Please note - All amended text, issues for consideration and consultation questions are shown in bold text and highlighted in grey.

Consultation – Part 1 questions about sections in the first edition of the Good Practice Guidelines

Good practice guidelines to the Environment Agency hydropower handbook - The environmental assessment of proposed low head hydropower developments

First published August 2009

We are The Environment Agency. It's our job to look after your environment and make it a better place – for you, and for future generations.

Your environment is the air you breathe, the water you drink and the ground you walk on. Working with business, Government and society as a whole, we are making your environment cleaner and healthier.

The Environment Agency. Out there, making your environment a better place.

Published by:

Environment Agency
Horizon house, Deanery Road
Bristol BS1 5AH
Tel: 0117 934 4000
Email: enquiries@environment-agency.gov.uk
www.environment-agency.gov.uk

Further copies of this consultation document are available from our National Customer Contact Centre: T: 08708 506506

E: enquiries@environment-agency.gov.uk.

Contents

1. Introduction

There are no consultation questions in this section.

This introduction will be revised and updated when we publish the revised version of the Good Practice Guidelines. The text below appeared in the first edition of the guidelines.

The number of hydropower schemes submitted to the Environment Agency has increased significantly over the last few years from less than 20 per year to more than 100 per year. This annex to the Environment Agency Hydropower Manual is based on work undertaken jointly by the Environment Agency and the British Hydropower Association (BHA) and funded by the Department for Trade and Industry (DTI) in 2006. The aim of the work was to provide Good Practice Guidance to supplement the Hydropower Manual on aspects that most often cause difficulty with hydropower proposals.

Four studies were commissioned:

1. An Environmental Site Audit (ESA) check list guide to assist in the initial environmental assessment of small hydro schemes.

2. How to establish the acceptable minimum flow in the depleted reach.

3. Monitoring flows abstracted by a hydropower scheme.

4. How to protect fish.

- The results of these studies have been supplemented by further input from the Environment Agency and BHA. Detailed technical data related to flow measurement has been removed to an Appendix at the end of the annex.
- This Good Practice Guidance was developed for low head hydropower, but the principles may apply to high head hydropower run of river sites.
- The Environment Agency has wide ranging responsibilities set out most particularly in the Environment Act 1995, Water Resources Act 1991, Land Drainage Act 1991, Salmon and Freshwater Fisheries Act 1975 and the Water Framework Directive (WFD) which came in to operation in 2004. Section 4 of the Environment Act requires us, in discharging our functions, to contribute to the objective of achieving sustainable development.
- The Environment Agency has statutory responsibility for flood management and defence in England and Wales. The Environment Agency advises Local Planning Authorities and applicants on flood risk from new development. Certain types of work affecting watercourses also require flood defence / land drainage consent from the Environment Agency.

This Guidance describes:

- baseline indications of hydropower potential that may be possible on a site while taking account of environmental concerns
- additional environmental factors that will need to be protected in some circumstances, and those that may, upon local inspection, be found to not apply. Where this is the case, there may be greater power potential at that site.

Some environmental aspects have to be satisfied as part of the developer's scheme and costs. Others can be met by wise site choice and application of best design principles that are available. There are some places where we believe the current high environmental status such as designated European sites means that the risks inherent with hydropower are likely to be unacceptable and we have incorporated advice accordingly. We also highlight the potential for cumulative impacts that would need to be addressed in some places.

There has been little monitoring of the ecological impacts of low head hydropower schemes. The Environment Agency will undertake a programme of work to investigate these impacts, but this is likely to require a number of years data pre and post hydro installation.

- This Good Practice Guide will also require regular revision in the light of operational experience.
- This guidance is for application on existing impoundments (weirs) and may affect existing or proposed hydropower generation.
- The recommendations that follow were developed for Low head hydropower schemes – weirs usually less than 4 metres high – but the principles may apply to High Head hydro schemes.
- Any proposals for new impoundments would be required to undertake more detailed Environmental Impact Assessments.

2 Environmental site audit (esa)

There are no consultation questions in this section.

This section has been separated from the Good Practice Guidelines. It has been published as a separate document available for download from the Environment Agency website at www.environment-agency.gov.uk/hydropower

As we update this guidance, we will be reviewing the checklists to ensure they stay relevant.

3 Ecological Requirements

There are three consultation questions in this section. These are in parts 3.7 Cumulative Impacts and 3.8 Weir pools.

3.1 Introduction

This guidance is intended to ensure sufficient water remains in the river. There is evidence that significant reductions in flows to watercourses lead to an impact on the ecology of that reach. As part of the WFD requirements, the Environment Agency through its regulation must aim to achieve good ecological status and ensure that there is no deterioration in the ecological condition of water bodies. It may be difficult to reconcile these requirements with a large loss of flow from main river channels. We are also obliged to consider the rights of land and fishery owners that may be affected.

Our evaluations indicate that hydropower schemes incorporated within or immediately adjacent to a main channel weir and which would avoid depleting main channel flows, are more likely to be environmentally acceptable.

3.2 Depleted Reach

A “depleted reach” may be an obvious length of watercourse, or it may be a weir pool when the turbine is situated on, or immediately adjacent to, an impoundment (see section 3).

Many old mill sites were built with either a moderate length of intake channel, a tailrace channel, or both (often partly culverted). This helped isolate the millhouse from flood flows and preserve the driving head during high flow conditions (when the weir itself might be drowned out). Many of these mill races still exist and provide the majority of current opportunities for low head projects.

Because of the cost of excavating new waterways, it is rare for a 'green-field' low-head scheme to involve more than a few tens of metres of new channel, so the depleted reach may be very short.

Where water is diverted from the main river, the length of channel from the diversion point to its re-connection will have a depleted flow with a consequential impact on its ecological and fishery status. If this is a migration route and the diversion channel has the majority of the flow, then the fish may be attracted to the higher flows. If the migratory fish enter the tailrace this may prevent migration (if there is no fish pass in the diversion channel), or delay migration possibly resulting in increased predation, disease or inability to reach the destination at the right time. Equally, downstream migrants may tend to migrate into the diversion channel with greater risk of impingement on screens and turbines. For these reasons the Environment Agency recommends avoiding such schemes as it recognises there will generally be less environmental risks for ‘on weir’ schemes and therefore possibly greater power production potential. This avoids causing a depleted reach and the flows can be held to one channel and so minimise fish migration problems and the associated costs for developers.

There is increasing understanding that depleted reaches need to retain a flow regime that mimics the natural flow fluctuations, and that all elements are important including floods, medium and low flows. A depleted reach, caused by a hydropower offtake, will be deprived of a varying proportion of the natural flow that has a complex relationship with the river type (high or low baseflow) and the maximum hydropower volume in relation to the Qmean flow of the river (see section 6). The ecological impact this may have will depend on the river’s ecological status, the length of the depleted reach, and could vary from being acceptable to being quite damaging.

To maintain the ecological integrity of the river, minimum flows in the depleted reach will need to be set and factors such as flow variability and spate flows will become more important for both maintenance of channel form and its ecology as the length of the depleted reach becomes longer. The quality of the fishery and its significance for fish passage are also likely to be affected. On shallow 'pool and riffle' type rivers there can be significant change in the 'wetted usable area' at low fows, especially below Q95 (the flow exceeded for 95% of the time, and used as a marker of low flow). Q95 is therefore the default 'Hands Off Flow' for licensing consumptive abstractions, see Environment Agency – Managing Water Abstraction. http://publications.environment-agency.gov.uk/pdf/GEH00508BOAH-E-E.pdf

Increased periods of low flow in the depleted reach will result from a hydropower proposal, and may have significant impacts on fish populations – both in coarse fish dominated rivers and salmonid rivers. There has been little scientific study on this undertaken in England and Wales, but evidence from Europe and elsewhere indicates a considerable reduction in biomass and density of both coarse and salmonid species in the depleted stretch when subjected to lengthy periods of very low residual flows. If an impoundment has no fish pass but fish are able to pass either at high flows or a flow "window", any diversion of water through a turbine will impact on the migration capacity. Therefore it is unlikely that a project would be allowed unless it included a suitable fish pass.

Weir pools are important habitats in some lowland rivers and, although the volume of water above and below the weir may be the same when the hydropower generation is 'on weir', the change in flow distribution and energy may have effects on the morphological character of the river. There will be different requirements depending whether the hydropower turbine is situated on or adjacent to the impoundment, or is on a channel (or leat) away from the main channel, and whether there are fish migration requirements (this is developed in the scenarios in section 5).

3.3 Salmon and Freshwater Fisheries Act (SFFA) and migratory rivers

Hydropower installations on rivers populated by migrating species of fish, such as salmon or sea trout, are subject to special requirements as defined in the Salmon and Freshwater Fisheries Act (SFFA). Broadly, and subject to certain conditions, the Act requires that "owners/operators of hydropower schemes on migratory rivers should, at their own expense, ensure that upstream and downstream fish passages, respectively, are catered for by the construction of appropriate fish passes, screens and by-washes".
In the context of licensing of abstracted flows, the key issues for migratory species are as follows:

- The need for fish passes to overcome the increased obstruction posed to upstream migration by weirs and other river structures that are deprived of flow.
- Where there is no fish pass, adequate residual flow over the weir during the migration seasons for adults (moving upstream) and juveniles (moving downstream).
- Adequate flow in the depleted reach during the migration seasons for adults (moving upstream) and juveniles (moving downstream).
- Protection of spawning areas and the seasonal flows required to allow spawning to occur.

A fish pass will be required on hydropower sites on rivers where there are migratory species if the ability to migrate is compromised. The residual flow calculation will need to include the flow required to service the fish pass.

The requirement for fish passes and screening is likely to extend to all species in the near future to meet the objectives of WFD. These changes will be made through amendment to fisheries legislation. Consultation on the proposals took place in spring 2009. Developers are advised to make themselves aware of the possible implications.

Further consideration of fish passes is in section 8.

3.4 Seasonal fish migration

Different fish species migrate upstream (particularly for spawning) and downstream for spawning, feeding and over-wintering, at different times of the year. The flow requirements for the different species vary significantly.

- Adult salmon and sea trout will generally migrate upstream from May to January to access spawning areas. Upstream migration is triggered by flow spates that will normally exceed Qmean flows. After spawning, adults move downstream through main flow routes in December to February.
- Smolts (juvenile salmon and sea trout) migrate downstream mainly in the spring, prompted by temperatures in excess of 9-10°C. There is evidence of a second migration period in autumn in some rivers.
- Trout will move upstream to spawn from October to February dependent on a range of factors.
- Coarse fish will generally seek to migrate to spawn during March to July, depending on the species.
- Lamprey adults migrate upstream to spawn (sea lamprey, February to June; river lamprey, September – March). Juveniles migrate downstream to feed (sea lamprey, October to December; river lamprey January to April).
- Eels make their main downstream migration mostly during autumn (September to November). Peak migrations will occur over short periods that may be predictable in relation to moon phase, water temperature and high flows.
- Elvers make their upstream migration during March to May depending on location. They may require only relatively low cost solutions to enable them to pass weirs and other impoundments successfully.

All these periods are approximations and vary according to the geographic location and in some case specific strain of fish present. Local confirmation of these will be available from Fisheries consenting teams.

3.5 Hydropower and WFD

Under the WFD Member States should aim to achieve good ecological status and to ensure that no deterioration of ecological status takes place. The freedom of movement of fish, upstream or downstream, is an important component of achieving or maintaining good status or potential. Hydropower schemes must be well designed and carefully sited if they are to avoid disruption of fish migration in both upstream and downstream directions, and thereby create an obstacle to achieving WFD Good Ecological Status. The ecological and amenity impacts in any depleted reach must be considered, both to the reach itself and to the catchment as a whole.

Rivers with low head hydropower structures are not necessarily designated under WFD as Heavily Modified Water Bodies for hydropower use, as the impacts are on a relatively short length of the river compared to the length within the water body.

The UK Technical Advisory Group (UKTAG) recommendations on flow standards for abstraction impacts (WFD 48) are for consumptive abstraction impact. They have been adopted by the Environment Agency in a slightly modified form for water resource regulatory purposes as 'Environmental Flow Indicators', and will be used in the Future Catchment Abstraction Management Strategies (CAMS) process for managing abstraction licences.

UK TAG guidance has also been provided on the assessment of abstraction impacts greater than those indicated in the WFD 48 project on short lengths of river within a water body but which would not be considered sufficient to cause a failure to support Good Ecological Status. The proposals presented here for considering the length of the depleted reach when assessing hydropower proposals meet the requirements of the UK TAG guidance.

Barriers to fish passage have been highlighted in WFD River Basin Planning as a major impact limiting fish populations, particularly of salmon and trout but also of coarse fish and eels. Improvements in water quality on many rivers in industrial areas have enabled the slow return of salmon and other fish species to rivers that lost their populations due to major weir construction for water use, and later, pollution from industrial processes. There are many thousands of such barriers in England and Wales. The Environment Agency is undertaking work to collate data on barriers, prioritise work to enable fish passage (by removal of the barrier or installation of a fish pass), and to obtain powers and funding to enable such work. The development of hydropower involving a weir that is a barrier to migration would lead to the need to install a fish pass.

3.6 Hydropower and Protected Areas - Habitats Directive and Sites of Special Scientific Interest

This section 3.6 will be replaced by the following expanded advice.

Where a hydropower proposal has been identified through the environmental site audit checklist as being likely to have an impact on a designated conservation site (Site of Special Scientific Interest (SSSI), Special Conservation Area (SAC), or Special Protection Area (SPA)) then further evaluation of its impacts will be necessary. Developers should contact the appropriate conservation agency – Natural England or the Countryside Council for Wales – as soon as possible. Early dialogue will ensure that any specific issues associated with the proposed development in or adjacent to designated sites are properly understood prior to making an application. Early contact will also ensure that applicants understand the information that will be expected from them to ensure any environmental impacts are properly assessed.

Environmental impact evaluation will include an assessment of:

- Effects on physical habitat form and function;
- Effects on the natural hydrological regime;
- Effects on biological connectivity/access.

Assessments are made in the light of the conservation objectives for the site and effects are evaluated in combination with the effects of other stresses. The applicant must demonstrate that the project will not adversely affect the integrity of the site.

Habitat form and function

Developers should be aware that strategic plans are being developed on river SSSIs/SACs in England to restore physical habitat conditions. Similar plans are being considered in Wales. These address all aspects of physical habitat modification and outline the measures needed to meet the site's conservation objectives. Addressing the ecological impacts of in-channel structures is a major component of these plans. This can have a major bearing on the scope for hydropower schemes. In-channel structures impound water and trap fine sediment, resulting in the loss of fast-flowing water, coarse substrates and aquatic habitats. They are frequently linked to flow diversions that affect the natural flow regime, and also to a loss of biological connectivity. Restoration plans flag structures for removal or, if the structure cannot be removed, for modification (where possible) to minimise adverse effects on characteristic wildlife. Hydropower proposals in designated sites that rely on structures flagged for removal or modification are likely to be, in the long-term, incompatible with site's conservation objectives.

Natural hydrological regime

Proposals that rely on structures that are not affected by river restoration measures will be considered for their effects on flow regime. Flow targets are set as part of the conservation objectives for river SSSIs/SACs, designed to protect characteristic biological communities from a range of impacts caused by significant alterations to flow. These are based on maximum acceptable levels of deviation from the natural flow regime and are applicable throughout the site. These targets relate to the combined impact of all sources of flow modification on the river, not any single source, such as hydropower.

Minor non-compliances with these flow targets are acceptable over short stretches of river but the total length of non-compliance in any one river reach should be small.

Biological connectivity

If a proposal is considered acceptable in relation to habitat form and function, and hydrological regime, its effects on biological connectivity will then be considered. The conservation agencies will consider effects on connectivity for the whole biological community, including priority species such as lampreys, bullhead (Cottus gobio) and white-clawed crayfish (Austropotamobius pallipes).

Fish passes are often designed for powerful migratory salmonid species and are not always passable for the great majority of other species. Fish passes may not therefore always address the full connectivity needs of the site. Even for salmonids, the in-combination effect of sequences of fish-passes along a river can be severe because fish passes are rarely 100% efficient. Passes should be seen as a mitigation

measure and not a full solution. They should be designed to be as permeable to as many species as possible but particularly to the priority species for the site. Appropriate screening measures for turbines are also required to avoid fish injury and mortality.

3.7 Cumulative Impacts

In regulating low-head hydro applications, the Environment Agency will take in to account potential cumulative impact of multiple sites on a river or in a catchment. Without effective fishery protection measures, cumulative impacts may be significant, particularly for diadromous species such as salmon, sea trout, lamprey, shad and eel. They may also be significant for other solely freshwater species that are obliged to migrate between habitats as part of their life cycle. Some rivers are potentially suitable for multiple sites for low-head hydropower applications. A high level of fishery protection needs to be maintained at such sites; even where sites have efficient and effective downstream and upstream passage facilities, the cumulative effects of delays and damage may cause the numbers of migrating fish to decline significantly but there has been no research carried out to provide evidence to show that this actually is happening.

The location of a proposed scheme within a catchment will also be relevant in terms of the environmental protection required. Risks for diadromous fish in particular will generally be higher the lower down the system the site is located. This is because the potential impacts in terms of the number of migrants and proportion of the population affected will be at the maximum for both upstream and downstream moving fish in the lower reaches of a river basin.

Consideration of cumulative and in combination effects is a specific requirement of the Habitats Directive. In the Water Framework Directive there is a requirement to ensure that activities in a water body do not prevent other water bodies from achieving their objective.

Issues for consultation

We have identified the potential for environmental effects through the development of multiple schemes within catchments. The current GPG is about shaping the design of individual schemes rather than multiples schemes

Individual scheme promoters are unlikely to have the information to consider cumulative effects. The Environment Agency will consider cumulative effects when necessary. This will depend on:-

- **The number of existing hydropower schemes in a catchment**
- **The number of known proposals for hydropower schemes in a catchment**
- **The environmental objectives for the catchment.**

The potential for catchment scale effects of hydropower schemes needs to be carried out in combination with other effects within a catchment. These include:

- **Flood risk**
- **Navigation rights**
- **The cumulative effects of weirs on fish migration**
- **The ecological effects of ‘ponding’ a reach of river.**
- **Disruption of instream processes such as sediment transport.**

When assessing catchment impacts, the effects on:

- **Designated habitats and species.**

- **The objectives of the Water Framework Directive (WFD) need particular attention.**

Consultation question 1
Are there other effects (both positive and negative) which should be considered on a cumulative basis?

Consultation question 2
We would value your comments how these cumulative effects should be considered and assessed.

3.8 Weir pools

This section previously appeared in Section 4 Hydropower Scenarios

- There are a few sites of high ecological value that have been identified by the Environment Agency where constraints will limit hydropower potential.
- Weir pools are important for spawning and fry development of several riverine fish species, such as barbel, dace, chub, bullhead, stone loach, and as a habitat for plants and invertebrates. These may contribute to the fishery and wider ecology for a distance downstream and therefore affect both WFD achievement of Good Ecological Status/Good Ecological Potential in water bodies and the fishery rights of others.
- The essential habitat for these species is formed and maintained by the energetic water entering the weir pool.
- Whilst flood flows may create the appropriate morphology, moderate flows will maintain it in a suitable condition.
- A turbine situated on, or immediately, adjacent to the weir may discharge water into the weir pool, but the flow pattern and energy will have been changed.

Issue for consultation

In some circumstances (in heavily impounded, low gradient watercourses) weir pools can be very important for the ecosystem.

Consultation question 3
Can you suggest ways in which additional protection can be provided for weir pools (where they have been identified as having special importance)?

4 Hydropower Scenarios

There are no consultation questions in this section.

In the revised document the scenarios will be expanded and transferred to an appendix of the document.
The section on weir pools has been moved to Section 3.8.

Hydropower sites fall in four main scenarios

1. Turbine on or immediately adjacent to an impoundment (weir) – with no fish migration issues.

2. Turbine on or immediately adjacent to an impoundment (weir) – with fish migration issues.

3. Mill leat used for hydropower abstraction – no fish migration issues.

4. Mill leat used for hydropower abstraction – fish migration issues.

4.1 Turbine on or immediately adjacent to an impoundment (weir) – with no fish migration issues

Situation:

- Where an impounding structure (weir) on the river is to have a turbine installed within its longitudinal footprint to return water at the impoundment toe.
- It is not a migratory salmonid river, or there is no Salmon Action Plan.
- Fish, which are interest features of protected sites including the river reaches above and below the weir, are achieving favourable conservation status.
- The river reaches above and below the weir are not failing Good Ecological Status due to obstructions to fish passage, of which this is one of the relevant sites.

Requirements:

- The maximum flow for hydropower will normally be Qmean (Table 2).
- The Hands-Off Flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash.
- The water is returned in the same longitudinal direction of the flow to maintain weir pool form.
- The weir has a required minimum depth of water flowing over it while generation is taking place, taking into account factors such as design of the weir, amenity and whether the river has a high baseflow.
- There are no other parties dependent on or adversely affected by the re-distribution of flows at the structure or the reduced kinetic energy of the flow into the weir pool.
- Where the weir pool is assessed to have high ecological importance – for example on a heavily impounded lowland river, a flow regime may be required to support its continued presence.

4.2 Turbine on or immediately adjacent to an impoundment (weir) – with fish migration issues

Situation:

- Where an impounding structure (weir) on the river is to have a turbine installed within its longitudinal footprint to return water at the impoundment toe.
- It is a migratory salmonid river, or there is a Salmon Action Plan.
- The river has other fish species which need to migrate past the weir to successfully complete their life cycle.
- The river has coarse fish for which it is failing Good Ecological Status due to migration obstructions or impoundment impacts of which this is one of the relevant sites.

Requirements :

- The maximum flow for hydropower will normally be Qmean (Table 2).
- The Hands-Off Flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash, to ensure safe downstream passage of migratory fish.
- The water is returned in the same longitudinal direction of the flow to maintain weir pool form.
- The weir has the required minimum depth of water flowing over it when generation is taking place, taking into account factors such as design of the weir, amenity and whether the river has a high baseflow.
- A fish pass will be required to a design approved by the Environment Agency.
- The fish pass and turbine outflow shall be co-located to ensure fish are preferentially drawn to the fish pass entrance and to ascending it throughout the flow ranges experienced at the site.
- There are no other parties dependent on or adversely affected by the re-distribution of flows at the structure or the reduced kinetic energy of the flow into the weir pool.
- That where fish survey data to classify for WFD above and below the site are not available, that these will need to be provided by the developer to enable assessment against Good Ecological Status (GES) to be made by the Environment Agency.
- Where the weir pool is assessed to have high ecological importance – for example on a heavily impounded lowland river, a flow regime may be required to support it.

4.3 Mill leat used for hydropower abstraction – no fish migration issues

Situation:

- Abstraction for hydropower through the mill leat creates a depleted reach greater than the longitudinal section of the weir.
- It is not a migratory salmonid river, there is no Salmon Action Plan.
- Fish which are interest features of protected sites including the river reaches above and below the weir are not failing to achieve favourable conservation status.
- The river reaches above and below the weir are meeting GES due to fish migration obstructions or impoundments of which this is one of the relevant sites.

Requirements :

- The maximum flow for hydropower will depend on the river type (Table 2).

- The Hands-Off Flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash.
- The weir has the required minimum depth of water flowing over it when generation is taking place, taking into account factors such as design of the weir, amenity and whether the river has a high baseflow.
- There are no other parties dependent on or adversely affected by the re-distribution of flows at the structure or the reduced kinetic energy of the flow into the weir pool.

4.4 Mill leat used for hydropower abstraction – fish migration issues

Situation:

- Abstraction for hydropower through the mill leat creates a depleted reach greater than the longitudinal section of the weir.
- It is a migratory salmonid river, or there is a Salmon Action Plan.
- The river has other migratory fish species.
- The river has coarse fish for which it is failing GES due to migration obstructions or impoundment impacts of which this is one of the relevant sites.

- As a development of Scenario 3, the difference this causes is that a fish pass is required and that the flow distribution between the leat and the depleted reach, and attraction flows for migratory fish are arranged to ensure fish migration through the overall site is readily achieved by all relevant species. This will specifically require the upstream route to be preferentially found and utilised even in high flows. For downward migrants, screening and by-wash arrangements must enable un-delayed and safe passage downstream.

Requirements :

- The maximum flow for hydropower will normally depend on the river type (Table 2).
- The Hands-Off flow value for that river type is preserved (Table 2).
- The turbine intake will have the screening arrangements specified in Figure 5, including a bywash.
- The fish pass and channels leading to it should be adequate for the relevant species to ensure their easy passage through the site.
- Under most flow conditions, including high flows, the majority of the flow and velocity will be sustained in the route and channel to the fish pass to ensure high attraction towards it.
- Flow distribution between the mill leat and the depleted reach, so as to ensure high attraction to the fish pass route will require careful design, and may require a reduction in the maximum hydropower flow below Qmean and/or a large Hands-Off Flow.

Suitable arrangements should be made to prevent migratory fish from entering the tailrace from the turbine where this is not the fish pass route, and that these arrangements do not interfere with any downstream movement of fish through the tailrace.

Where fish survey data to classify for WFD above and below the site are not available, these will need to be provided by the developer to enable assessment against GES to be made by the Environment Agency.

5 Permitting

There are no consultation questions in this section.

This is the existing text – it will be reviewed to reflect any changes in regulatory processes and legislation since publication of the first edition of the Good Practice Guidelines.

The permitting of hydropower schemes is not always straightforward, because of:

- The site-specific nature of individual site layouts.
- The fisheries and environmental needs of the watercourse.
- The requirement for a number of different 'approvals' contained within the water resources permit.
- The requirement for flood defence consent .
- The contentious nature of some hydropower schemes.

Early discussion with affected parties may help to resolve some of the concerns.

5.1 Water Resources permits

Where an abstraction is within the banks of the watercourse, it is currently considered not to require an abstraction licence. This situation may apply to weirs that contain the generating equipment within the weir.

An impoundment licence will be required if changes are made to the weir. This covers:

- a barrage-type project where turbines are installed on an existing weir and the water remains between the existing banks of the river. (b) a new scheme installed in the workings of an old mill site where the mill leat has been adopted as 'main river'.
- The Water Act 2003 amended the Water Resources Act 1991 to provide for three types of abstraction licences; Transfer, Temporary, Full Licences. All abstraction licences must be Time Limited – this will normally be 12 years, but will be to the Common End Date for the catchment, as set out in Catchment Abstraction Management (CAMS) documents.

Transfer Licence - where water is transferred from one 'source of supply' to another without intervening use. Hydropower schemes will normally be permitted using a Transfer Licence to authorise the removal of water from the main watercourse through a 'leat' or similar and returning the water to the main watercourse. There is no annual abstraction charge on a transfer licence.

Temporary Licence – authorises abstraction for a maximum of 28 days. Not applicable to hydropower.

Full Licence – authorises abstraction for a 'use' and is chargeable under the Environment Agency abstraction charging scheme. There is still an exemption from charges for hydropower under 5Mw, but Full Licences will not normally be used for hydropower schemes. Full licences will not be granted on hydropower schemes without the applicant agreeing to a derogation condition that enables the Environment Agency to grant abstraction licences upstream of the hydropower site in accordance with its CAMS policy.

Impoundment Licence - applies if changes are being made to structures which impound water, such as weirs and sluices, or if new structures are to be built.

The Environment Agency may also require a Section 158 Agreement to be drawn up, which defines certain further details on the way the scheme must be operated in order not to conflict with the Environment Agency's river management duties, e.g. rights of access, the control of river levels, maintenance of the weir and river structures, fisheries and other environmental protection duties, etc.

5.2 Salmon and Freshwater Fisheries Act and further regulations for WFD (see note)

The requirements for fish passes and fish screens will normally be conditions on the abstraction licence.

- Fish Pass approval - authorises the form and operating requirements where a fish pass is required or altered for the scheme proposed.
- Fish screen regulations - will require a fish screen or an exemption to be issued by the Environment Agency for new or altered intakes and discharges.

Note: Defra are implementing regulations in 2009 to broaden these to all waters and species.
The requirements of the Salmon and Freshwater Fisheries Act will normally be covered by conditions on the Water Resources permit and/or the Flood Defence/Land Drainage Consent, after internal consultation within the Environment Agency. These may affect the amount of water available and constraints of any scheme.

5.3 Flood Defence

The consent of the Environment Agency is required for:

- any works being carried out within, over or under the channel of a statutory 'main river', including its banks, including alteration of existing structures (Section 109 Water Resources Act 1991).
- erection of culverts or flow control structures within any watercourse, or alterations to these that will affect flow, where this is not in an Internal Drainage Board operating area (Section 23 Land Drainage Act 1991). In 2009 Defra and the Welsh Assembly Government are consulting on the draft Floods & Water Management Bill on transferring this duty, and responsibility is likely to change in future.
- erection of structures including buildings, walls and fences etc, within the 'byelaw margin' of a main river (Environment Agency Regional Land Drainage / Flood Defence Byelaws). This margin is specified in byelaws, which vary around the country. Developers should consult the local Environment Agency office over proposals for any structures within 20m of a main river, to ensure this requirement is assessed, though consent will not be required for every case.

Pre application discussions are encouraged, to confirm what formal consents may be required, and to ensure that appropriate works are designed. The Environment Agency booklet 'Living On The Edge' (available free from our customer contact centre, or by download from
http://www.environment-agency.gov.uk/homeandleisure/floods/31626.aspx) gives more information.

5.4 Other permissions

This section is not definitive and applicants will need to ensure they have met the requirements of any relevant authority.

- Erection of culverts, flow control structures, or alterations to these that will affect flow, within any Internal Drainage Board managed watercourse is likely to require consent from the Board concerned (Section 23 Land Drainage Act 1991). Internal Drainage Boards within their districts, or local authorities elsewhere, may have local byelaws relating to flood defence and land drainage on ‘ordinary watercourses’ (those that aren’t defined as main rivers). Developers should make enquiries locally as to whether any elements of a proposal are affected by these.
- Planning permission may be required from the local planning authority for ‘engineering operations’ (consult the relevant local authority for their interpretation of this requirement). Many weirs and mills are considered as ‘Heritage sites’ which may require permission for works.

6 Abstracted flow regime and flow in the depleted reach

There are two consultation questions at the end of this section.

We are proposing to extend the flow tables published in the first edition of the Good Practice Guidelines to include guidance for high head schemes and protected sites (see Part 2 of this consultation).

As noted in section 4, the Environment Agency will look more favourably on schemes that do not lead to a depleted reach.
The flow regimes proposed in this guidance set out a default position that is considered acceptable for hydropower generation without having an unacceptable environmental impact. Whilst we will consider variances from this guidance, these must be fully justified, for example:

- If the environmental audit has identified an important environmental impact, the acceptable flow regime may require more detailed assessment, which may limit the water available for the hydropower scheme. For example, an impoundment where migration is possible at higher flows, or where there is a diadromous fish spawning site.
- Hydropower proposals on a river that splits into more than one channel may require more careful consideration of the flow characteristics in each channel in order to determine an appropriate residual flow.

The hydrological design and regulation of hydropower schemes involves a number of inter-related factors, including:

- Flow for hydropower
- Flow in the depleted reach
- Length and ecological value of the depleted reach
- The baseflow characteristics of the river and/or its 'flashiness'
- The minimum depth of water passing over the weir crest, and whether a fish pass is present
- The nature of the ecology, including fish populations, especially in relation to flow sensitive communities, salmonid fish and other species which have to migrate to complete their life cycle such as lamprey, shad, & eel, as well as species migrating within the river
- The rights of owners, fishery interests and other uses that may be affected

The combination of these factors will determine whether a scheme is environmentally acceptable and will vary with each site. Default conditions are set out which are intended to safeguard the ecology of the majority of sites whilst allowing generating capacity. Information about a number of hydrological parameters is essential for the design of an environmentally acceptable scheme. These are set out below.

6.1 Hydrological Parameters

- Annual Hydrograph
- Flow Duration Curve
- Mean Flow (Qmean)
- Base Flow Index and the Ratio of Q95 to Qmean
- Residual Flow (QR) – the flow in the depleted reach
- Hands-Off Flow – a flow specified in the abstraction licence below which abstraction must stop.
- Design Flow (Qo)

6.2 Annual Hydrograph

There are two ways of expressing the variation in river flow over the year: the Annual Hydrograph and the Flow Duration Curve (FDC).
An annual hydrograph, as depicted in Figure 2, simply shows the day-by-day variation in flow over a specific time period (calendar year in Figure 2).
There is general recognition that ecologically important features of a hydrograph are:

- 'flow variability'
- natural low flows and the flow recession curve
- 'peak' flows sufficient for channel shaping and cleaning of substrata.
- Hydropower schemes generally have most impact on mid-range river flows, and a Hands-Off Flow or Level protects low flows.
- Flashy

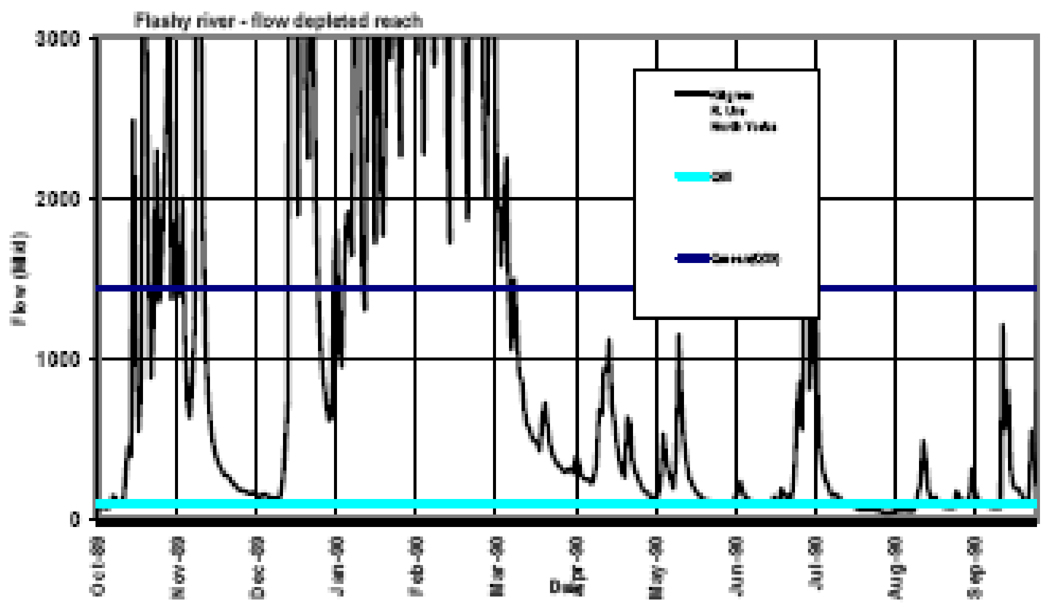


Figure 2 Hydrograph – daily flows
A flashy river – peak flows are in excess of 10000Ml/d

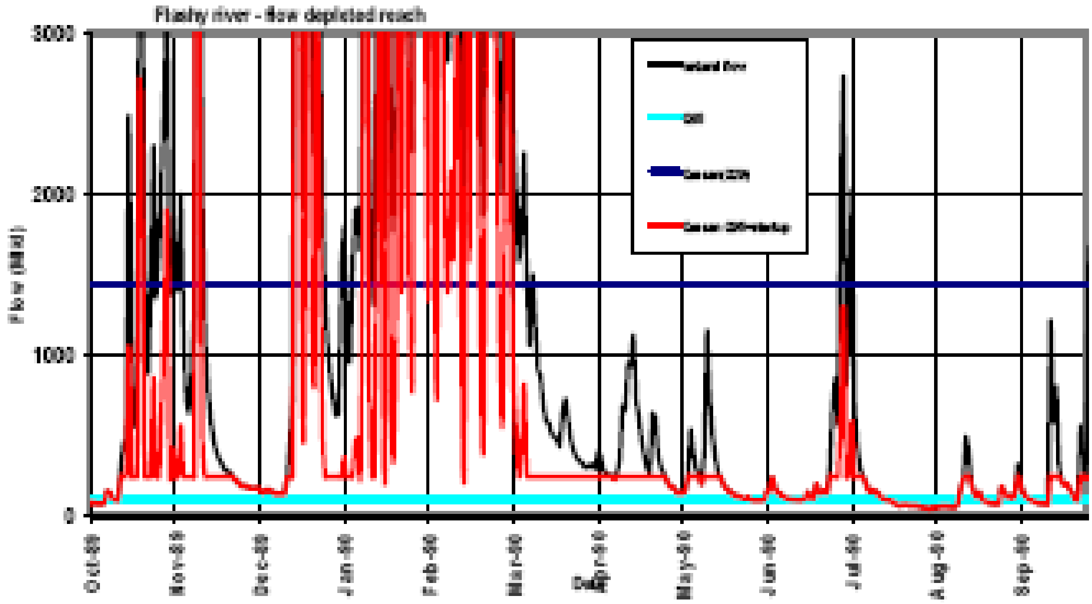
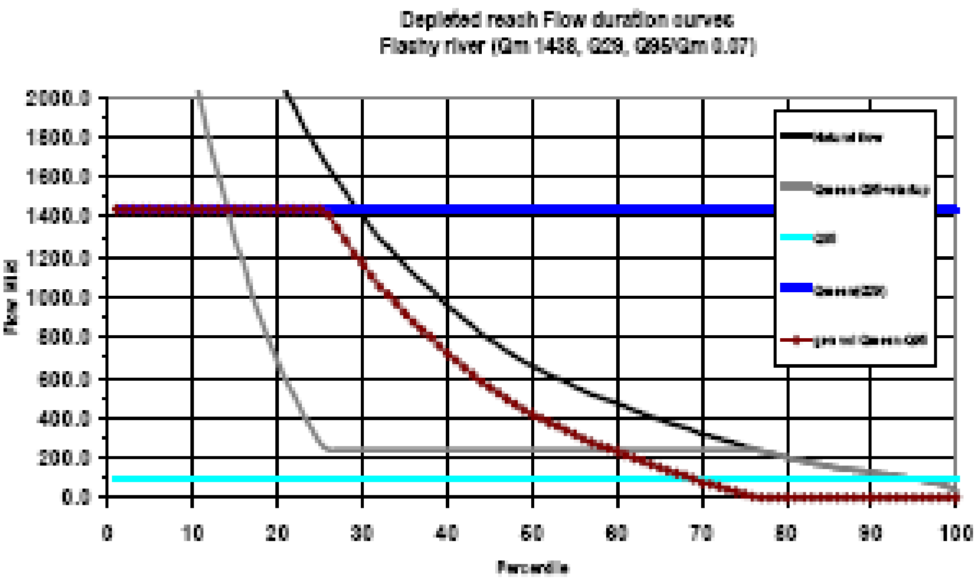


Figure 3 Hydrograph – showing impact of hydropower on flow in depleted reach (red line) – based on maximum turbine flow of Qmean, and Q95 Hands-Off Flow



6.3 Flow Duration Curve

The Flow Duration Curve (FDC) presents the statistical availability of any given flow, based on best available data. An example is shown in Figure 4. The vertical axis gives the flow rate, the horizontal axis gives the percentage of time that the flow is exceeded.

The FDC can immediately indicate the volume of flow which will be available for any percentage of time, for example the flow exceeded for at least 50% of the time is known as Q50 - the median flow. Q95 is a frequently used parameter because it is taken as the characteristic value for the natural low flow in the river.

The FDC is more relevant than the hydrograph when calculating the flow available for a hydro-power scheme. It enables the potential flows for hydropower to be assessed, and in turn the average energy output and revenue of the scheme, as well as enabling the assessment of the hydrological impact on flows in the depleted reach. The FDC is therefore the key tool for discussing abstracted and residual flow values.

The Environment Agency uses FDCs in its management of water resources and setting of 'Environmental Flow Indicators' in its Catchment Abstraction Strategies. Where a catchment has a gauging station it uses observed (measured) flows to derive the FDC.

On streams and rivers, where there may not be any gauged data for developing a Flow Duration Curve, the Low Flow 2000 hydraulic model developed by the Centre for Ecology and Hydrology can provide computed data for a FDC. The model examines rainfall data, catchment geology and gauged measurements from the nearest relevant gauging stations to model the flow characteristic at a given river location. This is the best available flow modelling tool for England and Wales.

Hydropower developers can also access this tool on a fee-paying basis by contacting the Centre for Ecology and Hydrology via www.hydrosolutions.co.uk/lowflows.

6.4 Mean Flow (Qmean)

As its name implies, the mean flow at a particular point in a river is the average of all flow measurements taken over a long period of time. Over a single year, the mean flow is the total volume of water delivered to the river from the catchment area in that year, divided by the number of seconds in a year. Relative to the Flow Duration Curve, Qmean is typically in the range Q30 for very flashy upland rivers to Q40 on lowland and high baseflow rivers, meaning that flows are greater than this for 30% and 40% of the time respectively.

6.5 Depleted reach

The depleted reach is between the point where water is abstracted from the river and the point where it is returned (Figure 1 and section 3 and 4).
The length of the depleted reach may range from the upstream water level to the downstream water level over the face of the weir (where the generating equipment is incorporated into or adjacent to, the weir) to many hundreds of metres, where water is conducted along a pipeline or open channel (a 'leat' or 'mill race') to the generating plant and until the water rejoins the main channel. A very long depleted reach may sometimes gain flow from tributaries. Longer depleted reaches on flashy rivers (Q95:Qmean $\leq$ 0.1) may require a Hands-Off Flow in excess of Q95.

6.6 Hands-Off Flow or Level

For both environmental and aesthetic reasons, a certain minimum flow needs to be reserved to continue over the weir and down the depleted reach. The Agency will normally set a Hands-Off Flow (HOF) or Level as a condition on hydropower schemes, such that when the flow or level falls below the set value, abstraction must stop.
To ensure that the HOF is complied with, hydropower abstraction will be unable to start operating until the flow is above the HOF by a quantity that is at least equal to the 'turbine start up flow' (see section 6.9). In some cases generation may start or stop at flows considerably higher than the HOF (especially flashy rivers where Q95:Qmean ≤ 0.1 and the maximum design flow is more than 10 times the HOF).

The residual flow in the river may therefore be greater than the HOF, and after generation has stopped may also naturally fall below the HOF. The amount of residual flow, and factors such as flow variability, may become more important as the length of the depleted reach increases, and it will often result in issues with fish migration.

6.7 Base Flow Index and the Ratio of Q95 to Qmean

Base Flow Index (BFI) is a term developed by the Institute of Hydrology to describe how river flow regimes vary with geology. It is intended to provide a measure of how much the river flow is affected by stored sources, such as permeable rock, which enables the 'base flow' in the river to be sustained in dry conditions (high BFI value), unlike rivers derived from clay or hard rock catchment areas, which would have a low BFI value.

For practical purposes, the BFI is a parameter which describes how widely the flow on a particular river varies on a daily basis and between wet and dry seasons. A 'flashy' river with high winter peaks but low summer flows would have a low BFI because the typical low flow is a small proportion of the mean flow.

The calculation of BFI following the specific methodology of the Institute of Hydrology, uses information that may not be readily available for a specific site. Therefore an alternative approach is proposed which allows a simple and rapid categorisation of the base-flow nature of any UK river.

This approach utilises the two flow parameters most commonly used by the Environment Agency in connection with rivers and streams of any size, namely:

- Qmean : the mean flow
- Q95: the flow exceeded for 95% of the year; usually taken as the characteristic value for the natural low flow in the river.

The ratio between Q95 and Qmean for a particular river provides a good estimate as to whether the BFI is high or low. Therefore, for the purposes of making a simple assessment of the baseflow characteristic for a river, the ratio Q95:Qmean will be used in these guidance notes

For the purposes of dividing UK rivers into categories for high, medium or low base-flow characteristics, the following values are easy to use and appear to fit well with the mix of UK rivers:

Category	Range	Examples
Low baseflow	$Q_{95}:Q_{mean} \leq 0.1$	Tamar, Conwy, Ribble, Lune, Kent
Medium baseflow	$0.1 < Q_{95}:Q_{mean} < 0.2$	Thames, Severn, Wharfe, Dee
High baseflow	$Q_{95}:Q_{mean} \geq 0.2$	Trent, Aire, Wey

Table 1 River types using Q95:Qmean ratios

High baseflow rivers include those with significant areas of major aquifers contributing to river flows, and also those with major urban areas providing large volumes of Wastewater Treatment Works (WWTW) effluent.
For both environmental and hydropower reasons it is important to distinguish the different types of rivers as indicated by the Q95:Qmean ratio. Acceptable hydro schemes where the hydro unit is 'on weir' may be very different hydrologically for a high baseflow river compared to a low baseflow (flashy) river.
Note: Where rivers are significantly impacted by abstraction (see CAMS results) it may be necessary to compare the gauged Q95 (Qg95) with the natural Q95 (Qn95). Qn values will be used in setting HOFs.

6.8 Maximum Design Flow (Qo)

Typically a hydropower developer will choose a design flow for the scheme which allows it to use a good proportion of the higher flows, but also to continue to operate down to reasonably low flows so that output can be sustained for as much of the year as possible. Common practice has been to use Qmean flow as the design flow.
From an environmental perspective, a high design flow reduces the flow variability in the deprived reach, particularly on flashy rivers. A maximum design flow greater than Qmean is unlikely to be acceptable and may need to be less on very flashy rivers.

6.9 Turbine start-up flow

Two factors must be considered in the start/stop of a hydropower generating unit.

- a water turbine only achieves a worthwhile efficiency when it can pass a good proportion of its design flow, typically between 15% and 30% depending on machine type. The turbine will also shut down when the available flow falls below this minimum operating value or start up flow.
- the turbine control system needs to add an additional margin to be sure that the turbine will not shutdown as soon as it starts up, and then 'hunt' around the start-up condition, switching on and off.

To observe the HOF, the hydropower turbine will be unable to start generating until the flow exceeds the HOF by the start up flow and will need to stop generating when the flow in the river falls to the HOF + start-up flow. For compliance purposes, generation cannot take place when flows are below the HOF or Hands-Off Level at the point specified in the permit.

6.10 Flow "Pulsing"

With a well designed low-head scheme, flow pulsing (caused by drawing the water level below the crest level of the weir, and then stopping generation to allow the water level to pond up behind the weir) should never occur. The design and control system must ensure this cannot happen. The requirement to maintain a specified flow over the weir while generating, and a HOF at which generation must cease will prevent pulsing.

6.11 Matrix of Design Flow and Hands Off Flow

Table 2 presents a table of default minimum flows relating to river types using the Q95:Qmean ratios (Table1). The maximum flow that may be considered for hydropower is Qmean

Q95/Qmean Depleted reach	Flashy river <0.1 fish migration issues	Flashy river <0.1 NO fish migration issues	0.1 to 0.2	high baseflow >0.2
Weir Max HOF	Qmean Q95	Qmean Q95	Qmean Q95	Qmean Q95 BUT see NOTE
Up to 200m Max HOF	Q40 Q90	Qmean Q90	Qmean Q95	Qmean Q95
>200m Max HOF	Q40 Q85	Qmean Q85	Qmean Q90	Qmean Q95

Table 2: Maximum hydropower flows, Hands Off Flows according to river type (Q95:Qmean)

Note
On large high baseflow rivers where the turbine is 'on weir', and a fish pass is installed OR there are NO fish migration issue, it is possible to consider a residual flow over the weir that is set for amenity criteria (see sections 4 & 5).
The values in this table are intended for low head schemes. Further work is required on high head schemes especially where there are long depleted reaches.

Consultation issues

We are required to use different levels of precaution for different legislative drivers to set flow standards.

The abstracted flow regimes published in the first edition of the Good Practice Guidelines took account of a number of inter-related factors, including:
- **Flow for hydropower**
- **Flow in the depleted reach**
- **Length and ecological value of the depleted reach**
- **The baseflow characteristics of the river and/or its 'flashiness'**
- **The minimum depth of water passing over the weir crest and whether a fish pass is present**
- **Nature of the ecology, including fish populations, especially in relation to flow sensitive communities, salmonid fish and other species which have to migrate to complete their life cycle such as lamprey, shad and eel, as well as species migrating within the river**
- **The rights of owners, fishery interests and other uses that may be affected**
- **Legal protection provided for different designated sites and corresponding degree of precaution and protection required over and above non-designated sites.**

Consultation questions 4
4a. Would you propose any changes to the flow tables for low head schemes? Y/N

4b. Please provide your reasons and any supporting evidence.
4c. If yes, what changes would you propose?

7. Flow Monitoring

There are no consultation questions in this section on monitoring compliance with flow requirements. We propose to extend monitoring guidance to include wider monitoring of environmental effects.

See Part 2 of this consultation for questions on monitoring of environmental effects.

7.1 Objective

Hydropower is largely a ‘local impact’ on the river system if the water is returned to the same watercourse. It is therefore control and monitoring of the local impact that is most important.

The Environment Agency will expect a control and monitoring system that ensures flow in the depleted reach is controlled and monitored and data recorded to demonstrate compliance with licence conditions. The method by which such flows or levels are measured and recorded is likely to differ in detail for each site, but should be provided by the developer.

Under the Water Resources Act 1991 the Environment Agency must specify on the abstraction licence the maximum volumes that may be abstracted, and also the Instantaneous, hourly and daily rates of abstraction. These can be calculated from the FDC and design parameters of the hydropower installation.

The maximum annual volumes will be set on the basis of 220 days of max. daily rate, as the maximum daily rate will not be available for 365 days. More detailed hydrological analysis should be made when assessing the potential of the scheme.
As the hydropower abstraction is normally non-consumptive on CAMS assessments it will be recorded as ‘0’ in the Environment Agency CAMS ledgers.

The main requirement of control and monitoring:

- Ensuring flow in the depleted reach is maintained, on a failsafe basis
- That Hands-Off Flow is complied with
- The assessment of flow through the hydropower plant.

7.2 Ensuring Compliance

Flow in the depleted reach can be maintained in a number of different ways, and will need to be suited to the specific site requirements. This may be through a physical arrangement such as a notch or pipe in the weir set to pass the Hands-Off Flow or through a ‘control level’ head over the weir and the use of a Gauge Board. Regular monitoring of the level will be required to demonstrate compliance with licence conditions. Electronic control systems monitoring the water level and controlling flow to, and operation of the hydropower unit should record the water level data for compliance purposes.

- Hands-Off Flow levels should trigger a reduction in abstraction and eventually a cessation of abstraction and generation.
- The measurement of flow in open channels is well documented (ref BS3680) and will normally be converted to 'control levels'.
- There are four methods for assessing that the approved abstracted flow regime is being adhered to (see Table 3). A developer can propose any of these providing the project is within the limits shown.

Flow Monitoring Method	Limits
1. Estimate the abstracted flows from the generation records in accordance with the procedures set out in the Appendix. Determine the residual flows achieved by comparison with actual flows recorded near the intake to the project. This method is most applicable where real time flows are used to control a 50/50 flow split.	There must be an existing automatic flow metering station near the intake to the project.
2. Open channel flow measurement by an automatic recorder of the residual flow e.g. a 'V' notch in the weir and water surface level recorder.	none
3. A fixed diversion that physically guarantees that the approved minimum residual flow cannot be diverted to the turbine e.g. a by pass pipe or notch in the weir.	none
4. An agreed minimum water level at the intake which physically ensures the agreed residual flow is maintained.	none

Table 3 Flow monitoring methods to ensure compliance with Hands-Off Flows and flow in the depleted reach.

7.3 Assessment of flow through the hydropower plant

Assessment of flow through the hydropower plant can be achieved through conversion of the records of electricity generated.

The conversion factor for each site will need to be calculated as detailed in the Flow Measurement Analysis guide (available on request).
As the hydropower abstraction is non-consumptive, information is only required to ensure compliance with the Hands-Off Flow conditions, and that abstraction conforms to the agreed abstraction rules.

For small hydropower projects that have a total generated capacity less than 5 MW the abstracted volumes can be monitored using the generation records in accordance with the procedures set out in the Flow Measurement Analysis guide. Other forms of flow measurement may be proposed by developers and approved providing their accuracy and reliability are at least as good as the generation record method.
For hydropower projects that have a total generated capacity less than 5 MW there is no specific requirement to monitor abstracted volumes.

8 Fish passage

There is one consultation question within section 8.1

8.1 Upstream Passes

Where there is an existing upstream fish pass, approved or otherwise, it is expected that the effectiveness and efficiency of that pass will be maintained by any hydropower development or improved where they are not satisfactory.

On migratory salmonid rivers, or designated recovering and rehabilitated salmonid rivers, where there is currently no fish pass, then normally it is expected that one will be required. On other rivers a fish pass may be required where it is considered that any reduction in fish passage may cause deterioration in ecological class status or that the absence of one is preventing achievement of good ecological status.

Circumstances requiring a fish pass

- Under the Salmon and Freshwater Fisheries Act, in waters frequented by salmon and sea trout, a pass will be required if:
    - a new impoundment is constructed, or
    - if an impoundment is rebuilt or reinstated over half its length, or
    - if an existing impoundment is altered physically, or
    - as a result of flow reduction so as to create an increased obstruction.

- Where an existing impounding structure is partially passable, removing flow from it to a hydropower scheme will in most circumstances reduce passage for fish. It may prevent passage altogether, or more likely reduce the window of opportunity for fish to pass.

- As a condition of the abstraction licence, impoundment licence or Flood Defence/ Land Drainage consent, if the species of fish present will experience increased difficulty completing their life cycles as a result of the installation, and which may lead to a deterioration in ecological status.

- Other legal obligations may be applied where sites or species affected have nature conservation designations e.g. under Habitats Directive, SSSI or are the subject of European conservation plans e.g. eel.

- Where fish passage will be impeded, such as in any long depleted reach, a fish pass may be required at the powerhouse.

It is only possible to provide comment on a case by case basis, and the developer will need to consult the local fisheries staff in order to establish whether an upstream fish pass will be a requirement.

If a fish pass is required, the design must be approved by the Environment Agency.

Consultation Question 5

What are your views on including a requirement to ensure fish passage around all new weirs?

Where a fish pass is already present, or where a fish pass is provided by the scheme, we expect the downstream fish pass entrance and the discharge from the turbine(s) to be co-located, since this will usually enhance attraction to the vicinity of the pass. Establishing a competing flow would reduce fish pass effectiveness and efficiency, and will not be acceptable.

Where they are co-located, a suitable pass attraction flow is around 10 per cent of maximum turbine flow (and subject to the minimum flow required to make any particular type of pass operational hydraulically and biologically).

Where a fish pass is present it may be considered to be part of the residual flow.

Where a fish pass is not included in a scheme, the Environment Agency may require sufficient flow and a suitable location be reserved for the installation of a fish pass in the future.

8.2 Environment Agency Upstream Fish Pass Manuals

The Environment Agency has produced a fish pass manual to guide its own staff and developers. A copy on CD can be obtained from the National Fish Pass Officer1

The manual contains background information on fish passes and the requirements of different species of fish, gives examples of designs which may be suitable in different circumstances and includes details of the approval process which the Environment Agency will use to formalise the approval on a site specific basis.

A separate Best Practice Guide is also available for eel & elver passes, and is available on the Environment Agency website

Developers are advised to consult the Environment Agency early in the development process to discuss the need for a fish pass. If the need is identified, developers are advised to submit their ideas at the concept stage to avoid the risk of abortive effort being spent on creating detailed proposals which may prove unsatisfactory.

8.3 Tailrace screens

Note: This section has been incorporated, with revisions, into 9 Fish Screening and Design as section 9.2 Tailrace screens

9 Fish screen requirements and design

There is one consultation question at the end of this section.

We propose to amend this section as follows:

This section provides procedures for determining the default fish screen requirements when designing a small hydropower scheme. Some regional variation in design requirements reflects the effect of climate and geology on fish growth, notably that salmonid smolts tend to be smaller in colder or more oligotrophic (nutrient poor) areas. Further information can be found in the Environment Agency Best Practice Guide for Intake and Outfall Fish Screening, available at http://publications.environment-agency.gov.uk/PDF/SCHO0205BIOC-E-E.pdf . The advice given here may not apply to areas with special conservation designations, e.g. under the EC Habitats Directive, for which special advice should be sought from Natural England and CCW.

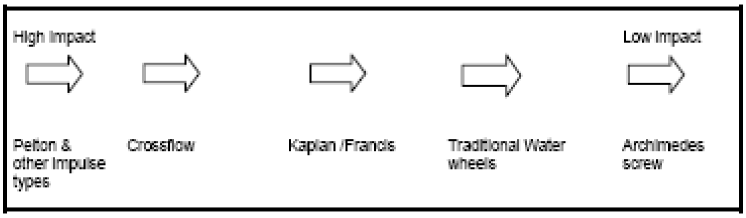
It is important to note that good downstream passage design is a combination of effective screening and diversion, and a safe bywash route.

9.1 Intake Screening

A screen or trash rack represents an obstacle in the flow-path and fish approaching the screen generally turn to face upstream upon meeting it.

However, their behaviour in front of the screen depends on the velocity conditions. By placing the screen or trash rack at a diagonal angle to the flow (as seen in plan view), fish can be guided to the lower end of the diagonal where a bywash is provided to permit their safe transit downstream. Furthermore, the angle of the screen can be set to ensure that the escape velocity is kept below required design value. Screen or trash racks should be set at a diagonal angle to the flow to bias the fish towards the bywash.

The impact on fish passing through low-head hydropower generating equipment is as follows



Generally, the smaller the turbine size the more damaging it is likely to be. Traditional water wheels are assumed to be benign, but the same may not be true of modern wheels. Screening requirements vary for fish species and age.

Pelton and Impulse turbines, normally used on high head systems, have almost nil survival rate for entrained fish. In most cases a 3mm screening drop through, self

cleaning screen is used to prevent the entry of debris that will damage the turbine. 3mm screens will prevent the entry of salmonid fry, under-yearling coarse fish and lamprey ammocoetes. Where these species are not present it may be acceptable to use 6mm screen to exclude salmonid parr, young of year coarse fish or silver eels.

Crossflow turbines are commonly used on low head schemes. The shape of the turbine and blades and the high rotation speed make the survival rate for entrained fish very low, and they need to be excluded by screening. 10/12.5mm screens will be required to prevent the entry of salmon and sea trout smolts. A 6mm screen is recommended for any period when salmonid parr, young of year coarse fish or silver eels are present or occur at the site.

Smaller propeller turbines (<1.5m3/sec) will require similar screening specification to crossflow turbines especially where autumn migrating smolts and juvenile trout are present. The Environment Agency will provide indications or evidence of this.

Larger Kaplan and Francis turbines are considered to be safer for fish passing through. The damage rate for fish passing through a propeller type of turbine depends on the size/capacity of the turbine and the length and species of fish at risk. For example, eels are at particular risk, and typically a 12.5mm aperture physical screen angled to the flow is required. Larger screen apertures may be appropriate in the more upstream catchments where larger eels (>50cm) are typically found. Lower down in the catchment, where there may be a preponderance of smaller male eels, a 9mm screen may be necessary. Full details on screening for eels can be found within the EA's Guidance on eel screening and downstream guidance technologies (Environment Agency (2011). Screening at intakes and outfalls: measures to protect eel (GEHO0411BTQD-E-E)**)**

Modern variants of Francis turbines which have snail-shaped feed pipes and relatively fast runner speed are the least suitable for fish but unlikely to be found on low head run-of-river schemes with the exception of the smaller "polymer" turbines. Fish will have a poor survival rate if they were to pass through these and therefore screening similar to that recommended for the crossflow turbine is required.

The older type of low-head Francis turbine is better for fish, but are no longer manufactured. Where re-furbished ones are used, a 10/12.5mm screen is necessary to exclude smolts, other similar sized fish and eels.

Where large Kaplan turbines are proposed, a risk assessment on screening will be required if the default size of screen is not being used.

Archimedean screw turbines have been demonstrated to cause minimal damage to fish, provided appropriate protection to the leading edge of the screw is applied. For turbines with a tip speed <3.5 m/sec a hard rubber extrusion should be used; for turbines with a greater tip speed a compressible silicone extrusion is required.

Behavioural screens – louvre bar, acoustic, BAFF and strobe – are sometimes advocated. A single type is unlikely to provide sufficient protection where a variety of species are present, but combined with other measures they can be effective. Where such screens are proposed a satisfactory supporting Risk Assessment will need to be carried out by the developer.

Intake screens

Situation	Intake Fish Screening Requirement		
Waterwheel Archimedes screw	Trash screen		
Excluding crossflow turbines, any turbine type with a vertical or horizontal bar, or mesh style screen at the off-take. Max turbine flow ≥1.5m^3 per second. Otherwise as below.[2]	Migratory salmonids	Y&NE, NW, SW (D&C) & Wa[1]	≤10.0mm
		Mid, Ang, SE, SW (Wessex)[1]	≤12.5mm
	Other species	≤ 12.5 mm	
Including crossflow turbines, any turbine type with a vertical or horizontal bar, or mesh style screen at the off-take and a maximum turbine flow ≤ 1.5 m^3 per second.	Migratory salmonids	Y&NE, NW, SW (D&C) & Wa	≤10.0mm
		Mid, Ang, SE, SW (Wessex)	≤12.5mm
	Other species	≤ 12.5 mm	
	Summer fry protection required[3]	6.0mm (May-September, outside this period as above)	
Pelton	Drop through screens ≤3.0mm		

Table 3a Turbine type and default intake screen requirements[7]

9.2 Tailrace screens

Upstream migrating fish may be diverted or delayed if they are attracted into tailrace channels. They must therefore be prevented from doing so.

Either physical or electric barriers are acceptable for salmonid or coarse fish waters. Physical barriers are preferred if there is a risk that fish could enter the turbine from the tailrace.

The use of the screen sizes laid out in the tables is also dependent on meeting the other criteria laid out in section 9.3 and 9.5 regarding approach and escape velocities and by-wash provision.

Placement of screens should be close to the edge of the river bank at the point of return of the turbine discharge to the river or lake.

Where fish are permitted to pass through turbines the design of the downstream screens must take account of the need for fish to pass in the downstream direction, while also acting as screens to prevent ingress of the upstream migrating fish.

Situation	Screen Type	Outfall Fish Screening Requirement [4]
All turbine types excluding Archimedes screw and waterwheel. [5]	Electric barrier	These should only be used where fish have been completely excluded from passing downstream through the turbines. Graduated field types are preferred. It is essential that they are operated 100 per cent of the time, even when the hydro plant is not running otherwise fish may enter the turbines and be present when they re-start. An externally visible indicator light or other means is required to confirm that barrier is switched on. Voltage field should be checked annually in the water using a suitable test device and compared to specification in order to ensure that electrodes are in good condition.
All turbine types excluding Archimedes screw and waterwheel. [5]	Physical Bar Screens	40 mm spacing for salmon, 30 mm where sea trout are present. Screens must be constructed from wedge wire, square or oblong metal bars - round or oval bars are more likely to gill fish.

Table 3b Turbine type and default tailrace screen requirements [7]

[1]Agency regions: Ang (Anglian), Mid (Midlands), NW (North West), SE (South East), SW(D&C) (South West, Devon & Cornwall), SW (Wessex) (South West, Wessex), Wa (Environment Agency Wales), Y&NE (Yorkshire and North East),
[2]For large turbines a risk assessment for the screen design may be undertaken in accordance with the Environment Agency Best Practice Guide for Intake and Outfall Fish Screening.
[3]The Agency recommends that 6mm screens are installed if there is evidence that there are young of year fish fry present.
[4]Upstream migrating fish may be diverted or delayed if they are attracted into tailrace channels. They must therefore be prevented from doing so. Either physical or electric barriers are acceptable for salmonid or coarse fish waters. Physical barriers are preferred if there is a risk that fish could enter the turbine from the tailrace.
[5]Archimedes screw types permit fish to pass down through the turbine. An outfall screen would prevent fish from returning to the watercourse.
[7]Further protection may be required for species protected under specific legislation such as lampreys, shad and bullhead etc

Notes to Tables 3a and 3b

Tables 3a and 3b give default screening spacing depending on the threat different turbine types pose to fish populations. Developers may, however, wish to propose different spacing based on the specifics of their scheme design, local environment and associated ecology. Any such proposal must be accompanied by a Risk Assessment, which should consider the species and size ranges that need protecting, the mortality rates associated with the turbine to be deployed, and the overall effect the proposed scheme may have on the fish population or other relevant animals and plants. The risk assessment must show that the proposed screening arrangements provide the same level of protection as would be provided by adopting the default screen requirements identified in Table 3.

Elements that should be included in the risk assessment include:

- **An assessment of the deflection efficiency of the screen for the appropriate fish species, including the variability associated with this measure.**
- **Mortality/injury rates for fish where some size classes of fish can pass through the turbine without injury.**
- **The performance of any additional mitigation measures employed, such as behavioural screens or cessation periods, presented as an additional deflection efficiency.**

There are a number of mitigating factors that can be deployed that may be compatible with using an over spaced screen (i.e. a screen that has wider apertures than specified in Tables 3a and 3b). These factors include:

- **Cessation of the turbine operation during periods of high risk of entrainment.**
- **The use of behavioural barriers, such as bubble curtains, which have been shown to be effective deterrents when deployed in combination with a physical screen.**

In the case of Kaplan turbines, larger turbines move slower and may have lower mortality rates for smaller fish, reducing the overall risk . Evidence of this would be required.

A number of hydropower schemes with Crossflow turbines are operating with 10mm screens but their effectiveness requires confirmation.

The Environment Agency is committed to undertake investigations to demonstrate the effectiveness of different size screens on the exclusion of fish fry at hydropower sites and will review the screening requirements in light of our findings. If consent is given by the Environment Agency for a hydropower developer to install screens, they may need to be replaced (at the developers expense) within a year of notice being given following evidence from its investigations being provided by the Environment Agency that these have failed to provide adequate protection.

9.3 Screen Approach Velocity

The approach velocity Ue (also known as 'escape velocity') for screen design purposes is defined as the velocity 10 cm upstream of the screen, perpendicular to the screen face. Where installed in a headrace, the screen should be angled diagonally across the flow, allowing low approach velocity even when the axial channel velocity Ua in the headrace is high. This has the added benefit of guiding fish towards the bywash entrance (Figure 6). Note that where multiple species are being considered the lowest common acceptable approach velocity will need to be used.

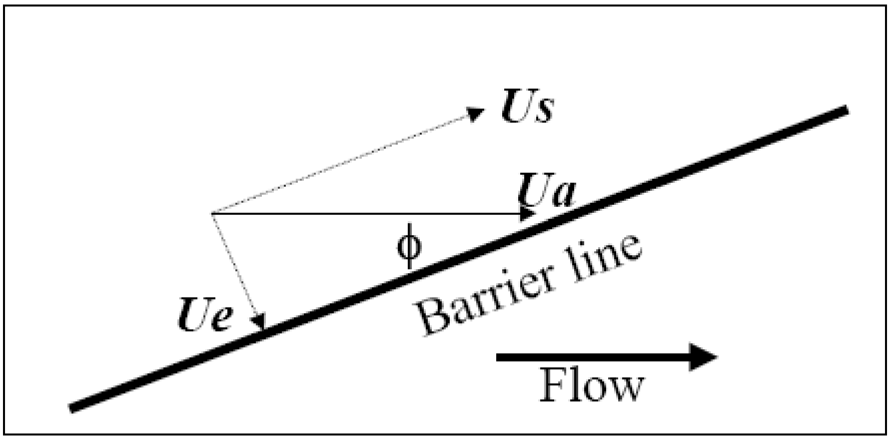


Fig 6 Flow velocity components in front of an angled fish barrier.
Ua is the axial channel velocity, Ue (=UsinΦ) is the fish escape velocity and
Us (=UcosΦ) is the sweeping velocity component along the face of the screen.

Salmonid

The maximum acceptable design velocity of approach towards any part of a screen is 0.60 m/s.

Coarse fish & Shad

The maximum acceptable design velocity of approach towards any part of a screen is 0.25 m/s.

Eel

The maximum acceptable design velocity of approach (escape velocity) towards any part of a screen is 0.50m/s.

Lamprey

The maximum acceptable design velocity of approach (escape velocity) towards any part of a screen is 0.30m/s.

9.4 Accounting for Debris

The blocking of the screen with debris will increase velocities in practice, particularly where the screen is at right angles to the flow. This means that an allowance must be made for some blocking when sizing the screens, such that the target approach velocity is not exceeded when screen performance is reduced by the accumulation of debris. The inclusion of an automatic screen cleaner will improve performance so that the additional area of screen required can be less. It is assumed that where screens are to be cleared manually the target approach velocity will need to be maintained with 50 per cent screen blockage, while with automatic screen cleaning it will need to be maintained with 10 per cent screen blockage.

9.5 Screen bywash

A screen bywash is required wherever the intake screen of the hydropower scheme is not located in the normal course of the river (i.e. it is within the headrace). For a diagonal screen alignment, the bywash entrance should be located at the downstream end of the screen to take advantage of the guidance effect. If the by-wash is well-designed, a typical bywash flow would be in the range 2-5 per cent of the scheme design flow. A higher proportion may be needed if by-pass design is poor e.g. aligned perpendicular to flow, located away from the end of the screen, poor hydraulic conditions at by-wash entry etc. Good screen by-wash design will include a sweeping velocity increasing smoothly into the by-wash entrance, adequate entrance size (minimum 0.4-0.5m wide and deep), avoidance of sharp shadows particularly at the entrance, a smooth and safe by-wash conduit to avoid damage to fish in transit, and a safe delivery to the downstream.

It is acceptable to use some types of fish pass as the bywash where they can be suitably positioned. Larinier, vertical-slot, pool and traverse or nature-like fish passes are suitable for this purpose. However, Denil, Alaskan A, or side-baffle passes might cause abrasion damage to fish and are therefore not suitable for joint use.
The bywash return point should be sufficiently deep to prevent fish being stranded or damaged on impact, with a depth at least 25 per cent of the differential head and no less than 0.9m.

Consultation question 6
Are these revised screening and by wash requirements adequate for the protection of fish as part of the design of hydropower schemes? Y/N

Please provide your reasons and supporting evidence