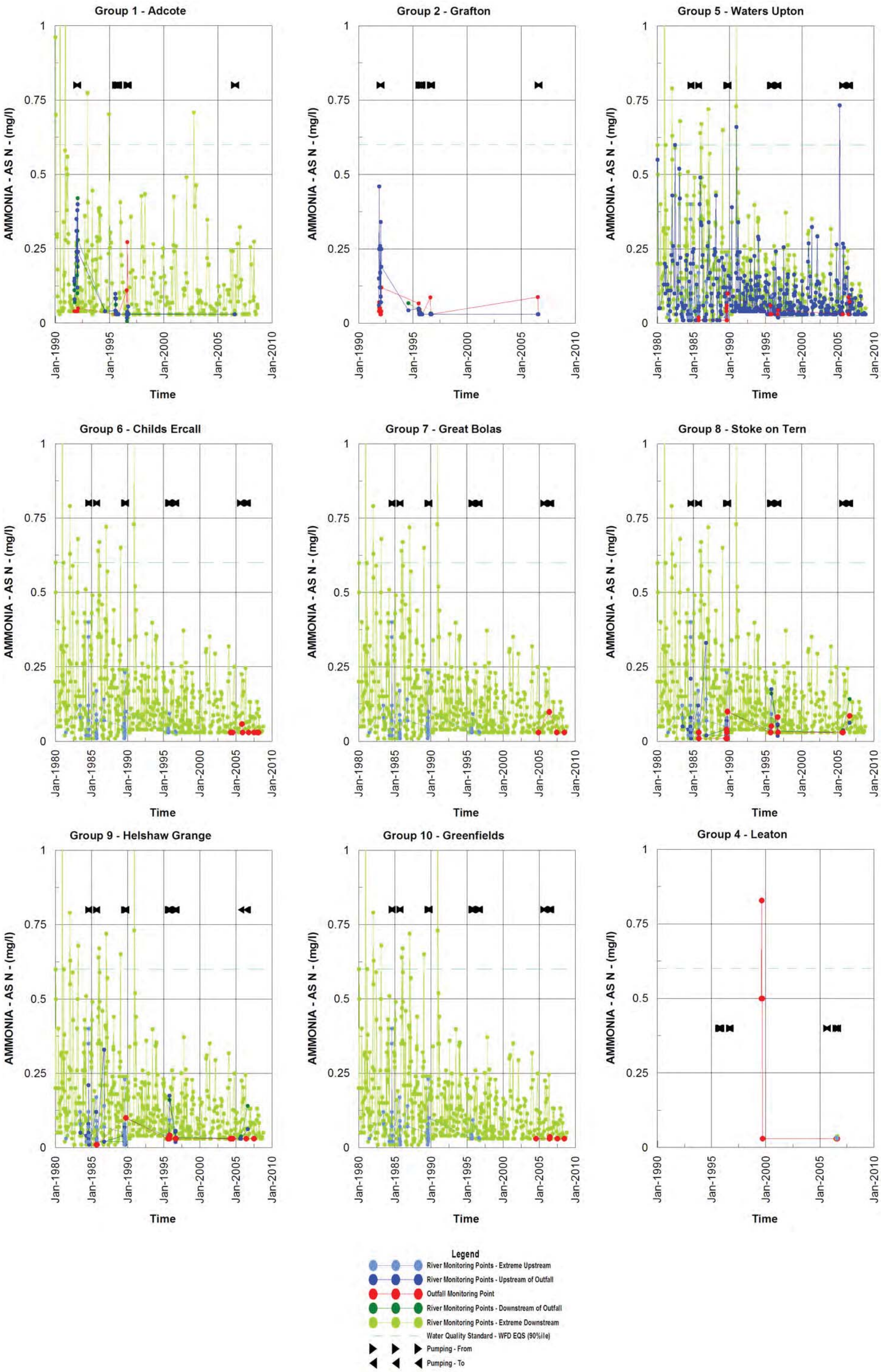

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
MAGNESIUM - AS MG - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To

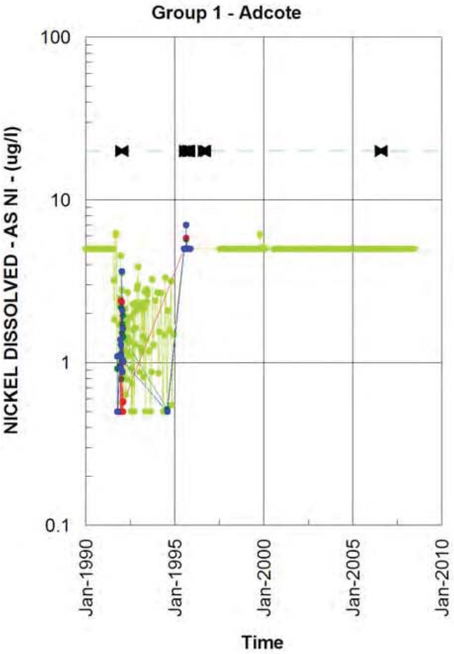


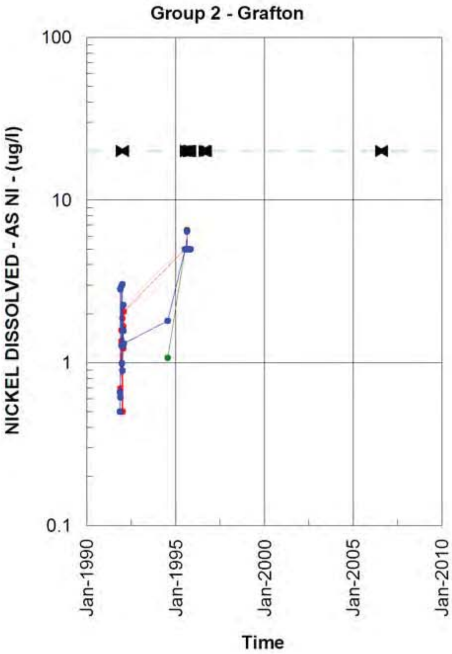
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
MANGANESE DISSOLVED - AS MN - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS - Dissolved (AA)
Water Quality Standard - WFD EQS - Dissolved (MAC)
Pumping - From
Pumping - To

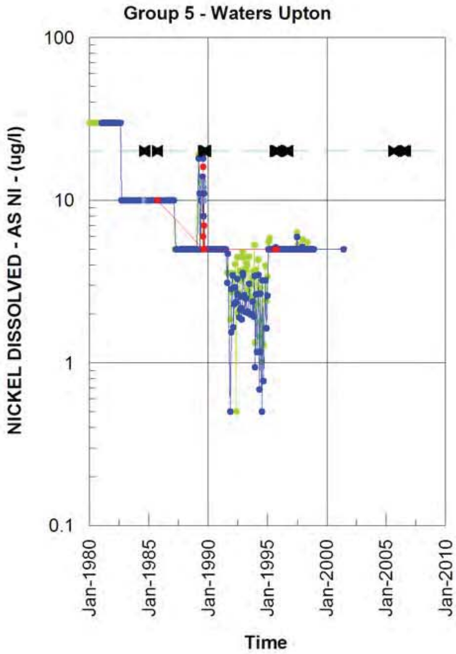

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
MANGANESE - AS MN - (ug/l)
Time
RE2 Standard = 30,000 ug/l
170,000 ug/l
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
Pumping - From
Pumping - To

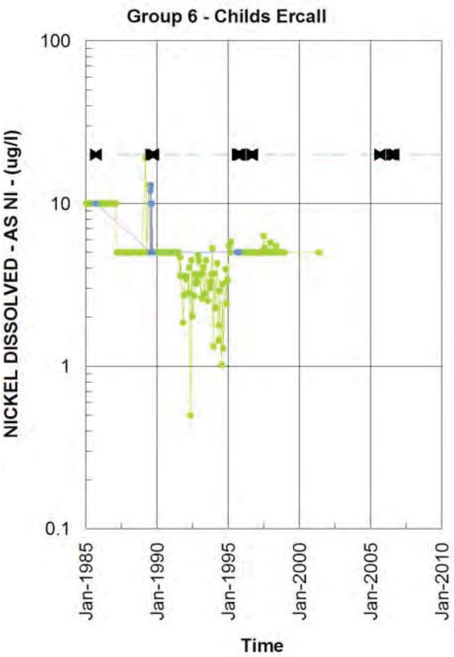

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
SODIUM - AS NA - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
RE2
Pumping - From
Pumping - To

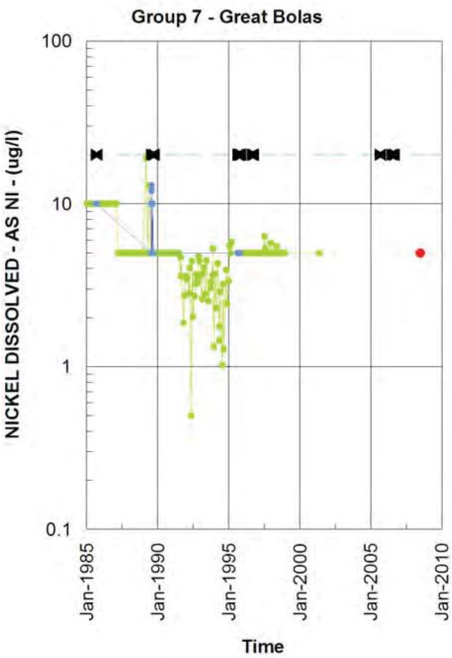

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
AMMONIA - AS N - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS (90%ile)
Pumping - From
Pumping - To

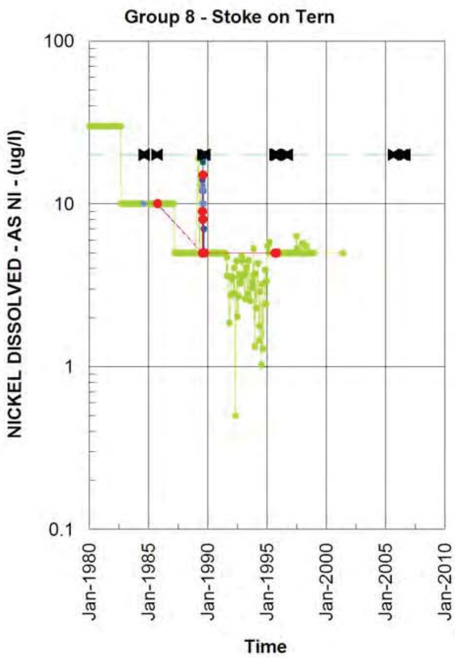

Group 1 - Adcote
NICKEL DISSOLVED - AS NI - (ug/l)
Time

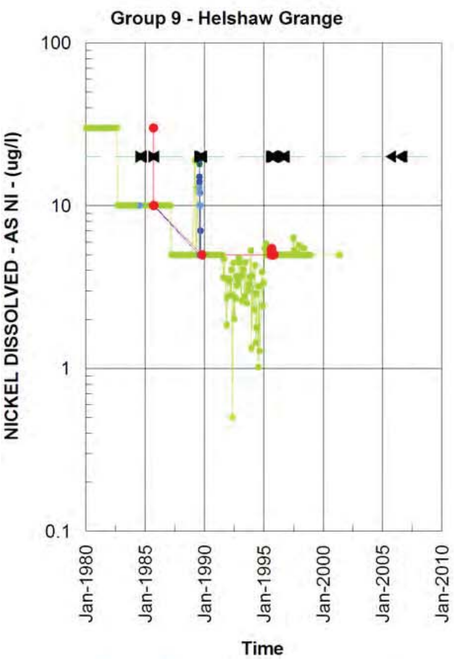

Group 2 - Grafton
NICKEL DISSOLVED - AS NI - (ug/l)
Time

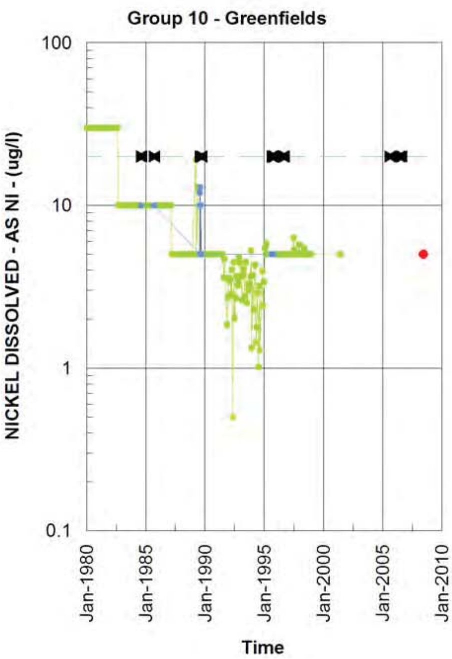

Group 5 - Waters Upton
NICKEL DISSOLVED - AS NI - (ug/l)
Time

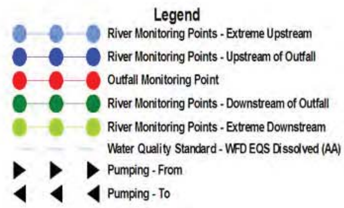

Group 6 - Childs Ercall
NICKEL DISSOLVED - AS NI - (ug/l)
Time

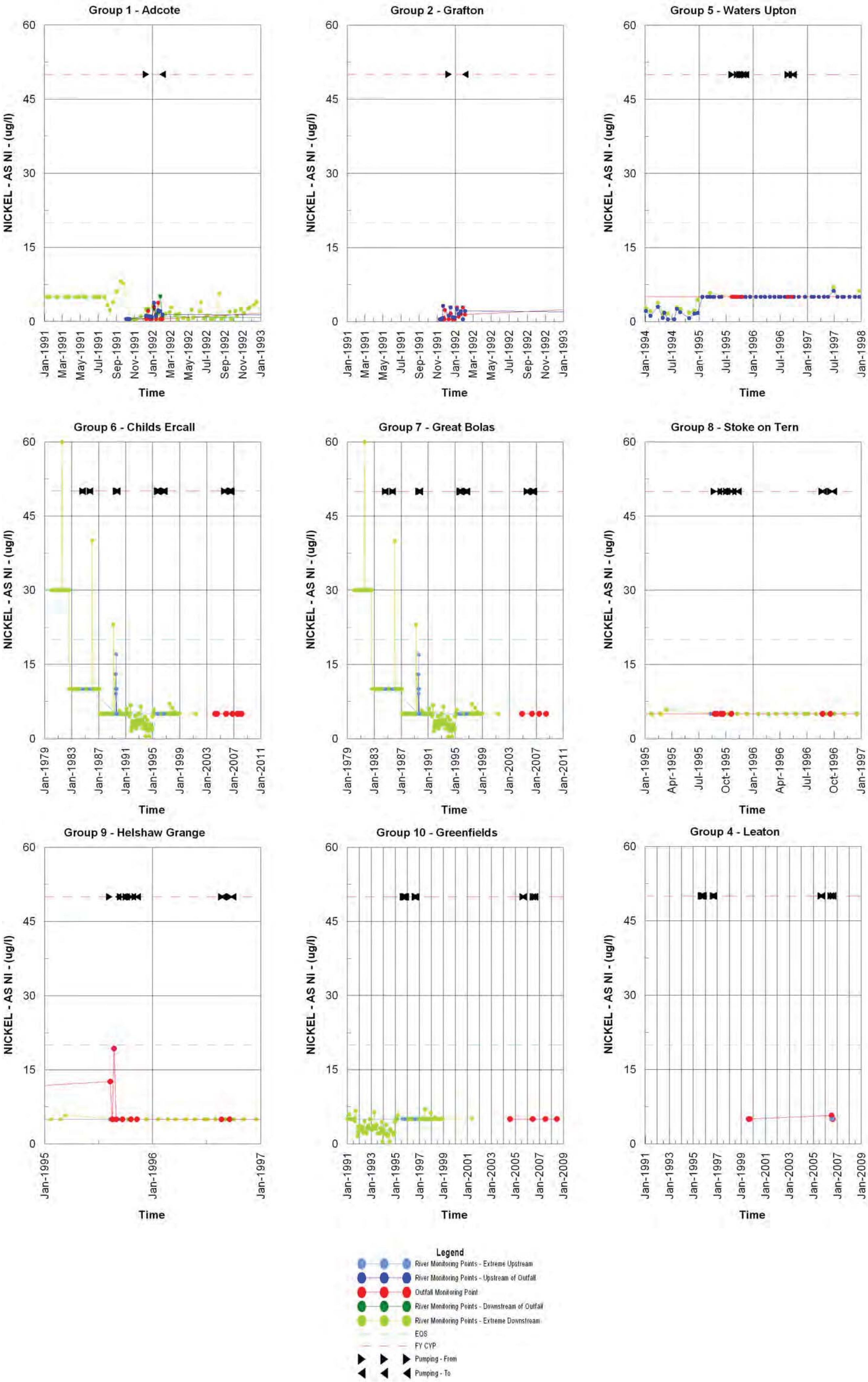

Group 7 - Great Bolas
NICKEL DISSOLVED - AS NI - (ug/l)
Time


Group 8 - Stoke on Tern
NICKEL DISSOLVED - AS NI - (ug/l)
Time

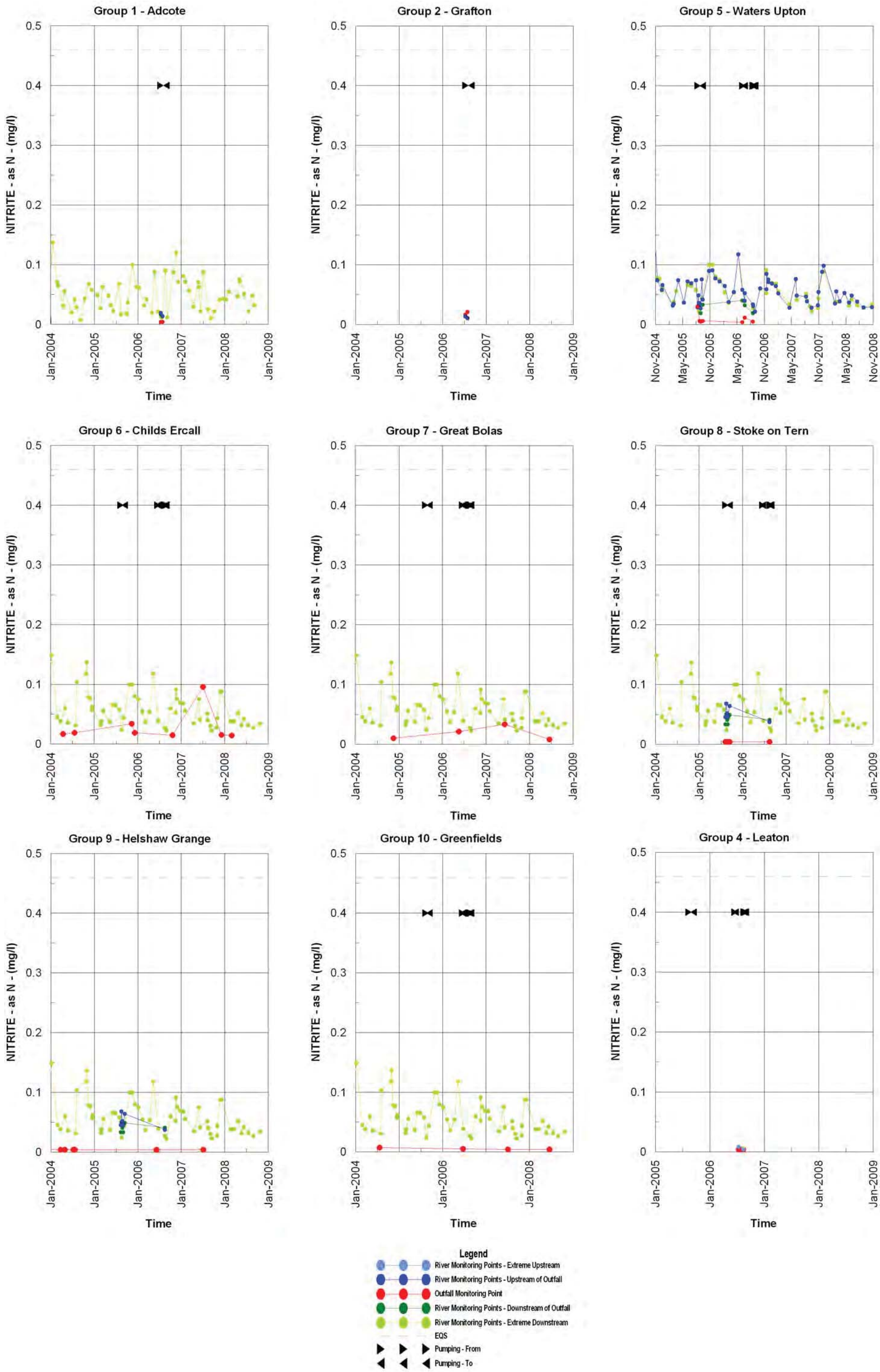

Group 9 - Helshaw Grange
NICKEL DISSOLVED - AS NI - (ug/l)
Time

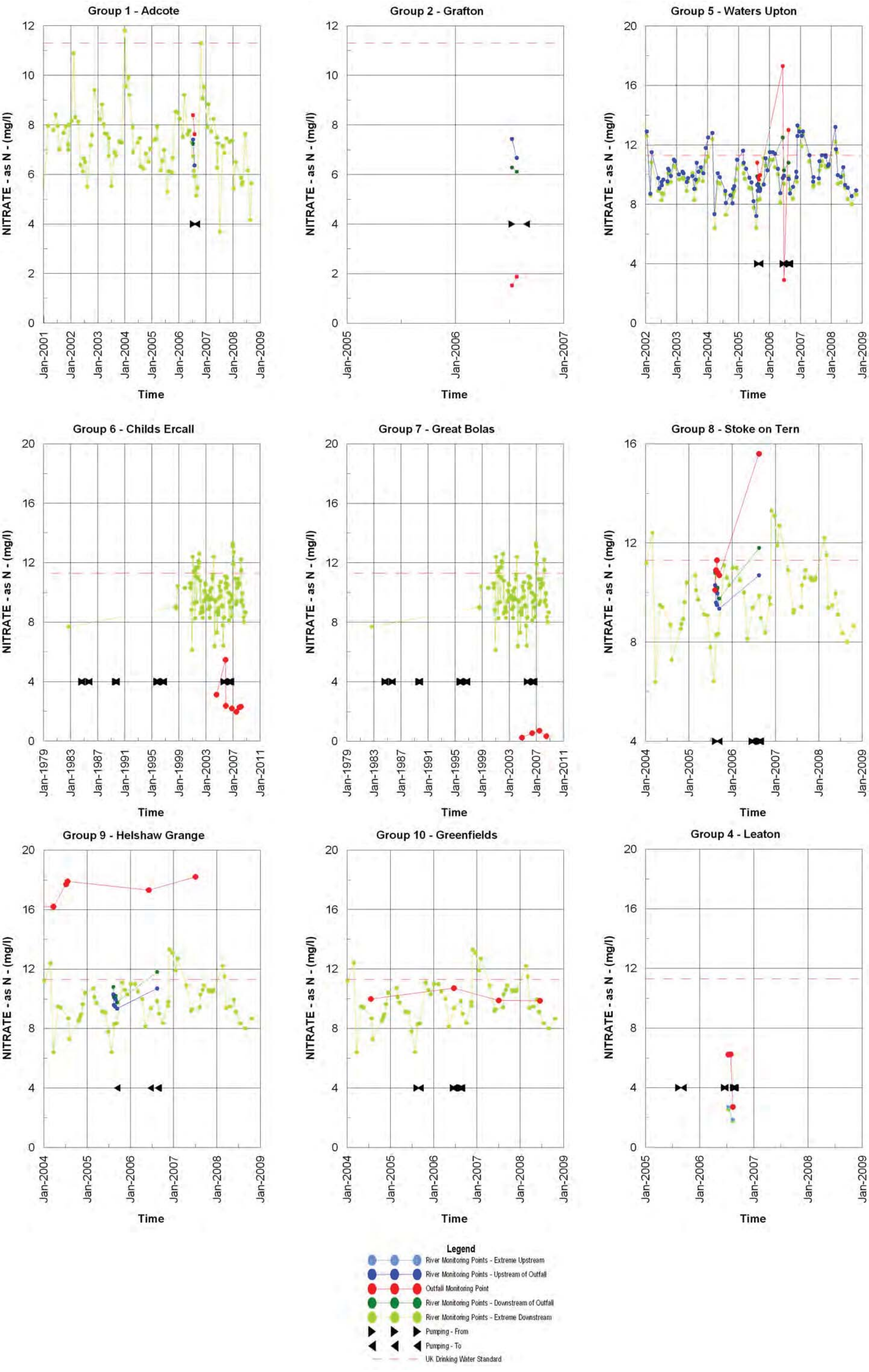

Group 10 - Greenfields
NICKEL DISSOLVED - AS NI - (ug/l)
Time


Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS Dissolved (AA)
Pumping - From
Pumping - To

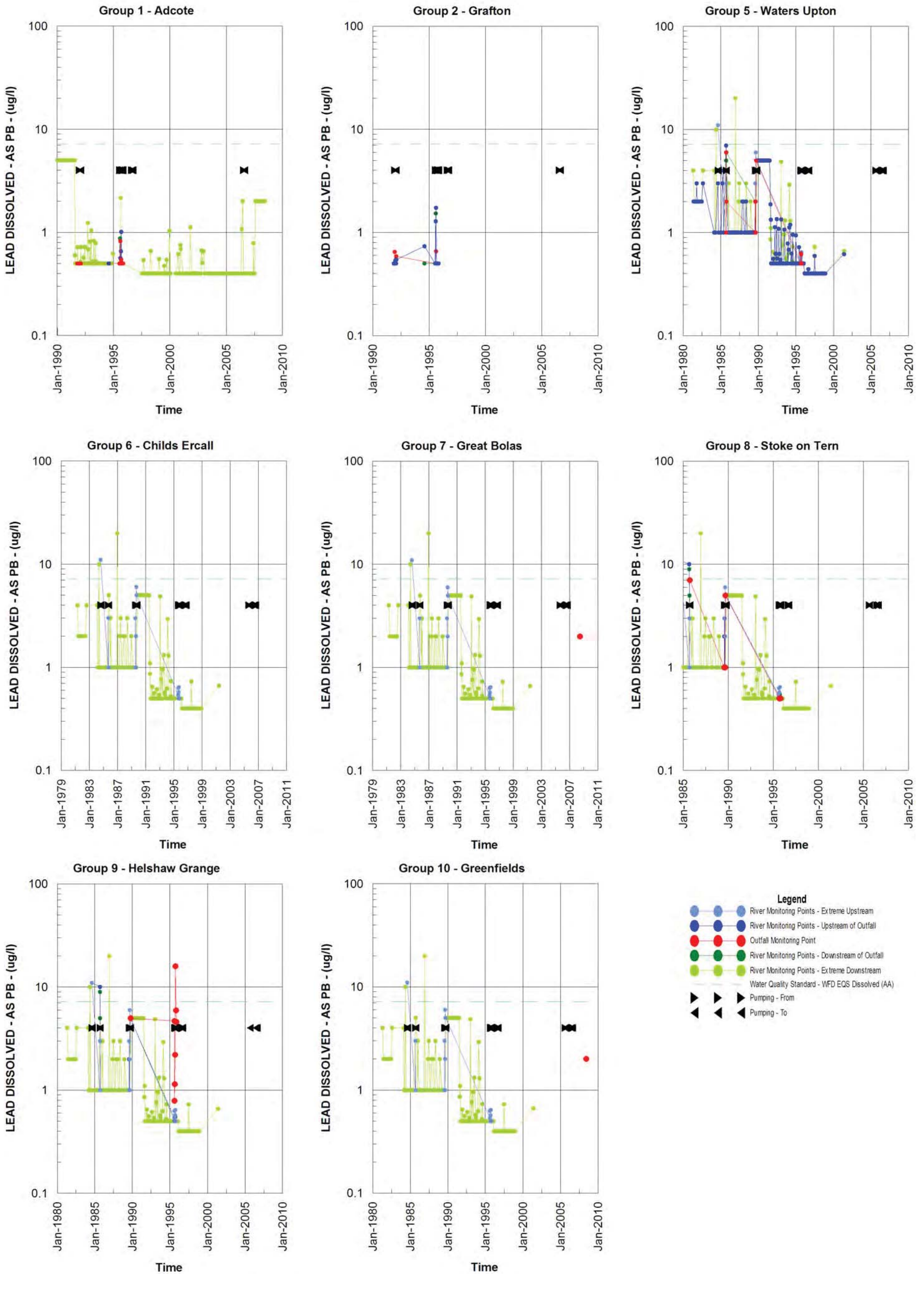


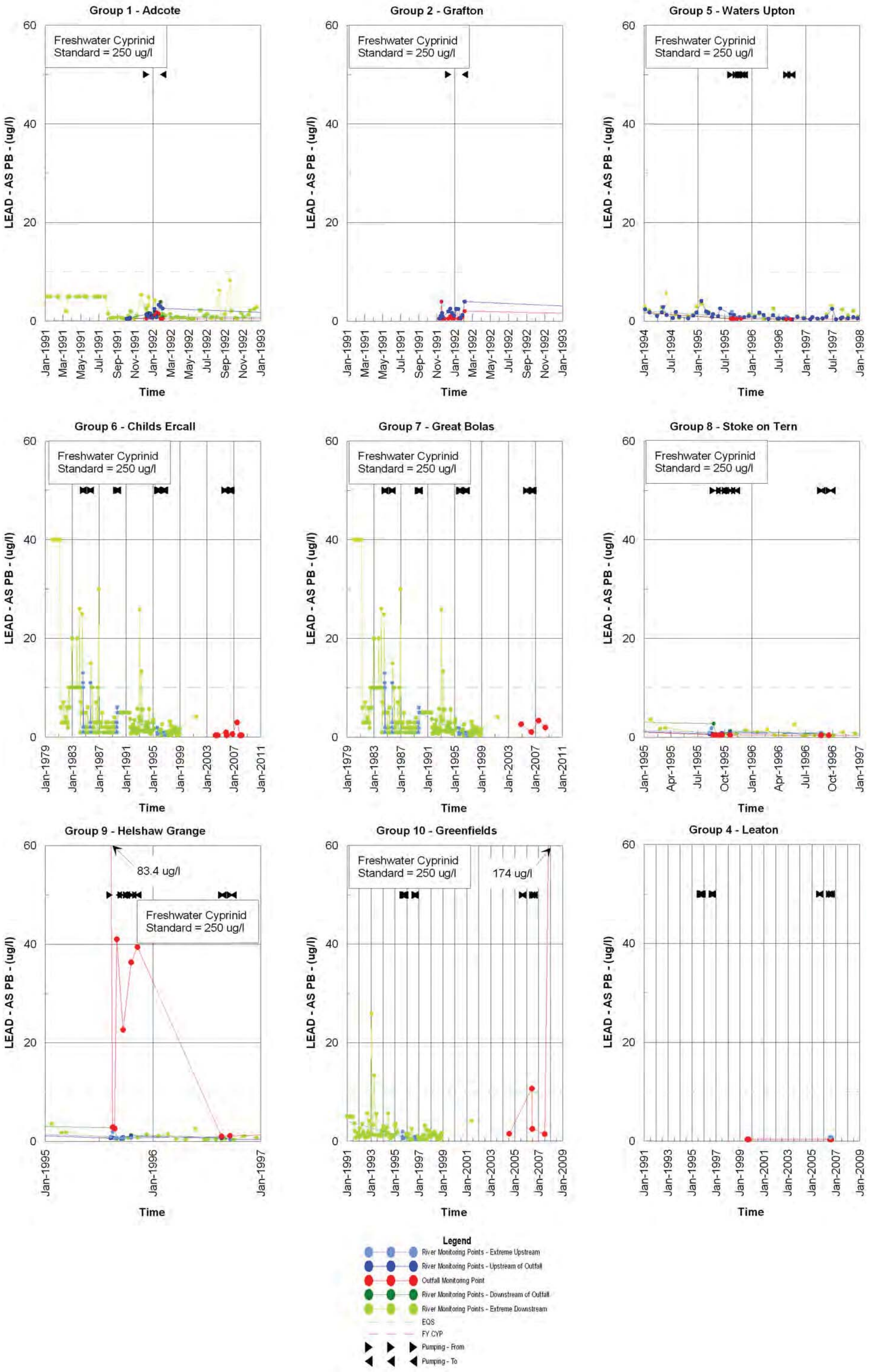
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
NICKEL - AS NI - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
FY CYP
Pumping - From
Pumping - To


Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
NITRITE - as N - (mg/l)
0
0.1
0.2
0.3
0.4
0.5
Jan-2004
Jan-2005
Jan-2006
Jan-2007
Jan-2008
Jan-2009
Nov-2004
May-2005
Nov-2005
May-2006
Nov-2006
May-2007
Nov-2007
May-2008
Nov-2008
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
Pumping - From
Pumping - To

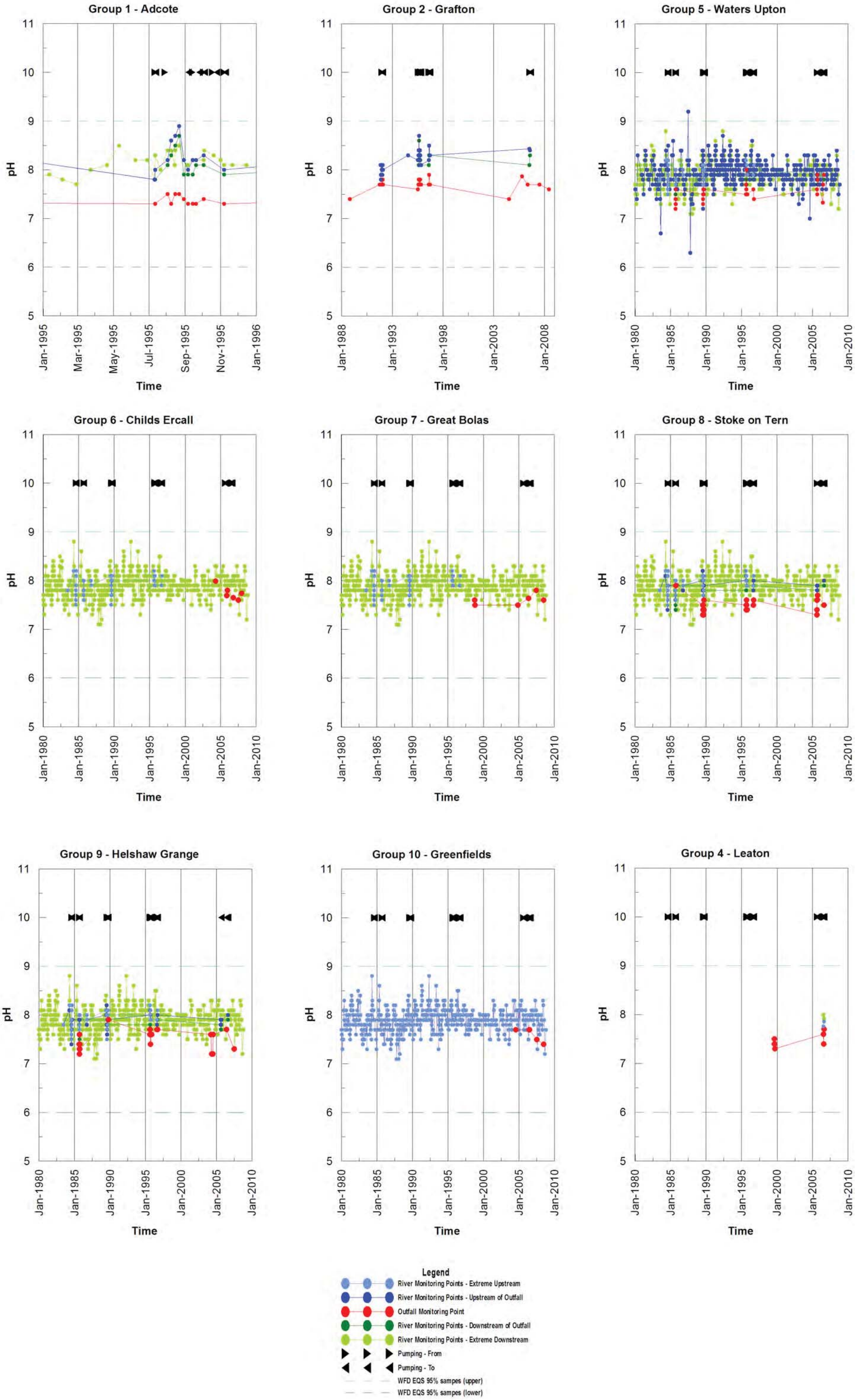


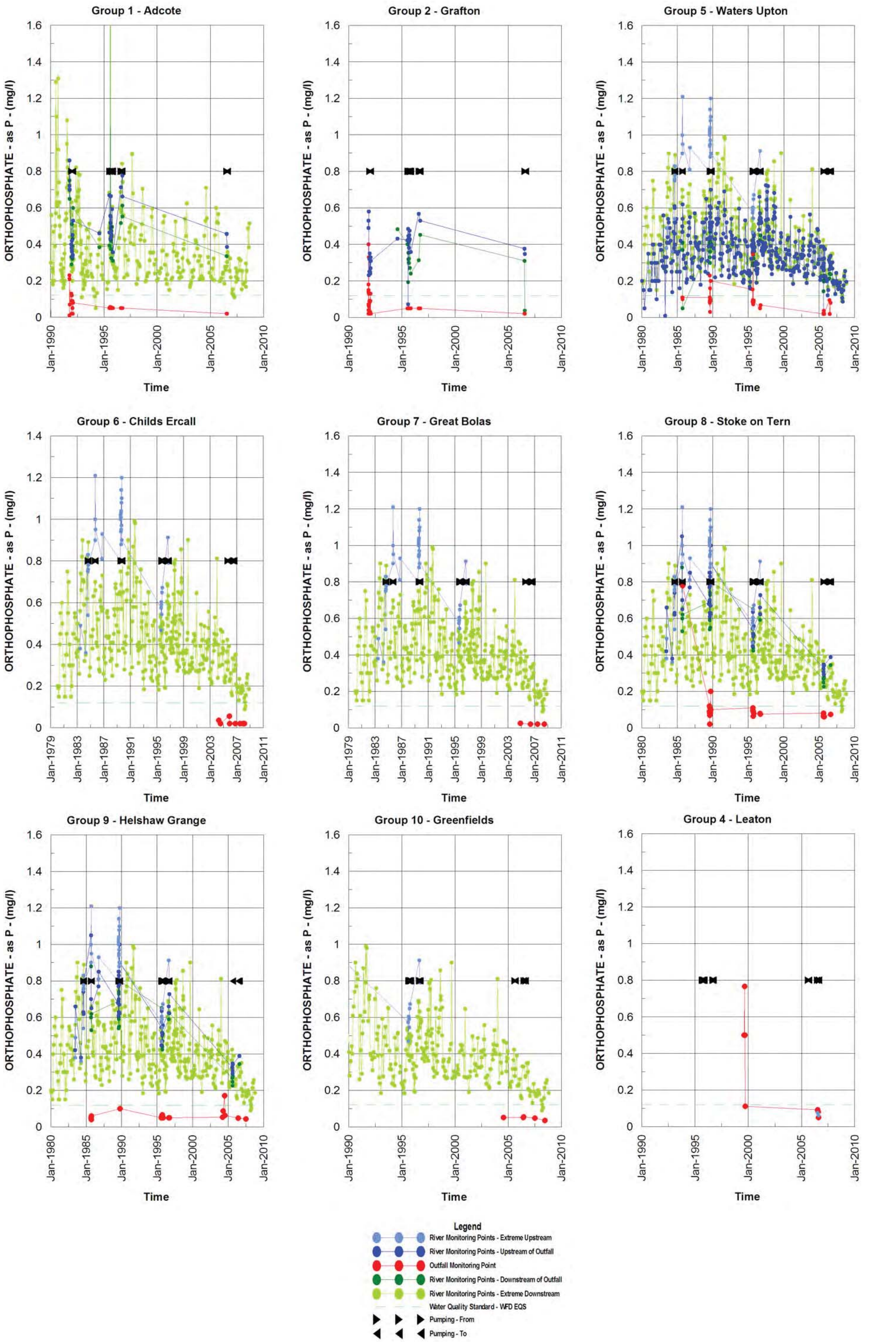
Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
NITRATE - as N - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
UK Drinking Water Standard


Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
LEAD DISSOLVED - AS PB - (ug/l)
Time
100
10
1
0.1
Jan-1979
Jan-1980
Jan-1983
Jan-1985
Jan-1987
Jan-1990
Jan-1991
Jan-1995
Jan-1999
Jan-2000
Jan-2003
Jan-2005
Jan-2007
Jan-2010
Jan-2011
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS Dissolved (AA)
Pumping - From
Pumping - To

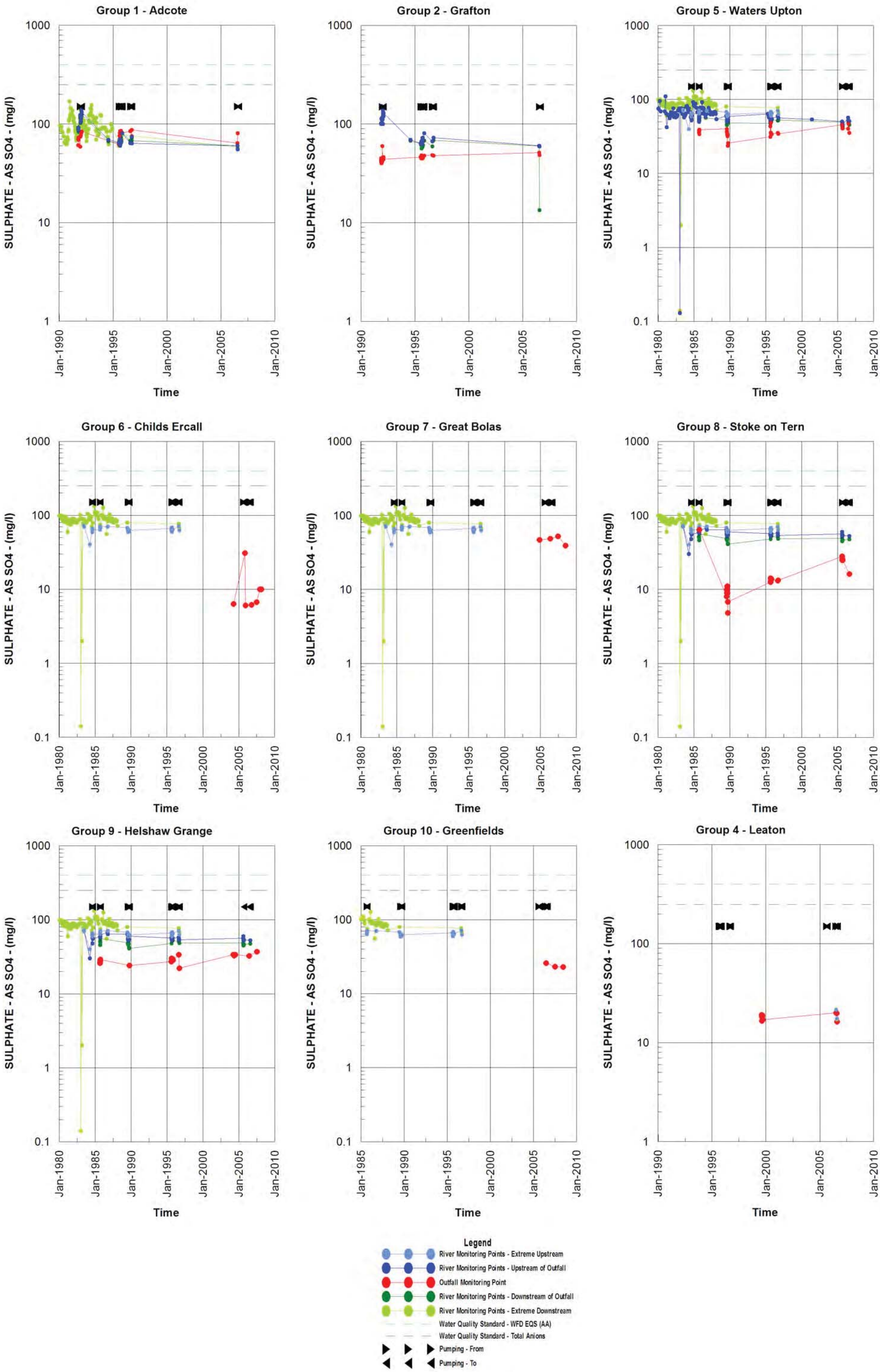


Group 1 - Adcote
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 2 - Grafton
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 5 - Waters Upton
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 6 - Childs Ercall
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 7 - Great Bolas
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 8 - Stoke on Tern
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 9 - Helshaw Grange
83.4 ug/l
Freshwater Cyprinid
Standard = 250 ug/l
LEAD - AS PB - (ug/l)
Time
Group 10 - Greenfields
Freshwater Cyprinid
Standard = 250 ug/l
174 ug/l
LEAD - AS PB - (ug/l)
Time
Group 4 - Leaton
LEAD - AS PB - (ug/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
EQS
FY CYP
Pumping - From
Pumping - To

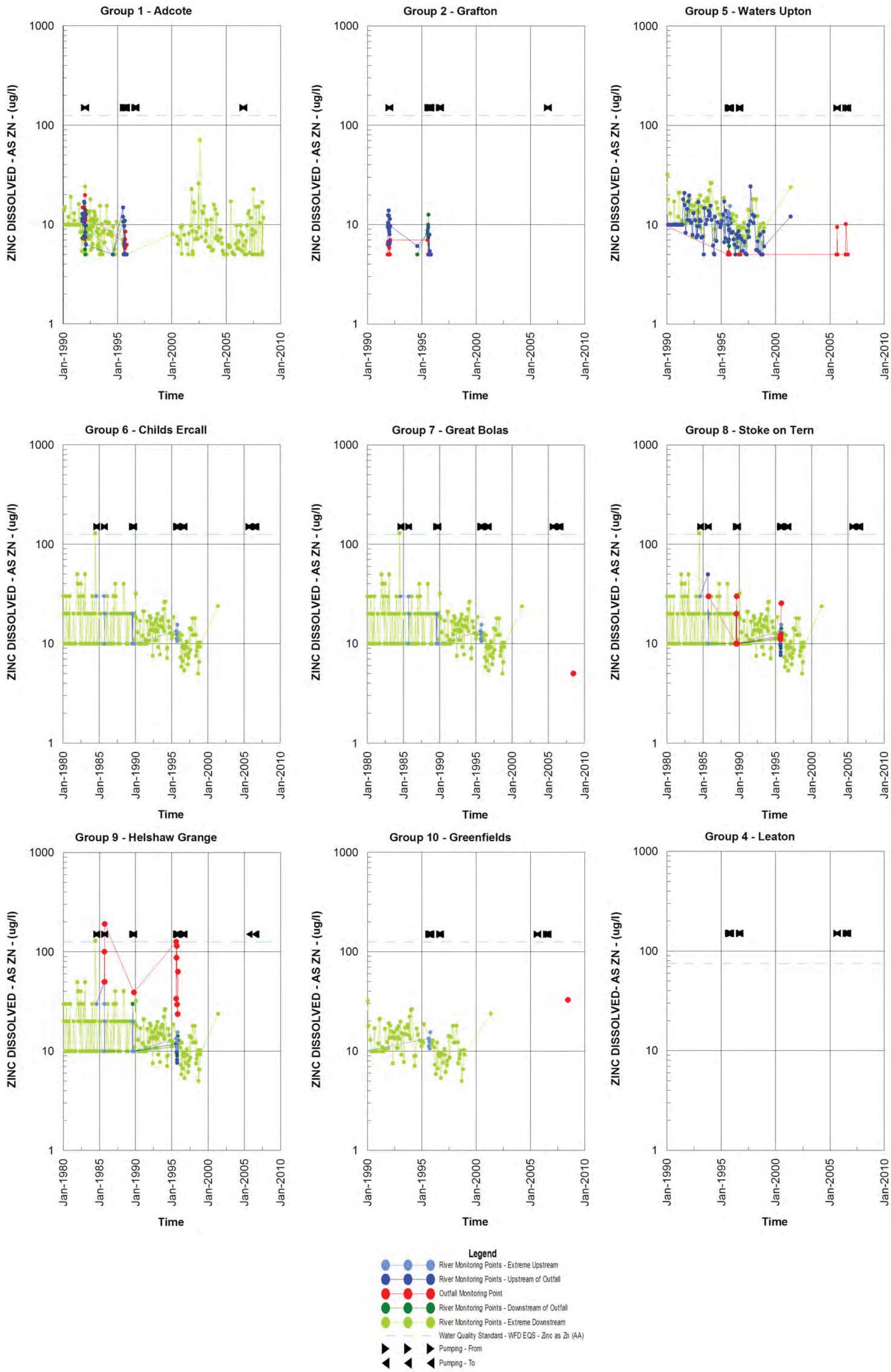

Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
pH
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Pumping - From
Pumping - To
WFD EQS 95% sampes (upper)
WFD EQS 95% sampes (lower)

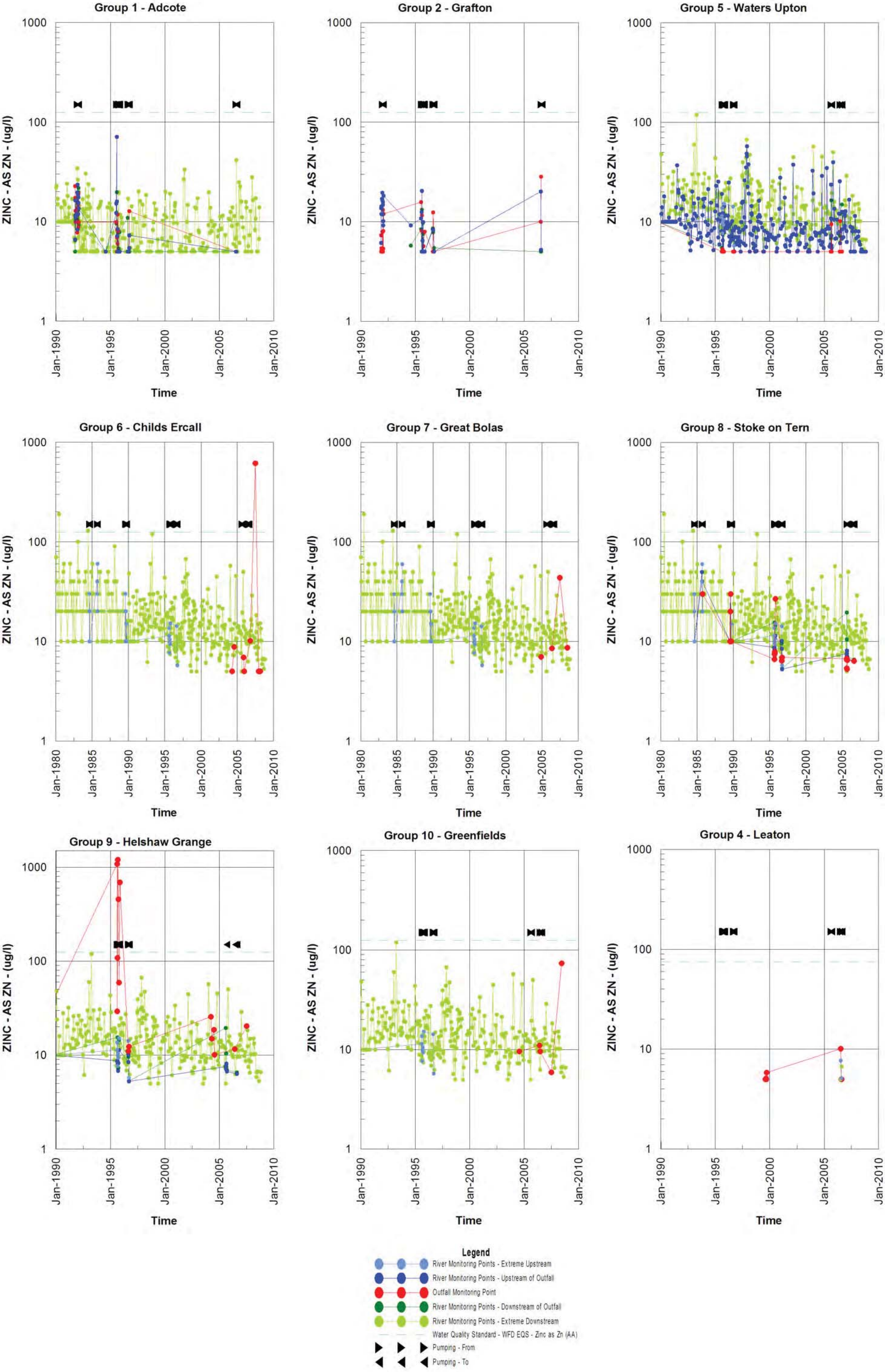


Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
ORTHOPHOSPHATE - as P - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS
Pumping - From
Pumping - To



Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
SULPHATE - AS SO4 - (mg/l)
Time
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS (AA)
Water Quality Standard - Total Anions
Pumping - From
Pumping - To


Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
ZINC DISSOLVED - AS ZN - (ug/l)
Time
1000
100
10
1
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS - Zinc as Zn (AA)
Pumping - From
Pumping - To



Group 1 - Adcote
Group 2 - Grafton
Group 5 - Waters Upton
Group 6 - Childs Ercall
Group 7 - Great Bolas
Group 8 - Stoke on Tern
Group 9 - Helshaw Grange
Group 10 - Greenfields
Group 4 - Leaton
ZINC - AS ZN - (ug/l)
1
10
100
1000
Time
Jan-1980
Jan-1985
Jan-1990
Jan-1995
Jan-2000
Jan-2005
Jan-2010
Legend
River Monitoring Points - Extreme Upstream
River Monitoring Points - Upstream of Outfall
Outfall Monitoring Point
River Monitoring Points - Downstream of Outfall
River Monitoring Points - Extreme Downstream
Water Quality Standard - WFD EQS - Zinc as Zn (AA)
Pumping - From
Pumping - To

Appendix I
Adcote Outfall Temperature Profiling

Information supplied by Kevin Voyce, EA.

Shropshire Groundwater Scheme Phase 2

Adcote Outfall Temperature Profiling of groundwater discharge (Frankbook pumping station) to river Perry under operational conditions 18 July 2006.

River Augmentation

Adcote outfall provides the groundwater discharge point to the River Perry for the Frankbrook abstraction borehole as a stand alone component of the Phase 2 area of the Shropshire Groundwater Scheme.

Pumping and Hydrological Regime

In-line with the rest of the Phase 2, Grafton commenced pumping on 10 July 2006 to provide operational regulation support. At the time of the temperature survey on 18 July Frankbrook had been operating for 7 days, delivering a gross constant rate yield of 4.75Ml/d to the River Perry.

On the day of the survey the river flow immediately up stream of Adcote outfall was estimated to be between 31.2 to 32.2 Ml/d, based on data from the Environment Agency's permanent river gauging station on the River Perry at Yeaton, 1.6km down stream of the outfall. As this gauge point included the augmented flow from Adcote, the naturalised flow was calculated as the gauge flow minus 90% of the Adcote discharge to reflect the previously assessed net gain.

Data Gathering

To measure the effect of the groundwater discharge on the receiving water course, data from a grid of sampling points extending 20m upstream and up to 25m down stream of the outfall were assessed. At each point a transect across the channel was obtained via wading access. This grid was designed to capture the ambient nature of the river water prior to the groundwater discharge, and then to monitor the effectiveness of the mixing of the two waters. Monitoring was intended to extend down stream until the return to ambient (upstream conditions) was recorded. However water depth and access to the channel restricted the last monitoring point to 25m downstream of the outfall.

Using a hand held multi-senor probe the following parameters were obtained from the groundwater prior to discharge to the river, the river water and the mixed river/ groundwater in the channel : temperature (ºC), conductivity (µS/cm), dissolved oxygen (% sat) and pH. The multi-parameter readings from probe are tabulated in Figure I1, and the temperature results illustrated in Figure I2.

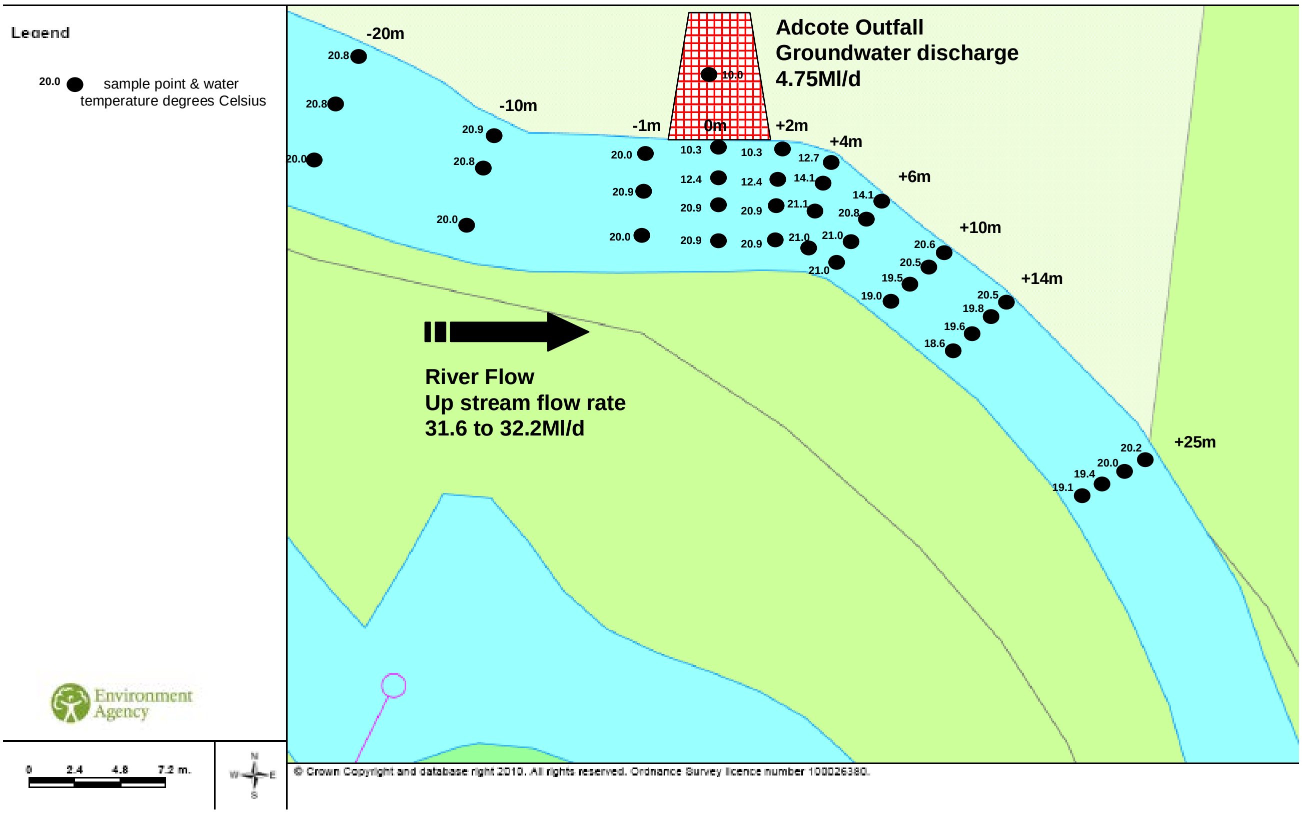
Figure I1 Table of Inriver Sampling Grid. (Data obtained using a hand held multi-senor probe)

Survey Distance to Outfall (-m U/S) (+m D/S)	Sample Point in Channel Metres from Left Bank	Temp ^{0}C	Cond us/cm	DO % sat	pH
-20m	1m	20.8	730	120	8.4
	2.5m	20.8	730	120	8.4
	5m	20.0	732	119	8.3
-10	1m	20.9	730	120	8.4
	2.5m	20.8	729	120	8.4
	5m	20.0	730	119	8.4
-1m	1m	20.9	733	120	8.4
	2.5m	20.9	773	120	8.4
	5m	20.0	733	119	8.4
Groundwater prior to mixing	0m	10	1140	61	7.1
0m (start of mixing zone)	0.5m	10.3	1148	65	7.3
	2.0m	12.4	1072	90	7.7
	3.0m	20.9	734	120	8.4
	5.0m	20.9	733	119	8.4
+2m	0.5m	10.7	1134	70	7.3
	2.0m	12.1	1073	71	7.4
	3.5m	20.9	740	120	8.4
	5.0m	21.0	738	118	8.4
+4m	0.5m	12.7	1032	75	7.5
	2.0m	14.1	1054	80	7.8
	3.5m	21.1	732	120	8.4
	5.0m	21.0	738	120	8.4
+6m	0.5m	14.1	1009	82	7.8
	2.5m	20.8	742	120	8.4
	3.5m	21.1	734	120	8.4
	5.0m	21.0	735	118	8.4
+10m	0.5m	20.6	760	118	8.4
	1.0m	20.5	757	117	8.4
	2.0m	19.5	757	115	8.4

Survey Distance to Outfall (-m U/S) (+m D/S)	Sample Point in Channel Metres from Left Bank	Temp ^{0}C	Cond us/cm	DO % sat	pH
	4.0m	19.0	739	116	8.4
+14m	0.5m	20.5	757	116	8.4
	1.0m	19.8	798	113	8.3
	2.0m	19.6	797	111	8.3
	4.0m	18.6	826	106	8.2
+25m	0.5m	20.2	774	112	8.2
	1.0m	20.0	786	112	8.3
	2.0m	19.4	811	109	8.3
	4.0m	19.1	822	107	8.2
End of survey					

Figure I2 Adcote Outfall to River Perry, Survey Grid Location of Sample Points

Shropshire Groundwater Scheme Phase 2 – Effects of groundwater discharge to River Perry at Adcote. Results of river temperature survey 18.07.06



Interpretation of Results

An interpretation of the temperature data from the survey is presented in Figure G3. In this illustration the mixing of the cool groundwater (10ºC) and warm ambient river water (20ºC) is depicted by six contoured zones of temperature with a 1.9ºC interval of separation.

Zone 1 – 20ºC ambient river temperature

Zone 2 - 10ºC to 11.9ºC (9ºC to 10ºC cooler than ambient temp)

Zone 3 - 12ºC to 13.9ºC (7ºC to 8ºC cooler than ambient temp)

Zone 4 - 14ºC to 15.9ºC (4ºC to 5ºC cooler than ambient temp)

Zone 5 - 16ºC to 17.9ºC (3ºC to 4ºC cooler than ambient temp)

Zone 6 - 18ºC to 19.9ºC (1ºC to 2ºC cooler than ambient temp)

The results of the temperature profiling exercise show that the groundwater discharge initially streams down the northern side of the river, initially running parallel with and hugging the bank. Using the hand held probe it was clear that for the first 4m very little mixing had taken place with a sharp contact existing between the cool groundwater and warm river water bodies.

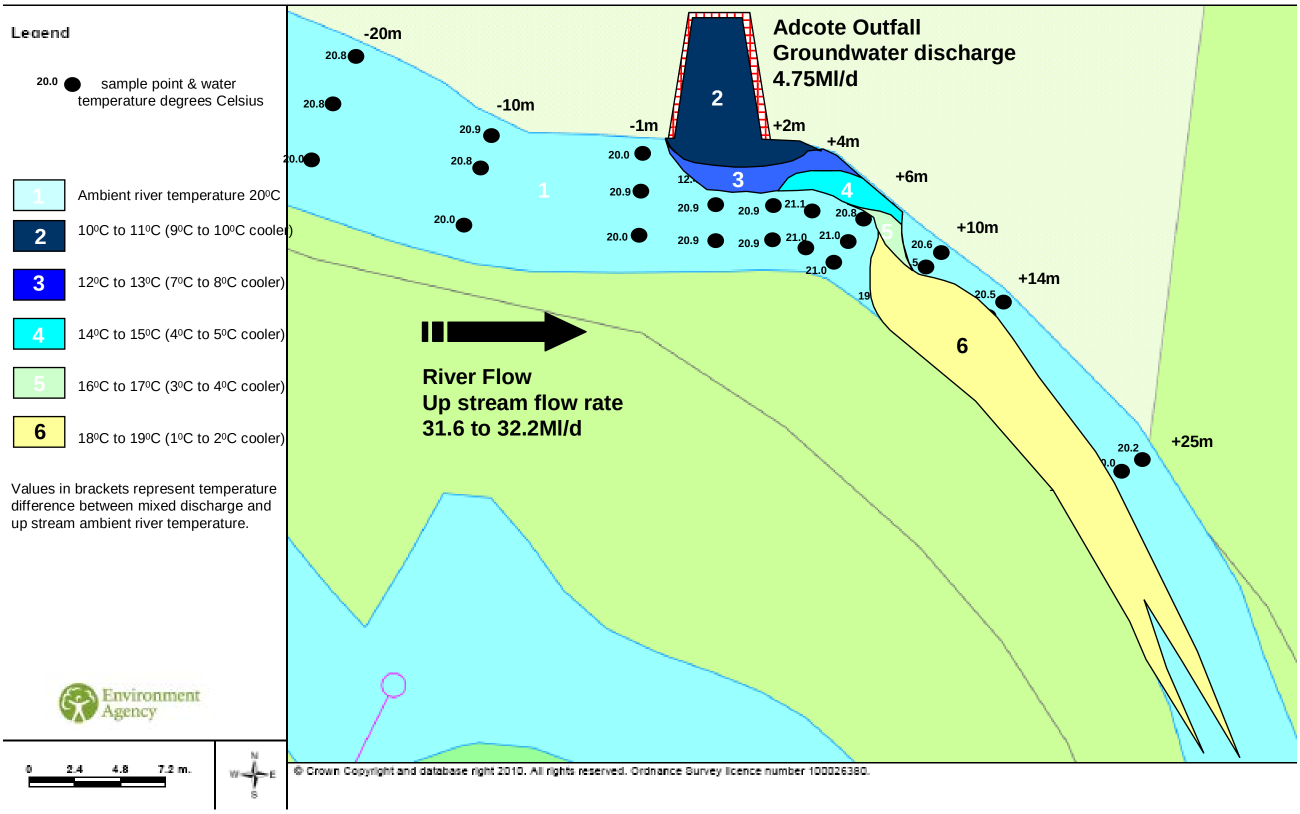
However beyond the bend in the river at +5m there is evidence for significant mixing between the two bodies with rapid warming of the blended groundwater with surface water. This point also marks the shift in the mixing stream from the northern to the southern side of the channel. Beyond 10m the residual tail of mixing extends along the southern half of the channel at least to 25m with water temperatures of between 18ºC to 19ºC (1ºC to 2ºC). Further readings beyond 25m downstream for the outfall could not be taken due to water depth and access restrictions to the channel.

The interpretation of the mixing response suggests that the river flow is initially laminar for a short distance past the outfall, discouraging mixing of the groundwater and surface water bodies. This quickly reverts to turbulent flow with the change in direction of the river channel causing significant mixing and the shift in the residual tail of influence from one side of the channel to the other.

The net result of this exercise demonstrates that significant temperature lowering by the Adcote groundwater discharge effected a third to half of the channel width over a distance of less than 10m downstream of the outfall. Full mixing of groundwater and surface water had occurred beyond 10m due to turbulence caused by the bend in the river. Between 10 to 25m downstream only a 0.9^{0}C to 1.7^{0}C residual net reduction in ambient river temperature remained again only affecting one half of the channel. Groundwater discharge to the river Perry at Adcote is therefore not considered to pose a significant thermal barrier to the migration of fisheries or invertebrates past the outfall.

Figure I3 Adcote Outfall to River Perry, Interpretation of Temperature Survey Results

Shropshire Groundwater Scheme Phase 2 – Effects of groundwater discharge to River Perry at Adcote. Interpretation of river temperature survey 18.07.06



Appendix J
Grafton Outfall - Temperature Profiling

Information supplied by Kevin Voyce, EA.

Shropshire Groundwater Scheme Phase 2

Grafton Outfall - temperature profiling of groundwater discharge (Grafton pumping station) to river Perry under operational conditions 18 July 2006.

River Augmentation

Grafton outfall provides the groundwater discharge point to the River Perry for the Grafton abstraction borehole as a stand alone component of the Phase 2 area of the Shropshire Groundwater Scheme. Due to the short delivery length of the pipeline (40 m), and low dissolved oxygen at the Grafton well head (<10%), a venturi system is employed in the pipe to significantly raise (80 to 102% sat achieved) the dissolved oxygen content of the groundwater prior to discharge to the river.

Pumping & Hydrological Regime

In-line with the rest of the Phase 2, Grafton commenced pumping on 10 July 2006 to provide operational regulation support. At the time of the temperature survey on 18 July Grafton had been operating for 7 days, delivering a gross constant rate yield of 3.52 Ml/d of groundwater to the River Perry.

On the day of the survey the river flow immediately up stream of Grafton outfall was estimated to be between 35.9 to 36.5 Ml/d, based on data from the Environment Agency's permanent river gauging station on the River Perry at Yeaton, 1.0 km upstream of the outfall. The river flow along this stretch would also contain groundwater from the SGS Frankbrook borehole, which was also discharging (4.75 Ml/d gross) to the River Perry 2.6 km upstream of Grafton at the same time.

Data Gathering

To measure the effect of the groundwater discharge on the receiving water course, data from a grid of sampling points extending 6m upstream and up to 40 m down stream of the outfall, and regular interval across the channel were obtained via wading access. This grid was designed to capture the ambient nature of the river water prior to the groundwater discharge, and then to monitor the effectiveness of the mixing of the two waters. Monitoring was extended down stream until the return to ambient (upstream conditions) was recorded.

Using a hand held multi-senor probe the following parameters were obtained from the groundwater prior to discharge to the river, the river water and the mixed river/groundwater in the channel: temperature (ºC), conductivity (µS/cm), dissolved oxygen (% sat) and pH. The multi-parameter readings from probe are tabulated in Table J1, and the temperature results illustrated in Figure J1.

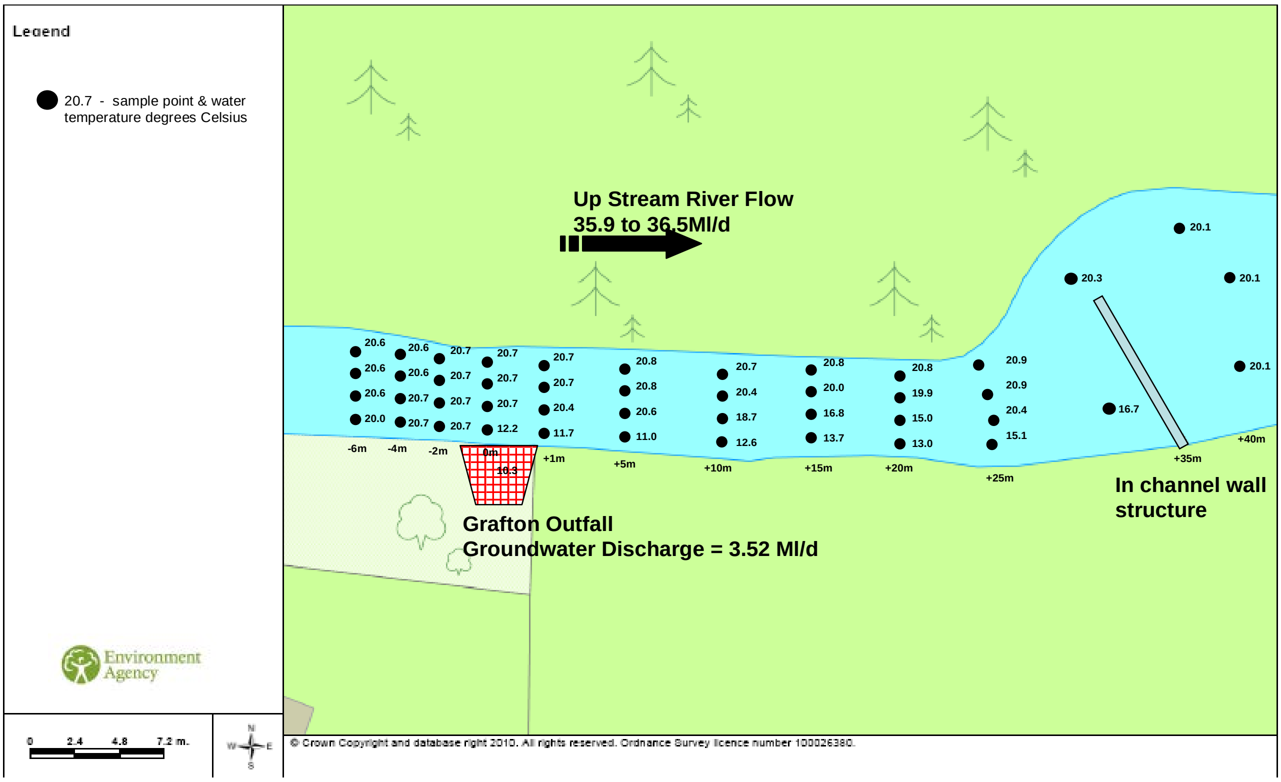
Table J1 Table of in River Sampling Grid. Data Obtained using a Hand Held Multi-senor Probe.

Survey Distance to Outfall (-m U/S) (+m D/S)	Sample Point in Channel Metres from Right Bank	Temp ^{0}C	Cond us/cm	DO % sat	pH
-6m	0.5m	20.0	787	116	8.4
	2m	20.6	785	122	8.4
	4m	20.6	785	124	8.4
	5.5m	20.6	784	125	8.4
-4m	0.5m	20.6	785	122	8.4
	2m	20.7	784	125	8.6
	4m	20.6	785	124	8.5
	5.5m	20.6	785	122	8.4
-2m	0.5m	20.7	785	122	8.4
	2m	20.7	785	124	8.5
	4m	20.6	785	124	8.4
	5.5m	20.7	785	123	8.4
Groundwater discharge only	0m	10.3	501	102	7.7
0m (start of mixing zone)	0.5m	12.2	580	104	8.1
	2m	20.7	786	123	8.5
	4m	20.7	786	124	8.4
	5.5m	20.7	785	123	8.5
+1m	0.5m	11.7	539	109	8.0
	2m	20.4	784	123	8.5
	4m	20.7	784	123	8.6
	5.5m	20.7	785	120	8.4
+5m	0.5m	11.0	541	102	8.1
	2m	20.6	783	122	8.5
	4m	20.8	785	123	8.5
	5.5m	20.8	783	123	8.5
+10m	0.5m	12.6	562	105	8.1
	2m	18.7	718	110	8.4
	4m	20.4	776	121	8.5

Survey Distance to Outfall (-m U/S) (+m D/S)	Sample Point in Channel Metres from Right Bank	Temp ^{0}C	Cond us/cm	DO % sat	pH
	5.5m	20.7	783	122	8.5
+15m	0.5m	13.7	590	107	8.2
	2m	16.8	673	113	8.4
	4m	20.0	765	120	8.5
	5.5m	20.8	784	122	8.5
+20m	0.5m	13.0	567	103	8.1
	2m	15.0	634	108	8.3
	4m	19.9	762	119	8.5
	5.5m	20.8	784	121	8.5
+25m	0.5m	15.1	624	109	8.3
	2m	20.4	773	119	8.5
	4m	20.9	784	120	8.4
	5.5m	20.8	784	122	8.5
+35m	3m	16.7	689	115	8.3
+35m	10m	20.3	776	117	8.4
+40m Pool	3m	20.1	767	116	8.5
+40m Pool	6m	20.1	761	114	8.4
+40m Pool	10m	20.3	773	118	8.5

Figure J1 Grafton Outfall to River Perry, Survey Grid Location of Sample Points

Shropshire Groundwater Scheme Phase 2 – Effects of groundwater discharge to River Perry at Grafton. Results of river temperature survey 18.07.06



Interpretation of Results

An interpretation of the temperature data from the survey is presented in Figure H1. In this illustration the mixing of the cool groundwater (10^{0}C) and warm ambient river water (20^{0}C) is depicted by six contoured zones of temperature with a 1.9^{0}C interval of separation as follows:

Zone 1 – 20^{0}C ambient river temperature;

Zone 2 - 10^{0}C to 11.9^{0}C (9^{0}C to 10^{0}C cooler than ambient temp);

Zone 3 - 12^{0}C to 13.9^{0}C (7^{0}C to 8^{0}C cooler than ambient temp);

Zone 4 - 14^{0}C to 15.9^{0}C (4^{0}C to 5^{0}C cooler than ambient temp);

Zone 5 - 16^{0}C to 17.9^{0}C (3^{0}C to 4^{0}C cooler than ambient temp); and

Zone 6 - 18^{0}C to 19.9^{0}C (1^{0}C to 2^{0}C cooler than ambient temp).

The results of the temperature profiling exercise show that the groundwater discharge preferentially streams down the southern side of the river, running parallel with and hugging the bank. Using the hand held probe it was clear that for the first 10 m very little mixing had taken place with a sharp contact existing between the cool groundwater and warm river water bodies approximately 1.75 m from the southern bank. A core of cooler (12^0C to 13.9^0C) still existed up 25 m from the outfall in contact with the bank. However beyond 10 m there is evidence for mixing between the two bodies with stratified warming of the blended groundwater and surface water over half the channel width.

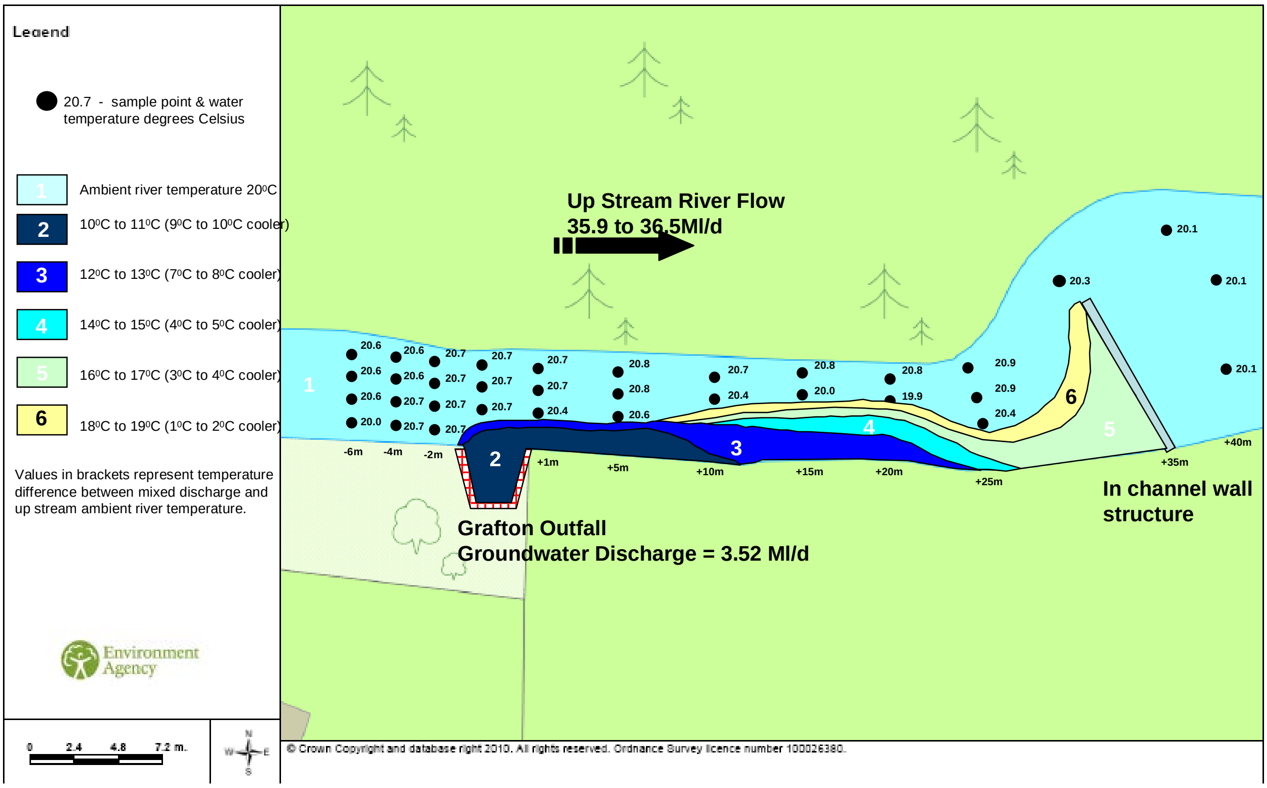
Between 20m and 35m mixing improves with a progressive transition to warmer water temperatures of between 16^0C to 19.9^0C by the time the blended flow pools against the in-channel wall structure. Immediately down stream of this obstruction the river has returned back to ambient temperature.

The interpretation of the mixing response suggests that the river flow is largely laminar past the outfall, initially discouraging mixing of the groundwater and surface water bodies. This causes the groundwater to preferentially stream down the southern side of the channel. Progressive mixing only occurs when turbulent flow is encouraged by the in-channel obstruction. The structure acts a holding area for the residual tail mixing, beyond which full mixing occurs.

The net result of this exercise demonstrates that temperature lowering by the groundwater discharge effected a third to half of the channel width over a distance of 35m. Full mixing of groundwater and surface water had occurred within 40m of the outfall, with only a 0.5^0C to 0.7^0C residual net reduction in ambient river temperature. Due to the laminar nature of the river flow at Grafton the groundwater mixing zone only effected up to third of the channel width. Groundwater discharge to the river Perry is therefore not considered to pose a thermal barrier to the migration of fisheries or invertebrates past the outfall.

Figure J2 Grafton Outfall to River Perry, Interpretation of Temperature Survey Results

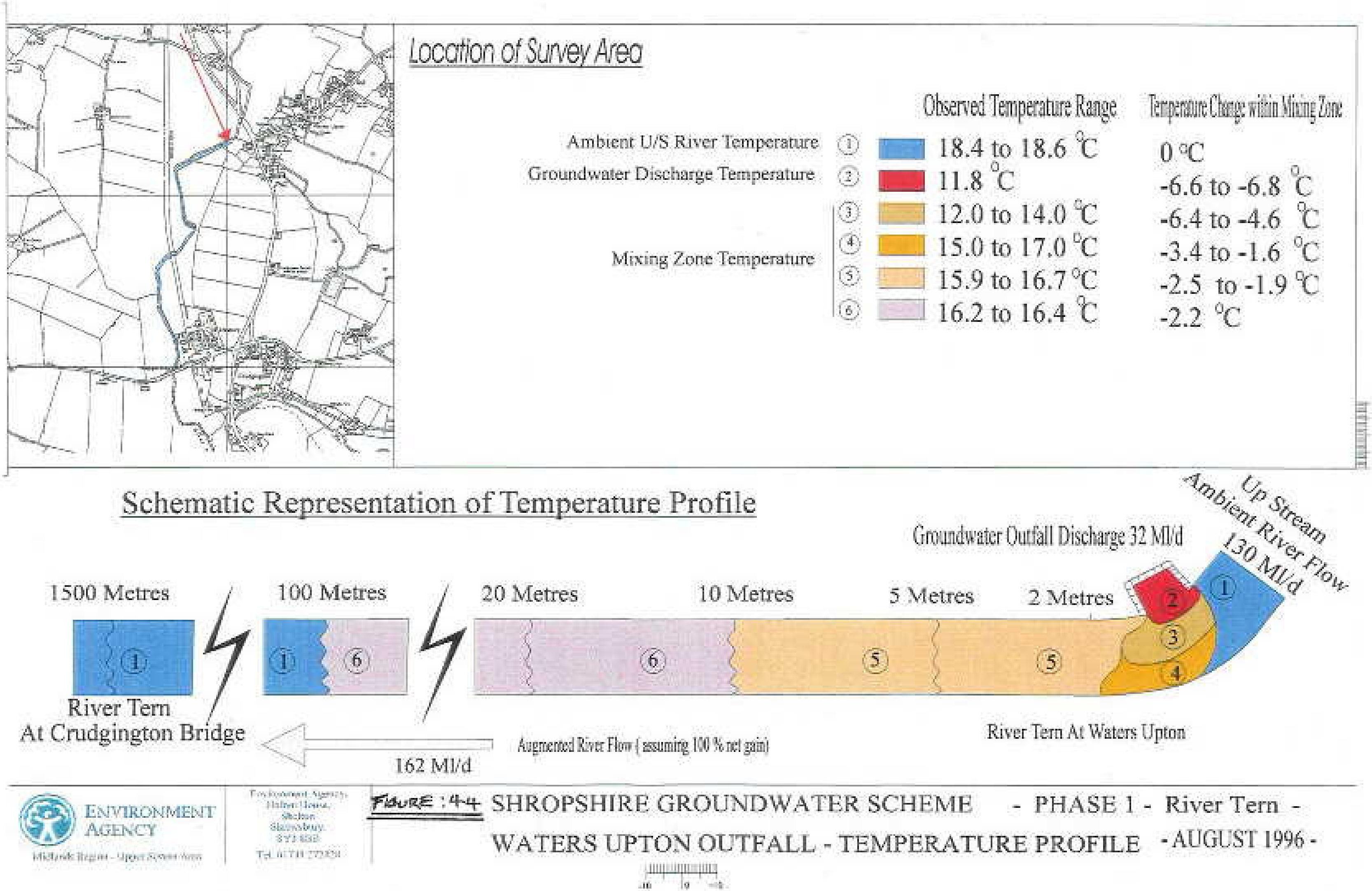
Shropshire Groundwater Scheme Phase 2 – Effects of groundwater discharge to River Perry at Grafton. Interpretation of river temperature survey 18.07.06



Appendix K
Waters Upton Outfall to River Tern, Temperature Profiling Exercise August 1996

Information supplied by Kevin Voyce, EA.

SGS Phase 1 Waters Upton Outfall to River Tern, temperature profiling exercise August 1996



Appendix L
Designated Sites

Name	Status	Easting	Northing	Area (ha)	Reason for designation	Water/wetland features	Condition	Hydraulic Connection to Sherwood Sandstone Watertable	Assessment
Old River Bed, Shrewsbury	SSSI	349700	314800	15.17	Former bed of River Severn cut off during the last glacial episode	Extensive sedge fen and inundation habitat	Favourable condition.	Sandstone Head Dependant Feature	Part of former river bed of River Severn. Water table <2mbgl. WFD GWDTE moderate risk from gw abstractions (at future predicted 2015 values) but abstraction pressure was rated as low. SGS Phase 3 will have an impact on groundwater levels beneath this site. Need to carefully review and quantify projected impact and possible mitigation measures (switch off Newton borehole?).
Old River Bed, Shrewsbury	SINC	349226	315064			Marshy grassland/carr		Sandstone Head Dependant Feature	Part of former river bed of River Severn. Water table <2mbgl. WFD GWDTE moderate risk from gw abstractions (at future predicted 2015 values) but abstraction pressure was rated as low. SGS Phase 3 will have an impact on groundwater levels beneath this site. Need to carefully review and quantify projected impact and possible mitigation measures (switch off Newton borehole?).
Platt Brook	SINC	362335	322545			Watercourse/river corridor		Sandstone Head Dependant Feature	Known issue with abstraction from Phases 1&4. Mitigation BHs in place. SGS Phase 1&4 will have an impact on groundwater levels beneath this site. Need to carefully review and quantify projected impact and possible mitigation measures through stream compensation boreholes Heath House No2 & Greenfields and Woodmill Farm Pool compensation scheme). Refer to MSc study on Potford & Platt Brooks.
Sundorne Pool	SINC	352618	316098			Open water/marsh		Complex Sandstone Head Feature	SGS Outer Protection Zone. Sandstone outcrop, groundwater level close to ground surface. Potential impact from Phase 3 wellfield on groundwater heads in lower catchment of Astley Brook where sandstone provides baseflow to Astley Brook which feeds pool.
Army Camp Grassland	SINC	336063	318678			Grassland		Insufficient Data	Regional sandstone groundwater level close to ground level but confined by large thickness of drift (>40m). The meadow sits just beyond the western marginal edge of the measured area of drawdown influence generated by operation of Phase 2 of SGS. The Wilcott Marsh observation borehole (2km to the east) lies in a confined zone which has recorded a 0.25 to 0.75m hydraulic drawdown response to past pumping of Phase 2. It is unclear whether the SGS Phase hydraulic influence would extend as far west as the Turmoor area and the Army Grassland site. Given its distance from the wellfiled this is a marginal call between no impact and possible impact.
Peplow Hall Heronry	SINC	364103	324650			Woodland		Sandstone Head Dependant Feature	In valley of River Tern, Sandstone groundwater level close to ground level. Given the hydrogeological conditions it is likely that the river corridor, and its permeable infill drift has good hydraulic connection with the sandstone aquifer. The woodland sits within soil moisture vulnerability class 1, indicating potential sensitivity to groundwater fluctuations. The sensitivity of the trees, in which the Herons nest, to fluctuations in groundwater levels will depend upon the type of tree, rooting systems and un-saturated zone thickness.
Wytheford Wood & Broom Coppice	SINC	358253	320845			Woodland		possible Sandstone Head Dependant Feature	Designated on oak/birch woodland. Ground level 64 to 66mAOD. groundwater level 60 to 65mAOD. Phase 1&4 modelled drawdown impact 0.6 to 0.9m. ADAS soil moisture vulnerability class 2 & 3 Wytheford Wood C1 drift domian reduces potential sensitivity. Broom Coppice A4 drift domain has higher sensitivity. Unknown what effect 0.6 to 0.9m fall in sandstone head would have on soil moisture balance for tree root uptake.
Alkmund Park Pool	SINC	347962	316082			Open water/woodland		Non-Sandstone Head Dependant Feature	Regional sandstone groundwater level ~20mbgl. Pool fed by drift watertable.
Boggy Coppice	SINC	355658	317698			Woodland/pond		Not Applicable	East of Hodnet Fault. Off sandstone, on Salop Formation. Southeast of SGS Phase 5 .
Boreatton Moss	SINC	341653	322552			Open water		Not Applicable	Mercia Mudstone, no connection to Sandstone aquifer.
Corbett Wood and Grinshill	LNR	351900	323700	27.39	No info	-		Not Applicable	Quarried sandstone edges covered in woodland, conifer and broad-leaved trees. Designated for geological importance. Regional sandstone groundwater level 15-30 mbgl. Not water dependent features.
Cottage Plantation Pools	SINC	341431	318211			Pools and woodland		Non-Sandstone Head Dependant Feature	Regional sandstone groundwater level 20mbgl. Pools fed by Drift system.
		341867	318257			Pools and woodland			
		341730	318456			Pools and woodland			
Cranberry Moss	SINC	336576	320921			Wet grassland/bog		Non-Sandstone Head Dependant Feature	SGS Outer Protection Zone. Regional Sandstone groundwater level ~10mbgl. Peat over glacial sands and gravels. With a 7 to 8m unsaturated zone between ground level and the sandstone head measured at Wolfshead it is very unlikely that the water balance for this surface feature relies upon groundwater from the sandstone. Similar to Lin can Moss it is likely that this feature drains vertically through the drift to recharge the sandstone below. Further more the site lies out side the projected area of influence of the Phase 2 wellfield.
Fenemere (part of Midland Meres & Mosses Ramsar complex)	SSSI and RAMSAR	344500	322800	15.4	Part of the Ramsar designated Meres and Mosses complex	Rich and interesting eutrophic mere (water body)	Unfavourable recovering/unfavourable no change - Game management - other, Public access/disturbance, Water pollution - agriculture/run off	Non-Sandstone Head Dependant Feature	Rich and interesting mere with eutrophic water. SGS Outer Protection Zone. North of Wem Fault, off sandstone subcrop. Regional sandstone groundwater level >20mbgl. Drift-fed system.
Folly Pool	SINC	338850	316810			Pool		Non-Sandstone Head Dependant Feature	BGS report estimates pool lies on between 60 to 80m thick sequence of lacustrine clays. Yes regional sandstone groundwater level close to ground level ~3 to 4m but this is a potentiometric head. Presence of intervening aquitard sufficient to prevent any hydraulic connection. Pool relies on run off from surface catchment
Grinshill (non SSSI)	SINC	351982	323793			Woodland		Not Applicable	This site is designated on sandstone outcrop, conifer & birch woodland, heath. Groundwater is 60mbgl.
Grinshill Quarries	SSSI	352500	323800	9.73	Geological SSSI - fossil remains of the Middle Triassic period	-	Favourable condition	Not Applicable	Notified for geological features (fossil remains). Not water dependent feature.
Hencott Pool (part of Midland Meres & Mosses Ramsar complex)	SSSI and RAMSAR	349000	316000	11.86	Part of the Ramsar designated Meres and Mosses complex	Fen, carr and peat bog with open water	Favourable condition.	Non-Sandstone Head Dependant Feature	Contains little open water. Regional sandstone system with groundwater level 15-30mbgl. System fed by drift.
Hodnet Heath	SSSI	362000	326200	39.5	Remnant wet and dry heath	Wet heath, bog and ponds	Unfavourable recovering	Non-Sandstone Head Dependant Feature	A small remnant of the heathland which was formerly more extensive in North Shropshire. Predominantly wet heath, but areas of dry heath and secondary woodland. There are also a number of ponds. Regional Sandstone groundwater level ~4mbgl, drift water table ~1-3mbgl. Evidence of poor connectivity between perched sand aquifer system and pumping effects on underlying sandstone head ~4mbgl.
Hungry Hatton	SINC	367488	327369			Woodland		Not Applicable	Regional sandstone groundwater level approx. 20mbgl. Feature not dependent on sandstone groundwater.
Kynnersley Moor Woods	SINC	365589	317751			Woodland/wet drains/watercourse		Non-Sandstone Head Dependant Feature	SGS Outer Protection Zone. Drained area outside main area of influence of SGS. Sandstone groundwater level >5mbgl.
Lin Can Coppice	SINC	337319	321121			Woodland		Non-Sandstone Head Dependant Feature	SGS Outer Protection Zone. Woodland. Adjacent to Lin Can Moss. Groundwater levels (2-4mbgl) recorded by the piezometers beneath Lin Can Moss represent perched groundwater storage within the drift sequence. The elevated heads suggest down ward vertical leakage through the drift sequence to recharge the underlying sandstone. Is it therefore unlikely that Lin Can Moss would be impacted by drawdown within the sandstone aquifer beneath the site. Aside to this issue the site lies out-side the projected area of influence of the Phase 2 wellfield.

Name	Status	Easting	Northing	Area (ha)	Reason for designation	Water/wetland features	Condition	Hydraulic Connection to Sherwood Sandstone Watertable	Assessment
Lin Can Moss	SSSI	337500	321100	1.99	Important as part of Meres and Mosses complex	A site on peat with a small quaking bog	Unfavourable recovering - no reason given.	Non-Sandstone Head Dependant Feature	SGS Outer Protection Zone. Developed in natural depression in drift. Peat site. Water table 2-4mbgl. WFD GWDTE moderate risk from gw abstractions (at future predicted 2015 values), but abstraction pressure was rated as low. Perched system with vertcial drainage to underlying sandstone water table 5 to 6mbgl. Also lies out side projected area of SGS Phase 2 hydraulic influence.
Marton Pool	SINC	344731	323364			Open water		Non-Sandstone Head Dependant Feature	SSSI. Adjacent to Fenemere. SGS Outer Protection Zone. North of Wem Fault, off sandstone subcrop. Regional sandstone groundwater level >20mbgl. Drift-fed system.
Merrington Green	SINC	346569	320906			?		Not Applicable	Woodland. Areas of grassland have been reopened, encouraging a range of wild flowers to return. There are also several ponds, restored under Trust management, attracting lots of dragon and damselfies. Regional sandstone groundwater level >40mbgl.
Nesscliff, Great Ness	SINC	338613	319490			Woodland		Not Applicable	Sandstone Hills. Regional sandstone groundwater level >30mbgl. Not water dependent features.
Old Wood	SINC	346063	320309			Woodland		Not Applicable	Regional sandstone groundwater level >40mbgl.
Pigeons Rough	SINC	350014	319650			Woodland		Not Applicable	Regional sandstone groundwater level >40mbgl. Sandstone unconfined.
Poynton Springs	SINC	355658	317698			Woodland/open water		Not Applicable	East of Hodnet Fault. Off sandstone, on Salop Formation. Southeast of SGS Phase 5 .
Pradoe Coppice	SINC	346584	321672			Woodland		Not Applicable	Regional sandstone groundwater level ~30mbgl.
Quarry Wood	SINC	368560	327284			Woodland		Not Applicable	Regional sandstone groundwater level approx. 20mbgl. Feature not dependent on sandstone groundwater.
RAF Tern Hill	SINC	363544	330860			unimproved grassland, ponds and willow carr		Not Applicable	Drift covered area, higher ground out of main valley of Tern (~20m increased elevation). RAF Tern Hill SINC is a collection of perched surface water bodies reliant on direct rainfall recharge. There is no evidence to support hydraulic connection with, or reliance upon groundwater from the underlying sandstone to maintain the water balance in the pools. Therefore groundwater pumping is not considered to impact upon water levels on the pools and therefore any reliance on the flora and fauna supported by this feature.
River Severn	SINC	339639	315263			River and corridor		Sandstone Head Dependant Feature	see SSSI above
River Severn	SINC	331324	316343			River and corridor		Sandstone Head Dependant Feature	see SSSI above
River Severn at Montford	SSSI	339600 343200	315300 315300	27.22	Geomorphological interest – underfit stream of the Osage type	River Severn and corridor	Favourable condition.	Non-Sandstone Head Dependant Feature	Underfit River, designated for geomorphological interest. Short term increased pumping impacts unlikely to be significant. No SGS impact on water balance to site.
River Tern	SINC	365129	332989			Watercourse/river corridor		Sandstone Head Dependant Feature	This section of the River Tern catchment is situated too far upstream for the effects of the Phase 1&4 wellfield to have a detrimental impact on baseflow contribution to the River Tern at Market Drayton. No impact from SGS.
Shrawardine Pool	SSSI	339800	316200	17.79	Important as part of Meres and Mosses series of sites in Cheshire – Shropshire plain.	Open water, swamp, fen and carr	Favourable condition.	Non-Sandstone Head Dependant Feature	Shallow (few feet) mere developed in natural depression in drift. Regional sandstone groundwater level 6-15mbgl. Pool system fed by drift. No SGS impact on water balance to site.
Stoke Heath	SINC	365466	330186			Mixed scrub with birch woodland, bracken and a pond		Sandstone Head Dependant Feature	Based on the available data the water features at the Stoke Heath SINC appear to be in good hydraulic connection with sandstone heads, and therefore potentially sensitive to localised groundwater abstraction from the sandstone. With the removal from operational use of the only SGS abstraction point to the east of the River Tern, the residual effects of the main Phase1&4 wellfield are not considered to have an impact on groundwater level beneath the site. Therefore the site is not considered to be impacted upon by the operation of the Shropshire Groundwater Scheme. No impact from SGS.
The Cliffe	SINC	339448	320921			Woodland		Not Applicable	Sandstone Hills. Regional sandstone groundwater level >60mbgl. Not water dependent features.
The Knolls	SINC	342442	317392			Woodland		Not Applicable	Regional sandstone groundwater level 20mbgl. Not water dependent features.
The Sydnall	SINC	368008	330891			Woodland		Not Applicable	SGS Outer Protection Zone. Small patch of woodland on higher ground, off Sandstone Subcrop, on underlain by Carboniferous Salop Formation. Unlikely to be water
The Yesters	SINC	343759	321925			?		Not Applicable	On Wem Fault. Close to railway and tributary of War Brook. Regional Sandstone groundwater level >15mbgl. More info required but not believed to be dependent on sandstone groundwater level.

KEY:

RED	Likely/known impact
ORANGE	Possible impact
GREEN	No impact predicted

Appendix M
Cultural Heritage Technical Note

Shropshire Groundwater Scheme

Appraisal of Potential Effects on Archaeological Sites

1. Introduction

1.1.1 This technical note presents a high-level appraisal of the potential for changes to groundwater levels predicted as a result of the Shropshire Groundwater Scheme (SGS) to have an effect on archaeological sites and monuments in the outer protected zone. The note includes an outline of the methodology used and the results of the appraisal, including a brief account of baseline conditions and an account of those sites identified which may be susceptible to change. A discussion of the likely effects on those archaeological sites identified, the significance of these and recommendations for any further work is also given.

1.1.2 This appraisal attempts to categorise archaeological sites in terms of the potential sensitivity of the deposits they contain to changes in water level. It then identifies which sensitive sites lie within areas where groundwater is relatively close to the surface -0-4m below ground level (bgl). The combination of these two measures is used to identify archaeological sites and monuments which are likely to be susceptible to changes in water level and an attempt is made to grade the susceptibility of sites according to a defined scale.

1.1.3 The study areas and the locations of potentially sensitive archaeological sites discussed in the text are shown on Figure 3.1.

2. Appraisal Methodology

2.1 Background

2.1.1 Some types of archaeological sites and monuments contain deposits which are potentially sensitive to changes in water levels. The most obvious of these are sites which include negative archaeological features, such as pits or ditches, which have either deliberately been infilled, have silted-up through natural processes, or a combination of the two. These may contain waterlogged artefacts of organic origin and ecofacts, which may be defined as naturally occurring, unfossilised objects or deposits of biological origin, not modified by human activity, which are contained within or forms an archaeological deposit. Examples include seeds, plant micro and macrofossils, animal bones, pollen and invertebrate remains. Both artefacts and ecofacts are invaluable to archaeology. Depending on local site conditions including the nature of the surface drift geology, these can be sensitive to changes in the water table and therefore to hydrological draw down.

2.1.2 Certain archaeological sites may present one of two additional considerations, distinct from the interest of their associated deposits:

- Sites for which water forms a part of the current monument, for example a moated site which retains water, could be sensitive to any change in water levels as this may affect the integrity of the monument and its immediate setting.

- Sites which lie directly on a water course and which may therefore be sensitive to changes in water levels within that water course.

2.2 Methodology

Study Area

2.2.1 Data was collected from the SGS Outer Protected Zone (Shrewsbury to Market Drayton area) in the first instance.

Data Sources

2.2.2 This appraisal uses three primary sources of data:

- A subset of the national data set on scheduled monuments, maintained by English Heritage.

- A subset of the national data set on listed buildings, maintained by English Heritage.

- Shropshire Historic Environment Record (HER), a county-based register of known archaeological and historical sites, maintained by Shropshire County Council.

Categorisation of Site Sensitivity

2.2.3 Some types of archaeological sites and monuments are more likely to contain deposits sensitive to changes in water levels than others. Data fields recorded on the HER include ‘monument record type’, which is a broad categorisation of the type of site to which the record pertains. Four categories are recorded in the received dataset:

- Building;

- monument;

- landscape; and

- findspot.

2.2.4 The only buildings taken forward for further assessment are bridges, as the fabric of these may be susceptible to changes in water level both through desiccation/saturation processes and directly through erosion. Otherwise monument record types other than ‘monument’ were screened out of the appraisal as these do not directly constitute archaeological deposits likely to be sensitive to changes in water levels.

2.2.5 HER records are further qualified by a more precise field of ‘monument type’, which is sufficiently specific (in most cases) to allow a judgement of potential sensitivity to be reached. Based on this typology, sites have been allotted a relative sensitivity on a scale of high, medium, low, and none, based on the criteria shown in Table 2.1. An additional criterion of ‘unknown’ was also used for sites where insufficient information was available to make a judgement.

2.2.6 It is important, in consideration of the judgement of sensitivity, to make the distinction that this appraisal judges the sensitivity of the archaeological site, in the first instance, based purely on the potential of the *type* of the site (or deposits therein) to be sensitive to changes in water level. This is not a judgement of the specific circumstances or archaeological potential/value of any particular site, as this information is not available at this level of the record and may not be available at all; many recorded archaeological sites have not been investigated.

2.2.7 No account has been taken of deposits which might be ‘sealed’, such that changes in ground water levels might not have an effect. The exception is that sites which are directly related to canals have been screened out, given that a canal is a sealed system.

2.2.8 The intrinsic, legislative or policy importance or value of sites has not been taken into account in judging their sensitivity, although will have a bearing on the significance of any identified effect. For example, in this appraisal a moated site designated as a scheduled monument is not considered any more sensitive than one which is not scheduled.

Table 2.1 Categorisation of likely sensitivity of archaeological sites

Sensitivity	Rationale
High	Deposits containing waterlogged artefacts and ecofacts are likely to be present and, if so, are likely to be key to, or a significant factor in, the interest of the site. The presence and visibility of water is an important element of the integrity of the site, or its setting, whether or not waterlogged artefacts or ecofacts may be present.
Medium	Deposits containing waterlogged artefacts and ecofacts may be present and, if so, will contribute to the interest of the site. The presence and visibility of water contributes to the integrity of the site, or its setting, whether or not waterlogged artefacts or ecofacts may be present.
Low	Deposits containing waterlogged artefacts and ecofacts may be present, and may be of some background interest, although are not likely to be integral to the archaeological interest of the site. The presence or absence of water would not be expected to contribute to the integrity of the site, or its setting.
None	Deposits containing waterlogged artefacts and ecofacts which are in any way connected to the site are not likely to be present. Where such deposits may be present, they are unlikely to have any bearing on the archaeological interest of the site.

2.2.9 Features which are evidently inextricably linked to water, such as moated sites, have generally been taken as being of High sensitivity. Domestic sites have normally been taken as being of Medium sensitivity, while agricultural features and those representing land boundaries have normally been taken as being of Low sensitivity.

2.2.10 Industrial sites vary in their sensitivity according to the processes involved. These have generally been judged as being of Low sensitivity (e.g. saw mill) or None (e.g. engine works), although exceptions would include tanneries and water mills, which have been judged as High sensitivity. Generally, a precautionary principle has been followed in assigning sensitivity to archaeological sites. For example, enclosure features, where it is not recorded whether these are domestic or agricultural, are taken as being of Medium sensitivity.

2.2.11 The majority of sites recorded as monument record type 'monument' on the HER have been classified as being of medium sensitivity. This is partly a product of the high-level nature of this appraisal; an Iron Age enclosure and a medieval settlement may both include features containing waterlogged deposits. Such deposits could be key to the interest of the site, although in the absence of any specific indicator that these may be key to the interest of the site, further assessment would be needed to ascertain this. Therefore, sites identified as being of high sensitivity are those where the very nature of the site marks it out, such as moated sites.

Identification of Susceptible Archaeological Sites

2.2.12 Archaeological deposits typically extend to depths of not more than a few metres. Using the parameters displayed in P1 and P2 groundwater depths, it is judged that sensitive archaeological sites may be affected in areas where groundwater is either between 0 and 2 metres, or possibly between 2 and 4 metres below ground level. However, as some site types are more sensitive than others and groundwater depths vary, an attempt has been made to use the sensitivity of archaeological sites against the depth of groundwater bgl to arrive at a score for the susceptibility of individual sites. A scale of 1 to 5 is used, with 1 being most susceptible as shown in the matrix of potential susceptibility, below.

Table 2.2 Potential Susceptibility Matrix

Water Depth bgl	**0-1m**	3	2	1
	1-2m	4	3	2
	2-4m (+[1])	5	4	3
		Low	**Medium**	**High**
		Sensitivity		

2.2.13 It should be noted that the susceptibility score is a relative grading in order to give an indication of the magnitude of the overall likely effect and the proportion of sites which are likely to be more or less susceptible to change. This does not therefore mean that individual sites should be treated differently in terms of any further assessment required.

2.2.14 Sites which lie in areas where groundwater depth is more than 4m bgl are not likely to be susceptible to changes caused by SGS. However, owing to the high level nature of this appraisal, some sites have been identified as 'special' cases where these are either likely to be particularly sensitive to changes in groundwater (such as wells), or where the type of feature is such that they warrant further assessment, such as fish weirs, which would be expected to be found in water courses. These have not been scored

[1] 'Special cases' such as wells

according to the matrix above, but have not been discounted where the depth to groundwater is more than four metres and therefore are recorded as a separate data subset.

2.2.15 The identification of areas where changes in the water table are likely to occur to the extent that these might have a bearing on archaeological sites or deposits is based on data collected as part of the SGS and no other data have been used.

3. Results

Baseline

Scheduled Monuments

3.1.1 There are 27 scheduled monuments within the study area, the majority of which (19) are judged to be of high sensitivity. Four monuments lie outside P1 and P2 areas and therefore there is no groundwater data for these. However, of these four, two lie above the 100m contour and are therefore unlikely to be affected. A further monument (32297 Round barrow cemetery and parts of a field system 500m west of Whitmore House) lies *c*. 20m above the nearest watercourse and has therefore also been judged as being unlikely to be affected. The fourth monument for which there was no data is nevertheless considered to be susceptible to changes in groundwater owing to its riverine position and the types of deposits which might be expected to be connected with the type of monument (a castle).

3.1.2 Twenty-two of the scheduled monuments within the study area are unlikely to be susceptible to changes in groundwater levels, according to the methodology above (they lie in areas where groundwater is more than 4m bgl). The remaining five are shown in the table below.

Table 3.1 Scheduled Monuments

No.	Name	X	Y	Sensitivity	Groundwater Depth (m)	Comments
33835	Ringwork and bailey castle 390m west of Buntingsdale Hall	365087	332540	High	No data	No data available, although cannot be discounted owing to riverine position and the nature of the monument
34907	Wall Camp in the Weald Moors: A large low-lying multivallate hillfort	368088	317819	High	6.33 (P1)	This is somewhat of a special case –the monument is some distance above groundwater, although this type of monument can include substantial ditched ramparts. Further research is warranted
19217	Motte Castle 140m south east of Wilcot Hall	337963	318526	High	3.00 (P2)	-

No.	Name	X	Y	Sensitivity	Groundwater Depth (m)	Comments
27557	Moreton Corbet Castle	356131	323162	High	3.91 (P1); 1.00 (P2)	Monument includes 3 scheduled areas
		355875	323093		5.04 (P1); 2.00 (P2)	
		356102	322996		4.11 (P1); 1.00 (P2)	
32315	Moated site 140m east of St Mary's Church	356057	321148	High	4.61 (P1); 2.00 (P2)	-

Other Features Recorded on the HER

3.1.3 The HER search returned 1813 entries recorded within the study area. However, 1151 of these are recorded as monument record type ‘building’ (and not sub-type ‘bridge’) and have therefore been discounted. A further 62 entries relate to findspots, which were also discounted.

3.1.4 A further 75 HER entries were discounted as being of no sensitivity to changes in groundwater levels, owing to site/monument typology. Thirteen HER entries contained insufficient information on which to base a judgement as to their likely sensitivity (although two of these were outside P1/P2 areas and a further five were more than 4m above groundwater levels and are therefore unlikely to be affected).

3.1.5 112 HER entries fall outside P1 and P2 areas and therefore there is no groundwater data against which to assess any potential effect.

3.1.6 397 HER entries were therefore identified within the study area as being of either High, Medium or Low sensitivity to changes in groundwater levels and also within P1 and/or P2 areas. Of these 125 fall within areas where groundwater lies within 4m of the ground level and are therefore judged as being potentially susceptible to changes in groundwater levels. Eight of these 125 are bridges under monument record type ‘building’, which have not been scored as to their susceptibility as it is the structure, rather than archaeological deposits, which may be affected. These are shown on Figure 3.1 and listed in Appendix A.

3.1.7 A breakdown of the above process is shown in the table below.

Table 3.2 Breakdown of Analysis of HER Sites

HER Sites	Sites Discounted	Running Total (Susceptible Sites)
Total recorded HER Sites within outer protected zone	1810	
'Buildings' discounted (bridges excepted)	1151	659
'Findspots' discounted	62	597
Other non-sensitive HER Sites	75	522
Insufficient recorded information	13	509
Sites outside P1 & P2 areas (no groundwater data)	112	397
Subtotal (HER sites of High/Medium/Low sensitivity within P1 & P2 areas)	-	**397**
Sites where groundwater >4m bgl	272 (of which 15 'special' sites)	125
Monument record type 'building' and monument type 'bridge'	8	117
HER entries type 'monument' susceptible to changes in groundwater within P1 & P2 areas (excluding bridges and 'special' sites)		**117**
'Special' sites (in areas where groundwater >4m bgl)		+15

3.1.8 The potential susceptibility of the 117 sites is broken down as follows:

- 1 (most susceptible) = 39 archaeological sites;
- 2 = 24 sites;
- 3 = 33 sites;

- 4 = 16 sites; and
- 5 (least susceptible) = 5 sites.

3.1.9 As detailed in Table 3.2, a further 15 HER entries have been taken as 'special' cases, according to the stated methodology, which if affected would warrant further consideration. This has been decided purely on professional judgement and no scoring mechanism has been applied. These features are also shown on Figure 3.1

3.1.10 Eight bridges recorded as monument record type 'building' on the HER are also shown on Figure 3.1.

Appraisal Limitations

3.1.11 Data on designated features (scheduled monuments and listed buildings) is a direct subset of the national dataset correct to 13th January 2009.

3.1.12 Data available from the HER at this level of search represents point data only and does not reflect the spatial extent of archaeological sites and monuments, although a field recording whether the record pertains to a 'point' or an 'area' is included. Similarly the data, at this level, contains no qualitative information as to the complexity or degree of survival of individual sites. Some entries may be 'site of' and no remains will necessarily survive, although this may not be transparent at this level of the record.

3.1.13 Owing to the size of the study area and resulting large number of archaeological sites and monuments recorded within this area, data obtained from the HER necessarily included only brief details of each record entry.

3.1.14 Standing buildings have generally been discounted from the appraisal as noted above. However, these may be susceptible to changes in ground water levels, for example through shrinkage of the substrate, or salt crystallisation in historic building materials as a result of changes in moisture content. Archaeological deposits associated with the excluded monument record types may also be sensitive to change, although the requisite information to determine this is not available. Therefore a church recorded under monument record type 'building' is screened out of the appraisal, whereas a church recorded under monument record type 'monument', is not screened out.

3.1.15 The grading of both the potential sensitivity of archaeological sites and their susceptibility to change is based on brief information as to the monument type and is therefore intended as a guide only. All monuments identified as being susceptible to changes in groundwater may be affected and, where such effects are identified, all will warrant further assessment.

4. Conclusions

4.1.1 A total of 117 archaeological sites have been identified which may be affected by changes in water levels, or hydrological 'draw down'. This has been gauged by comparison of 'sensitive' archaeological site types and areas where the existing water table is found within 4m of the ground surface. These sites vary in their susceptibility, which has been scored based on the sensitivity of the site type and the proximity of groundwater below ground level, although all of these should be taken as being potentially susceptible.

4.1.2 Eight bridges have also been identified where their structure might be directly affected by changes in water levels (and flows).

4.1.3 A further 15 features have been identified which may be of special sensitivity to changes in water levels, although the recorded groundwater level is greater than 4m below ground level. These may or may not be susceptible to changes in groundwater levels and can be taken as being of low susceptibility, or risk, although further assessment would be required were they to be in areas affected by changes in water levels as part of the SGS.

4.1.4 This appraisal includes all features within the SGS outer protected zone, not all of which will fall in areas where effects will occur as a result of abstraction from the wellfields. Crucially, this appraisal does not, at this stage, take into account the results of predicted changes in water levels as part of SGS and the number of archaeological sites which will actually be affected is likely to be considerably reduced following comparison with this analysis. Given that up to two thirds of the susceptible archaeological sites identified lie outside the areas currently identified as experiencing an effect from existing Wellfields 1, 2, 3 and 5, it is likely that as few as 35 to 40 sites will potentially be affected in these areas.

4.1.5 Furthermore, it is reasonable to assume both that:

- the likelihood of an effect on most archaeological sites will decrease with the increasing depth of groundwater below ground level; and
- the potential for effects on those archaeological sites identified would depend on the degree of change in comparison to existing water levels.

4.1.6 In consideration of the above, roughly a quarter of the 120 'susceptible' archaeological sites identified are in areas where the groundwater is more than 2m below ground level. Data for comparison of likely changes in water levels to existing groundwater levels is not available at the time of this appraisal.

4.1.7 The data and the methodology used at this level of appraisal are not infallible, such that it is possible that a sensitive archaeological site could be screened out of the assessment in error and likely that sites have been concluded as 'susceptible' to changes in water levels based on their recorded type, where in fact no such remains exist.

Author: Rob Johns

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Reviewer:

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Appendix A
Susceptible Archaeological Sites

6 Pages

Table A.1 Archaeological Sites within SGS Outer Protected Zone Potentially Susceptible to Changes in Groundwater Levels (east to west)

HER No.	Monument Type	NGR	Sensitivity	P1 m bgl	P2 m bgl	Susceptibility Score
MSA3036	Field Boundary, Ridge And Furrow	SJ 35244 17624	low		0.0	3
MSA2803	Non Antiquity?, Ring Ditch?, Pond?	SJ 35503 17301	med		0.0	2
MSA2751	Enclosure	SJ 35698 20148	med		0.0	2
MSA14544	Rectangular Enclosure	SJ 35856 20173	med		1.0	2
MSA19133	Ridge And Furrow	SJ 36311 17931	low		0.0	3
MSA19132	Watermill, Leat	SJ 36372 18005	high		0.0	1
MSA2749	Linear Feature, Pit Alignment	SJ 36948 21044	med		4.0	4
MSA23710	Well	SJ 37042 20663	high		1.0	1
MSA1641	Toll House	SJ 37158 20769	low		2.0	4
MSA16728	Culvert	SJ 37178 20532	low		2.0	4
MSA4093	Park	SJ 37637 15832	low		0.0	3
MSA802	Motte, Ringwork?, Tower Keep	SJ 37971 18535	high		3.0	3
MSA3346	Pond	SJ 38060 18703	high		1.0	1
MSA14519	Ring Ditch?, Henge?, Enclosure?	SJ 38153 19137	med		0.0	2
MSA13982	Ditch, Field System	SJ 38818 21605	low		4.0	5
MSA3347	Pond	SJ 38852 16818	high		1.0	1
MSA12699	Fishpond	SJ 39109 22117	high		0.0	1
MSA12709	Tenement	SJ 39219 22168	med		0.0	2
MSA12707	Market Place	SJ 39229 22213	low		0.0	3
MSA1942	Fish Weir	SJ 39236 15221	high		0.0	1
MSA12717	Tanning Pit	SJ 39274 22154	high		1.0	1
MSA2379	Watermill	SJ 41900 14500	high		0.0	1
MSA357	Farmhouse	SJ 41964 14612	med		1.0	2

HER No.	Monument Type	NGR	Sensitivity	P1 m bgl	P2 m bgl	Susceptibility Score
MSA1941	Fish Weir	SJ 42218 14488	high		0.0	1
MSA14665	Enclosure?, Non Antiquity?	SJ 43022 15158	med		0.0	2
MSA17008	Watermill	SJ 43063 19243	high		2.0	2
MSA17008	Watermill	SJ 43063 19243	high		2.0	2
MSA17009	Watermill	SJ 43558 19201	high		1.0	1
MSA17009	Watermill	SJ 43558 19201	high		1	1
MSA1627	Fish Weir	SJ 43841 16564	high		0.0	1
MSA17011	Watermill	SJ 44041 17483	high		3.0	3
MSA17011	Watermill	SJ 44041 17483	high		3.0	3
MSA17010	Watermill	SJ 44405 18058	high		1.0	1
MSA17010	Watermill	SJ 44405 18058	high		1.0	1
MSA1938	Fish Weir	SJ 45295 18196	high		0.0	1
MSA14964	Rectangular Enclosure	SJ 45497 18057	med		2.0	3
MSA14513	Fish Weir	SJ 45500 16900	high		3.0	3
MSA1939	Canal, Fish Weir	SJ 45557 16278	high		2.0	2
MSA3359	Factory, Watermill	SJ 45886 15975	high		0.0	1
MSA17012	Watermill	SJ 46155 16285	high		1.0	1
MSA89	Circular Enclosure	SJ 46824 14459	med		3.0	4
MSA1197	Watermill	SJ 48395 14695	high		3.0	3
MSA18810	Ridge And Furrow	SJ 48462 13879	low		1.0	3
MSA1183	House, Vicarage, Motor Vehicle Showroom	SJ 49266 13210	med		0.0	2
MSA1183	House, Vicarage, Motor Vehicle Showroom	SJ 49266 13210	med		0.0	2
MSA18804	Bridge	SJ 49401 15041	high		4.0	3
MSA3368	Saw Mill	SJ 49415 13305	low		2.0	4
MSA3399	Saw Mill	SJ 49465 13595	low		1.0	3
MSA14713	Enclosure	SJ 49470 14170	med		4.0	4
MSA1910	Grange	SJ 52435 16255	med		4.0	4
MSA23549	Ridge And Furrow	SJ 53062 16260	low		0.0	3
MSA18279	Augustinian Grange	SJ 53157 16525	med		0.0	2
MSA23551	Ornamental Lake	SJ 53213 16921	high		0.0	1
MSA13814	Circular Enclosure	SJ 53383 17885	med		4.0	4
MSA3318	Paper Mill	SJ 55495 25795	low		0.0	3

HER No.	Monument Type	NGR	Sensitivity	P1 m bgl	P2 m bgl	Susceptibility Score
MSA1427	Castle, Gazebo?	SJ 55581 26532	high	0.00	0.0	1
MSA13849	Linear Feature, Ring Ditch	SJ 55637 23051	med	7.58	4.0	4
MSA854	Settlement	SJ 55744 25286	med	1.72	0.0	2
MSA3321	Watermill	SJ 55876 24721	high		0.0	1
MSA17058	Watermill	SJ 55885 24725	high	0.00	0.0	1
MSA844	Keep, Country House, Castle, Formal Garden	SJ 56006 23095	low	4.67	2.0	4
MSA13852	Trackway	SJ 56031 22559	low	6.15	4.0	5
MSA843	Moat, Moated Site	SJ 56056 21151	high	4.61	2.0	3
MSA3324	Watermill	SJ 56169 21318	high	0.00	0.0	1
MSA1872	Deserted Settlement	SJ 56300 23253	med	1.42	0.0	2
MSA13860	Rectangular Enclosure	SJ 56457 20620	med	2.36	2.0	3
MSA17059	Watermill	SJ 56625 24075	high	0.00	0.0	1
MSA13854	Enclosure	SJ 56651 21834	med	1.90	1.0	2
MSA14123	Deer Park	SJ 56700 24700	low	9.96	2.0	4
MSA16679	Pit Alignment	SJ 56706 20051	med	1.84		3
MSA13853	Field System, Trackway	SJ 56957 22254	low	0.94		3
MSA16678	Curvilinear Enclosure	SJ 56997 20387	med	1.77		3
MSA17060	Watermill, Corn Mill, Saw Mill	SJ 57435 22733	high	0.00		1
MSA845	Circular Enclosure?, Non Antiquity?	SJ 59086 22188	med	1.77		3
MSA2977	Enclosure	SJ 59298 22572	med	1.64		3
MSA2658	Fishpond, Mill Pond, Watermill	SJ 60500 19800	high	0.00		1
MSA1311	Baiting Place	SJ 61055 19905	low	0.59		3
MSA3094	Ridge And Furrow	SJ 61254 19822	low	0.90		3
MSA13921	Ditch, Pit Alignment?, Ring Ditch	SJ 62362 18739	med	1.27		3
MSA16681	Rectilinear Enclosure, Pit Alignment, Field Bo	SJ 62583 18304	med	0.00		2
MSA16521	Water Meadow	SJ 62624 29938	high	0.72		1
MSA1312	Bridge, Bridge	SJ 62715 17965	high	0.00		1
MSA17046	Watermill	SJ 62725 23025	high	2.19		3

HER No.	Monument Type	NGR	Sensitivity	P1 m bgl	P2 m bgl	Susceptibility Score
MSA3330	Corn Mill, Watermill	SJ 62740 22926	high	1.18		2
MSA2981	Enclosure?, Trackway	SJ 62755 17405	med	0.00		2
MSA16522	Water Meadow	SJ 62834 29431	high	1.08		2
MSA1315	Farmhouse, Moat, Moated Site, Findspot	SJ 62951 17806	high	0.59		1
MSA3326	Pond	SJ 63189 26674	high	3.00		3
MSA1298	Bridge	SJ 63681 27851	high	1.84		2
MSA2173	Moat, Earthwork, Moated Site	SJ 63756 27954	high	1.96		2
MSA3327	Pond	SJ 63768 25371	high	2.26		3
MSA1053	Church	SJ 63820 27983	med	1.95		3
MSA17110	Watermill	SJ 63998 27341	high	0.00		1
MSA17110	Watermill	SJ 63998 27341	high	0.00		1
MSA351	Turbine, Watermill	SJ 64204 24357	high	0.06		1
MSA13533	Watermill, Paper Mill	SJ 64406 21216	high	0.33		1
MSA1616	Bridge	SJ 64655 21976	high	0.00		1
MSA858	Moat, Fishpond, Manor House, Moated Site	SJ 64656 27651	high	3.71		3
MSA17045	Watermill	SJ 64915 23085	high	0.00		1
MSA13532	Paper Mill, Watermill	SJ 64921 20862	high	1.96		2
MSA1069	Spring	SJ 65215 17955	high	0.04		1
MSA4055	Park	SJ 65500 27500	low	0.00		3
MSA13373	Burnt Mound	SJ 65906 17754	low	1.91		4
MSA13372	Burnt Mound	SJ 66118 17680	low	3.81		5
MSA13536	Well Head	SJ 66285 24965	high	3.13		3
MSA14664	Rectilinear Enclosure?	SJ 66354 23207	med	2.03		4
MSA13371	Burnt Mound	SJ 66421 17732	low	2.23		5
MSA17049	Watermill	SJ 66645 21075	high	2.50		3
MSA13365	Burnt Mound	SJ 67460 19090	low	1.63		4
MSA13366	Burnt Mound	SJ 67538 18990	low	1.94		4
MSA1909	Grange	SJ 67768 25348	med	3.76		4
MSA13368	Burnt Mound	SJ 67835 18585	low	3.72		5
MSA17048	Watermill, Paper Mill	SJ 68136 20447	high	0.01		1
MSA17048	Watermill, Paper Mill	SJ 68136 20447	high	0.01		1

HER No.	Monument Type	NGR	Sensitivity	P1 m bgl	P2 m bgl	Susceptibility Score
MSA860	Castle?	SJ 69068 26061	med	0.00		2
MSA3328	Pond	SJ 69205 26745	high	0.00		1
MSA14391	Bridge	SJ 69258 26006	high	0.00		1

Table A.2 Sites Considered to be 'Special Cases'[2] (east to west)

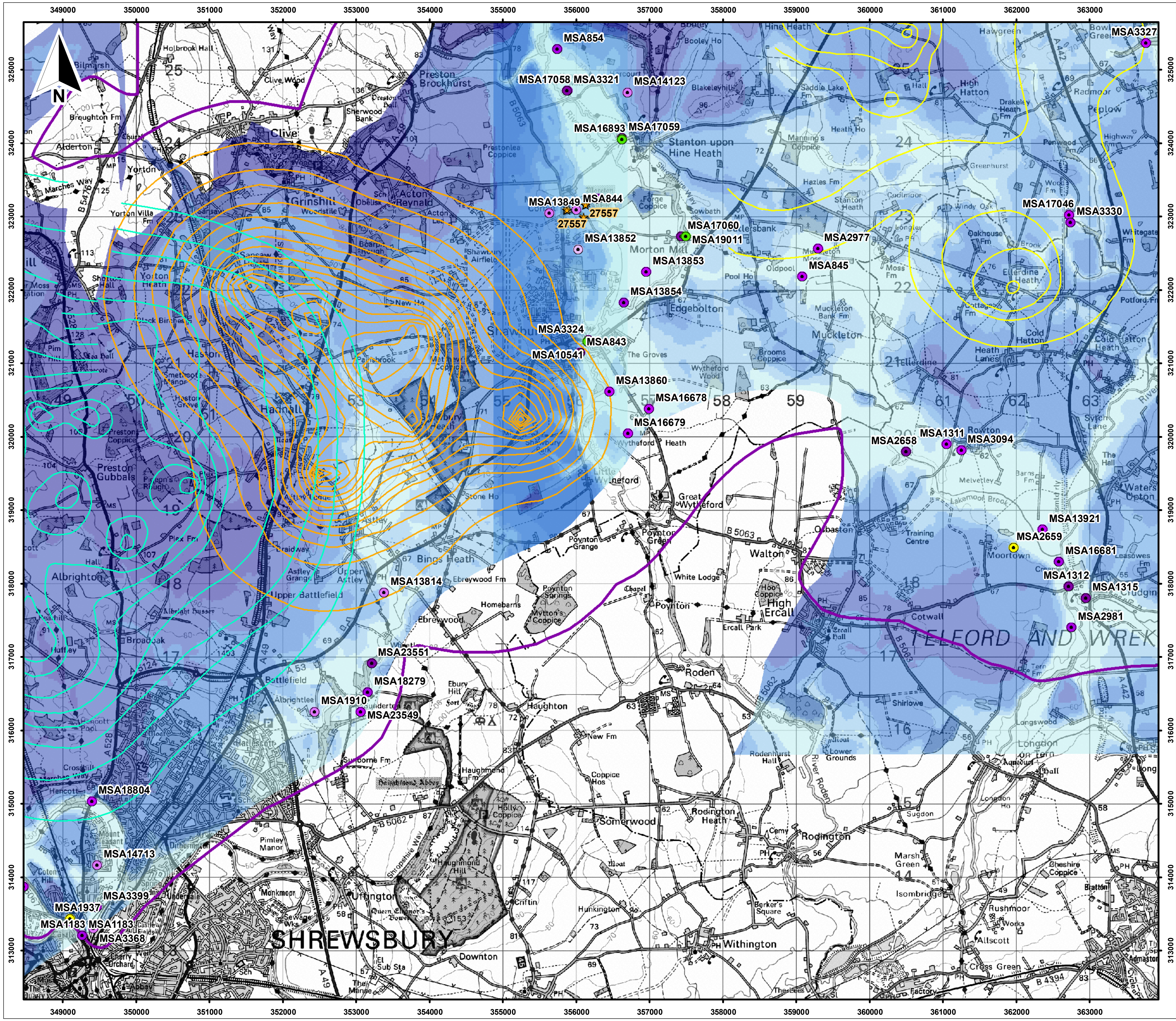
HER No.	Monument Type	NGR	Sensitivity	P1 m bgl	P2 m bgl
MSA1898	Watermill	SJ 42125 20375	high		7
MSA17007	Watermill	SJ 42227 19648	high		6
MSA17007	Watermill	SJ 42227 19648	high		6
MSA127	Fishpond	SJ 43449 14404	high		7
MSA1940	Fish Weir	SJ 44200 16700	high		5
MSA1937	Fish Weir	SJ 49100 13439	high		11
MSA17610	Watermill	SJ 61860 28930	high	7.46	
MSA2659	Fishpond, Reservoi	SJ 61966 18494	high	4.92	
MSA16523	Watermill, Watermi	SJ 62505 29835	high	4.28	
MSA3232	Pond	SJ 65145 29916	high	4.45	
MSA1204	Moat, Moated Site	SJ 66563 20138	high	5.90	
MSA1061	Castle	SJ 67789 19258	high	5.37	
MSA819	Multivallate Hillf	SJ 68131 17882	med	4.20	
MSA13537	Holy Well, Spring	SJ 68767 21754	high	7.62	

Table A.3 Bridges within SGS Outer Protected Zone Recorded on HER

HER No.	Monument Type	NGR	Sensitivity
MSA10541	Bridge	SJ 56155 21302	med
MSA10557	Bridge	SJ 54861 26761	med
MSA11025	Bridge	SJ 43939 17046	med
MSA16893	Bridge	SJ 56625 24055	med

[2] Sites which may require further consideration before they are discounted from further assessment

HER No.	Monument Type	NGR	Sensitivity
MSA19011	Road Bridge	SJ 57495 22735	med
MSA7703	Road Bridge	SJ 43195 15317	med
MSA8695	Bridge	SJ 64855 20705	med
MSA8896	Bridge	SJ 68105 20475	med



Key:

- SGS outer protected zone
- Scheduled monument

HER records

Susceptibility to changes in groundwater (1-5)

- 1
- 2
- 3
- 4
- 5
- Special case
- Bridge

P1/P2 groundwater depth map

Depth to groundwater (m)

- < 2
- 2 - 4
- 4 - 6
- 6 - 15
- 15 - 30
- > 30

0.5 0.25 0 0.5 1 1.5 2 Kilometres

Scale: 1:50,000 @ A3

Shropshire Groundwater Scheme
Archaeological Appraisal -Stage 1

Figure 3.1a
Potentially Susceptible Archaeological Sites

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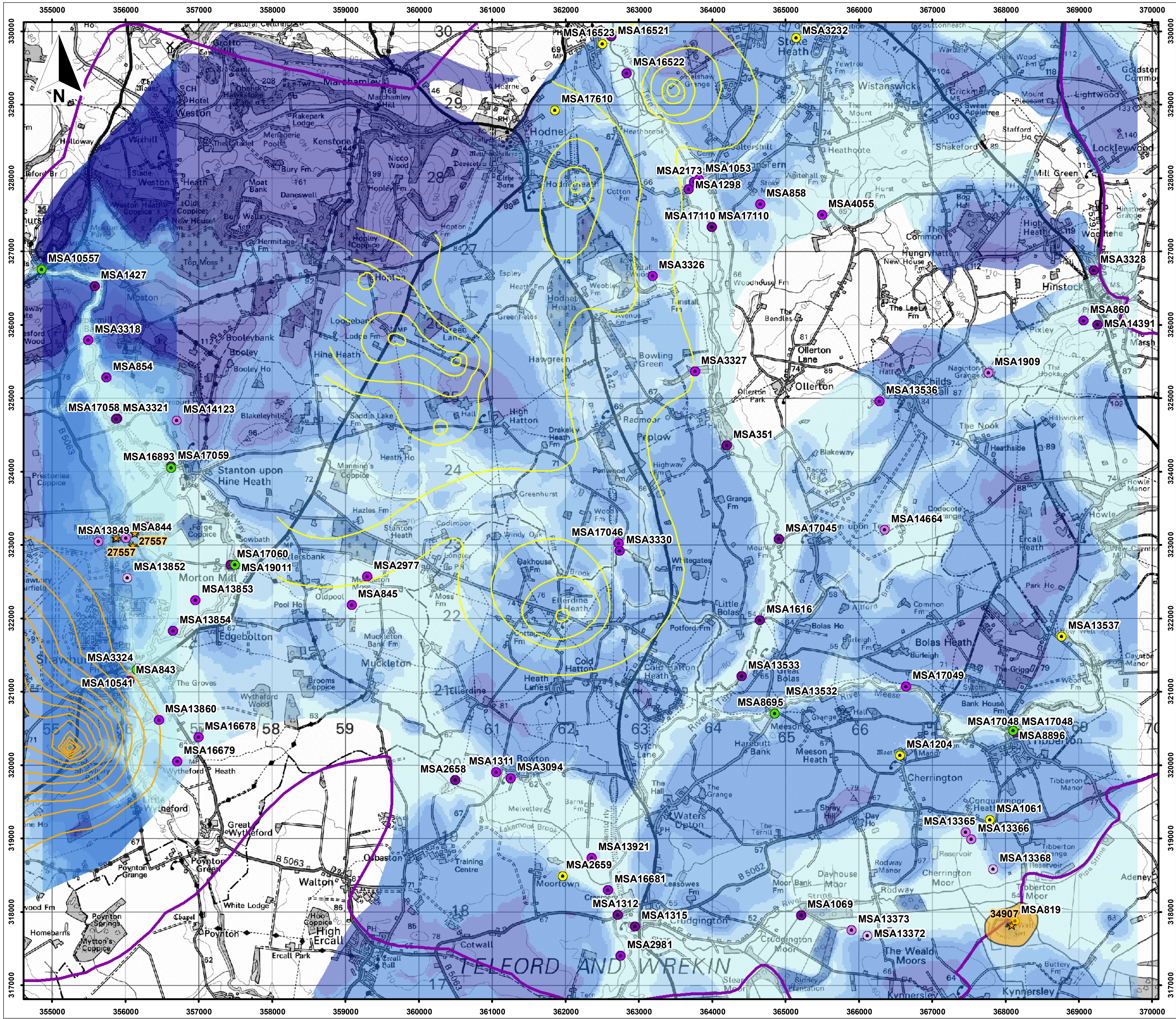

Key:

- SGS outer protected zone
- Scheduled monument

HER records

Susceptibility to changes in groundwater (1-5)

- 1
- 2
- 3
- 4
- 5
- Special case
- Bridge

P1/P2 groundwater depth map

Depth to groundwater (m)

- < 2
- 2 - 4
- 4 - 6
- 6 - 15
- 15 - 30
- > 30

0.5 0.25 0 0.5 1 1.5 2 Kilometres

Scale: 1:50,000 @ A3

Shropshire Groundwater Scheme
Archaeological Appraisal -Stage 1

Figure 3.1a
Potentially Susceptible Archaeological Sites

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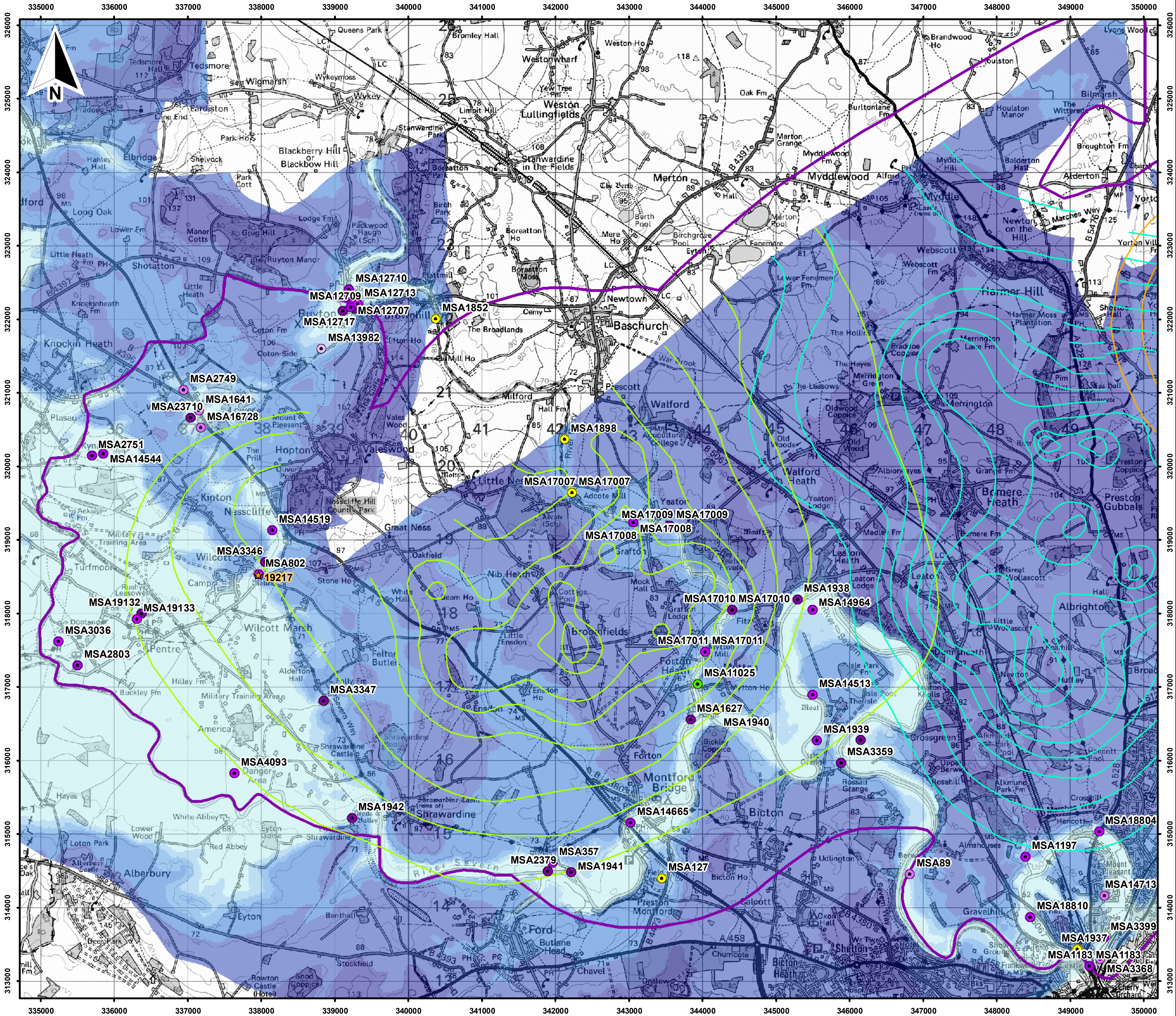

Shropshire Groundwater Scheme
Archaeological Appraisal -Stage 1

Figure 3.1a
Potentially Susceptible Archaeological Sites

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