Environment Agency

Evidence

Assessment of the impact of hydropower on weir pool features

Report appendix – SC120077/R2

We are the Environment Agency. We protect and improve the environment and make it a better place for people and wildlife.

We operate at the place where environmental change has its greatest impact on people's lives. We reduce the risks to people and properties from flooding; make sure there is enough water for people and wildlife; protect and improve air, land and water quality and apply the environmental standards within which industry can operate.

Acting to reduce climate change and helping people and wildlife adapt to its consequences are at the heart of all that we do.

We cannot do this alone. We work closely with a wide range of partners including government, business, local authorities, other agencies, civil society groups and the communities we serve.

This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH

www.gov.uk/government/organisations/environment-agency

ISBN: 978-1-84911-362-5

Author(s):
Dr David Mould, Jonathan Whitmore, Sebastian Bentley, Laura Thomas, Dr Helen Moggridge

Dissemination Status:
Publicly available

Keywords:
Hydropower, weir pools, river habitats, depleted reach, predictive tool, on-weir

Research Contractor:
JBA Consulting, Salts Mill, Victoria Road, Saltaire, Shipley, BD18 3LF.
Telephone: +441274714269

Environment Agency's Project Manager:
Stephanie Cole, Evidence Directorate

Project Number:
SC120077/R2

Evidence at the Environment Agency

Evidence underpins the work of the Environment Agency. It provides an up-to-date understanding of the world about us, helps us to develop tools and techniques to monitor and manage our environment as efficiently and effectively as possible. It also helps us to understand how the environment is changing and to identify what the future pressures may be.

The work of the Environment Agency's Evidence Directorate is a key ingredient in the partnership between research, guidance and operations that enables the Environment Agency to protect and restore our environment.

This report was produced by the Scientific and Evidence Services team within Evidence. The team focuses on four main areas of activity:

- **Setting the agenda**, by providing the evidence for decisions;
- **Maintaining scientific credibility**, by ensuring that our programmes and projects are fit for purpose and executed according to international standards;
- **Carrying out research**, either by contracting it out to research organisations and consultancies or by doing it ourselves;
- **Delivering information, advice, tools and techniques**, by making appropriate products available.

Miranda Kavanagh

Director of Evidence

Contents

1	**Purpose of appendix**	**5**
2	**Legislative protection of weir pool features**	**7**
2.1	Overarching legislation	7
2.2	Protected species	8
2.3	Protected habitats	10
3	**Romney Weir**	**13**
3.1	Site characteristics	13
3.2	Previous studies and supplied data	14
3.3	Current status	15
3.4	Scoping process	18
3.5	Hydraulic modelling details	22
3.6	Hydraulic habitat change	28
3.7	Interpretation	33
4	**Pershore Weir**	**37**
4.1	Site characteristics	37
4.2	Previous studies and supplied data	37
4.3	Current status	37
4.4	Scoping process	39
4.5	Hydraulic modelling – details	43
4.6	Hydraulic habitat mapping	48
4.7	Interpretation	53
5	**Goring Weir**	**57**
5.1	Site characteristics	57
5.2	Previous studies and supplied data	57
5.3	Current status	58
5.4	Scoping process	60
5.5	Hydraulic modelling – details	63
5.6	Hydraulic habitat mapping	70
5.7	Interpretation	74
References		**77**

List of tables and figures

Table 2.1 Relevant BAP species 9
Table 3.1 Previous studies at Romney Weir 14
Table 3.2 Other information used at Romney Weir 14
Table 3.3 Environment Agency fish population survey data at locations in proximity to Romney Weir 15
Table 3.4 Macrophyte species recorded at Romney Weir 17
Table 3.5 Information on adjacent instream structures from Environment Agency River Obstructions Database 18
Table 3.6 Is the site in an SSSI/SAC? (i.e. in a designated site) 19
Table 3.7 Are fish species known to be present at low frequencies/densities in the catchment likely to be exploiting the complex of habitats associated with the weir pool? 20
Table 3.8 Is the weir pool type habitat rare? (i.e. is the deeper pool and gravel shoal type environment found frequently either locally or elsewhere along the river system, beyond the influence of the weir itself and where the flow and sediment regime is less constrained or influenced?) 20
Table 3.9 Is the morphology of the habitat complex good quality? (i.e. is the gravel shoal relatively clean and free from fine sediment, providing better habitat condition?) 22
Table 3.10 Grid building approach – Romney 23
Table 3.11 Modelled flows before hydropower installation 24
Table 3.12 Modelled flows after scheme installation 25
Table 3.13 Summary of Romney model boundaries 25
Table 3.14 Comparison of 2D and 3D results 32
Table 4.1 Supplied data – Pershore 37
Table 4.2 Environment Agency fish population survey data at locations in proximity to Pershore Weir 38
Table 4.3 Information on adjacent instream structures from Environment Agency Rivers Obstructions Database 39
Table 4.4 Is the site in an SSSI/SAC? (i.e. in a designated site) 41
Table 4.5 Are fish species known to be present at low frequencies/densities in the catchment likely to be exploiting the complex of habitats associated with the weir pool? 42
Table 4.6 Is the weir pool type habitat rare? (i.e. is the deeper pool and gravel shoal type environment found frequently either locally or elsewhere along the river system, beyond the influence of the weir itself and where the flow and sediment regime is less constrained or influenced?) 42
Table 4.7 Is the morphology of the habitat complex good quality? (i.e. is the gravel shoal relatively clean and free from fine sediment, providing better habitat condition?) 42
Table 4.8 Summary of DEM build approach at Pershore 43
Table 4.9 Pershore modelled scenarios 44
Table 4.10 Flow availability and splits at Pershore Weir 45
Table 4.11 Summary of Pershore model boundaries 45
Table 4.12 Pershore model calibration 47
Table 4.13 Water depth tolerances of species present (from Newbold and Mountford 1997) 54
Table 5.1 Data supplied for Goring Weir 57
Table 5.2 Previous studies at Goring Weir 57
Table 5.3 Environment Agency fish population survey data at locations in proximity to Goring Weir 58
Table 5.4 Information on adjacent instream structures from Environment Agency Rivers Obstructions Database 60
Table 5.5 Is the site in an SSSI/SAC? (i.e. in a designated site) 62
Table 5.6 Are fish species known to be present at low frequencies/densities in the catchment likely to be exploiting the complex of habitats associated with the weir pool? 62
Table 5.7 Is the weir pool type habitat rare? (i.e. is the deeper pool and gravel shoal type environment found frequently either locally or elsewhere along the river system, beyond the influence of the weir itself and where the flow and sediment regime is less constrained or influenced?) 62
Table 5.8 Is the morphology of the habitat complex good quality? (i.e. is the gravel shoal relatively clean and free from fine sediment, providing better habitat condition?) 63
Table 5.9 Details of Goring DEM generation 63
Table 5.10 Flow availability and splits at Goring Weir 65
Table 5.11 Details of Goring model boundaries 66
Table 5.12 Recorded water levels (calibration) 67
Table 5.13 Goring model calibration results 67

Figure 3.1 Digital elevation model used in the hydraulic model 13
Figure 3.2 Location of adjacent instream barriers given in Table 3.5 19
Figure 3.3 Google Earth aerial imagery at Romney Weir (image copyright Google Earth 2014) 21
Figure 3.4 Google Earth Aerial imagery at meander adjacent to Windsor Racecourse showing point bar 21
Figure 3.5 Google Earth imagery just upstream of meander showing possible shallow gravel features 22
Figure 3.6 Romney Weir 2010 ADCP survey extent 24
Figure 3.7 Romney model schematic 26
Figure 3.8 Q30 Manning's roughness sensitivity plot (velocity) 27
Figure 3.9 Q95 pre-installation downstream boundary sensitivity plot (velocity) 28
Figure 3.10 Difference maps showing the change in modelled velocities 30
Figure 3.11 Cumulative frequency plots of velocity (whole weir pool complex) 31
Figure 3.12 Cumulative frequency plots of velocity (shoal only) 32
Figure 4.1 Location of adjacent instream barriers given in Table 4.3 40
Figure 4.2 Pershore Weir December 2012 ADCP survey extent 44
Figure 4.3 Pershore post-installation model grid 46
Figure 4.4 Q20 Manning's roughness sensitivity plot 47
Figure 4.5 Q20 Manning's roughness sensitivity plot 48
Figure 4.6 Frequency plots for Pershore 49
Figure 4.7 Pershore difference maps – Q95 50

Figure 4.8 Pershore difference maps – Q50 51
Figure 4.9 Pershore difference maps – Q20 52
Figure 5.1 Location of adjacent instream barriers given in Table 5.4 61
Figure 5.2 Data availability for Goring DEM generation 64
Figure 5.3 Goring post-installation model grid (2013) 66
Figure 5.4 Model calibration plots (Goring) 68
Figure 5.5 Sensitivity test results (Goring) 69
Figure 5.6 Comparison of 2013 and 2014 results 71
Figure 5.7 Velocity cumulative frequency plots (Goring) 72
Figure 5.8 Difference maps (Goring) 73
Figure 5.9 Changes in spawning Habitat Suitability Index predicted at Goring at Q50 76

1 Purpose of appendix

This report forms an appendix to the main report of project SC120077/R1, 'Assessment of the impact of hydropower on weir pool features', and as such does not form a standalone document and should not be read in isolation. Each of the chapters within this appendix provides specific supplementary information for a section of the main report. Section 2 of this appendix provides supplementary background information to the review of legislative protection to weir pools presented in section 2.1 of the main report. Sections 3, 4 and 5 of this appendix provide further details on the work conducted at each of the case studies presented in the main report.

2 Legislative protection of weir pool features

2.1 Overarching legislation

Weir pools that contain protected species or habitats may be covered by specific legislation or by more general overarching legislation protecting the quality of rivers and their flora and fauna.

Under the Environment Act 1995,[1] the Environment Agency has a general duty to promote:

- The conservation and enhancement of the natural beauty and amenity of inland and coastal waters and of land associated with such waters.
- The conservation of flora and fauna which are dependent on an aquatic environment.
- The use of such waters and land for recreational purposes and in this respect the Agency should take into account the needs of the persons who are chronically sick or disabled.

The European Water Framework Directive (WFD) was transposed into national law in 2003 by the Water Environment (Water Framework Directive) (England and Wales) Regulations 2003 (HMSO 2003). Its purpose is to establish a framework for the protection of water bodies (including lakes, streams and rivers), groundwaters and dependent ecosystems, estuaries and coastal waters which aims to:

- Prevent deterioration in the status of aquatic ecosystems, protect them and improve the ecological condition of waters.
- Achieve at least good ecological status/potential for all waterbodies by 2015. Where this is not possible, aim to achieve good status/potential by 2021 or 2027.
- Promote sustainable use of water as a natural resource.
- Conserve habitats and species that depend directly on water.
- Progressively reduce or phase out the release of individual pollutants or groups of pollutants that present a significant threat to the aquatic environment.
- Progressively reduce the pollution of groundwater and prevent or limit the entry of pollutants.
- Contribute to mitigating the effects of floods and droughts.

The quality elements for classification of ecological status (Rivers) are stated in Annex V of the Directive.[2] Of particular interest with respect to hydropower impacts are the biological and hydromorphological elements, as noted below.

---

[1] http://www.legislation.gov.uk/ukpga/1995/25/contents. Accessed 7 November 2013.

[2] http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ%3AL%3A2000%3A327%3A0001%3A0072%3AEN%3APDF. Accessed 7 November 2013.

Biological elements

- Composition and abundance of aquatic flora
- Composition and abundance of benthic invertebrate fauna
- Composition, abundance and age structure of fish fauna

Hydromorphological elements supporting the biological elements

- Hydrological regime
- Quantity and dynamics of water flow
- Connection to groundwater bodies
- River continuity
- Morphological conditions
- River depth and width variation
- Structure and substrate of the river bed
- Structure of the riparian zone

The Environment Agency has a duty to ensure that permitted development does not compromise the ability of a waterbody to meet appropriate ecological status. Therefore, the impacts of a hydropower scheme on the above biological and hydromorphological elements have to be fundamentally considered in the design and operation of a hydropower scheme by both the developer and the regulator. The Water Framework Directive also requires that there should be no deterioration in ecological status.

The Water Resources Act 1991 (Amendment) Regulations 2009 SI 3104 amends the Water Resources Act 1991 by extending the use of Water Protection Zones and Works Notices, in particular to deal with harm to aquatic ecosystems caused by the physical characteristics of a watercourse such as the condition of river banks. As in the Water Framework Directive, hydromorphological quality elements include physical characteristics of waterbodies, such as quantity and dynamics of flow; shape, width, depth and pattern of the channel; and condition of beds, banks and riparian zone (in the case of rivers) and shores (in the case of lakes and coastal waters). These interact with and affect the biological and chemical quality of water.

2.2 Protected species

The Wildlife and Countryside Act 1981[3] implements the Convention of European Wildlife and Natural Habitats, the Bern Convention, European Union directives on the conservation of wild birds and the Natural Habitats and Wild Fauna and Flora Directive.

Section 9 of Part 1 of the Act prohibits the intentional killing, injuring or taking, the possession and the trade in wild animals listed in Schedule 5. In addition, places used for shelter and protection are safeguarded against intentional damage, destruction and obstruction, and animals protected under the relevant part of Section 9 must not intentionally be disturbed while occupying those places. The following species are included in Schedule 5: Allis Shad (*Alosa alosa*), Atlantic Crayfish (*Austropotamobius pallipes*), Freshwater Pearl Mussel (*Margaritifera margaritifera*) and Twaite Shad (*Alosa fallax*).

[3] http://www.legislation.gov.uk/ukpga/1981/69/contents. Accessed 7 November 2013.

Similarly, Section 13 identifies measures for the protection of wild plants. It prohibits the unauthorised intentional uprooting of any wild plant species and forbids any picking, uprooting or destruction of plants listed on Schedule 8. It provides certain defences (e.g. provision to cover incidental actions that are an unavoidable result of an otherwise lawful activity). The only relevant plant listed in Schedule 8 is the Adder's Tongue (*Ranunculus ophioglossifolius*) and this is very rare in the UK, isolated in one site at Badgerworth, Gloucestershire.

The Natural Environment and Rural Communities (NERC) Act 2006[4] sets out Natural England's statutory purpose:

> *To ensure that the natural environment is conserved, enhanced and managed for the benefit of present and future generations, thereby contributing to sustainable development.*

Furthermore, Section 40(1) of the NERC Act 2006 imposes a duty on public authorities to conserve biodiversity:

> *Every public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity.*

Section 41 of the NERC Act states that the Secretary of State will produce a list of living organisms and types of habitat which are of principal importance for the purpose of conserving biodiversity. The England Biodiversity Action Plan (BAP) list of species of principal importance satisfies the requirements of section 41 of the NERC Act. The UK Biodiversity Action Plan (UK BAP) was first published in 1994, as the UK Government's response to the Convention on Biological Diversity (CBD), which the UK signed up to in 1992 in Rio de Janeiro. This was succeeded in July 2012 by the 'UK Post 2010 Biodiversity Framework' (JNCC and Defra 2012), which demonstrates how current work contributes to achieving the targets and identifies the activities required to complement the biodiversity strategies in achieving the targets. Table 2.1 shows the English BAP species relevant to the current review.

Table 2.1 Relevant BAP species

Fish	Allis Shad (*Alosa alosa*), Twaite Shad (*Alosa fallax*), European Eel (*Anguilla anguilla*), Spined Loach (*Cobitis taenia*), River Lamprey (*Lampetra fluviatilis*), Sea Lamprey (*Petromyzon marinus*), Atlantic Salmon (*Salmo salar*), Brown/Sea Trout (*Salmo trutta*)
Invertebrates	Norfolk Hawker (*Aeshna isosceles*), Brown Diving Beetle (*Agabus brunneus*), Pale Pin-palp (*Bembidion testaceum*), Minutest Diving Beetle (*Bidessus minutissimus*), One-grooved Diving Beetle (*Bidessus unistriatus*), Northern February Red (*Brachyptera putata*), Southern Silver Stiletto-fly (*Cliorismia rustica*), Southern Damselfly (*Coenagrion mercurial*), Small Grey Sedge (*Glossosoma intermedium*), Spangled Diving Beetle (*Graphoderus zonatus*), Window Winged Sedge (*Hagenella clathrata*), New Forest Mud Beetle (*Helophorus laticollis*), Gravel Water Beetle (*Hydrochus nitidicollis*), Lesser Water-measurer (*Hydrometra gracilenta*), Ron's Diving Beetle (*Hydroporus necopinatus* subsp. *roni*), Oxbow Diving Beetle (*Hydroporus rufifrons*), Scarce Grey Flag (*Hydropsyche bulgaromanorum*), Scarce Brown Sedge (*Ironoquia dubia*), Scarce Yellow Sally (*Isogenus nubecula*), Sussex Diving Beetle (*Laccophilus poecilus*), Iron Blue Mayfly (*Nigrobaetis niger*), Yellow Mayfly (*Potamanthus luteus*), River-shore Cranefly (*Rhabdomastix japonica*)

[4] http://www.legislation.gov.uk/ukpga/2006/16/contents. Accessed 7 November 2013.

Macrophytes	Ribbon-leaved Water-plantain (*Alisma gramineum*), Floating Water-plantain (*Luronium natans*), Sharp-leaved Pondweed (*Potamogeton acutifolius*), Grass-wrack Pondweed (*Potamogeton compressus*), Three-lobed water crowfoot (*Ranunculus tripartitus*)

It is worth noting that many of the invertebrates listed in Table 2.1 are extremely rare, sometimes limited to a single site and in general the macrophyte species prefer slow flowing water so are unlikely to be prevalent in weir pools.

The Salmon and Freshwater Fisheries Act (1975)[5] and the Eels Regulations (2009)[6] also provide significant protection for their species of interest; however, the legislation is not directly relevant to the protection of weir pool hydromorphology or ecology.

2.3 Protected habitats

Part II of the Wildlife and Countryside Act 1981[7] provides for the designation of protected areas including sites of Special Scientific Interest (SSSIs) and National Nature Reserves. SSSIs are legally protected under the Wildlife and Countryside Act 1981, as amended by the Countryside and Rights of Way (CROW) Act 2000[8] and the NERC Act 2006.

The legislation gives Natural England power to ensure better protection and management of SSSIs and safeguard their existence into the future. By 2020, the government's objective is to see that 50% of the total area of SSSIs is in a favourable condition, while at least 45% of the remaining SSSIs are in a stage of recovery and can be expected to reach favourable condition, once management plans have taken effect.

Under Section 28G of the Wildlife and Countryside Act 1981 (as amended), a number of authorities (known as 'Section 28G authorities' and those to which Section 40 of the NERC Act 2006 also apply) have a duty to take reasonable steps, consistent with the proper exercise of their functions, to further the conservation and enhancement of the flora, fauna or geological or physiographical features by reason of which a site has been designated an SSSI. Section 28G authorities include the Environment Agency and local authorities.

The Conservation of Habitats and Species Regulations 2012 (as amended)[9] consolidate all the various amendments made to the Conservation (Natural Habitats, &c.) Regulations 1994 in respect of England and Wales. The 1994 Regulations transposed Council Directive 92/43/EEC on the conservation of natural habitats and of wild fauna and flora (EC Habitats Directive) and Directive 79/409/EEC on the conservation of wild birds into national law.

European sites include Special Areas of Conservation (SACs) and Special Protection Areas (SPAs), which together are known as 'Natura 2000' sites. SACs are strictly protected sites designated under the EC Habitats Directive.

Article 3 of the Habitats Directive requires the establishment of a European network of important high quality conservation sites that will make a significant contribution to conserving the 189 habitat types and 788 species identified in Annexes I and II of the Directive (as amended). Annex II species include Atlantic Salmon (*Salmo salar*), Brook Lamprey (*Lampetra planeri*), River Lamprey (*Lampetra fluviatilis*) and the Freshwater

5 http://www.legislation.gov.uk/ukpga/1975/51/contents. Accessed 7 November 2013.
6 http://www.legislation.gov.uk/uksi/2009/3344/contents/made. Accessed 7 November 2013.
7 http://www.legislation.gov.uk/ukpga/1981/69/contents. Accessed 7 November 2013.
8 http://www.legislation.gov.uk/ukpga/2000/37/contents. Accessed 7 November 2013.
9 http://www.legislation.gov.uk/uksi/2012/1927/contents/made. Accessed 7 November 2013.

Pearl Mussel (*Margaritifera margaritifera*). The listed habitat types and species are those considered to be most in need of conservation at a European level. These listed habitats and species are described as ‘Special Interest Features’ and form the key focus of the Conservation Objectives of SAC sites, all of which are also SSSIs.

3 Romney Weir

3.1 Site characteristics

Romney Weir is located on the River Thames near Eton. Romney Weir was installed as part of the Thames Navigation and before hydropower construction consisted of 10 radial gates, each around 4.5 m wide (bays 2 to 11), with an 11th smaller gate on the left hand bank (2.44 m wide). A fish pass was located adjacent to the right bank (bay 1).

A hydropower scheme was installed and became operational from January 2013. The scheme involved the installation of two Archimedes screw turbines located in bays 2 and 3 adjacent to the right bank. The fish pass in bay 1 was also improved. A number of studies have been undertaken as part of the consenting process for this scheme (section 3.2).

Before the scheme was installed, the majority of the flow was released through gates close to the left hand bank (ARUP 2013).

The 2010 bathymetric survey shows a large weir pool followed by a shallow depositional gravel shoal around 80 m downstream of the weir (Figure 3.1). The gravel shoal is a key feature as it can provide spawning habitat for rheophilic fish in an otherwise slow flowing stretch of river. The gravel shoal is composed of fine to coarse gravels with some cobbles (no specific sediment size information was available at the time of writing). There was little fine sediment found in the weir pool during the ecological sampling in 2013 (Jacobs 2013a).

Some variation in weir pool bathymetry was observed by Jacobs (2013a) between the 1998, 2003 and 2010 surveys, mainly as a result of gate operational patterns, possible dredging by the Environment Agency and flood events between surveys.

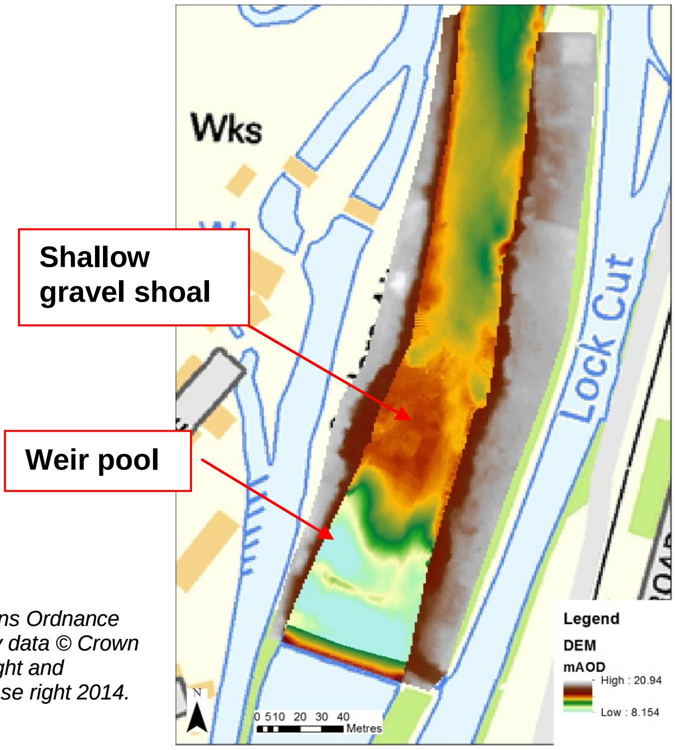


Figure 3.1 Digital elevation model used in the hydraulic model

3.2 Previous studies and supplied data

A number of previous studies have been undertaken at this site (Table 3.1).

Table 3.1 Previous studies at Romney Weir

Desk study	A morphological and ecological desk study was undertaken by Jacobs in 2012. The study concluded the risk of morphological change resulting from the scheme was small and any adverse impact on aquatic habitat localised, and made recommendations for further ecological sampling.
Modelling	ARUP (2013) undertook three-dimensional (3D) computational fluid dynamics (CFD) modelling of Romney Weir. The report concluded that although the flow patterns were altered following the installation of the hydropower scheme, scalar velocities over the key gravel shoal of interest showed only a minor increase compared to pre-change simulation results. The results from the current modelling study will be compared against these findings.
Ecological survey	There was a macroinvertebrate survey of Romney Weir by APEM (2008). The results suggested that the water quality at the site was good and not influenced by organic pollution. No rare species were found with a requirement for high flow velocities.
	A baseline survey (Jacobs 2013a), building on the 2012 Jacobs desk study undertook macroinvertebrate and macrophyte sampling. The macrophyte status downstream of Romney Weir could be classified as good, with the nationally scarce Constricted Feather-moss *Amblystegium humile* recorded in small numbers. The macroinvertebrate survey found a number of species with a preference for moderate to fast water velocities, and four species of conservation interest.

Further to the reports listed in Table 3.1, a range of other information, provided by the Environment Agency, was used in this work (Table 3.2).

Table 3.2 Other information used at Romney Weir

Survey	October 1998 soundings survey of Romney Weir pool and surroundings, undertaken by Environment Agency, Thames Region.
	July 2003 Romney Weir pool bathymetry survey, undertaken by the Environment Agency, Thames Region.
	September 2010 Romney Weir pool bathymetry survey, undertaken by the Environment Agency, Thames Region.
	Drawings produced by Atkins as part of the Romney 'A' weir Urgent Works project, which gives detailed dimensions of the weir in plan and long sections. Drawings 5103334/WA/003 and 5103334/WA/002 were used.
Ecological data/survey reports	The Environment Agency provided invertebrate, macrophyte and fisheries data for nearby sites. Further details are given in the relevant sections.

3.3 Current status

Romney Weir sits within the River Thames (Cookham to Egham) heavily modified waterbody (ref GB106039023231) that is currently classed as achieving moderate ecological potential and therefore failing Water Framework Directive objectives. The fish, macrophyte and macroinvertebrate quality elements are currently classed respectively as moderate, high and no information.

3.3.1 Fish populations

The nearest available fish population survey data held by the Environment Agency relates to juvenile surveys undertaken at the following sites in the summer of 2012: Boveney 1.5 km upstream of Romney Weir; Eton 0.45 km downstream of Romney Weir. This data revealed the presence of both rheophilic and eurytopic freshwater fish species, with no statistical difference in species composition between the two survey sites (Nunn et al. 2013).

The Environment Agency also provided fish survey data which included a further site at Boveney, approximately 3.2 km upstream of Romney Weir, and a site at Datchet, approximately 0.8 km downstream of Romney Weir. Again, both rheophilic and eurytopic species were caught at both sites. Adult European Eel *Anguilla anguilla* were also caught at both sites during surveys undertaken in 2013. Brook Lamprey *Lampetra planeri* ammocoetes were caught 3.2km upstream of the Boveney site in 2004. Table 3.3 summarises the species caught at each site mentioned above.

Table 3.3 Environment Agency fish population survey data at locations in proximity to Romney Weir

Site name	Grid reference	Approximate location	Date of survey	Species recorded
Boveney	SU956774	1.5 km upstream of Romney Weir	Aug 2012	Rheophilic: Chub; Dace; Gudgeon; Barbel; Minnow Eurytopic: Bleak; Common Bream; Perch; Roach
Boveney	SU9454777812	3.2 km upstream of Romney Weir	Sept 1995; Sept 1998; annually (in Sept) 2000 to 2010 inclusive	Rheophilic: Chub; Dace; Gudgeon; Barbel; Brook Lamprey; Brown Trout; Brook Lamprey Eurytopic: Bleak; Common Bream; Perch; Pike; Ruffe; Roach; Common carp varieties; Mirror Carp; European Eel; Silver Bream Limnophilic: Tench
Eton	SU969779	0.45 km downstream of Romney Weir	Aug 2012	Rheophilic: Chub; Dace; Gudgeon; Minnow Eurytopic: Bleak; Common Bream; Perch; Roach
Datchet	SU9860676374	0.8 km downstream of Romney Weir	Annually (in Sept) 2005 to 2013 inclusive	Rheophilic: Dace Eurytopic: Bleak; Common Bream; Perch; Pike; Ruffe; Roach; European Eel Limnophilic: Tench

A diversity of fish guilds were found to be present both upstream and downstream of Romney Weir.

3.3.2 Invertebrate populations

Invertebrate baseline data from the site was available for 2008 (APEM 2008) and for 2012 (Jacobs 2013a). The 2008 survey (conducted in spring) consisted of a spatial comparison of invertebrate communities from upstream and downstream (60−260 m) of Romney Weir and from two side channels. Within the main channel, the survey showed similarities in community composition upstream and downstream of the weir and overall LIFE (Lotic Invertebrate Index for Flow Evaluation, Extence et al. 1999) scores of around 6.95−7.13. Invertebrate communities were predominantly common species of large, lowland rivers, although two species of significant conservation value were found: *Macronychus quadrituberculatus*, listed in the Red Data Book as 'rare' (RBD3) and recorded in the main channel upstream and downstream of the weir; and *Stenelmis canaliculata*, listed as vulnerable (RDB2) and recorded in a side channel. Also of note was a recording of the Depressed River Mussel *Pseudanodonta complanata*, listed as 'notable' by Chadd and Extence (2004), in the main channel 260 m downstream of the weir.

The invertebrate survey of 2012 sampled at three locations (left, centre and right of the channel) on and around the gravel shoal and 200 m downstream of the weir, in spring and autumn. Analysis of similarity of community composition between samples showed distinctions between seasons and greater similarity between left and centre samples from the gravel shoal rather than right samples. Samples also showed some similarity with communities 200 m downstream. The survey recorded the same three species of conservation interest as found in the 2008 survey: *Macronychus quadrituberculatus* and *Pseudanodonta complanata* were recorded downstream of the weir (left and right bank, respectively) and *Stenelmis canaliculata* was recorded both downstream of the weir (left bank) and on the gravel shoal (left bank). Additionally, *Leptocerus lustianicus*, designated as 'vulnerable' by Chadd and Extence (2004), was recorded downstream of the weir (right bank). None of these species are known to require fast flows or be highly sensitive to sedimentation.

The survey reported invertebrate communities in and around the gravel shoal to be indicative of moderately sedimented (centre) and sedimented conditions (left and right bank), following Extence et al.'s (2011) classification, although this is partly attributed to sampling in deep water habitat. Some species classified as highly sensitive to fine sediment deposition were recorded on and around the gravel shoal samples, although these were generally in very low abundances. Of these, *Brachycentrus subnubilus*, listed as 'regionally notable' according to its distribution (following Chadd and Extence 2004), was the most abundant. Other highly sensitive species included the Blue-winged Olive *Serratella ignita* (very common) and *Hydropsyche pellucidula* (common). Invertebrate samples 200 m downstream of the weir showed a similar trend, although with greater abundances of highly sensitive species such as *Ancylus fluviatillis* (very common) and *Aphelocheirus aestivalis* (local), especially on the right bank.

LIFE scores were also derived for all the sample sites in the 2012 survey, which were comparable to the 2008 survey. These showed consistently higher values in the centre of the gravel shoal (c. 7.3−7.7), indicative of faster flowing conditions, than the right (c. 6.9−7.2) and left bank (c. 7.0−7.4), with higher values in autumn rather than spring. A high proportion of the species recorded on both the gravel shoal and 200 m downstream of the weir had preferences for moderate to fast flows (0.2−1 m/s) (Extence et al. 1999). The most abundant of these were: *Brachycentrus subnubilus, Gammarus pulex* (very common) and *Theodoxus fluviatillis* (frequent), found in reasonably high abundances at all sites; *Elmis aenea* (very common) and *Ephemera danica* (very common), found in all samples, but most abundant 200 m downstream; and Simuliidae spp., found in all samples but most abundant left and centre of the gravel shoal.

Data was also available from the Environment Agency from Boveney Weir (1.5 km upstream of Romney Weir), from routine sampling, from May 1995 to September 2010. Overall LIFE scores for samples from the site (derived from family rather than species scores) were approximate to Romney Weir (average 6.47, range 5.92−7.14) and all four species of conservation interest observed at Romney were recorded.

3.3.3 Macrophyte populations

Baseline data on aquatic macrophytes has been obtained from previous ecological surveys around the weir undertaken in August 2012 (Jacobs 2013a). This survey involved sampling aquatic macrophytes from a boat within a 100 m section, crossing the river in a zig-zag pattern. Percentage cover of each taxon was also recorded along with an estimate of the overall percentage cover of macrophytes. The data was also analysed using the LEAFPACs methodology, which uses macrophyte species composition, diversity and abundance to assess the ecological status of a river. The survey area was undertaken within 50 m of the weir, and included the significant gravel bars just downstream of the deep weir pool.

A total of 16 species were recorded at Romney Weir, as detailed in Table 3.4 (Jacobs 2013a). This total number is relatively small given the size of the river; however, given the river's generally modified characteristics and uniformity in habitats within the channel, it is not unsurprising.

Table 3.4 Macrophyte species recorded at Romney Weir

Scientific name	Common name
Algae	
Cladophora glomerata	-
Gongrosira sp.	-
Stigeoclonium sp.	-
Vaucheria sp.	-
Bryophytes	
Amblystegium humile	Constricted Feather-moss
Fontinalis antipyretica	Greater Water Moss
Leptodictyun riparium	Kneiff's Feather-moss
Vascular plants	
Elodea nuttallii	Nuttall's Waterweed
Iris pseudacorus	Yellow Iris
Lycopus europaeus	Gypsywort
Lythrum salicaria	Purple loosestrife
Myosotis scorpioides	Water Forget-me-not
Ranunculus fluitans	River Water Crowfoot
Rorippa amphibia	Great Yellow-cress
Sparganium emersum	Unbranched Bur-reed
Symphytum officinale	Common Comfrey

Jacobs (2013a) report that River Water Crowfoot *Ranunculus fluitans* is the most dominant species, covering approximately 30% and located throughout the survey area and also rooted in the large mid-channel gravel bar and in the soft mud at the margins.

Percentage cover of the remaining taxa was small, with the exception of *Cladophora glomerata* which had a percentage cover value of 0.1%. The bryophytes recorded were mostly found attached to stones within the channel, but also occurred on the silty banks and occasionally on tree bases (Jacobs 2013a). Some algae species (e.g. *Gongrosia* sp.) were also found encrusted on rocks.

Nuttall's Waterweed *Elodea nuttallii*, a non-native invasive species listed on Schedule 9 of the Wildlife and Countryside Act 1981 (as amended), was recorded in small patches along the left and right banks. Across the surveyed reach, species found within the centre of the channel and across the gravel bar were species typically tolerant of coarse substrates. Species such as Unbranched Bur-reed *Sparganium emersum*, which are commonly found in slower flowing water over fine substrates, were not recorded in the central, gravely section of the channel, but were instead found within the silty margins (Jacobs 2013a).

3.4 Scoping process

3.4.1 Rationale

The purpose of this section is to apply the weir pool importance scoping process to the Romney site. This assessment has been undertaken using two approaches: the first uses freely available online resources and routine monitoring datasets held by the Environment Agency (reported under 'Desk study' in the tables below), and the second where all available information was used in the application of the scoping process (reported under 'Available reports' in the tables below).

3.4.2 Connectivity/weir pool rarity

The Environment Agency River Obstructions Database was used to determine the presence of potential instream barriers to migration in proximity to Romney Weir. Table 3.5 lists information relating to these barriers and Figure 3.2 shows their location.

Table 3.5 Information on adjacent instream structures from Environment Agency River Obstructions Database

Order	Barrier	Longitudinal/ lateral[1]	Distance from target barrier (km)[2]	Fish pass present (type)?	Head over barrier (P_HEAD; Z_Head; 25 m_Head; m)[3]	Total number of barriers to mean high water (STOTAL)	Approx. distance to mean high water – km (SLENGTH)
-	Romney Weir (13234)	-	0	Y (Alaskan-A)	1.077; 1.01; 2.78	9	42.2
1	11272	Lat (Colemorton Brook)	0.6 (0.05)	Unknown	1.018; 1.832; 1.872	9	41.7
2	11703	Lat (Willow Brook)	0.05	Unknown	0.33; 1.505; 2.531	9	41.3
3	13314	Long	1.1	Unknown	0.046; 0.139; 0.09	8	41.1
4	11505	Lat (Jubilee River)	1.7 (0.3)	Unknown	0.41; 0.33; 0.782	8	41.0
5	12662	Lat (Broad Water)	2.3 (0.04)	Unknown	-1.193; 1.259; -0.164	8	40.0
6	13228	Long	4.5	Y (Plain baffle Denil)	1.018; 1.139; 3.532	7	37.0
1 u/s	13316	Long	3.4	Larinier	0.607; 0.771; 1.846	10	45.5

Order	Barrier	Longitudinal/ lateral[1]	Distance from target barrier (km)[2]	Fish pass present (type)?	Head over barrier (P_HEAD; Z_Head; 25 m_Head; m)[3]	Total number of barriers to mean high water (STOTAL)	Approx. distance to mean high water – km (SLENGTH)
Notes 1 – Position of the barrier in relation to connectivity with main river channel 2 – Value given in parenthesis is distance from given barrier to main river channel 3 – Environment Agency River Obstructions Database derives head over weir in a number of ways. Values given relate to the respective method used to calculate head.							

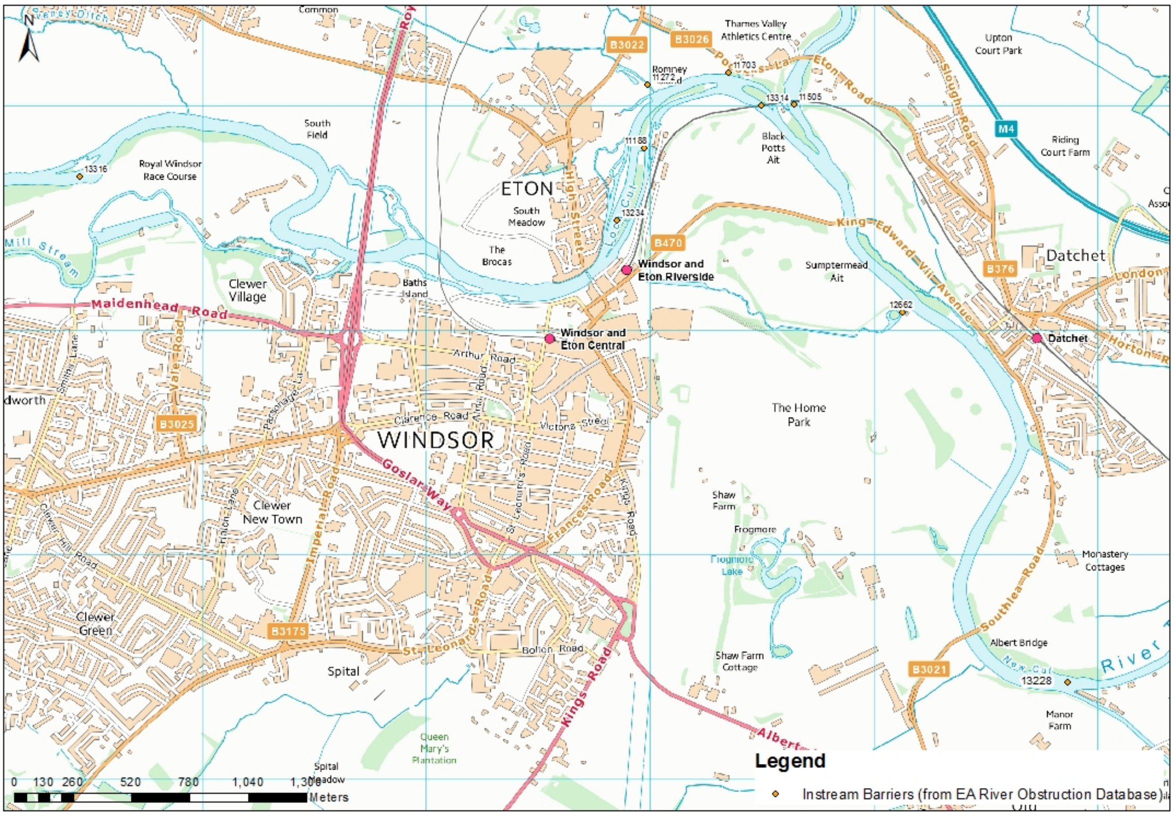


Figure 3.2 Location of adjacent instream barriers given in Table 3.5

3.4.3 Application of scoping process

Table 3.6 Is the site in an SSSI/SAC? (i.e. in a designated site)

	Evidence	Finding
Desk study	The Thames and surrounding area local to Romney Weir is not designated an SSSI or SAC.	No
Available reports	The Thames and surrounding area local to Romney Weir is not designated an SSSI or SAC.	No

Table 3.7 Are fish species known to be present at low frequencies/densities in the catchment likely to be exploiting the complex of habitats associated with the weir pool?

	Evidence	Finding
Desk study	Fish species of diverse habitat requirements were found both upstream and downstream of Romney Weir.	No
Available reports	Three macroinvertebrate species of significant conservation value are present in or near the weir pool complex.	Yes

Table 3.8 Is the weir pool type habitat rare? (i.e. is the deeper pool and gravel shoal type environment found frequently either locally or elsewhere along the river system, beyond the influence of the weir itself and where the flow and sediment regime is less constrained or influenced?)

	Evidence	Finding
Desk study	We used the Environment Agency River Obstructions Database and Google Earth imagery, both of which should be available at the scoping stage. Google Earth imagery shows limited evidence of local active areas (e.g. exposed gravel features and higher energy flow types) upstream and downstream of the site. There is a partial exposed point bar upstream at the meander close to Windsor Racecourse (Figure 3.4) and in the reach immediately upstream there are possibly some shallower areas where gravel has deposited (this is unclear from the imagery, Figure 3.5). The growth of the upstream point bar is likely to be limited by protected banks (although this cannot be verified from the imagery). Further upstream, ponded flow behind the weir at Boveney Lock controls channel processes with less morphological activity. Although it is not possible to determine whether the upstream shallow areas are significant gravel features from aerial imagery, the scoured weir pool at Romney Weir, and in particular the associated gravel shoal just downstream, could be considered as a relatively rare morphological unit in the context of the rest of the local system (albeit a morphology controlled by weir processes rather than natural processes). Romney Weir and Old Windsor Weir downstream have fish passes which are likely to make the potentially rare riffle habitat between and above the two sites accessible to salmonids and large coarse fish, and therefore potentially important (more so than in the hypothetical situation where Romney Weir and the Old Windsor site are impassable to a broader range of species and life stages). At a larger scale, however, the Environment Agency River Obstructions Database indicates that Romney Weir is clearly not unique in terms of a barrier on the Thames; a further nine barriers are reported between Romney	Possibly

	Evidence	Finding
	Weir and the mean high water extent 42 km downstream (although the range of head across the structures is variable). Furthermore, a number of instream structures are present within the tributaries that enter the Thames between Romney Weir and Old Windsor.	
Available reports	No wider-scale geomorphological discussion included in the previous reports. No further information than that generated in the desk-based study.	Possibly

Figure 3.3 Google Earth aerial imagery at Romney Weir (image copyright Google Earth 2014)

Figure 3.4 Google Earth Aerial imagery at meander adjacent to Windsor Racecourse showing point bar

Figure 3.5 Google Earth imagery just upstream of meander showing possible shallow gravel features

Table 3.9 Is the morphology of the habitat complex good quality? (i.e. is the gravel shoal relatively clean and free from fine sediment, providing better habitat condition?)

	Evidence	**Finding**
Desk study	The quality of this gravel shoal cannot be determined from the Google Earth imagery due to the resolution. To confirm, this would require a site walkover and assessment (which would also be used to determine the river typology and gravel feature condition elsewhere in the system).	No info
Available reports	The Jacobs geomorphology (2012) report describes the gravel shoal immediately downstream of Romney Weir as relatively clean and therefore not prone to significant amounts of fine sediment deposition and infilling which would affect the quality of the morphological unit and habitat condition. The velocities extracted from the ARUP 3D modelling suggest that velocities over the shoal are sufficient over a range of flows (Q95 to Q30) so as to prevent fine sediment deposition over the bar. Velocities appeared to be >0.3 m/s. Flows of greater than 0.3 m/s will suspend fine sediment so it is unlikely that fine sediment will accumulate in the bar.	Yes

3.5 Hydraulic modelling details

3.5.1 Digital elevation model generation

The following, key information was used in the creation of the DEM grid for the hydraulic model.

- 2007 Environment Agency Bathymetry survey

- 2010 Environment Agency Bathymetry survey
- LIDAR data (provided by the Environment Agency)
- 2011 ARUP drawings of the weir structure.

As discussed in the literature review (main report), a key limitation of Acoustic Doppler Current Profiler (ADCP) bathymetry surveys is an inability to survey depths shallower than around 0.6 m. This leads to gaps in the bathymetry data provided by both the 2007 and 2010 surveys, in this case around the margins of the river and the shallow gravel shoal around 80 m downstream of the weir (Figure 3.6). The same approach for 'filling in' these data gaps was used in this modelling as in the ARUP 2013 report, namely:

- The ADCP dataset was manually extended at the margins using the expert judgement and the nearest bed data value.
- The gravel shoal was assumed to be 0.1 m higher than surrounding bed levels.

Table 3.10 outlines the approach taken to building the grid for key features of interest.

Table 3.10 Grid building approach – Romney

Bathymetry	The 2007 and 2010 raw bathymetry data was interpolated into two grids with a cell size of 0.5 m. The 2010 survey did not extend far beyond the gravel shoal and it is unwise to locate the downstream boundary of a hydraulic model close to an area of interest. Therefore, the 2007 data was used to further extend the model. These two grids were then combined to give a single grid dataset representing the bathymetry of the Thames.
Weir dimensions	The weir dimensions were taken from the 2011 ARUP drawings. The topographic variations of the piers, weir face and area immediately downstream of the weir were interpolated into a grid dataset representing the topography of the weir.
River banks	The banks of the river were extracted from LIDAR data.

Following the creation of the three grid datasets, they were combined into a single grid dataset which represents all the key features of the weir structure and Thames downstream of the weir at Romney. This DEM was used in each of the scenarios modelled (Figure 3.6).

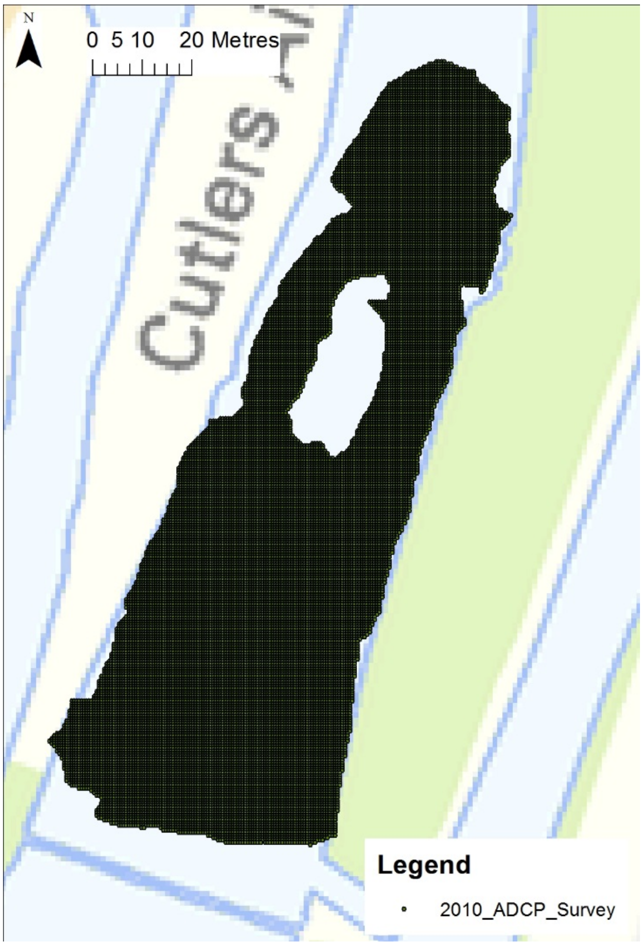


Figure 3.6 Romney Weir 2010 ADCP survey extent

3.5.2 Model boundaries

The inflows to the model are the same as those used in the ARUP (2013) modelling study. The pre-scheme weir structure was divided up into 12 gates with a fish pass adjacent to the right hand bank (gate 1). Table 3.11 shows that at low flows (Q95 – the flow exceeded 95% of the time) the flow is shared relatively equally between the gates, whereas at Q60 the majority of the flow is released by gate 11, and at Q30, the majority of the flow is released by gates 9 and 11.

Table 3.11 Modelled flows before hydropower installation

%	FP	2	3	4	5	6	7	8	9	10	11	12
Q95	0.5	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.48	0.24
Q60	0.5	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.11	20.0	0.05
Q30	0.5	0	0	0	0	0	0	0	21.0	0	28.0	0

The second scenario modelled represents the hydropower scheme as it was installed. The fish pass remains in gate 1, with the two Archimedes screw turbines located in gates 2 and 3 towards the right hand side of the channel. Table 3.12 shows that at Q95 the flow remains relatively evenly distributed along the weir, but at Q60 (and to a slightly lesser extent Q30), the predominant flow path has switched from the left hand side of the structure to the right hand side of the structure.

Table 3.12 Modelled flows after scheme installation

%	FP	T1	T2	4	5	6	7	8	9	10	11	12
Q95	1.25	1.75	0	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.15
Q60	1.25	12.5	5.25	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.29	0.15
Q30	1.25	12.5	12.5	0.33	0.33	0.33	0.33	0.33	0.33	0.33	20.8	0.17

The final scenario is a hypothetical scenario, effectively the mirror image of the constructed scheme, with the fish pass and turbines 'relocated' to the equivalent gates on the left hand side of the weir. This is designed to explore the impact of a hydropower scheme on either side of the weir.

The other boundaries used in the model are outlined in Table 3.13.

Table 3.13 Summary of Romney model boundaries

Cell size	A cell size of 0.5 m was used. This is smaller than the 1 m resolution of the LIDAR, but consistent with the resolution of the ADCP bathymetric data used as the basis for the instream topography.
Roughness	The Manning's roughness in the channel was specified using descriptions of the channel from provided reports. In the absence of any spatial sediment maps a constant Manning’s roughness value of 0.06 was used.
Downstream boundary	A fixed water level was specified at the downstream boundary Q95 = 16.27 mAOD, Q60 = 16.37 mAOD and Q30 = 16.5 mAOD. This data was calculated by the Environment Agency from a downstream water level record of around 10 years in length. The location of the downstream boundary is shown in Figure 3.7.
Initial water levels	Corresponded to the water levels used to define the downstream boundary.

Figure 3.7 Romney model schematic

3.5.3 Calibration

No calibration data was available for this reach. An ADCP survey was conducted in 2010, but unfortunately this data was not georeferenced and so the sampled velocities were not suitable for use in model calibration.

3.5.4 Sensitivity test

Figure 3.8 shows changes to the modelled velocities as a result of altering the bed roughness in the model (Q30 pre-installation scenario). The Manning's roughness values were varied around the design value of 0.06 (increased to 0.08 and decreased to 0.04). Figure 3.8 shows that the changes to the velocity distribution in the weir pool complex following hydropower installation, which occur in the Q30 simulations, are greater in extent than the changes to the velocity distribution driven by changes in Manning's roughness in the channel. This indicates that however small, any changes to the velocity distribution caused by the hydropower scheme installation are likely to be greater in magnitude than any changes relating to model uncertainty.

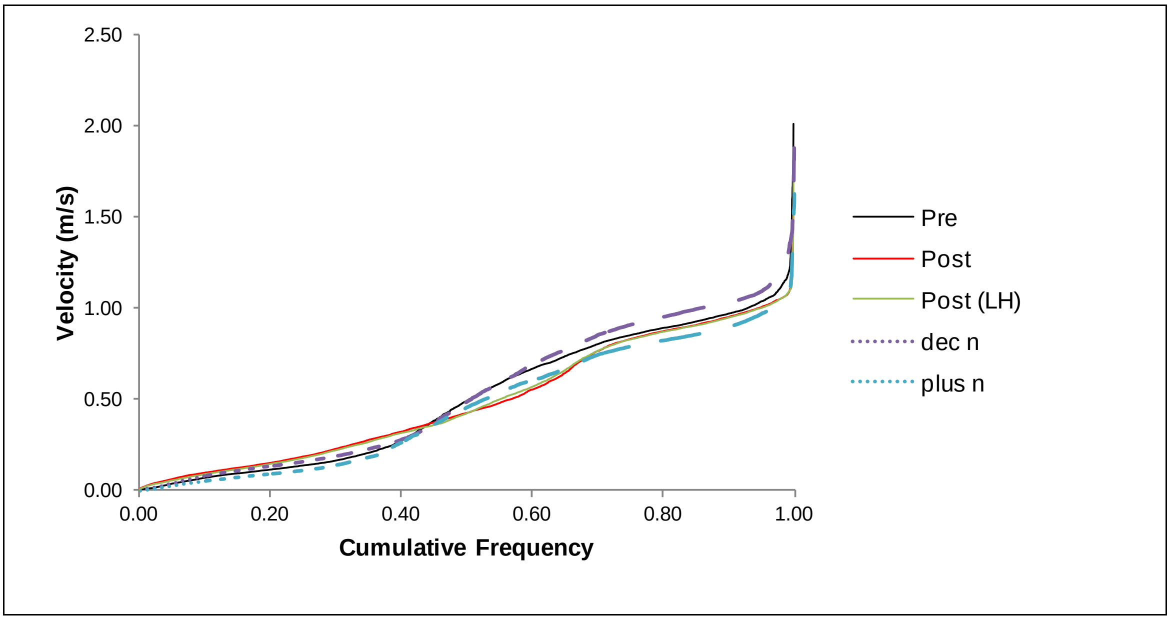


Figure 3.8 Q30 Manning's roughness sensitivity plot (velocity)

3.5.5 Site-specific limitations/considerations

Downstream water levels were provided by the Environment Agency, and were calculated from a long record of downstream water levels. These water levels are therefore believed to be the best available source of information for the downstream boundary of the model. One consequence of using these water levels is that the water levels in the modelled reach are high, and this subsequently leads to low water velocities (especially at Q95). These velocities are low when compared to the results of the ARUP 3D modelling and the velocity requirements to keep gravel clean from sand deposits (see hydromorphological implications section in main report).

It should be noted that the 2010 ADCP survey which was used as the basis for the bathymetry of the weir pool was provided in depths rather than bed level in mAOD. In the survey, the ADCP produced 'no results' at depths less than around 0.6 m. This is about standard for ADCP equipment. The drawing stated that the soundings were measured in metres below standard tail water level (16.121 mAOD). The bed levels in mAOD were calculated by subtracting the depth from 16.121 mAOD. The downstream water level at Q95 provided by the Environment Agency is 16.27 mAOD. As this water level controls the levels in the model, depths in the gravel shoal area cannot get any lower than around 0.8 m.

The downstream boundary of the model was lowered to the standard tail water level for Romney Weir (16.121 mAOD) and a pre-change Q95 flow was run through the model. This level was chosen as it may represent the potential error from any datum issues. Figure 3.9 shows that although reducing the water level of the downstream boundary does lead to increased velocities, the modelled velocities are still low compared to those that would be expected to keep the gravel shoal clean from sand deposition. This suggests that the potential discrepancy in datum level is not responsible for the low velocities in the weir pool complex.

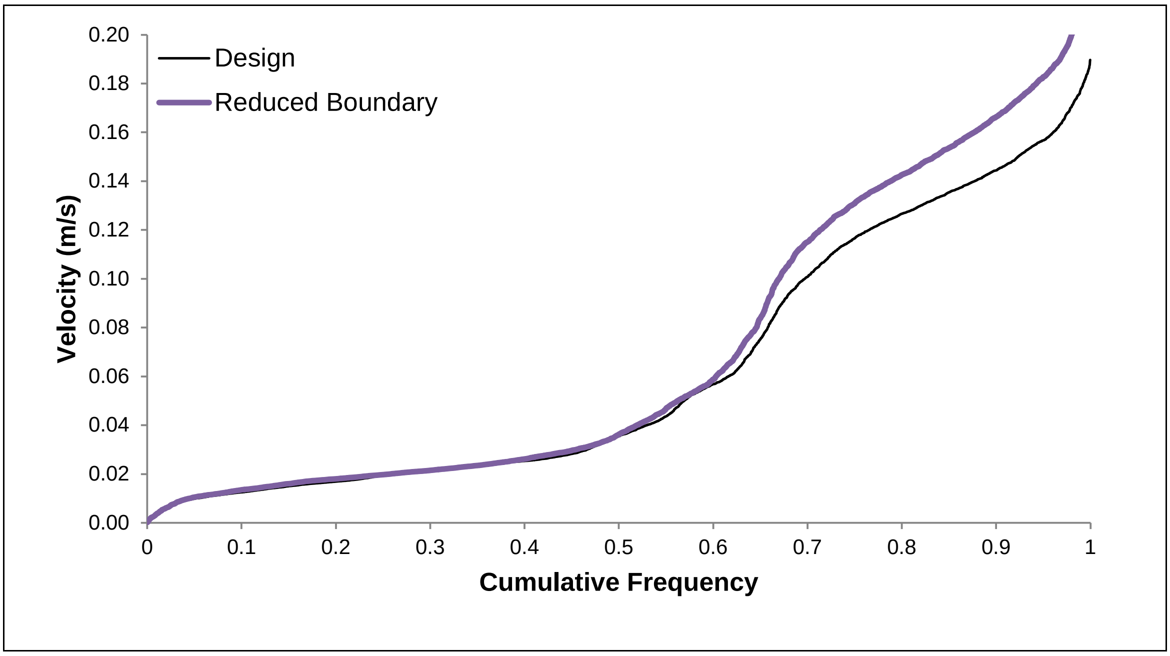


Figure 3.9 Q95 pre-installation downstream boundary sensitivity plot (velocity)

Ironically, the key area of interest in this weir pool is the gravel shoal for which there is no topographic data. This highlights the fundamental importance of gathering good topographic data to improve model performance. Greater confidence could be gathered from the model predictions had the gravel shoal been surveyed (possible using means other than an ADCP).

3.6 Hydraulic habitat change

Hydraulic results – whole weir pool complex

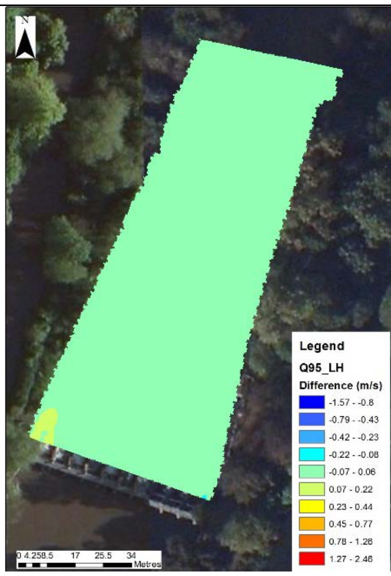
As outlined above, the depths predicted in the model are controlled by the water level specified at the downstream boundary of the model. As flows at the downstream model boundary will be the same in the pre- and post-construction scenarios, the water levels at the downstream boundary will not change following installation of the scheme, since the same downstream boundary water level has been used in all model scenarios. Therefore, the modelled water depths do not change between scenarios.

Velocity difference maps (and derived statistics) focus on the area which is defined as the weir pool (i.e. the deep scour hole and following bar features). The model extends further downstream, but this data is not included in the analysis as it is outside the defined weir pool complex. The gravel shoal is located towards the downstream end of the displayed reach.

There is very little difference between the three scenarios at low flow (Q95), with any observed change being close to the gates (Figure 3.10). Small changes can be observed in the cumulative frequency plots (Figure 3.11) as slight decreases in the overall availability of slow flow, but there is a general increase in availability of higher flow velocities.

At moderately high flows (Q60) the differences are more marked (Figure 3.10). The installation of the hydropower scheme on the right hand bank, leads to an increase in velocities adjacent to the right hand bank and a corresponding decrease in velocities on the left hand bank. The reverse pattern is observed when the hydropower scheme is located on the left hand bank (albeit with a smaller increase in velocities on the left hand bank since a significant portion of the flow used gates in that area under the pre-installation conditions). Velocities over the gravel shoal, which is located towards the downstream end of the mapped reach, appear relatively unchanged between the three scenarios. The cumulative frequency plot shows a general decrease in velocities in the reach, with the change in velocities being largely independent of scheme location.

At Q30, largely similar flow pattern changes are observed in both of the post-construction hydropower scenarios, with an increase in velocities on the right bank and a decrease adjacent to the left bank (Figure 3.10). In the pre-change scenario most of the flow is routed through gates towards the left hand bank. Following hydropower installation (on either bank) the flows are more evenly distributed across the channel with less flow associated with the left hand bank and more flow associated with the right hand bank. The exact flow splits differ when the location of the hydropower scheme is changed, but the overall pattern of flow change (i.e. an increase in velocities adjacent to the right bank and a decrease adjacent to the left bank) does not. The cumulative frequency plots again show very little difference in the modelled velocities between the two post-installation scenarios. A similar pattern to that observed under Q95 flow can be seen, with a decrease in availability of low flows, but a slight increase in availability of high flows.

<table>
<tr><th></th><th>Post-installation as designed minus pre-change</th><th>Post-installation scheme on left bank minus pre-change</th></tr>
<tr><td>Q95</td><td>
</td><td>
</td></tr>
</table>

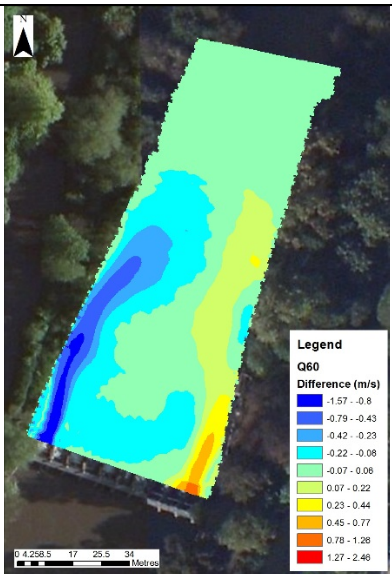
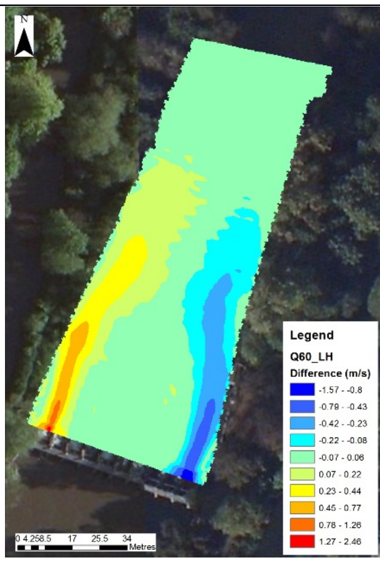
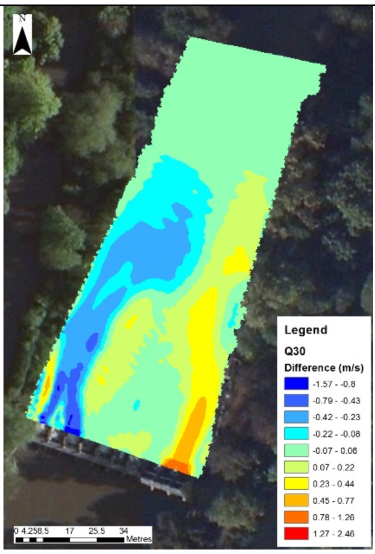
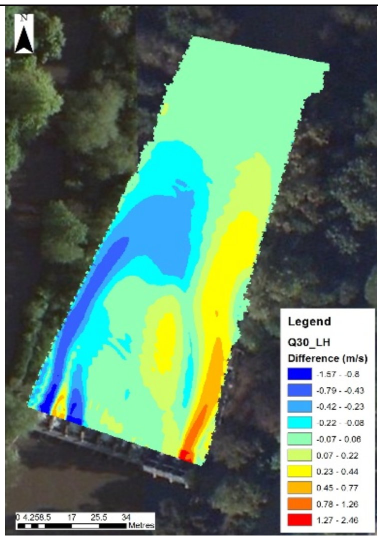
<table>
<tr><td></td><td>Post-installation as designed minus pre-change</td><td>Post-installation scheme on left bank minus pre-change</td></tr>
<tr><td>Q60</td><td>
</td><td>
</td></tr>
<tr><td>Q30</td><td>
</td><td>
</td></tr>
</table>

Figure 3.10 Difference maps showing the change in modelled velocities

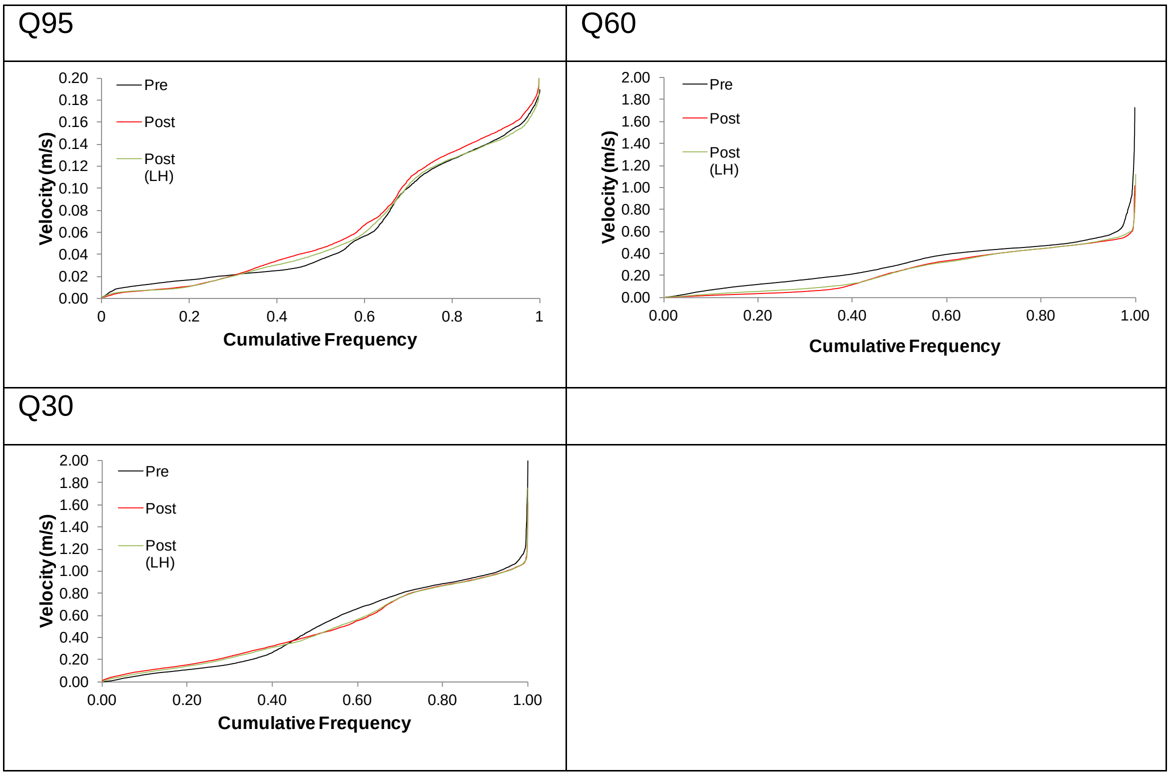


Figure 3.11 Cumulative frequency plots of velocity (whole weir pool complex)

Hydraulic results – shoal only

The difference maps (Figure 3.10) suggest that any changes in the modelled velocities caused by the installation of a hydropower scheme at Romney Weir do not propagate downstream to the gravel shoal. However, to ensure that any changes to the shoal hydraulics were not masked by changes to the hydraulics in the wider weir pool, the hydraulic results were extracted from an area thought to approximately represent the extent of the shoal.

There is generally very little change in velocities over the gravel shoal at low flow (Q95 Figure 3.12). The hydropower scheme on the right bank leads to a very slight increase (in the order of 0.01 m/s) in modelled velocity, while the scheme on the left bank leads to a reduction in availability of higher velocities.

The patterns observed in the Q60 and Q30 scenarios are relatively similar, with little change in the middle range of modelled velocities followed by a decrease in the frequency of higher velocities. In the Q30 simulation there is also a slight decrease in the availability of lower velocities.

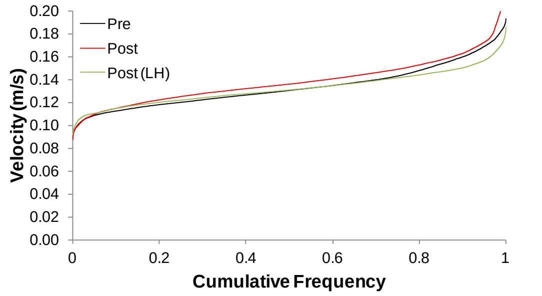
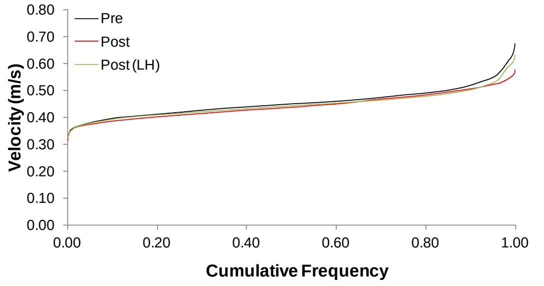
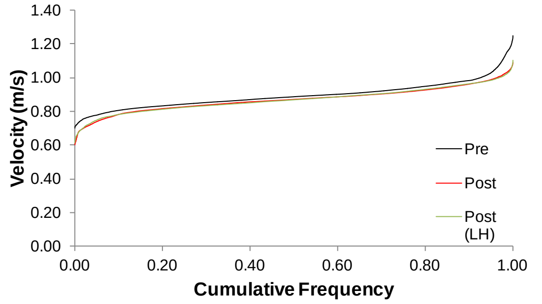
Q95	Q60
	
Q30	
	

Figure 3.12 Cumulative frequency plots of velocity (shoal only)

3.6.1 Comparison with 3D modelling

ARUP (2013) undertook 3D CFD modelling of Romney Weir pool and in particular the gravel shoal. The overall finding of both the CFD modelling and 2D case study modelling is that the changes to the velocities over the gravel shoal following hydropower installation is minimal.

Differences between the current modelling results and the ARUP modelling results are evident at Q95 where the ARUP modelling showed velocities ranging from 0.2 m/s close to the bed of the river to 0.8 m/s around 0.4 m above the bed, while the maximum velocity observed in the 2D modelling is around 0.2 m/s. The possible reasons for this are listed in Table 3.14.

Table 3.14 Comparison of 2D and 3D results

No direct comparison	No digital data was available on the precise extent of the gravel shoal used in the 3D modelling; different sampling areas could lead to differences in the comparison.
	No digital results data was available from the ARUP study, as it was not stored due to file size. All comparisons are therefore done by eye against graphs in the report.
Difference in modelling approach	2D modelling provides velocities in terms of depth-averaged velocities only; 3D modelling provides them at a range of depths. The ARUP report did not present any water depths, only velocities at a range of distances up from the bed, and it is therefore difficult

	to rationalise those velocities in terms of depth-averaged velocity.
	2D and CFD modelling approaches use different roughness treatments which may impact on modelled velocities, although the sensitivity test suggests that the 2D model is not very sensitive to the choice of roughness.
Different topographic data	Although best efforts were made to build a bed geometrically consistent with that used by ARUP, it is possible that differences in bed geometry persist. In particular, the treatment of the data gap over the gravel shoal may be different.

3.7 Interpretation

3.7.1 Hydromorphological implications

The impacts under Q95 flow conditions are minimal; however, the changes within the deeper pool areas under higher flows show that there could be a change in the morphology as a result of the turbines. These changes might be areas of increased deposition across the weir pool away from the outflow location and possible increased scour at the outflow location and immediately downstream of this point extending down the side of the gravel shoal.

Velocities within the increased velocity zone along the edge of the gravel shoal under higher flows may result in a minor change to the gravel fraction within this zone, with smaller gravel being eroded and transported downstream. However, anything carried in suspension from upstream will be deposited as the higher flows recede (this is supply limited).

Any changes to the extent of the gravel shoal predicted by the changes in processes shown are dependent on the supply of gravel from upstream. The impounding influence of the weir is likely to limit the supply of gravels to the gravel shoal and therefore any changes are likely to occur over longer timescales.

The composition of the gravel shoal is unlikely to be significantly influenced by the installation of turbines at either location. Velocities remain within bands similar to those for pre-installation conditions for all the flow events, with only subtle changes evident.

The magnitude of change in the cumulative frequency plots for each flow are unlikely to be significant enough to dramatically change the general depositional and erosive processes occurring across the reach, with only localised variations as described in sections above.

3.7.2 Macroinvertebrate implications

The changes to velocity predicted at the shoal (both reductions and increases) will drive some changes to the current invertebrate communities within these areas, although these are likely to be relatively minor. Some species recorded at the site have preferences for faster flow and/or are highly or moderately sensitive to fine sediment deposition, but changes in their abundance (as a result of the installation of the hydropower scheme) are likely to be localised and are unlikely to fundamentally alter community composition. Furthermore, none of the recorded species of conservation note are within this sensitive category. Some differences in community composition were noted between the left and right banks around the gravel shoal (and between the left and right banks further downstream), although differences in the proportion of flow or sediment-sensitive species between samples were not distinctive. Thus, the siting of the hydropower scheme on the left or right side of the channel is not anticipated to make any notable difference to the impact on invertebrates. Impacts on invertebrate community composition 200 m downstream of the weir are also not anticipated to be significant, particularly when considered relative to the hydrological impacts from the management of the weir gates and the general variability of the system.

The most marked hydrological changes are predicted to be in the deep weir pool immediately downstream of the weir. Unfortunately, this particular habitat patch was not directly sampled in baseline surveys (due to safety issues) so specific predictions of invertebrate community response are not possible. Communities in this habitat are likely to be adapted to fast flowing environments and thus may be impacted by any increases or decreases. However, such changes are likely to be relatively localised (scenarios post-hydropower operation show areas of increasing **and** decreasing velocity, so there is likely to be a change in habitat distribution rather than net loss) and will probably be of no greater significance than hydrological changes from weir gate management and/or system variability. Furthermore, records from the system do not indicate any particular species of conservation concern are likely to be present that would be especially sensitive to any flow or sediment changes. Thus, the implications of the hydropower scheme on invertebrate communities are not expected to be of major consequence.

3.7.3 Macrophyte implications

Lack of macrophyte distribution data limits interpretation of modelled impacts. Macrophyte communities will be sensitive to velocity changes which are expected to be small.

A potential significant impact is displacement of Nuttall's Waterweed (a non-native invasive species listed on Schedule 9 of the Wildlife and Countryside Act, 1981) due to higher velocities, or change in flow patterns, which may occur as a result of construction of the hydropower scheme. Displacement of this species may then cause its spread downstream. This species was reported as being present in small patches along the left and right banks (Jacobs 2013a) and under the hydropower installation modelling results velocities do increase along the channel margins, which could potentially cause displacement.

Changed velocities may also impact on the occurrence of Unbranched Bur-reed as, according to Haslem (2006), this species is most closely associated with slow to moderate flows. As with Nuttall's waterweed this species was recorded in the siltier channel margins, and therefore any consistent increase in flow in the marginal areas from installation of a hydropower scheme on the left or right bank, as indicated by the modelling results, may result in the loss of this species from this section (however, other species may in turn colonise this area).

Ranunculus flutians, the dominant species in the channel, is however a species more associated with fast flow and also rivers liable to spate (Haslem 2006). Therefore, the faster flows that are generated in the central part of the river channel, in both the left and right bank scenario, are unlikely to significantly impact on this species' occurrence. Other species are unlikely to be affected by changed velocities as they tend to show little preference to flow type (Haslem 2006). The bryophyte species recorded are generally those that are characteristic of slow flowing or stagnant waters, and are usually attached to rocky substrates.

However, under all scenarios there still remains a balance of slower flowing areas and faster flowing areas, although the distribution of these areas changes across the channel length and cross-section. Therefore, the species communities within the channel may gradually adjust to these velocity changes following installation. The only significant impact may be the displacement of Nuttall's Waterweed downstream, should flow be increased in an area of the channel where this is present.

3.7.4 Fisheries implications

Rheophilic species (such as Chub *Leuciscus cephalus*) have a preference for spawning in relatively fast flowing, shallow water. Arlinghaus and Walter (2003) reports that Chub have a preference for spawning in velocities ranging from 0.15 to 0.75 m/s in water between 0.1 and 0.3 m deep. The modelled depths over the shoal present downstream of Romney Weir were approximately 0.8 to 1.0 m at Q95, which suggests that the shoal may not be ideal spawning habitat for rheophilic fish as it is too deep. This depth is consistent between the three post-change scenarios modelled suggesting that the gravel shoal may not represent substantial spawning habitat for the rheophilic species known to be present below the weir, in the pre- and post-change scenarios.

The hydromorphological condition of the gravel shoal is unlikely to be modified by hydropower installation at the weir. Any significant changes are likely to result from high flow flood events, the impact of which the hydropower scheme will not influence. Hydropower construction is therefore unlikely to impact upon availability of spawning habitat exploitable by rheophilic species.

The macrophyte analysis above was unable to draw exact spatial distribution conclusions as a result of the change in velocity distribution. However, it was able to conclude that because a balance remained between areas of fast and slower flowing water, the macrophyte communities are unlikely to fundamentally change. Changes in distribution of Nuttall's Waterweed as a result of its displacement downstream could have an effect of reducing macrophyte diversity, which may have an impact on availability of phytophilic spawning/refugia habitat, but a fisheries population-level impact may be hard to discern.

Adult fish of most species tend to prefer deeper water habitats, which in this case would be provided by the deep pools close to the weir. The hydromorphological interpretation suggests that the location of the pools may shift slightly due to the change in predominant flow paths/velocities, but as evidenced by the cumulative frequency plots there is no change in the overall variety of velocities. Adult fish are mobile, and so while a redistribution of velocities may have short-term impacts, long-term impacts are unlikely.

4 Pershore Weir

4.1 Site characteristics

Pershore Weir pool is located on the River Avon at Pershore, west Worcester (SO 95228 45677). Pershore Weir and its associated locks and sluices are one of a number of structures built to formalise navigation along the Avon. The structure consists of a weir, lock and sluice gate. The hydropower scheme is to be located on the left hand bank adjacent to the weir, with no changes to the weir itself anticipated.

4.2 Previous studies and supplied data

A range of data has been supplied by the Environment Agency (Table 4.1).

Table 4.1 Supplied data – Pershore

ADCP	An ADCP survey was undertaken of the channel downstream of Pershore Weir on 12 December 2012. Both bathymetry and velocity data are available for use from this survey.
Fish pass design (Renewables First 2011)	Form supplied to the Environment Agency for fish pass approval. Contains details of pass dimensions, river flow and subsequent flow splits and upstream and downstream water levels.
	Fish pass design supporting information (Renewables First 2011). Further information relevant to the fish pass application.
Layout drawings	A series of layout drawings produced by Renewables First showing the layout and dimensions of the proposed scheme (drawings PESH001 to PERSH005).
Ecological survey	A river corridor and protected species survey was undertaken in 2011 by Keystone Environmental on behalf of Renewables First. This study focused primarily on terrestrial ecology.
Fisheries impact assessment	Fishtek Consulting (January 2012a) undertook water depth, velocity and substrate sampling to assess the quality of the weir pool and the potential impacts of the hydropower scheme on the weir pool.
	Fishtek Consulting (July 2012b) produced an appendix linked to their January 2012 report.
Ecological data/survey reports	The Environment Agency provided invertebrate, macrophyte and fisheries data for nearby sites. Further details are given in the relevant sections.

4.3 Current status

Pershore Weir sits within the River Avon (Evesham to confluence with River Severn) heavily modified waterbody (GB109054044403) that is currently classed as achieving moderate ecological potential and therefore failing Water Framework Directive objectives. The fish, macrophyte and macroinvertebrate quality elements are currently classed as moderate, no information and good respectively.

4.3.1 Fish populations

The nearest available fish population survey data held by the Environment Agency relates to surveys undertaken at the locations given in Table 4.2.

Table 4.2 Environment Agency fish population survey data at locations in proximity to Pershore Weir

Site name	Grid reference	Approximate location	Date of survey	Species recorded
Birlingham	SO9310043900	c. 3.3 km downstream of Pershore Weir	10 June 1993	Rheophilic: Chub Eurytopic: Bleak; Pike; Roach; European Eel Limnophilic: Tench
Pershore	SO9520045100	c. 600 m downstream of Pershore Weir	10 June 1996	Rheophilic: Chub; Dace; Gudgeon Eurytopic: Bleak; Perch; Pike; Roach; European Eel Limnophilic: Rudd
Wick, upstream Tiddle Widdle Islands	SO9690047100	c. 2.1 km upstream Pershore Weir	10 June 1993	Eurytopic: Bleak; Pike; Roach
Wyre Piddle	SO9550046500	c. 1 km upstream Pershore Weir	10 June 1993	Eurytopic: Bleak; Perch; Pike; Roach; European Eel

The surveys listed in Table 4.2 revealed the presence of eurytopic species only, upstream of the weir, with rheophilic species being recorded downstream (Chub and Bleak being caught at all sites and Dace and Gudgeon also being caught at Pershore).

4.3.2 Invertebrate populations

Available data from the Environment Agency is from Pershore (500 m downstream of weir), Wyre Piddle (2.5 km upstream), Lench Ditch (3.3 km upstream) and Piddle Brook tributary, which joins the Avon approximately 900 m upstream of Pershore Weir. Records are mostly to family level and span just one or two years, with few samples after 1994 from the main channel (records from small tributaries are not considered comparable). The habitat characteristics of the sample sites are not directly comparable to the study reach upstream of Pershore Weir. Recorded communities show a mix of taxa with preferences for flowing/standing water and moderately fast flows, with no species of conservation concern present. However, this data cannot be considered representative of the invertebrate communities presently at the study site.

4.3.3 Macrophyte populations

Baseline data on aquatic macrophytes for Pershore Weir is extremely limited, with only a basic river corridor and protected species survey report available (Keystone

Environmental 2011). This focused primarily on terrestrial habitats, with recording of aquatic macrophytes limited to bankside observations with species often only recorded to generic type (e.g. reeds, sedges). Mapping of the extent of each vegetation type has however been undertaken.

Keystone Environmental (2011) report that, from the right bank, no aquatic vegetation was visible downstream of the weir in the weir pool. Upstream of the weir, visible aquatic vegetation was limited to small patches of emergent monocotyledons (grasses and rushes) and a small patch of submerged dicotyledons (a water-lily species).

In marginal areas, a band of reed/sedges, dominated by Reed Canary-grass *Phalaris arundinacea*, occurred along the length of the right bank upstream of the weir. Downstream of the weir on the right bank, there is one small section of reed/sedges, dominated by Common Reed *Phragmites australis*, with locally dominant rushes (species not identified) and occasional Bulrush (presumably *Typha latifolia*). Another area of vegetation of this type is also present in front of the slump (Keystone Environmental 2011). No information is available on percentage cover.

4.4 Scoping process

4.4.1 Rationale

The purpose of this section is to apply the weir pool importance scoping process to the Pershore site.

This assessment has been undertaken using two approaches: the first uses freely available online resources and routine monitoring datasets held by the Environment Agency (reported under 'Desk study' in the tables below), and the second where all available information was used in the application of the scoping process (reported under 'Available reports' in the tables below).

4.4.2 Connectivity/weir pool rarity

The Environment Agency River Obstructions Database was used to determine the presence of potential instream barriers to migration in proximity to Pershore Weir. Table 4.3 lists information relating to these barriers and Figure 4.1 shows their location.

Table 4.3 Information on adjacent instream structures from Environment Agency Rivers Obstructions Database

Order	Barrier	Longitudinal/lateral[1]	Distance from target barrier (km)[2]	Fish pass present (type)?	Head over barrier (P_HEAD; Z_Head; 25 m_Head; m)[3]	Total number of barriers to mean high water (STOTAL)	Approx. distance to mean high water – km (SLENGTH)
1 u/s	Wyre Mill Weir (4358)	Long	1.6 (0.1)	Ramp and bristle	0.006; 0.008; 0.003	2	42.3
-	Pershore Weir (4353)	-	0	Ramp and bristle	1.135; 1.15; 2.953	2	40.76
1	4075	Long	0.0 (adjacent to Pershore Weir)	Unknown	0.668; 2.746; 3.027	2	40.6

Order	Barrier	Longitudinal/lateral[1]	Distance from target barrier (km)[2]	Fish pass present (type)?	Head over barrier (P_HEAD; Z_Head; 25 m_Head; m)[3]	Total number of barriers to mean high water (STOTAL)	Approx. distance to mean high water – km (SLENGTH)
2	3749	Lat	7 (0.1)	Unknown	13.052; 0.752; 1.112	3	34.0
3	4389	Long	8.2	Super-active (Larinier)	0.689; 1.213; -1.25	2	32.6
4	3978	Long	13.9	Unknown	0.072; 0.312; 2.227	2	26.7
5	4391	Long	14.1	Ramp and bristle	1.22; 1.125; 2.346	2	26.4

Notes
1 – Position of the barrier in relation to connectivity with main river channel
2 – Value given in parenthesis is distance from given barrier to main river channel
3 – Environment Agency Rivers Obstructions Database derives head over weir in a number of ways. Values given relate to the respective method used to calculate head.

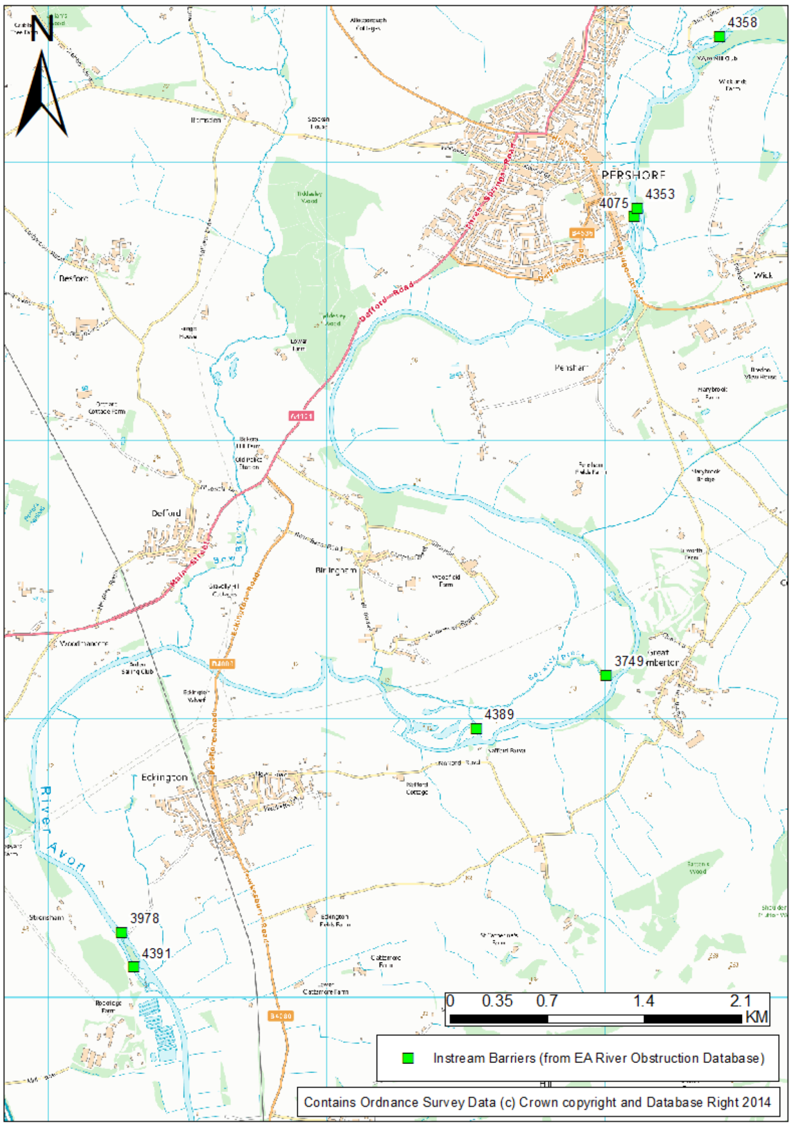


Figure 4.1 Location of adjacent instream barriers given in Table 4.3

4.4.3 Application of scoping process

Table 4.4 Is the site in an SSSI/SAC? (i.e. in a designated site)

	Evidence	Finding
Desk study	There are no designated sites close to Pershore Weir that are likely to be impacted by changes in flow dynamics as a result of operation of a hydropower scheme.	No
Available reports	As above.	No

Table 4.5 Are fish species known to be present at low frequencies/densities in the catchment likely to be exploiting the complex of habitats associated with the weir pool?

	Evidence	Finding
Desk study	Rheophilic species only caught downstream of the weir.	Yes
Available reports	No other information available.	Yes

Table 4.6 Is the weir pool type habitat rare? (i.e. is the deeper pool and gravel shoal type environment found frequently either locally or elsewhere along the river system, beyond the influence of the weir itself and where the flow and sediment regime is less constrained or influenced?)

	Evidence	Finding
Desk study	The information given in Table 4.3 indicates that there is approximately 8 km of main river channel downstream of Pershore Weir before the next nearest instream barrier on the Avon (Nafford Weir, ID 4389; has a Larinier fish pass) is reached. A number of tributaries enter the River Avon within this reach, with the Environment Agency River Obstructions Database identifying only one such tributary containing a potential barrier to fish migration (ID 3749). Only two other instream barriers exist in the main river channel downstream between Nafford Weir and the mean high water extent 32 km downstream. It could be concluded therefore that the complex of habitats immediately below Pershore Weir is relatively rare in the context of the catchment between Wyre Mill Weir and mean high water, with the presence of riffle features potentially contributing to sustaining the presence of the rheophilic species recorded in the Environment Agency fish surveys in the reach downstream of the weir.	Yes
Available reports	No wider-scale geomorphological discussion included in the previous reports. No further information than that generated in the desk-based study.	Possibly

Table 4.7 Is the morphology of the habitat complex good quality? (i.e. is the gravel shoal relatively clean and free from fine sediment, providing better habitat condition?)

	Evidence	Finding
Desk study	The quality of this gravel shoal cannot be determined from the Google Earth imagery due to the resolution. However, the lack of vegetation cover across the gravel bar suggests fine sediment infilling may not be significant. To confirm this would require a site walkover and assessment (which would also be used to determine	Possibly

	the river typology and gravel feature condition elsewhere in the system).	
Available reports	The Fishtek report says that some sections of gravel bed within the weir pool may be suitable spawning habitat which suggests the gravels are relatively clean and have limited fine sediment infilling. The modelled flow velocities in the report for a Q80 flow event are up to 0.8 m/s in shallower areas, which would be energetic enough to prevent significant fine sediment deposition on the bed of the channel.	Yes

4.5 Hydraulic modelling – details

4.5.1 Digital elevation model generation

The following information was used in the creation of the DEM grid for the hydraulic model:

- 12 December 2012 Environment Agency bathymetry survey
- LIDAR data (provided by the Environment Agency)
- Layout drawing of proposed scheme

As discussed previously, a key limitation of ADCP bathymetry survey is an inability to survey depths shallower than around 0.6 m. This leads to gaps in the bathymetry data provided by the ADCP survey, in this case around the margins (Figure 4.2). The bed levels in the margins were estimated using the closest ADCP survey point and the levels provided by the LIDAR data.

Table 4.8 outlines the approach taken to generate the DEM for the key components of the Pershore study reach.

Table 4.8 Summary of DEM build approach at Pershore

Bathymetry	The results of the ADCP bathymetry survey were used to interpolate a grid representing the bed. The model was extended as far as possible downstream of the weir pool to ensure that the choice of downstream boundary does not influence model predictions.
Weir dimensions	No engineering drawings of the weir structure were able to be obtained from the Environment Agency; however, the general characteristics of the face and apron of the weir were sampled in the LIDAR data, and these dimensions were used to define the weir face and apron.
River banks	1 m resolution LIDAR data was obtained from the Environment Agency.

Each of the components outlined in Table 4.8 were combined to form a single grid representing the Pershore study reach. This grid was used in each of the modelled scenarios.

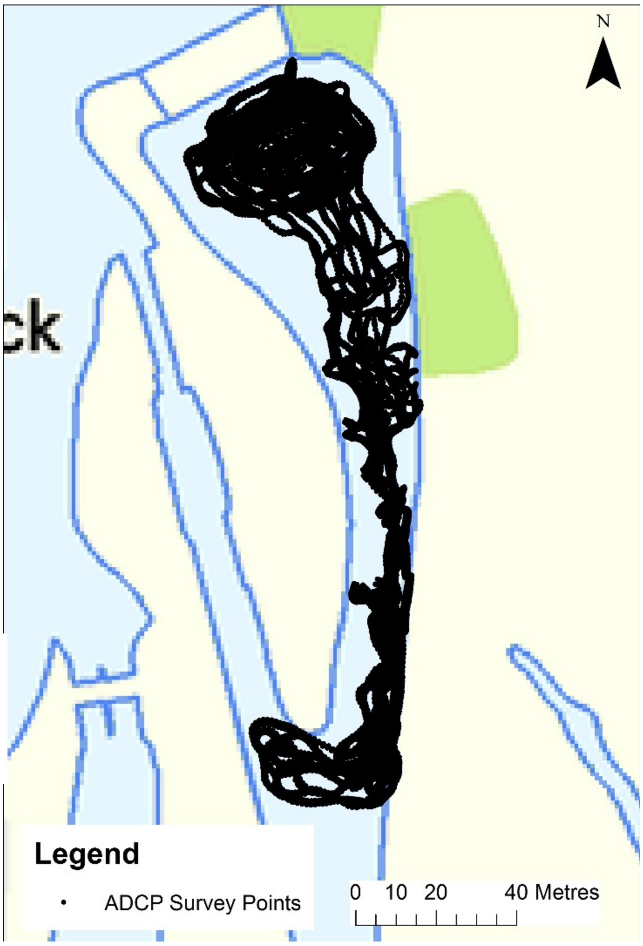


Figure 4.2 Pershore Weir December 2012 ADCP survey extent

4.5.2 Model boundaries

The inflows to the model are taken from the hydrological analysis presented by Renewables First (2011) (Table 4.10), which detailed the proposed flows through the turbine, fish pass and the residual flow for the weir and flood sluice (Figure 4.3). Renewables First (2011) reported a 70:30 flow split between the weir and the sluice gate. This ratio has been used to split the residual flow between the weir and the flood sluice. As the flood sluice is not explicitly modelled, this flow is not included in the model.

Three scenarios have been modelled at three exceedance flows which cover a range of flows (Q95, Q50 and Q20) (Table 4.9). Q20 is a moderately high flow with flows exceeding this value only 20% of the time.

Table 4.9 Pershore modelled scenarios

Pre-installation	The flow over the weir is assumed to be the sum of the fish pass, turbine and weir flow specified in the Renewables First (2011) report. This ensure the same discharge passes through the weir pool complex in the pre- and post-installation scenarios.
Post-installation	Inflows defined by using the values specified in the Renewables First (2011) report. The location of the inflows was specified using the layout drawings.
Depleted	A hypothetical scenario in which the turbine flow was removed from the post-installation run, reflecting a mill leat that returns flow back to the

reach	main channel downstream of the model extent. The location of the fish pass was modified to reflect best practice.*
*According to the current Environment Agency good practice guidelines (Environment Agency 2013b), the maximum depleted reach abstraction in a high baseflow river (such as the Avon) is QMean, with a Q95 hands off flow. The mean daily flow at Pershore is 15.40 m^3/s, which is only slightly lower than the maximum turbine flow of 16.40 m^3/s. Current guidance would not allow the depleted reach hydropower to operate at Q95.	

Table 4.10 Flow availability and splits at Pershore Weir

Q%	**Pre-installation flow (m^3/s)**			**Pre-installation weir flow (m^3/s)**
	Fish pass	Turbine	Weir	Flow
20	0.76	16.40	3.79	20.95
50	0.53	7.45	1.22	9.2
95	0.53	2.28	1.22	4.03

The other boundaries used in the model are outlined in Table 4.11.

Table 4.11 Summary of Pershore model boundaries

Cell size	A cell size of 0.5 m was used. This is smaller than the 1 m resolution of the LIDAR, but consistent with the resolution of the ADCP bathymetric data used as the basis for the instream topography.
Roughness	The Manning's roughness in the channel was specified using descriptions of the channel from provided reports. In the absence of any spatial sediment maps a constant Manning's roughness value of 0.06 was used. This roughness value was also tested during model calibration (see section 3.5.4).
Downstream boundary	A normal depth downstream boundary with a slope of 0.005 (i.e. a drop of 1 m vertically every 200 m horizontally) was specified by estimating the general downstream channel slope from LIDAR data.
Initial water levels	An initial water level of 12.5 mAOD was used to stabilise the model in the early stages of the simulation.

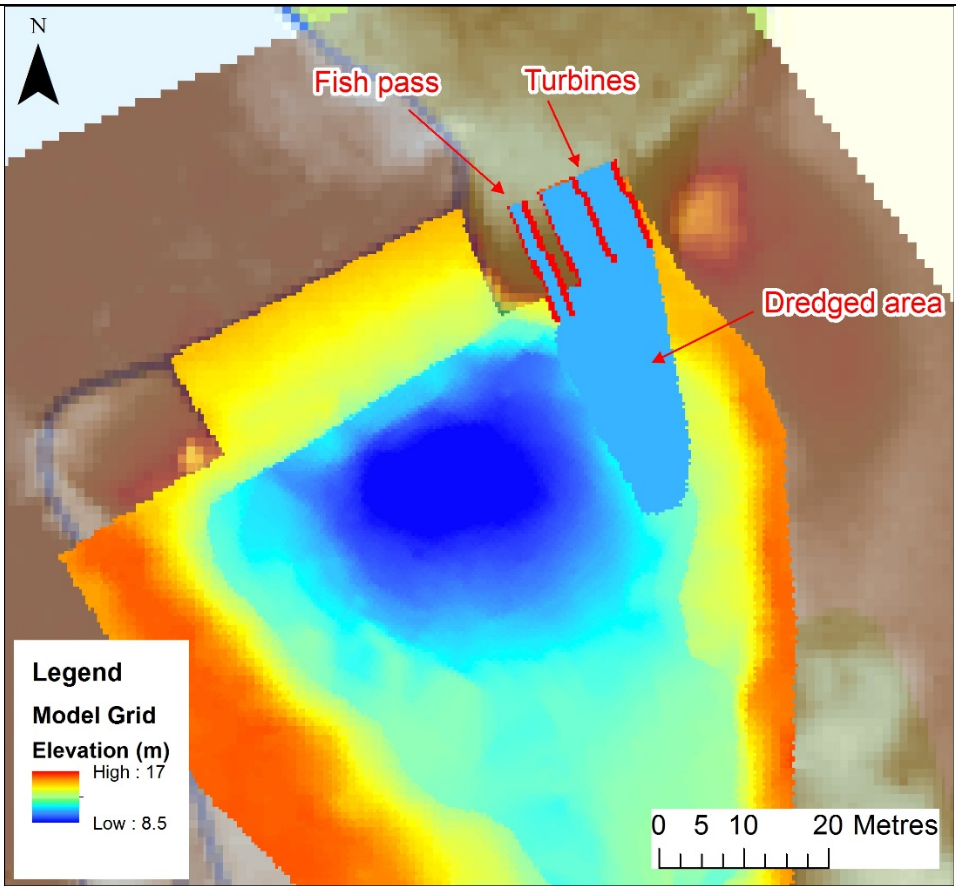


Figure 4.3 Pershore post-installation model grid

4.5.3 Calibration

As part of the December 2012 ADCP survey, flow velocities were collected alongside water depths. Using the recorded flow depths and velocities, a discharge of 4.4 m^3/s was calculated in the study reach at the time of the survey.

As a model calibration exercise, the pre-installation model was run with a discharge of 4.4 m^3/s, and the modelled velocities were compared to the velocities sampled by the ADCP. Table 4.12 shows that in general the TUFLOW model is over predicting velocity slightly compared to the sampled ADCP velocities and largely independently of the Manning's roughness value used. The average and standard deviations of the difference between the modelled and observed velocities are similar for each of the roughness values tested. Increasing the Manning's roughness to unrealistically high values did improve the calibration. However, as this study is a relative comparison of potential changes following hydropower installation, rather than a single definitive scenario study, it was thought more appropriate to use a roughness parameter which would be representative of the bed conditions rather than forcing the model to match the observed velocities by specifying roughness values outside the range of sensible model parameterisation. Increasing model roughness outside of a sensible range could potentially dampen the impact of any changes to the modelled velocities as a result of hydropower installation. Therefore, a roughness of 0.06 was used in the channel.

Table 4.12 Pershore model calibration

Model parameters	Difference (modelled – observed)	
Manning's roughness	**Average (m/s)**	**Standard deviation (m/s)**
0.04	0.09	0.18
0.06	0.07	0.19
0.07	0.07	0.18

4.5.4 Sensitivity test

The model was run with an increased Manning's roughness of 0.08 and decreased Manning's roughness of 0.04 around the design Manning's roughness of 0.06. Figure 4.4 shows that the changes in modelled velocity attributable to the alteration of model parameters are smaller than the changes associated with the installation of the hydropower scheme. This indicates that any changes to the velocity distribution as a result of hydropower installation are greater in magnitude than any potential variation in the modelled velocities arising from model uncertainty.

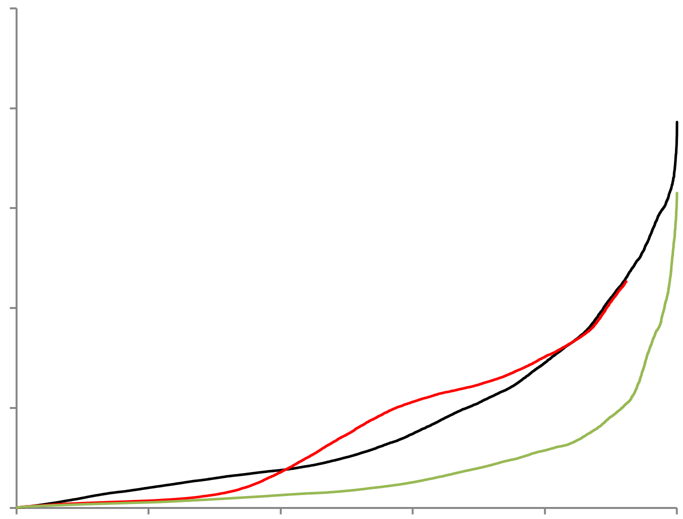


Figure 4.4 Q20 Manning's roughness sensitivity plot

The downstream boundary slope in the model was increased (0.0075) and decreased (0.0025) around the design slope of 0.005. Figure 4.5 shows that increasing the slope of the downstream boundary makes no difference to the modelled velocities in the weir pool complex. Decreasing the downstream boundary slope leads to a slight decrease in the higher modelled velocities; however, this decrease is modest compared to the scale of change to the downstream boundary (i.e. a halving of the slope).

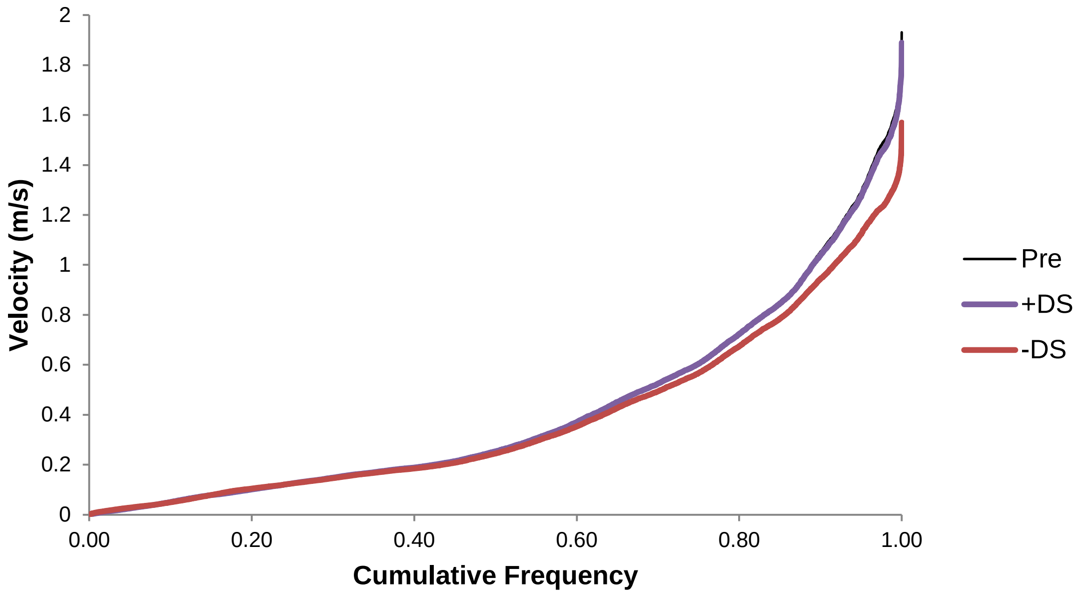


Figure 4.5 Q20 Manning's roughness sensitivity plot

4.5.5 Site-specific limitations/considerations

Bathymetry data from ADCP surveys is calculated by subtracting the depth information sampled by the ADCP device from a survey datum (often the water level on the day of the survey). Unfortunately, on the day of the Pershore ADCP survey the water level was not recorded. Using information from water level sensors associated with the sluice gate complex at Pershore and photographs taken on the day of the survey an estimated water level was obtained. While every effort was made to ensure that this water level was representative of the water level on the day of the survey, an error could have persisted through to the bathymetry of the weir pool complex. This, combined with other confounding factors such as ADCP measurement error, could perhaps explain the slight over prediction of velocities observed in the calibration exercise.

4.6 Hydraulic habitat mapping

The whole of the model extent was not used in this assessment, because the model needs to extend beyond the area of interest to prevent the downstream boundary from adversely influencing the model results. The hydraulic habitat assessment focused on the deep weir pool and associated gravel bars and riffles downstream of the pool. In this case, the weir pool complex is assumed to reach approximately 60 m downstream of the toe of the weir.

At Q95, post-installation depths increase from 1 m to 1.5 m. This is associated with the dredging and bank lowering adjacent to the left hand bank that is required as part of the scheme. Figure 4.6 shows that a significant area of the weir pool complex becomes dry under the depleted reach scenario. The velocity changes associated with the on-weir scheme are located close to the turbine, while the decrease in velocities associated with the depleted reach hydropower scheme are more prominent in the shallower reaches further downstream from the weir pool complex.

Similar patterns are observed with Q50 and Q20 inflows to the model. Installation of an on-weir hydropower scheme leads to an increase in depths associated with the dredging to a slight decrease in the availability of slower velocities, an increase in availability of moderate velocities and no change to the highest modelled velocities. The increase in moderate velocities is associated with the outflow from the turbine. The depleted reach hydropower scheme leads to a decrease in water depths across the whole weir pool complex and across the whole range of depths, and at Q50 this leads to drying out of the left hand bar. Modelled velocities also decrease under the depleted reach scheme, with the most pronounced differences being observed in the downstream reaches of the weir pool complex.

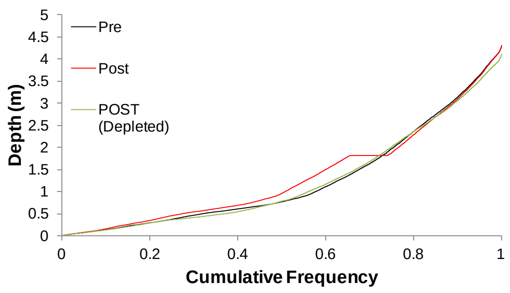
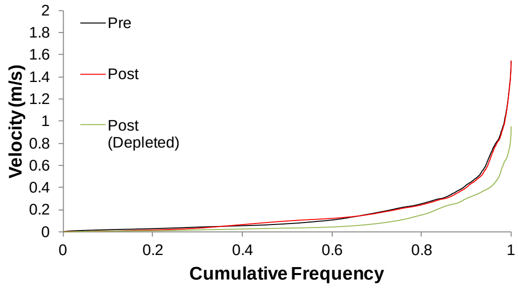
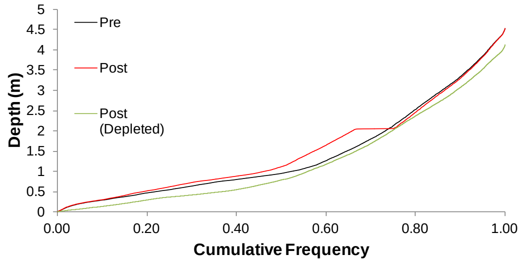
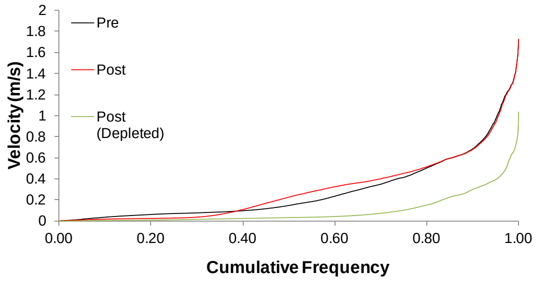
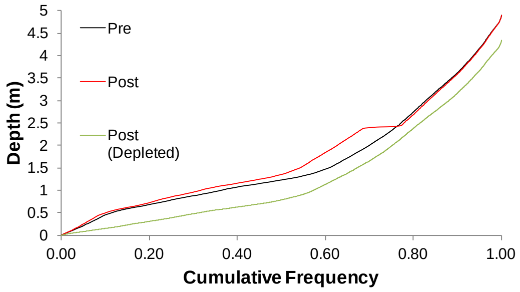
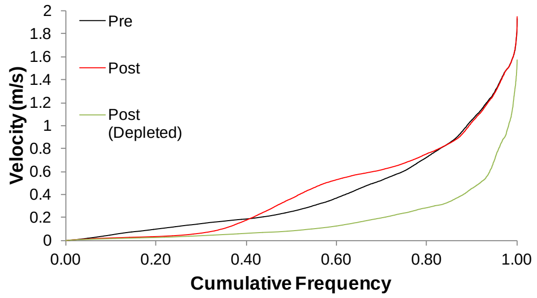
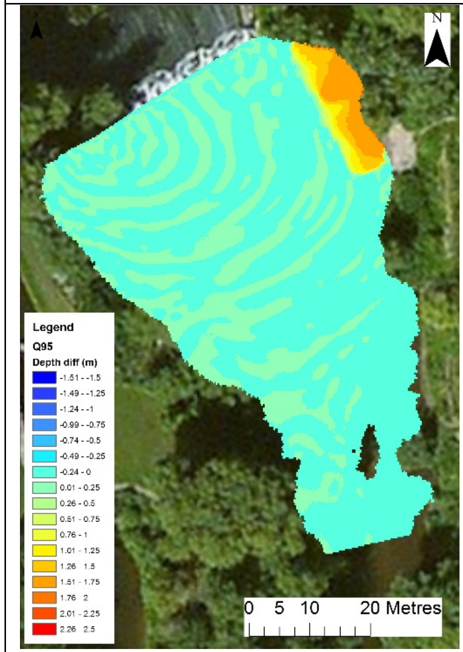
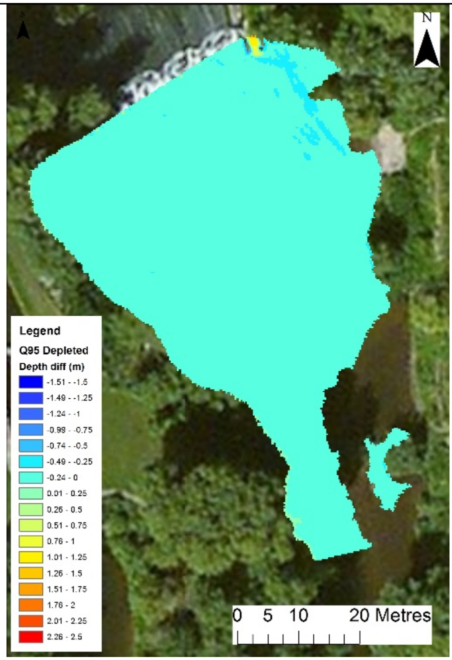
Q95 Depth	Q95 Velocity
	
Q50 Depth	**Q50 Velocity**
	
Q20 Depth	**Q20 Velocity**
	

Figure 4.6 Frequency plots for Pershore

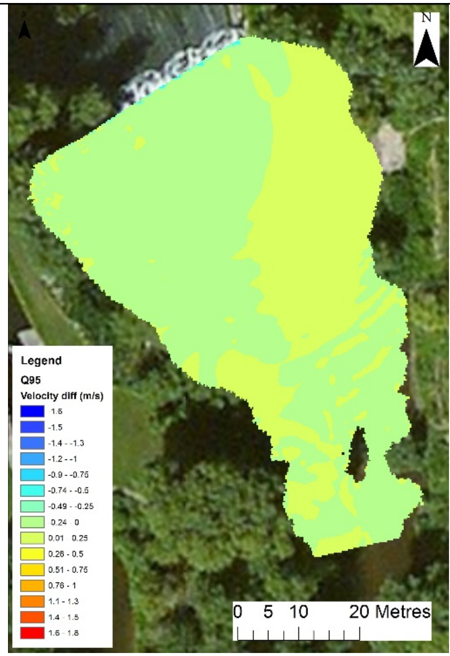
Q95 Depth. On-weir hydropower



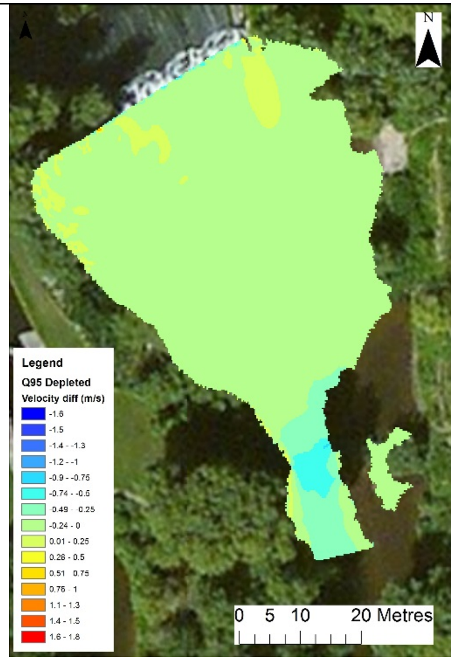
Q95 Depth. Depleted reach



Q95 Velocity. On-weir hydropower



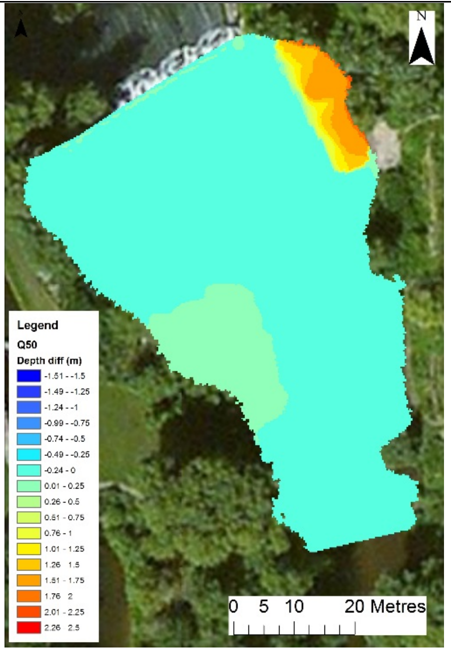
Q95 Velocity. Depleted reach



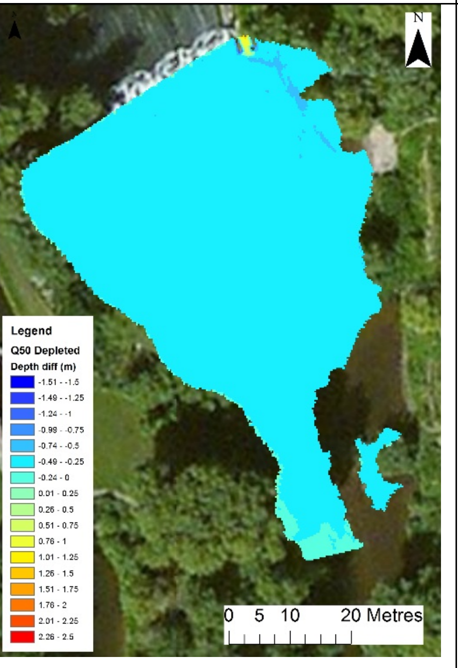
Difference = post-installation minus pre-installation.

Figure 4.7 Pershore difference maps – Q95

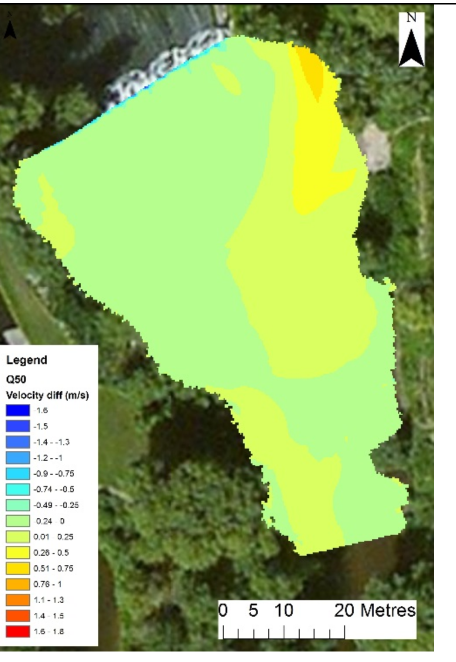
Q50 Depth. On-weir hydropower



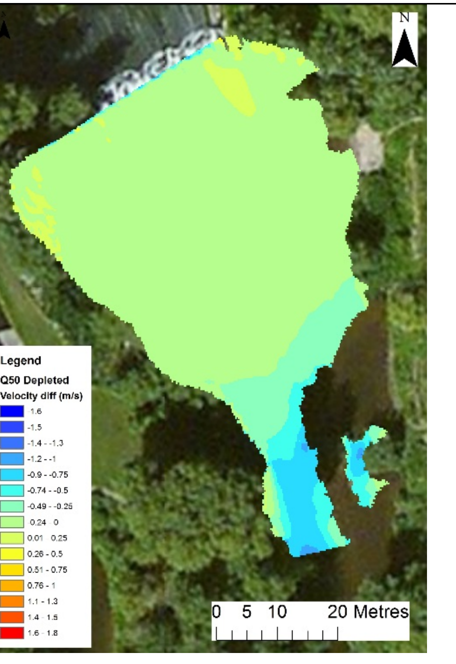
Q50 Depth. Depleted reach



Q50 Velocity. On-weir hydropower



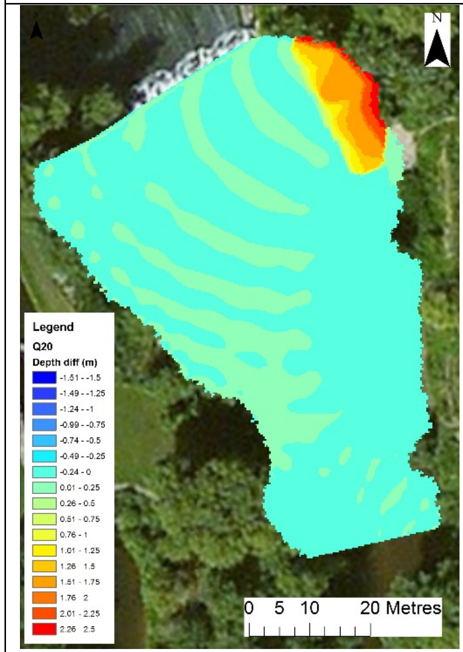
Q50 Velocity. Depleted reach



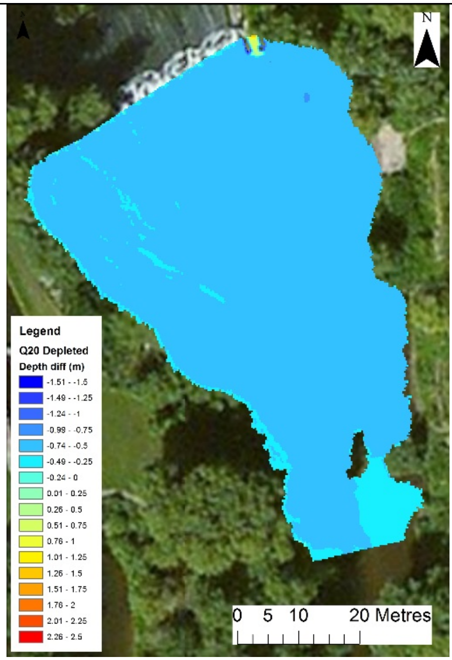
Difference = post-installation minus pre-installation.

Figure 4.8 Pershore difference maps – Q50

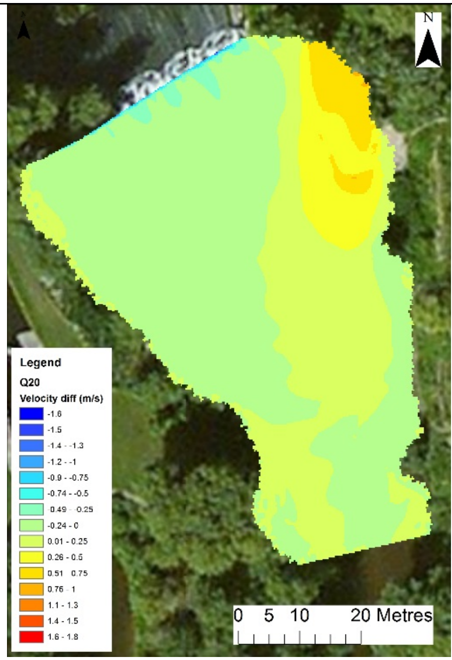
Q20 Depth. On-weir hydropower



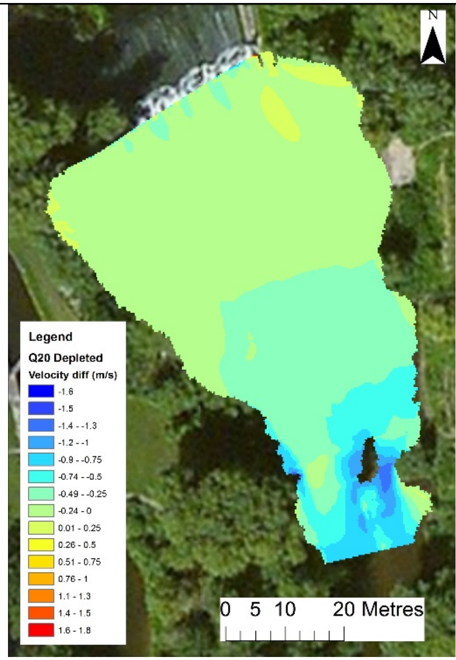
Q20 Depth. Depleted reach



Q20 Velocity. On-weir hydropower



Q20 Velocity. Depleted reach



Difference = post-installation minus pre-installation.

Figure 4.9 Pershore difference maps – Q20

4.7 Interpretation

4.7.1 Hydromorphological interpretation

Within the deep pool downstream of Pershore Weir Q95 velocities remain relatively unchanged between pre- and post-scenario hydropower conditions with velocities remaining in the order of 0.001 to 0.04 m/s, with only minor reductions experienced as a result of the hydropower scheme. Velocities of this magnitude are likely to result in some deposition of sands.

Velocity changes are slightly more significant for Q50 flow conditions where there is a general reduction in velocities of up to 0.3 m/s as a result of operation of the on-weir hydropower scheme. This could alter the depositional process for this flow where larger sands are deposited under the hydropower scenario that would normally be transported through the pool.

Changes are also more significant under Q20 flow conditions with velocities reducing by up to 0.3 m/s, to values below 0.1 m/s in general as a result of operating the hydropower scheme. This is again likely to result in deposition of larger sands in the deeper pool zone compared to existing conditions where transport of some smaller gravels could occur through the pool.

Under Q95 flow conditions, velocity changes are low as a result of operation of the hydropower scheme with velocities remaining between 0.1 and 0.5 m/s across the large gravel bar feature with only minor local variations. These velocities are high enough to limit the amount of fine sediment infilling of the gravel feature.

For Q50 flow conditions, the greatest change in velocity is at the upstream end of the bar feature where velocities increase by up to 0.25 m/s. This results in flow velocities of up to 0.6 m/s and could transport gravel-sized material off the point bar, which has a lower chance of occurring under existing flow conditions. Therefore, the composition of the upstream end of the gravel bar feature may change over time with larger gravel material dominating the upstream section.

Q20 flow conditions and impacts are similar to Q50 flow conditions where the greatest increases in velocities are experienced at the upstream end of the gravel bar feature as a result of the location of the outfall on the left hand bank from the hydropower scheme. Velocities could reach up to 0.8–0.9 m/s, which is capable of transporting gravel-sized material as bedload.

The impacts on flows under Q95 flow conditions are minimal; however, the deeper pool areas could suffer from a change in morphology as a result of a greater rate of deposition of larger sand material due to lower velocities.

Processes across the gravel shoal may be affected as a result of the changes in the flow dynamics associated with the hydropower scheme. Higher flow dynamics are impacted to a greater degree and could result in a change to the composition of the upstream end of the gravel shoal in the medium to long term. This would be through gradual coarsening and possible small-scale erosion of the upstream end of the point bar feature as a result of the increase in velocities at higher flows under post-hydropower scheme conditions. However, dependent on the supply of gravel material from upstream, any eroded material may be replaced as the flood event recedes.

Any changes to the extent of the gravel shoal predicted by the changes in processes shown are dependent on the supply of gravel from upstream. The impounding influence of the weir is likely to limit the supply of gravels to the gravel shoal and therefore any changes are likely to occur over longer timescales.

4.7.2 Macroinvertebrate interpretation

The lack of any macroinvertebrate data for the complex of habitats immediately below Pershore Weir means that no conclusions can be drawn from the results of the modelling.

4.7.3 Macrophyte interpretation

Very limited data on macrophyte composition and distribution restricts interpretation of the modelled impacts; macrophyte communities can be sensitive to velocity and depth changes, but these are expected to be small.

The tall emergent species present along the river margins (i.e. Reed Canary-grass, Common Reed and Bulrush) generally have a wide tolerance of water depths in which they will grow, as do the two common species of water-lily found in the UK (Table 4.13). Changes in water depths as a result of the hydropower scheme may result in changes to the marginal vegetation communities present, but these are likely to be negligible, with communities shifting towards Reed Canary-grass where depths become shallower, potentially with a slight decline in abundance of Common Reed and Bulrush. However, given the broad water depth tolerances for the species present, changes in depth associated with both hydropower scenarios are unlikely to substantially drive macrophyte distribution and abundance.

Table 4.13 Water depth tolerances of species present (from Newbold and Mountford 1997)

Species		**'Dry' tolerance limit (cm)**	**Preferred water level conditions (cm)**	**'Wet' tolerance limit (cm)**
Reed Canary-grass	*Phalaris arundinacea*	-60	-40 to 0	+30
Common Reed	*Phragmites australis*	-100	-20 to 0	+50
Bulrush	*Typha latifolia*	-20	+10 to +75	+100
Yellow Water-lily	*Nuphar lutea*	-10 to 0	+30 to +200	
White Water-lily	*Nymphaea alba*		+30 to +250	
Note: the minus sign indicates water table below ground levels, the plus sign indicates water level above ground level (i.e. depth of water).				

With regards to velocity, Reed Canary-grass can be found in a wide variety of habitats, from swift hill streams to more stagnant ditch habitats (Haslam 2006), and it is unlikely to be affected by any velocity changes as a result of the hydropower scheme. Common Reed, however, is more closely associated with slacker, negligible flows (Haslam 2006) and therefore a slight decrease in flow velocity in the weir pool is likely to have an impact on this species, potentially allowing the marginal stands to extend further. Similarly, Yellow water-lily is also associated with slow flowing waters and therefore decreases in flow velocity where this species is present may also help the population to expand (Haslam 2006) (no information is available for flow preferences of White Water-lily). The most significant changes therefore are likely to arise in the depleted reach scenario where an increase in the extent of Common Reed and Yellow Water-lily may arise, particularly towards the downstream end of the weir pool complex.

4.7.4 Fisheries interpretation

The lack of change in extent and diversity of submerged/emergent plants in the on-weir hydropower scenario is unlikely to change the availability of spawning substrate for, and therefore have discernible population-level impacts on, phytophilic fish species known to be present downstream of the weir (i.e. Rudd). The potential for increased extents of Common Reed and Yellow Water-lily under the depleted reach scenario may, however, benefit phytophilic species.

The lack of significant change in depth (at all flows) associated with the on-weir scheme means there is unlikely to be any immediate change in availability of deeper holding pool features. The deposition (associated with reduced velocities at moderate and higher flows) of larger sands in the deeper pool features may result in a gradual reduction in pool depth over time, although this will depend on the frequency of flood flows which could again scour and remove any such accumulated sediments.

At moderate flows (Q50), the co-location of optimal water depths and velocities for lithophilic/phytolithophilc spawning coarse fish is largely confined to the large bar feature adjacent to the left bank, approximately 60 m from the weir apron. The post-installation on-weir scenario results in a small increase in the extent of such habitat (associated with an area immediately downstream of the tailrace). Velocities that can maintain clean gravels on the upstream end of the gravel bar are sustained in the on-weir hydropower scenario, with any increase in the size of gravel particles in this area potentially limiting exploitation to larger individuals, in the situation when replacement by smaller grains does not occur.

It should be noted that despite sampled grain size data being used in information available on the Pershore site (Fishtek 2012a), actual grain size distribution data was not available to this study and therefore could not be overlain on top of spatial information on optimal depths and velocities for lithophilic/phytolithophilc spawners. The changes to extent of optimal velocities and depths cannot therefore be considered an accurate assessment of changes to availability of spawning habitat. What is obvious, however, is that the reduction in depths associated with the depleted reach scenario results in a drying out of the bar feature during Q95 and Q50 flows, rendering a significant area of this feature unavailable as fish habitat. Under this scenario, co-located optimal water depths and velocities for lithophilic/phytolithophilc spawning coarse fish shift towards the right bank, off the now exposed bar feature. The lack of grain size data does not allow confirmation of whether sediments in this area are likely to be exploitable by such species.

5 Goring Weir

5.1 Site characteristics

Goring Weir is located in a heavily modified section of the Thames. The weir consists of two broad-crested weirs with three sluice gates and a fish pass located between the two weirs. A lock is situated adjacent to the Goring Weir and around 100 m downstream of Goring Weir is a further weir and sluice complex (Streatley Weir). The water levels upstream of the weir are controlled by lockkeepers using the sluice gates and other structures nearby.

The proposed hydropower scheme consists of three Archimedes screw turbines and a new fish pass, located in the area currently occupied by the easterly of the two broad-crested weirs. The proposal also includes the provision of a fourth sluice gate adjacent to the existing gates.

5.2 Previous studies and supplied data

A range of data has been supplied by the Environment Agency (Table 5.1).

Table 5.1 Data supplied for Goring Weir

Bathymetric survey	A number of bathymetric surveys have been undertaken at this site. Surveys from 1936, 1974, 1986, 1989, 1990, 1997 and 2012 were provided. The latest survey in 2012 was undertaken by Maltby Land Surveys.
ADCP	ADCP surveys were undertaken by the Environment Agency's Technical Advisor on Hydro-acoustics in June 2013 and February 2014.
Weir dimensions	Around 50 engineering drawings, which dated from 1988 and the Thames Water reconstruction of Goring and Streatley weirs.
	Topographic survey of Goring Lock and Weirs undertaken in 2010 by Jacobs (drawing numbers 10614/01 to 10614/03).
Layout drawings	Drawing IMP/001/2 site plan, showed the proposed layout of the scheme.
Water level and flow data	Upstream water levels were provided from 1995 to 2014, downstream water levels from 2008 to 2014.
Ecological data/survey reports	The Environment Agency provided invertebrate, macrophyte and fisheries data for nearby sites. Further details are given in the relevant sections.

Table 5.2 Previous studies at Goring Weir

Design study	A 2008 report by Mann Power, which provided details of the system layout, construction methods, hydrology and an overview of potential environmental issues.
Environmental	An environmental report undertaken by David Rogers Associates in July 2009 included sections on landscape and visual impact, river

reports	corridor, macroinvertebrates and fish.
	An environmental report (Eeles 2014) commissioned by the Goring and Streatley Sustainability Group.
Hydrological assessment	A brief hydrological assessment was conducted by the Environment Agency in 2011. This assessed the hydrological requirements of the scheme relative to available water.
Desk study	Jacobs (2013b) undertook a morphological and ecological desk study. The report highlighted a potential localised ecological impact of the hydropower scheme, especially on macroinvertebrates, and recommended further monitoring.

5.3 Current status

Goring Weir sits within the River Thames (Wallingford to Caversham) heavily modified waterbody (GB106039030331) that is currently classed as achieving moderate ecological potential and therefore failing Water Framework Directive objectives. The fish, macrophyte and macroinvertebrate quality elements are currently classed as no information, no information and good respectively.

5.3.1 Fish populations

The nearest available fish population survey data held by the Environment Agency relates to surveys undertaken at the locations given in Table 5.3.

Table 5.3 Environment Agency fish population survey data at locations in proximity to Goring Weir

Site name	Grid reference	Approximate location	Date of survey	Species recorded
Goring Weir pool	SU5958780760	Approximately 60 m downstream of Goring Weir	20 July 2008 13 July 2009 19 July 2010 20 July 2011 28 July 2012 9 July 2013	Rheophilic: Chub; Dace; Gudgeon Eurytopic: Bleak; Common Bream; Perch; Pike; Ruffe; Roach; Common carp varieties; Mirror Carp; European Eel Limnophilic: Tench
Cleeve-Goring	SU5970081300	Approximately 500 m upstream of Goring Weir	15 July 2004 14 July 2005 19 July 2007 13 Aug 2007 20 July 2008 12 July 2009 18 July 2010 19 July 2011 27 July 2012 08 July 2013	Rheophilic: Chub; Dace; Gudgeon Eurytopic: Bleak; Common Bream; Perch; Pike; Ruffe; Roach; Common carp varieties; Mirror Carp; European Eel; Silver Bream Limnophilic: Tench

Both rheophilic and eurytopic fish species were caught upstream and downstream of Goring Weir. Barbel are also thought to be present downstream of Goring Lock (David Rogers Associates 2009).

5.3.2 Invertebrate populations

Data on invertebrate communities around the site has been collected upstream and downstream of Goring Weir, including in the weir pool, 180 m downstream and within a side channel (David Rogers Associates 2009) and at the weir pools of the adjacent Middle and Southern Linear weirs (Eeles, 2014), providing a single baseline of invertebrate populations. The samples from the study by David Rogers Associates (2009) showed that invertebrate communities around the site were of moderate diversity and abundance, with highest taxon richness upstream of the weir (41 taxa, sampled 40 m upstream). The LIFE scores of the samples generally reflected preferences for moderate flow velocities ($6.2{-}7.1 m^3 s^{-1}$) and there were no species of conservation concern recorded. Two taxa were recorded as unique to the weir pool in the study, Polycentropidae and *Valvata cristata*, although both have been recorded upstream of the weir in routine Environment Agency monitoring, so are not considered genuinely unique to the pool. Neither are known to be of conservation concern (although note this cannot be stated with certainty without identification to species level for Polycentropidae). While no species of conservation concern were found in the main channel, the southern linear weir pool (associated with the most westerly arm of the river and remote from the weir proposed for the hydropower) included the dragonfly *Gomphus vulgatissimus*, of notable conservation status (Chadd and Extence 2004) and the mayfly *Ephemera lineata*, listed as vulnerable in the Red Data Book. The latter species, while nationally rare, has been commonly observed along the mid-Thames (Eelea, 2014) and has a preference for slow/sluggish waters (Extence et al. 1999). In summary, the invertebrate populations in the Goring Weir pool and surrounding areas are of moderate abundance and diversity, without specific preferences for fast flowing waters and with no species of major conservation concern.

5.3.3 Macrophyte populations

David Rogers Associates (2009) report that no submerged or floating aquatic vegetation was seen in the area, except for a light covering of the algae *Cladophora* sp. covering a concrete weir under the road bridge of the Streatley channel. This lack of aquatic macrophyte data was attributed to the turbidity of the water. However, in contrast, while Eeles (2014) also note a lack of submerged, floating-leaved and emergent macrophytes at the site, they attribute this primarily to a lack of light due to the overshadowing of weirside margins by trees and shrubs. This lack of aquatic macrophyte presence in the channel is reinforced by Jacobs (2013b).

Environment Agency ecology data on plants at Goring was not available as no survey had been conducted. Macrophyte data was available for Whitchurch; however, this cannot be considered analogous to Goring as it is from a site several kilometres downstream, the habitat present at this site is unknown and previous surveys at Goring identified a lack of plant species.

Emergent vegetation at Goring was similarly limited, with David Rogers Associates (2009) reporting only one small patch of emergent plant species on the right bank; however, the species was not specified. This lack of emergent vegetation can be considered to reflect the heavily modified nature of the bankside habitat with the right bank being reinforced with concrete or steel shuttering and the left bank alongside the turbines also reinforced with concrete.

5.4 Scoping process

5.4.1 Rationale

The purpose of this section is to apply the weir pool importance scoping process to the Goring site.

This assessment has been undertaken using two approaches: the first uses freely available online resources and routine monitoring datasets held by the Environment Agency (reported under 'Desk study' in the tables below), and the second where all available information was used in the application of the scoping process (reported under 'Available reports' in the tables below).

5.4.2 Connectivity/weir pool rarity

The Environment Agency River Obstructions Database was used to determine the presence of potential instream barriers to migration in proximity to Goring Weir. Table 5.4 lists information relating to these barriers and Figure 5.1 shows their location.

Table 5.4 Information on adjacent instream structures from Environment Agency Rivers Obstructions Database

Order	Barrier	Longitudinal/ lateral[1]	Distance from target barrier (km)[2]	Fish pass present (type)?	Head over barrier (P_HEAD; Z_Head; 25 m_Head; m)[3]	Total number of barriers to mean high water (STOTAL)	Approx. distance to mean high water – km (SLENGTH)
1 u/s	Cleeve (11260)	Long	0.85	Unknown	0; 0; 0	24	111
	Goring Weir (12517)	-	0	Alaskan 'A' Denil	0; 0; 0	23	110
1	Whitchurch (13437)	Long	6.5	Unknown	0.801; 0.807; 1.263	22	104
2	Pangbourne (13462)	Lat	7.7 (1.7)	No	-0.026; 0.179; 0.297	22	105
3	Mapledurham (13424)	Long	10.2	Alaskan 'A' Denil	0; 0; 0	22	100
4	Caversham (13378)	Long	17	Larinier	2.422; 2.963; 2.994	21	93
5	Blakes Weir (13368)	Lat	18.2 (0.6)	Larinier	-0.434; 0.145; 1.097	21	92
6	Sonning Weir (13448)	Lat	21	Plain baffle Denil	0; 0; 0	20	89

Notes
1 – Position of the barrier in relation to connectivity with main river channel
2 – Value given in parenthesis is distance from given barrier to main river channel
3 – Environment Agency River Obstructions Database derives head over weir in a number of ways. Values given relate to the respective method used to calculate head.

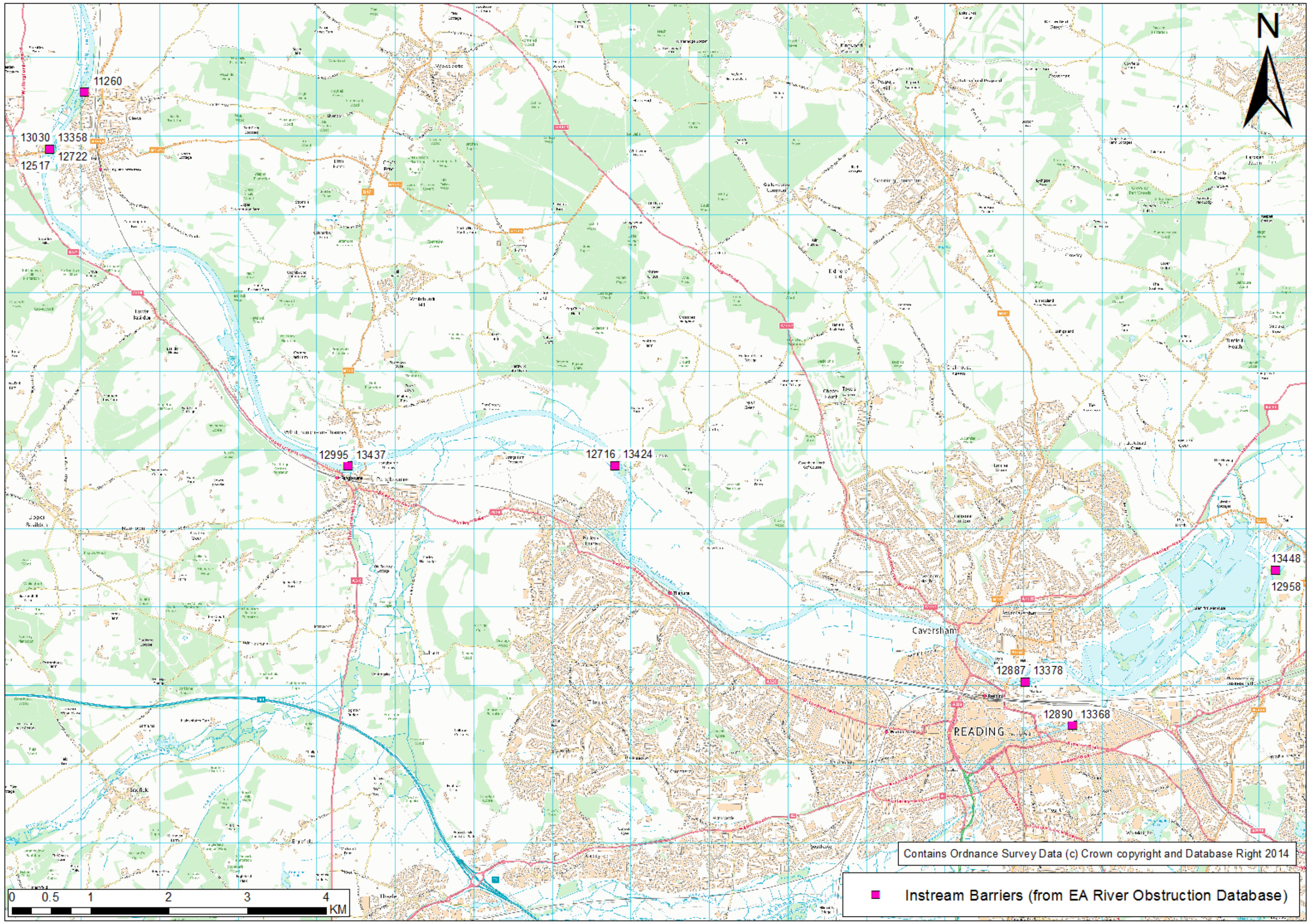


Figure 5.1 Location of adjacent instream barriers given in Table 5.4

5.4.3 Application of scoping process

Table 5.5 Is the site in an SSSI/SAC? (i.e. in a designated site)

	Evidence	Finding
Desk study	There are no designated sites close to Goring Weir that are likely to be impacted by changes in flow dynamics as a result of operation of a hydropower scheme.	No
Available reports	As above.	No

Table 5.6 Are fish species known to be present at low frequencies/densities in the catchment likely to be exploiting the complex of habitats associated with the weir pool?

	Evidence	Finding
Desk study	A variety of fish guilds were found both upstream and downstream of Goring Weir.	No
Available reports	No further information available.	No

Table 5.7 Is the weir pool type habitat rare? (i.e. is the deeper pool and gravel shoal type environment found frequently either locally or elsewhere along the river system, beyond the influence of the weir itself and where the flow and sediment regime is less constrained or influenced?)

	Evidence	Finding
Desk study	The information given in Table 5.4 indicates the nearest weir downstream (Whitchurch Weir; ID13437) is approximately 6.5 km from Goring Weir (which has an Alaskan-A fish pass). Aerial imagery and OS Open (Streetview) base mapping suggests there are relatively few tributaries entering the Thames in this stretch (Child-Beale Nature Reserve is connected to this stretch and is seemingly accessible from the main river channel although consists primarily of still waterbodies). Between Whitchurch Weir (fish pass presence unknown although a navigation lock is present) and Mapledurham Weir (ID13424; approximately 4 km further downstream; Alaskan-A fish pass present) a reasonable number of tributaries flow into the Thames, most without any in-channel structures (as given in Environment Agency dataset). Despite the lack of obvious gravel bar features immediately downstream of Goring Weir from aerial imagery, shallower riffle habitat potentially associated with Goring Weir is therefore partially accessible and could be considered of moderate rarity (given the lack of	Possibly

	Evidence	Finding
	similar structures in the stretch 10 km downstream to Mapledurham Weir).	
Available reports	No wider-scale geomorphological discussion included in the previous reports. No further information than that generated in the desk-based study.	Possibly

Table 5.8 Is the morphology of the habitat complex good quality? (i.e. is the gravel shoal relatively clean and free from fine sediment, providing better habitat condition?)

	Evidence	Finding
Desk study	The quality of any present gravel shoal cannot be determined from the Google Earth imagery due to the resolution and flow levels when this was undertaken. To confirm, this would require a site walkover and assessment (which would also be used to determine the river typology and gravel feature condition elsewhere in the system).	Possibly
Available reports	The Jacobs (2013b) geomorphology report suggests that any shallower bar and bed features generally have a dominance of fine sediment mixed with some coarser material in some sections. This is similarly reflected in the Eeles (2014) report where channel margins and shallow water areas tend to have a finer sediment/silt covering. The bed of the channel within the deep pools is described as being composed of larger, cleaner gravels in the Eeles (2014) report, which is unsurprising given the turbulence associated with flow over the structures and the scour it creates. Despite this, the shallower gravel features within the weir pool complex are of poor quality due to fine sediment and silt infilling.	No

5.5 Hydraulic modelling – details

5.5.1 Digital elevation model generation

ADCP bed level data gathered in mid-2013 and early 2014 (i.e. either side of the Christmas floods on the Thames) was available. This allowed the hydropower installation to be analysed against the kind of changes in weir pool hydraulics that could result from changes in bathymetry associated with flood events. The key data used to generate the DEM is outlined in Table 5.9.

Table 5.9 Details of Goring DEM generation

Bathymetry	The results from the 2013 and 2014 surveys were interpolated to create two grids covering the area surveyed. Where this did not cover the entire extent of the channel, the 2012 survey was used (Figure 5.2).
Weir dimensions	The elevations and dimensions of the weir structure were taken from a topographic survey undertaken by Jacobs for the

	Environment Agency in November 2010 (drawing number 10614/01.pdf). This drawing included no details of the bathymetry in the vicinity of the sluice gates. This information was obtained from Thames Water engineering drawings (1988) in particular drawings ENG11576-08 and ENG11576-09.
River banks	1 m resolution LIDAR data was obtained from the Environment Agency.

As expected there are discrepancies between the bed levels observed in the 2012 survey and those observed in the 2013 and 2014 surveys at the boundaries between the datasets. These areas were ‘smoothed’ using a ‘z-shape’ polygon within the TUFLOW model.

2013	**2014**

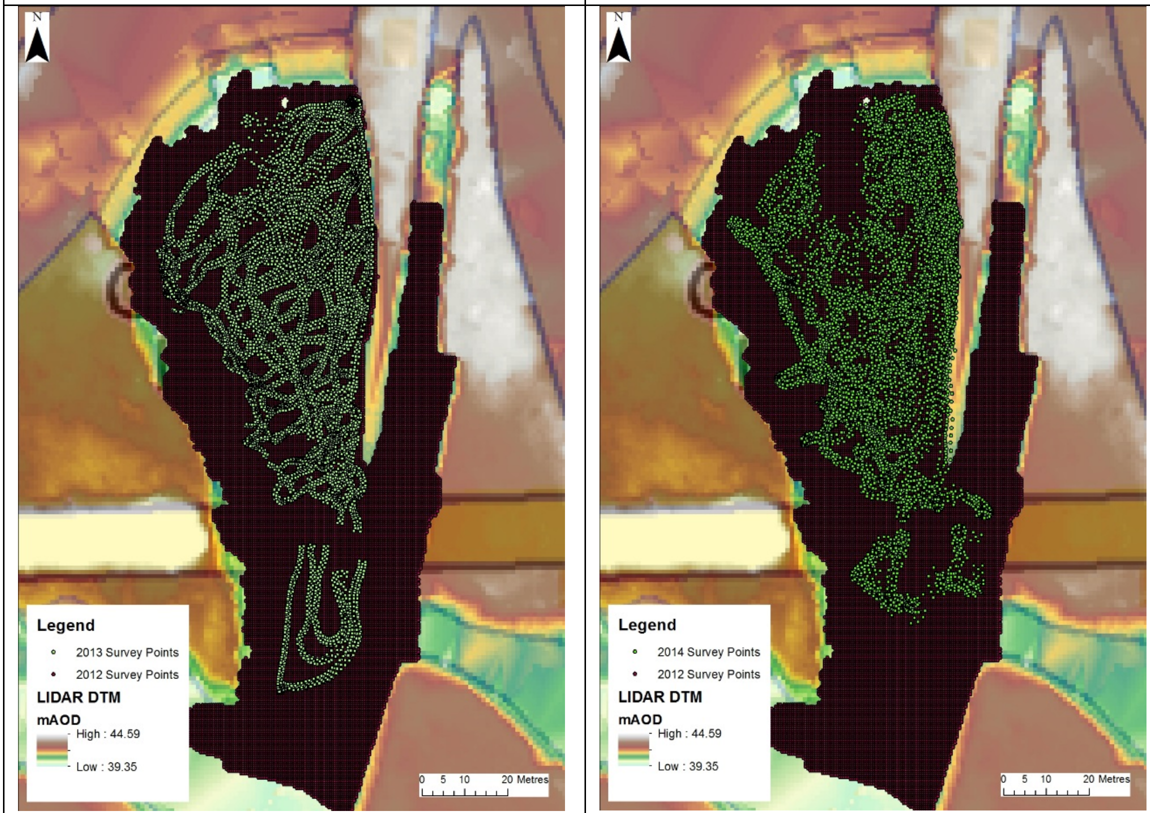


Figure 5.2 Data availability for Goring DEM generation

5.5.2 Model boundaries

Due to the complex nature of the site, there are no records of the relative flow between the weir and the sluice gates. However, the Environment Agency does have a good record of upstream water levels. The water level upstream of the weir is maintained by lockkeepers. Therefore, the amount of flow over the weir structure is controlled by the lockkeepers rather than there being a more straightforward relationship between flow and weir dimensions, as would be the case at most weirs.

A stage–duration curve (analogous to a flow duration curve) was therefore used to determine the flow over the weir. Again, three exceedances have been modelled for each scenario (95th percentile, 50th percentile and 20th percentile).

The water level upstream of the weir has been set to the appropriate exceedance level with the weir crest defined from survey data included in the model. The flow over the weir and any preferential flow paths on the weir face were therefore calculated by TUFLOW.

Liaison with the Environment Agency suggested that the sluice gates are kept closed unless the river is in flood. When closed the gates allow some water to flow over the sluice structure, and because the effective hydraulic invert of the sluice gates is known (Jacobs 2013b), the weir equation has been used to calculate the flow over the sluice gates at different exceedance stages.

The model calibration process (comparing modelled velocities to observed ADCP velocities) showed an under prediction of velocity by the model in the area near and downstream of the sluice gates. The ADCP surveys were taken at Q3 and Q38 (relatively high flows), suggesting that at flows such as these, the gates at Goring Weir are used to control water levels upstream. However, there is no record of the discharge through the sluices for each exceedance flow, and indeed this may vary depending on the operation of other structures in the vicinity of the weir.

Two pre-installation scenarios have therefore been modelled:

- Assuming that the sluice gates are closed, so that the sluice gates effectively act as a weir. The flow over the sluice gates is small, and the addition of the turbines in the post-change scenario leads to an increase in discharge in the channel downstream of the weir.
- The flow through the sluice gates is assumed to be equivalent to the flow that will be passed through the turbines in the post-change scenario (i.e. the flows in the pre- and post-change model are identical). There is no need to run this for the 95th percentile as there is no turbine flow.

These two scenarios create a range of possible change, since if the sluice gates are kept largely closed, the introduction of the hydropower scheme will reflect the changes predicted when the pre-installation (gates closed) model results are compared to the post-installation results. Whereas, if the gates are currently operated to release similar discharges to the proposed hydropower scheme, the changes will reflect those observed when comparing the pre-installation (gates open) scenario with the post-change scenario. In effect, this is a best and worst case scenario.

The details of the turbine and fish pass requirements were taken from the Mann Power (2008) study (Table 5.10). The layout of the proposed hydropower scheme is illustrated in Figure 5.3.

Table 5.10 Flow availability and splits at Goring Weir

		Pre-installation flow (m^3/s) gates closed scenario			**Pre-installation flow (m^3/s) gates 'open' scenario**			**Post-installation**			
%ile	Water level	FP	Sluice	Weir	FP	Sluice	Weir	FP	Turbines	Sluice	Weir
20	41.54	0.5	0.92	8.27	0.5	20.92	8.27	1.2	20	1.23	5.65
50	41.50	0.5	0.58	6.16	0.5	15.58	6.16	1.2	15	0.77	4.27
95	41.42	0.5	0.10	2.98	0.5	0.10	2.98	1.2	0	0.14	2.19

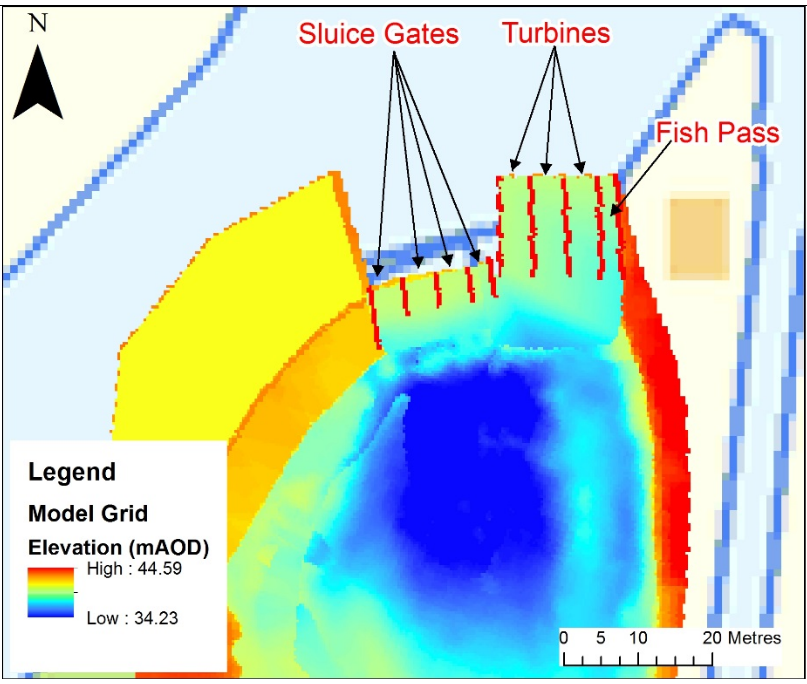


Figure 5.3 Goring post-installation model grid (2013)

The other boundaries used in the model are outlined in Table 5.11.

Table 5.11 Details of Goring model boundaries

Cell size	A cell size of 0.5 m was used. This is slightly smaller than the 1 m resolution of the LIDAR, but consistent with the resolution of the ADCP bathymetric data used as the basis for the instream topography.
Roughness	A Manning's roughness value of 0.05 was used in the channel downstream of the weir. See the calibration section (5.5.3) for more details.
Downstream boundary	The downstream water levels supplied by the Environment Agency were used to calculate a stage–duration curve for downstream water levels (record from November 1995 to May 2014). The table below summarises the water levels used for each of the exceedance stages of interest. **Percentile** – **Stage (mAOD)** 20th – 40.19 50th – 39.87 95th – 39.17
Initial water levels	Corresponded to the water levels used to define the downstream boundary.

5.5.3 Calibration

The velocities in the weir pool were sampled during the ADCP surveys. The water level data provided by the Environment Agency gives an understanding of the observed water levels on the day of the survey (Table 5.12).

Table 5.12 Recorded water levels (calibration)

Date of survey	Upstream water level (mAOD)	Downstream water level (mAOD)	Approx. exceedance
12 June 2013	41.52	39.88	38th percentile
24 February 2014	41.68	41.20	3.4th percentile

The 2013 ADCP survey was conducted with upstream water levels at the 38th percentile and it is possible that the sluice gates were open to some extent at that time. It is considered very likely that the sluice gates will have been open during the 2014 survey (3.4th percentile). However, there is no record available of the flows through the sluice gate. Therefore, in the following analysis, it is assumed that the gates are closed.

As the downstream boundary of the model is defined by observed water level, the key model parameter controlling modelled velocities is the Manning's roughness in the channel downstream of the weir.

Table 5.13 shows that the model is under predicting velocities compared to the 2013 ADCP survey and is also insensitive to the choice of Manning's roughness value. On average the model is under predicting velocities by around 0.1 m/s. This under prediction is more marked in the 2014 calibration, with the average under prediction in the order of 0.5 m/s.

Table 5.13 Goring model calibration results

		Velocity difference (modelled minus observed) (m/s)	
	Manning's	Mean	Standard deviation
2013 calibration	0.04	-0.1	0.11
	0.05	-0.09	0.11
	0.06	-0.1	0.11
2014 calibration	0.05	-0.55	0.34
	0.06	-0.49	0.33

Figure 5.4 shows that the main areas of under prediction are found immediately downstream of the sluice gates. This under prediction is much greater in extent in the 2014 calibration compared to the 2013 calibration.

Figure 5.4 also shows that the model is slightly over predicting velocities in the areas of the channel not influenced by the outflow from the sluice gates. It is difficult to pinpoint whether this over prediction is due to the model, or influenced by confounding factors such as the turbulence and flow complexity associated with the sluice flow, the method used to calculate flows over the weir, topographic survey inaccuracies and/or ADCP sampling errors. If an ADCP survey could be conducted with the sluice gates closed, it would allow a more robust calibration of the model.

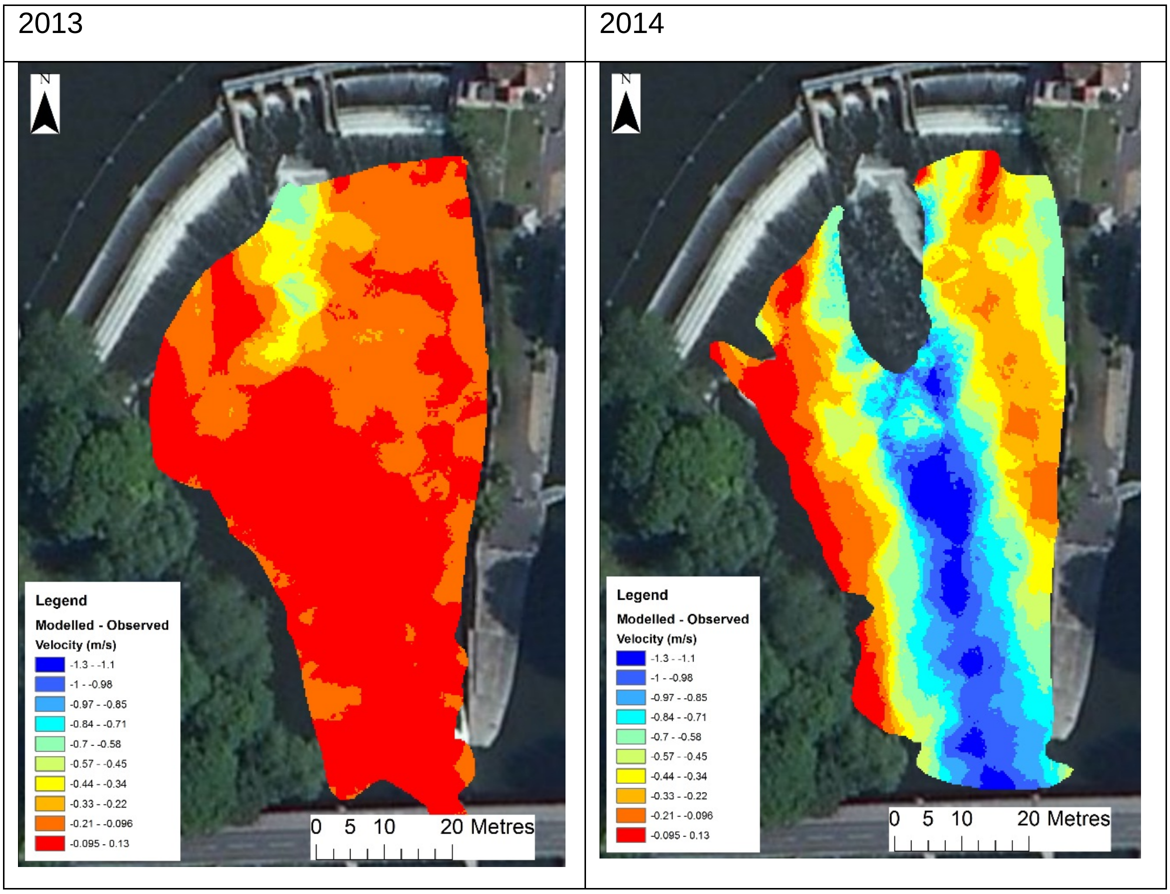


Figure 5.4 Model calibration plots (Goring)

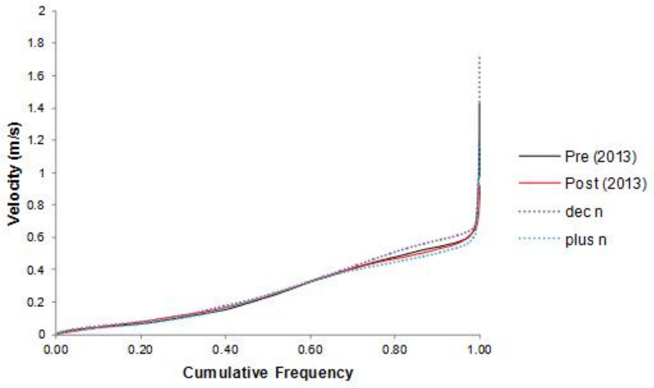
5.5.4 Sensitivity test

The sensitivity of the model to changes in Manning's roughness and downstream boundary was tested (Figure 5.5). The Manning's roughness was decreased to 0.03 and increased to 0.07 around the design value of 0.05, while the downstream boundary was decreased to 40.09 and increased to 40.29 around the 20th percentile design stage of 40.19 mAOD.

Figure 5.5 shows that while the model is relatively insensitive to roughness, the change in modelled velocities as a result of altering Manning's roughness is actually greater in scale than the changes in modelled velocity generated by the hydropower scheme, when compared to the pre-installation gates open scenario. However, the sensitivity to roughness was smaller than the changes associated when the pre-installation gates closed scenario was compared to the post-installation scenario.

Changing the water level of the downstream boundary led to changes in the velocity frequency in the weir pool complex. As expected, lowering the downstream boundary led to a slight increase in modelled velocities, and vice versa for increasing the water level at the downstream boundary. Since the data used to specify the downstream boundary is of a good quality and the scale of change is small, the choice of downstream boundary is considered robust.

Manning's roughness



Downstream boundary

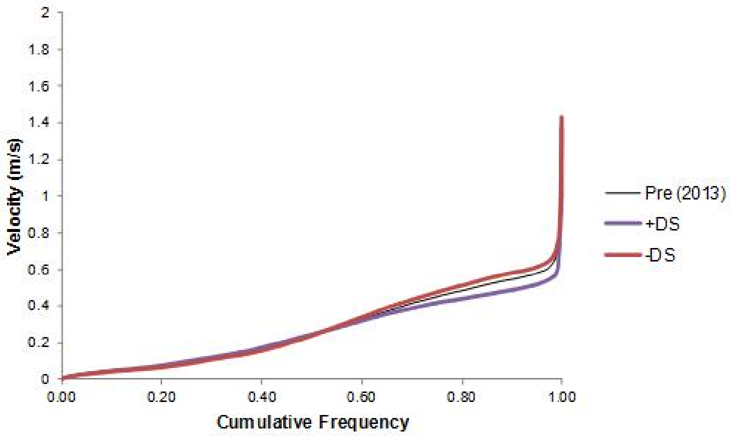


Figure 5.5 Sensitivity test results (Goring)

5.5.5 Site-specific limitations/considerations

The key uncertainty in the Goring analysis has been the lack of information about the flow through the sluice gates. Every effort has been made to produce a suite of results that will encompass this uncertainty within an envelope of possible change, by producing results from scenarios which correspond to the minimum and maximum likely change following hydropower installation. Depending on the operation of the sluice gates, the impact of installing a hydropower scheme may lie somewhere within that envelope of change.

5.6 Hydraulic habitat mapping

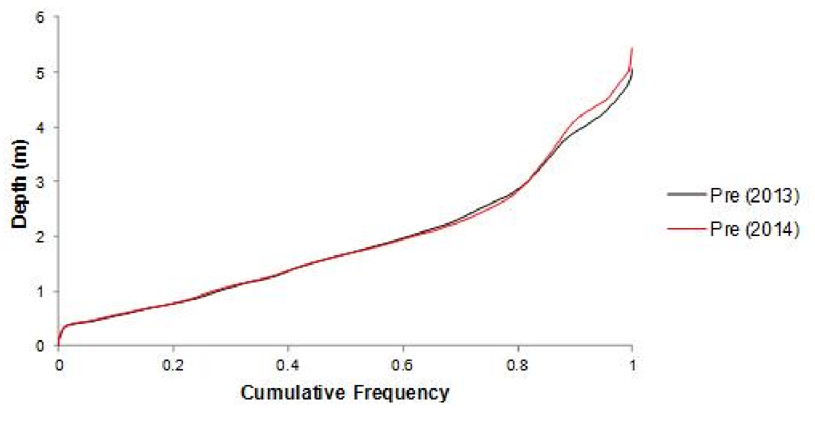
The whole of the model extent was not used in this assessment because as discussed above the model needs to extend beyond the area of interest to prevent uncertainty associated with the downstream boundary from influencing the model results. The hydraulic habitat assessment was focused on the deep weir pool and associated gravel bars and riffles downstream of the pool. In this case, the weir pool complex is assumed to reach approximately 60 m downstream of the toe of the weir.

5.6.1 Comparison of 2013 and 2014

The ADCP surveys in 2013 and 2014 were used to generate two model grids, which were representative of the channel before and after the floods at Christmas 2013. The aim was to set any changes in weir pool hydraulics as a result of hydropower installation against changes in weir pool hydraulics caused by the topographic change resulting from a flood event.

There are some differences between the bathymetry of the weir pool before and after the flood event, and these differences are reflected in the model results which predict a slight increase in water depth following the flood event (Figure 5.6). However, there is very little difference in the modelled velocities between the 2013 and 2014 bathymetries (and very little change in modelled depths). Thus, the key driver for weir pool velocities appears to be the distribution of the inflows (i.e. flow splits between different weirs, turbines etc.), rather than the bathymetry of the weir pool.

95th percentile comparison of depths (pre-change)



95th percentile comparison of velocities (pre-change)

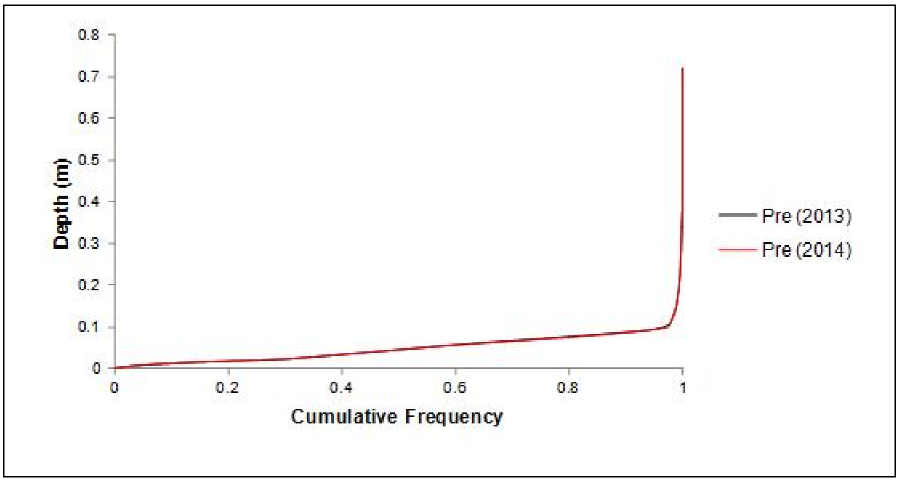


Figure 5.6 Comparison of 2013 and 2014 results

5.6.2 Impact of hydropower

Building on the conclusions of section 5.6.1, and for ease of presentation, the results below are those produced using the 2013 grid.

In the 95th percentile scenario there is no turbine flow. While, the cumulative frequency plots show little overall change in the distribution of velocities in the weir pool complex, decreases in velocity are observed close to where the exit of the pass was before construction and increases in velocity are predicted near the entrance of the new fish pass adjacent to the left hand bank.

Similar patterns are observed under the 50th percentile and the 20th percentile flows. When the sluices closed pre-installation scenario is compared to the post-change scenario a significant increase in velocities in the weir pool is observed (Figure 5.7), most noticeably in the vicinity of the turbine but propagating through the whole weir pool complex (Figure 5.8). When the post-change scenario is compared to a pre-change open sluice scenario, there is little difference in the frequency distribution of velocities in the weir pool complex. Although there are changes in the spatial distribution of velocity, the changes propagate less distance downstream compared to the no sluice gate flow comparison.

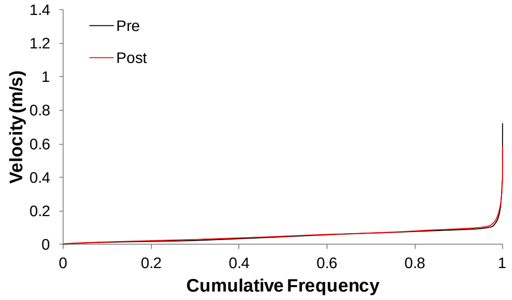
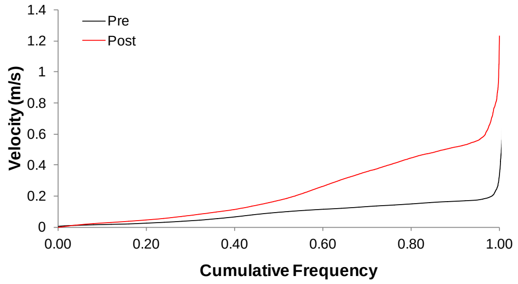
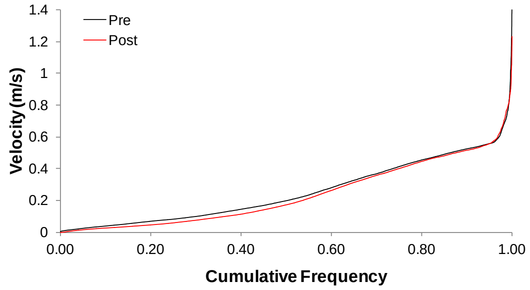
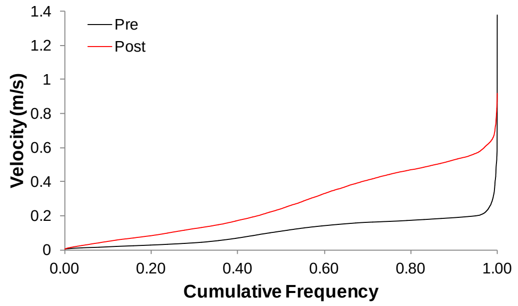
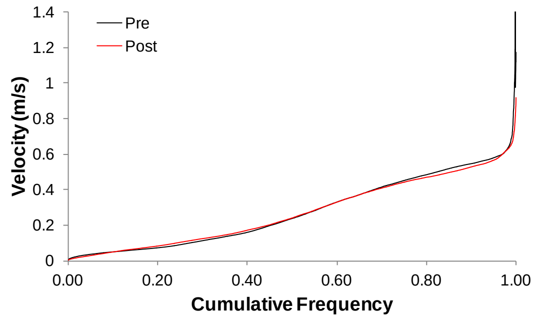
95th percentile sluice gates closed	95th percentile sluice gates passing ‘turbine flow’
	As left, no turbine flow
50th percentile sluice gates closed	**50th percentile sluice gates passing ‘turbine flow’**
	
20th percentile sluice gates closed	**20th percentile sluice gates passing ‘turbine flow’**
	

Figure 5.7 Velocity cumulative frequency plots (Goring)

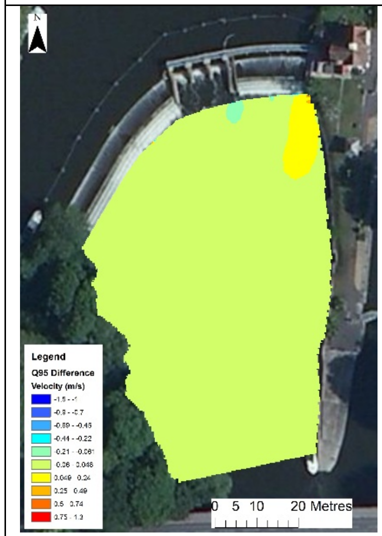
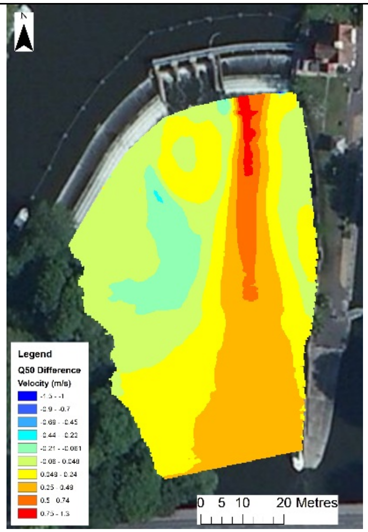
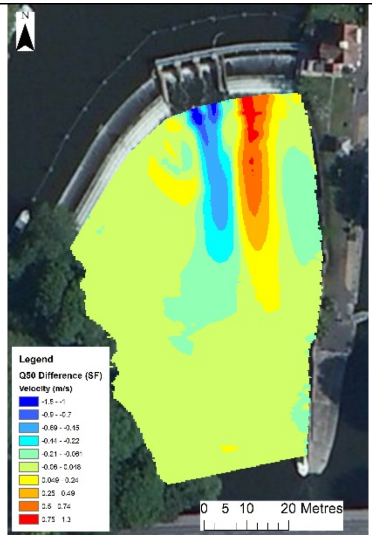
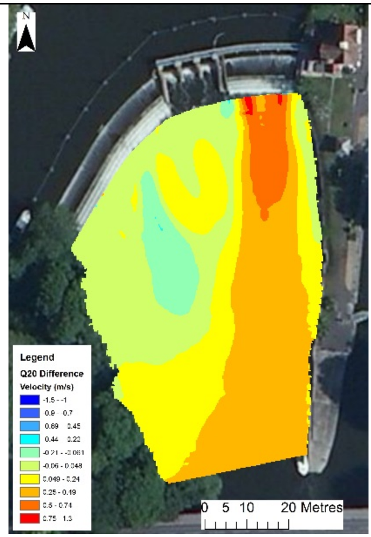
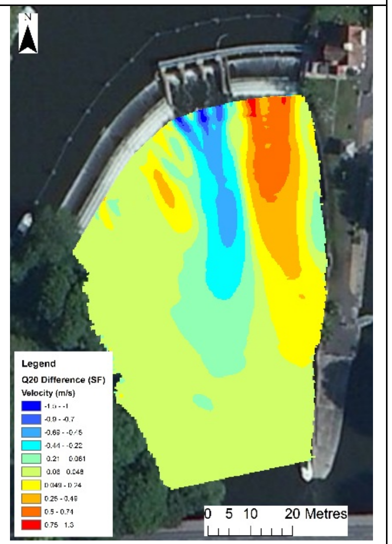
Q95 (both pre-change scenarios)	Q50 sluices closed	Q50 sluices passing turbine flow in pre-change scenario	Q20 sluices closed	Q20 sluices passing turbine flow in pre-change scenario
				
Difference = post-change minus pre-change				

Figure 5.8 Difference maps (Goring)

5.7 Interpretation

5.7.1 Hydromorphological interpretation

Within the deep pool and further downstream of Goring Weir velocities remain relatively unchanged between pre- and post-hydropower conditions for Q95 flow conditions with velocities remaining around 0.01 to 0.2 m/s across the weir profile. These velocities have been compared to the Hjulstrom Curve and are likely to result in deposition of sands and silt, but small areas of exposed gravels will potentially exist in higher velocity zones.

For the Q50 and Q20 sluices closed scenario there are significant increases in velocities downstream of the main weir as a result of all flow being directed through the turbine rather than through the sluice gates. This concentration of flow increases velocities by up to 1.3 m/s and could result in the transportation of gravel material on the channel bed in the section of channel immediately downstream of the turbine outfall. These velocities could be capable of moving and transporting gravel-sized material. Further downstream both the right and left banks have increased velocities of up to 0.2–0.4 m/s; this could mobilise some stored fine sediment and expose any stored gravels suitable for spawning habitat. The right hand side of the weir pool is likely to experience a reduction in flow velocity that could result in the deposition of finer material carried in suspension across the weir crest.

Under the scenario where sluices are passing turbine flow pre-change, there is a significant reduction in flow velocity for the Q50 and Q20 flow conditions immediately downstream of the sluice gates that could result in an increased rate of fine deposition on the channel bed. Downstream of the main weir, similar increases in velocities are experienced to the sluices closed scenario that could result in the transport of gravel on the channel bed.

Under Q20 flow conditions the left hand bank channel section that is currently shallow may have more energetic flows as a result of the sluice closed and passing of turbine flow scenarios because of the re-direction towards this bank. This could result in exposing of some gravel habitat where fine silts have been readily deposited in the past but could also result in the movement of some of the stored smaller gravel as velocities could reach up to 0.2 m/s.

5.7.2 Macroinvertebrate interpretation

The bed substrate in the reach downstream of Goring Weir is variable but principally composed of medium–coarse gravels in the faster flowing areas (i.e. close to the weir gate), with finer sediment in slower flowing areas (Eeles, 2014). At higher discharges (Q20 and Q50), the model of the main weir pool shows an increase in velocities around the turbines, with a shift in flow towards the left bank, and with possible decreases around the sluice gates depending on operation. These velocity changes will impact the physical habitat within the weir pool, through alteration of bed substrate and hydraulic change from velocity alteration. The impacts will differ according to the operation of the sluice gates; at Q50, for example, the increases in velocity predicted with the closed sluice gates will increase scour, while the open sluice gate scenario and associated velocity decreases will cause slower flowing waters and possible sediment deposition in the central section of the weir pool. While the model scenarios indicate a shift in flow towards the left bank, no impacts on marginal habitats are expected as the bank is artificial (Jacobs 2013b).

The predicted velocity changes in the two scenarios will have differing impacts on physical habitat, changing towards either a slower flowing, depositional environment or a faster flowing, more erosive environment, both causing some change to invertebrate populations. However, current invertebrate communities within the weir pool are not of particularly high abundance or diversity or of unique assemblage from the main channel. There are no species of conservation concern and taxa exhibit variable flow requirements. Thus, they are not considered to be sensitive to any changes. Furthermore, given the existing heavily modified nature of the system, the changes caused from the turbine are likely to be negligible. While some species of conservation concern were recorded in the weir pool associated with the south-western arm of the channel, this environment is not expected to be altered from the hydropower installation.

5.7.3 Macrophyte interpretation

The lack of macrophytes in the weir pool at Goring means that no interpretation of the impact of the hydropower scheme can be undertaken.

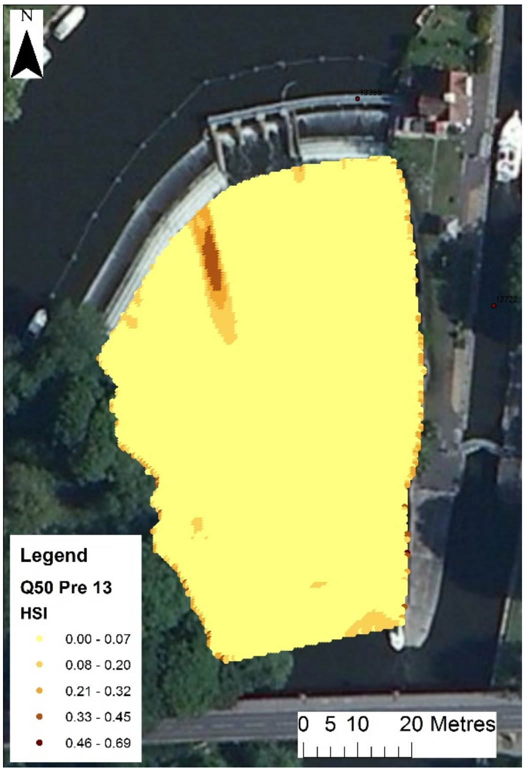
5.7.4 Fisheries interpretation

The lack of appreciable change in depth across the study area between the pre- and post-change scenarios means that the location and extent of adult fish holding habitat is very unlikely to have population-level effects.

An absence of emergent and aquatic macrophyte stands immediately downstream of Goring Weir suggests the phytophilic spawners known to be present in the stretch (i.e. Tench) are unlikely to use the habitats in the downstream stretch influenced by a hydropower scheme for spawning. Despite potentially lower velocities (as exploited by phytophilic spawners, Mann 1996) arising post-change in the margins, availability of phytophilic spawning substrate is unlikely to change following installation, given shading and light levels are thought to be the most significant factor limiting macrophyte/emergent plant abundance.

At higher flows (Q50 and Q20), the greatest potential impact on fisheries habitat occurs in the pre-change scenario where the sluice gates are closed. Optimal depths and velocities for lithophilic/phytolithophilc spawners in the absence of a hydropower scheme are largely confined to the very margins of the channel (left bank and right bank) and the periphery of the pool downstream of the right bank weir crest. In the post-change scenario, the area of optimal depths and velocities for lithophilic/phytolithophilc spawners is greatly increased and occurs across a much greater proportion of the channel; application of JHab reveals the Total Habitat Suitability Index (THSI; a measure of the overall habitat availability) increases from 219 to 2,071 with an increase in Habitat Quality Index (a measure of the quality of the available habitat) from 1.3 to 12.

Pre-hydropower (sluice gate closed)



Post-hydropower

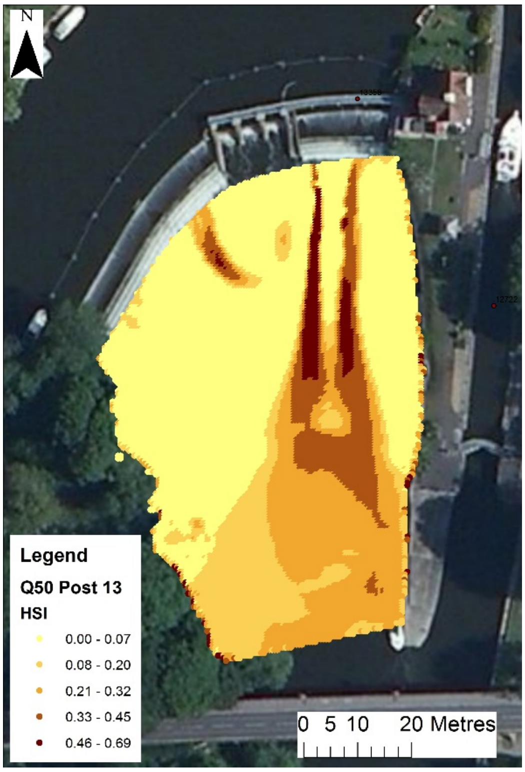


Figure 5.9 Changes in spawning Habitat Suitability Index predicted at Goring at Q50

The potential for increased sediment mobilisation (redistribution of coarser materials and maintenance of cleaner gravels) in the post-change scenario in the areas where optimal depths and velocities are predicted to occur is likely to result in an increase in availability and quality of spawning habitat.

It is worth noting at this point that any potential increase in quality and/or availability of spawning habitat is likely to be much reduced when the changes are determined using the pre-change, sluice gates open condition.

References

See main report: SC120077/R1.

Would you like to find out more about us or about your environment?

Then call us on
03708 506 506 (Monday to Friday, 8am to 6pm)

email
enquiries@environment-agency.gov.uk

or visit our website
www.gov.uk/environment-agency

incident hotline 0800 807060 (24 hours)
floodline 0345 988 1188 / 0845 988 1188 (24 hours)

Find out about call charges: www.gov.uk/call-charges

Environment first: Are you viewing this on screen? Please consider the environment and only print if absolutely recessary. If you are reading a paper copy, please don't forget to reuse and recycle if possible.