WG197 SMALL HYDROPOWER IN WATERWAYS ENVIRONMENTAL WG197

Introduction

Whenever the infrastructure around rivers or canals is modified, improved or even just maintained, additional environmental constraints are likely to be placed on the owners and operators. The development of a new hydro power plant in conjunction with existing infrastructure will undoubtedly raise such issues. Even if the infrastructure has been in place for many years and the introduction of a hydro plant will do little more that divert some of the water in the waterway through a different route around an existing weir, the environmental authorities are likely to insist that the new installation improves the situation for migratory fish rather than just maintaining the status quo.

This paper looks at some of the environmental issues that can arise during the development of hydro power plant on inland navigations and how they might be approached and mitigated.

Environmental legislation and regulation

Every country has its own environmental regulations. Even the countries of the European Union, whilst bound by common EU directives, implement these directives in their own way. There can be regional interpretations of any one country's own regulations so what applies in the south doesn't necessarily apply in the north.

As a result, this paper cannot present solutions that are applicable in every case, but rather a series of solutions that have been used successfully in some countries to give owners and operators a view of the scale of the issues and they ways in which they can be successfully addressed. Every development is different, the actual solution applied in each case will have to take account of the country rules and regulations.

The constrains and requirements of environmental regulations will increase the cost of the hydro power plant development. Sometimes, the increases can start to affect the economic viability of the scheme to the point where its viability is reduced or even eliminated.

The environmental effects can be broken down into a number of areas:

- Fish and eel migration upstream and downstream
- Floating Debris
- Sediment transport and redistribution

Fish and eel migration

Migratory fish and eel species are of considerable importance to the wider environment and, in some cases, are economically significant as well. The fishing of salmon is particularly important in some areas of the Northern hemisphere and the downstream migration of the juvenile fish – known as smolts – is key to the continued survival of the species. Eels have suffered major population declines in recent years and there are legal protections in place to protect eels and ensure that their migrations up and down rivers can take place unhindered.

Upstream migration - fish

The key elements for upstream migration are:

- Provision of passes for fish and eels
- Exclusion of fish and eels from the turbine discharge

The type of fish pass required varies by country and by fish species. There are three basic types of fish passes:

- Pool
- Baffle
- Active

Pool fish passes

A pool fish pass consists of a series of linked pools with water cascading between each pool either over horizontal barriers, through vertical slots or through submerged orifices. The pools separated by horizontal barriers are suitable for fish that can jump or leap over barriers in their progress upstream. The vertical slot variant can have additional materials on the bed to facilitate the movement of benthic (bottom dwelling) fish up the fish pass. In both cases the water velocities, turbulence and pool size are carefully calculated to enable the required fish species to pass through them. There are a number of variants and combinations of vertical slots, submerged orifices and horizontal barriers to make the fish passes applicable to particular fish species.

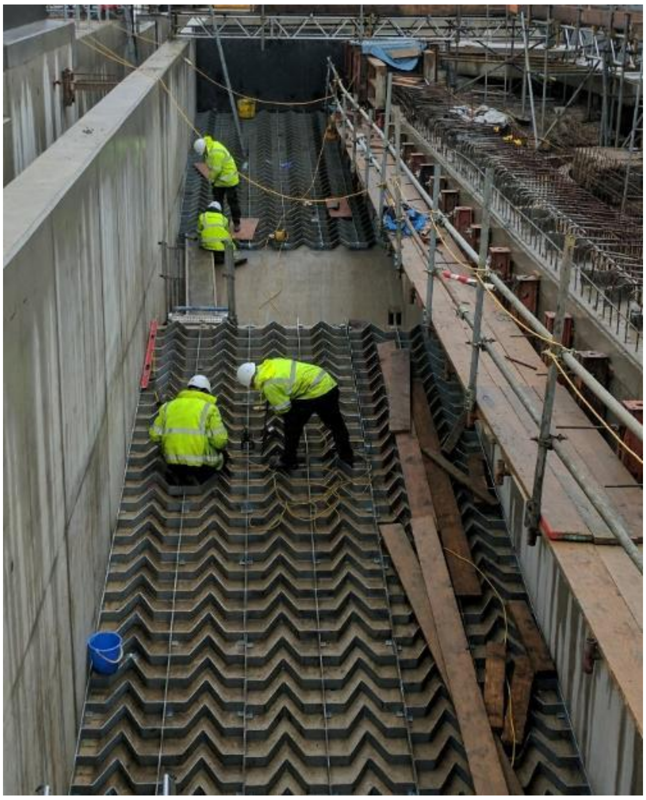
Vee shaped slots, horizontal barriers with notches and submerged orifices that have been used in different counties and the choice is very much country specific. The construction costs of all of these can be a significant proportion of the overall cost of the hydro power station development.

Pool fish pass in France with two vertical slots in each pool. The bed of the fish pass has additional moulded protrusions to assist the passage of benthic fish.

Pool fish pass in Scotland with submerged orifice

Baffle fish passes

Baffle fish passes use a series of shaped steel plates in a concrete trough. Long runs have resting pools part way up. The baffles come in many forms and shapes that are designed to facilitate the passage of various species of fish. In recent years, the Larinier type of super-active baffles have found favour in Europe because of their ability to facilitate the passage of a large number of species of fish.



Larinier super-active baffle type fish pass under construction and in operation on the Aire & Calder Navigation in England – Pictures from Yorkshire Hydropower Ltd.

Active fish lifts

Active fish lifts are mechanised structures that attract fish and then lift them either in the manner of a navigation lock or in a tank that is moved on rails between the lower and upper water levels. These tend to be associated with a large difference in levels such as at hydro-power dams.

Turbine discharges

Migratory fish are attracted to waterflows in their quest to swim upstream. Where the discharge from a hydro power station forms a large part of the flow in the waterway, there is always the possibility of the fish following the turbine flow rather than being attracted to the fish pass flow. It may be necessary to put screens on the turbine outlet to prevent fish trying to follow this flow. Such outlet screens don't need to be raked because the debris is on the downstream side, but they do need to be carefully designed to prevent head loss and the back-up of the water level downstream of the turbine.

Upstream migration - eels

The facilitation of eel migration is of significant concern in Europe. Migrating eels are poor swimmers and cannot use the more traditional types of fish pass. Eel specific passes will be required where eel migration occurs.

Eel passes require a wet substrate that the juvenile eels, or elvers, can wriggle through to climb. Bristle type materials, artificial grass or specifically designed rough plastic substrates that are wetted by a continual flow of water have been successfully used. The amount of water needed is quite small, a few litres per second can provide enough to allow the eels to use the pass.

The pass can either be an open channel or a closed conduit such as a plastic pipe. Careful design is needed to provide an entry and exit from the eel pass to ensure that it is kept clear of debris and doesn't let the emerging eels get swept back over the weir.

Various forms of eel pass

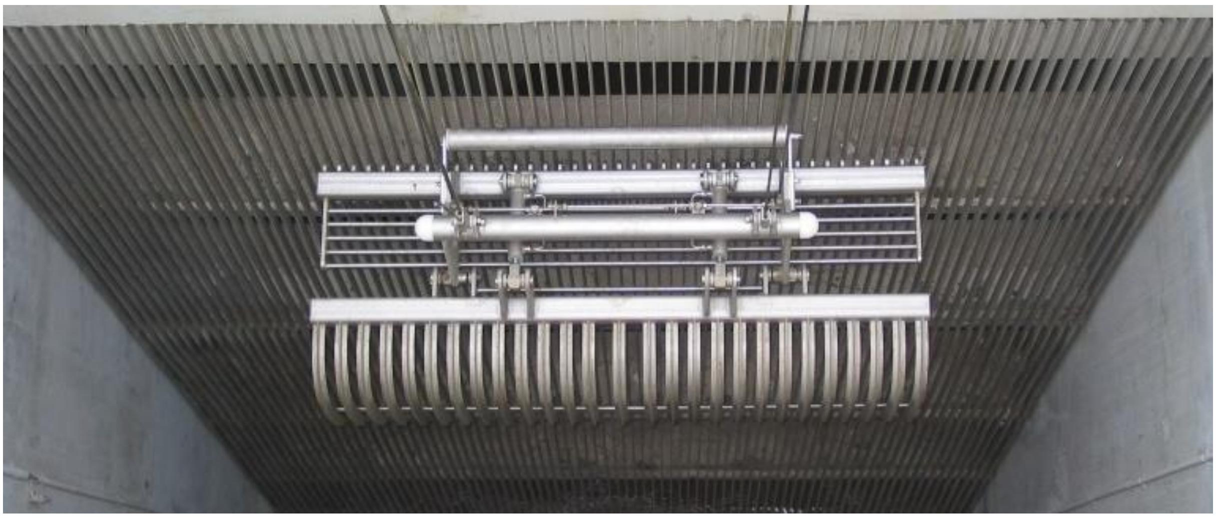
Downstream migration - fish

There are two approaches to dealing with migratory fish going downstream associated with a hydro power plant:

- Exclusion of fish – keeping the fish out of the turbine
- Fish friendly turbine – a significant number of the fish can pass through the turbine unharmed

Exclusion of fish

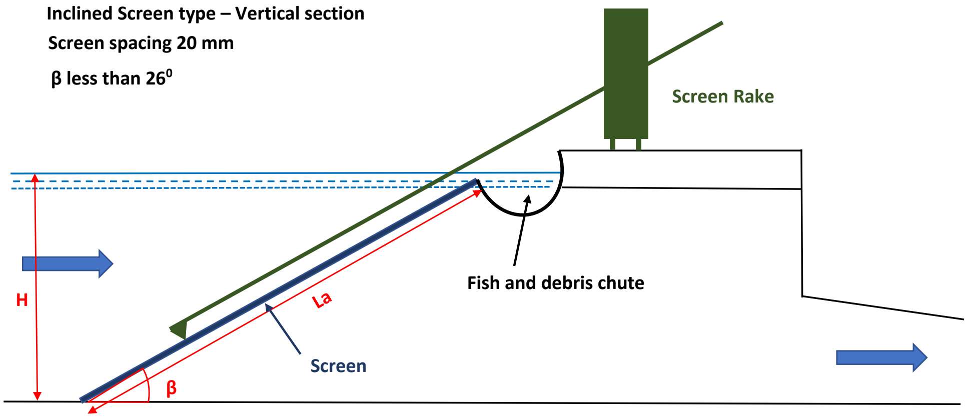
The inlets to all turbines must be guarded or screened to prevent floating debris from entering and damaging the turbine. Traditionally, these screens have been made from sloping panels of steel bars. The gap between the bars is in the range 50mm to 100mm to keep out debris that might cause damage or blocking in the turbine. Such screens can be raked by an automatic screen rake that rakes up the bars lifting the debris up the sloping screen panel to remove debris that could block the screens and increase the head loss on entry to the turbine. The debris can either be lifted out of the water for dry disposal or directed into a channel that sluices it downstream.

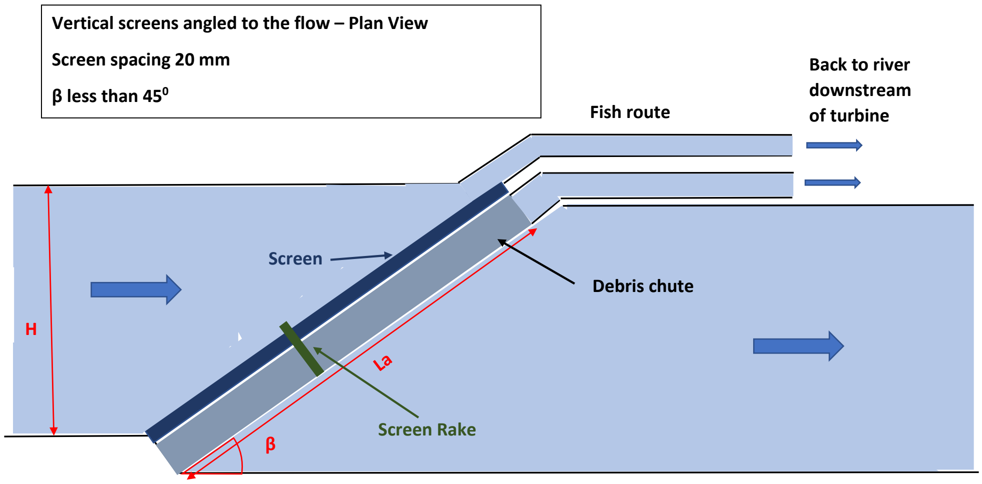


Traditional turbine intake screen with automatic rake

Such screens with wide bar spacing does little to keep fish out especially small juvenile fish such as salmon smolts. To exclude salmon smolts, the bar spacings will need to be 12. This is about the minimum gap that can be raked vertically by a traditional raking machine.

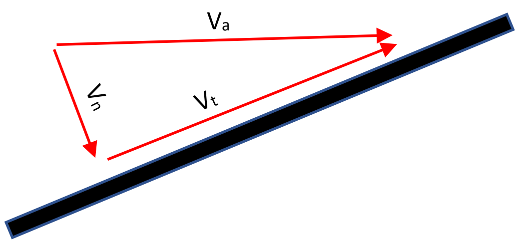
The required gap in such screens is very much the decision of the individual country regulators. In France for example, a minimum gap of 20 mm between the bars is generally used but with specific requirements concerning the angle of the screen to the flowing water, the water velocity normal to the screen and the water velocity on the face of the screen. The screens can be at right angles across the waterway and inclined to vertical as below, or the screens can be vertical and angled across the waterway.



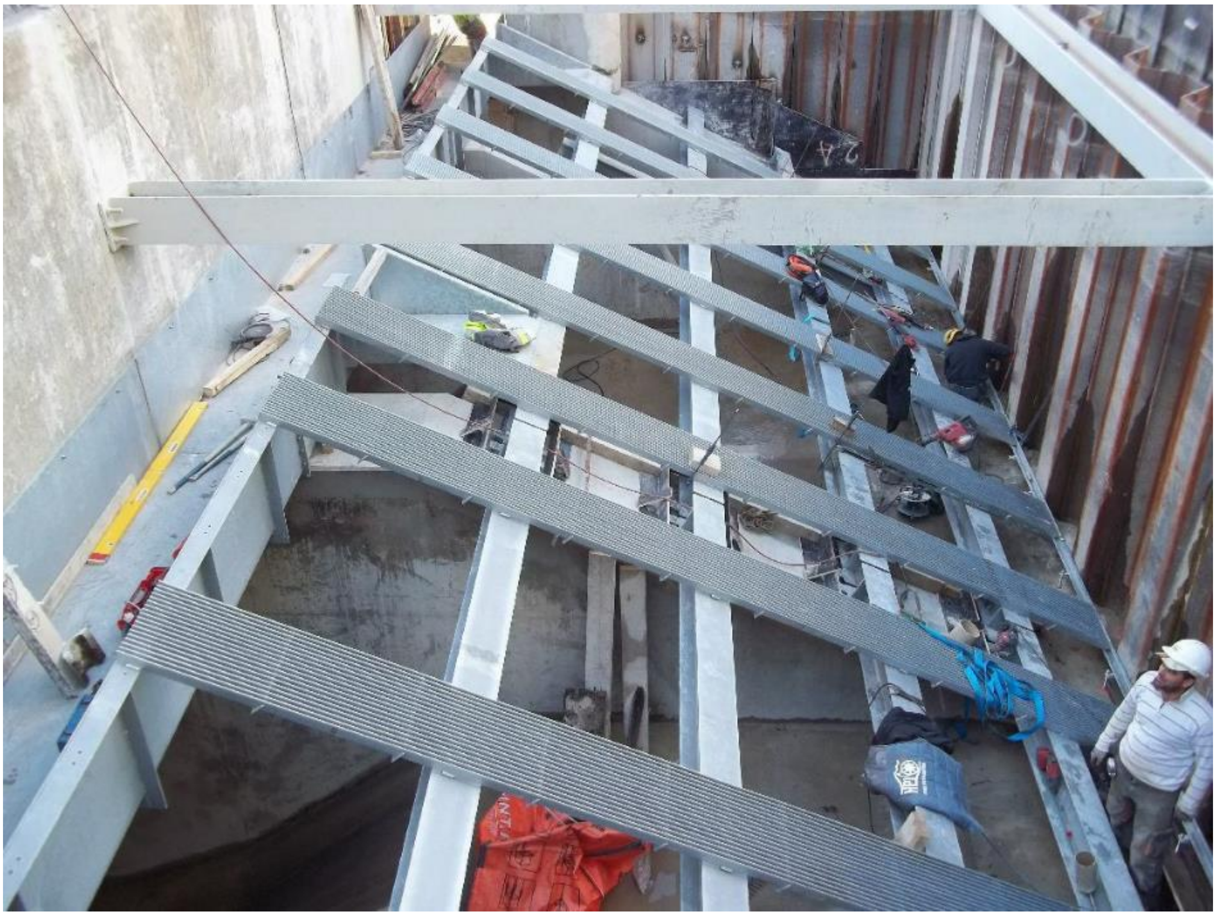


Vertical screen at an angle across the waterway.

In both cases, a side channel is provided for the fish to enter a bypass channel that then discharges back into the waterway downstream of the turbine intake. The water velocities are also specified.



V_a – water velocity
V_n – water velocity normal to screen
V_t – water velocity up the face of the screen
$V_t \geq 2V_n$ for an inclined screen
$V_t \geq V_n$ for vertical screens angled across the flow
$V_n \leq 0.5$ m/s in all cases



A sloping screen under construction, giving an example of the scale of the installation for a small hydro power plant.

In some cases, the environmental regulators require smaller gaps to keep fish from the turbine intakes. Screen gaps down to 6 mm have been successfully employed on hydro power plants on inland navigations. Traditional vertical bars and raking methods are not suitable and the bars are arranged horizontally. The screens are cleaned by wiping the face of the screens with a bristle or other resilient material from the upstream end to the downstream end, pushing the debris into chute that discharges downstream of the turbine intakes.

Horizontal bar screens with 6 mm gap

As the gaps between the bars become smaller, the blockage effect of the bars increases, and to maintain the flow area for the turbine, the size of the screens increases as a result. The head loss through the screen is not linear with the size of the gap. Smaller gaps have a larger head drop for the same flow velocity than larger gaps, so the flow areas are correspondingly larger for the same head loss. With small head differences available on inland navigations, the head loss through the screen can be a significant proportion of the head available. These all combine to make the screen areas potentially very large and, as a consequence, expensive to construct.

Gaps as low as 3 mm have been proposed by environmental regulators for some mini or micro hydro power schemes. With such small gaps, the size and cost of the screens can destroy the financial viability of the hydro power plant.

Large intake screens parallel to the main river flow on the Aire & Calder Navigation in England. These screens have the 6 mm bar spacing shown above and a horizontal automatic rake that pushes the debris into a debris chute. The picture illustrates the large size of the screens in relation to the hydro power plants output of 500 KW.

Fish friendly turbines

Fish can be damaged by passing through turbines by contact with the moving blades, being crushed in small clearances between moving parts or by the rapid changes in water pressure. To be considered fish friendly, a percentage of the fish passing through the turbine should survive.

Unfortunately, there is no international definition of a fish friendly turbine or how it should perform in relation to fish mortality. The definitions can be different for the same river passing through different countries.

The range of turbine operating head applicable to inland navigations usually leads to a choice of two types of turbine being employed:

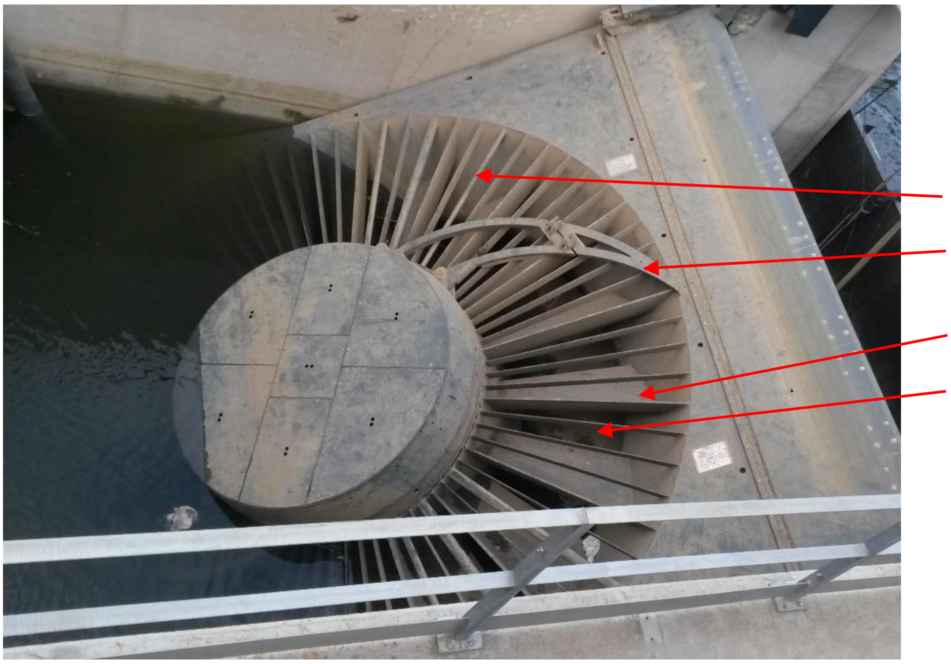
- Kaplan with variable or fixed pitched runner blades (propeller)
- Archimedean Screw

Kaplan turbines are more efficient energy converters and physically much smaller for the same power output than the Archimedean Screw turbines.

Various manufactures of turbines as well as the environmental regulators have done research on how fish friendly each type is. There is a considerable difference of opinion amongst the environmental regulators as to which turbines are fish friendly. However, Archimedean screws are considered to be fish friendly by environmental regulators throughout Europe.

Kaplan turbines are not usually considered to be fish friendly environmental regulators and their intakes must be screened. Depending on the type of screening required for a non-fish friendly turbine, the economics of overall scheme may favour a more expensive fish friendly turbine whose cost is offset by reductions in cost of the intake screens.

One variant of the Kaplan turbine the Very Low Head turbine, is considered to be fish friendly and widely used with 50 mm screen bar spacing upstream. This turbine has an applicable head range from 1.5 m to 3.4 m although this can be extended to 4.5 m.



Very Low Head turbine employed in the River Meuse in France showing the

turbine inlet screen

screen cleaner

the fixed guide vanes

the turbine runner

Floating Debris

Floating debris is a problem for all inland navigations whether the debris comes from vessels navigating the waterway, from trees on the banks or items dumped in the navigation. Traditionally this debris has collected on weirs or navigations locks and been flushed downstream during operation or in times of flood. Weirs with gates are often designed to allow the gates to be lifted clear to flush debris downstream.

The need to protect the intakes of hydro power stations from floating debris by the use of the screens will lead to a build-up of debris against the screens. The debris can either be lifted out of the waterway or left in the waterway and routed around the turbine intake and discharged into the downstream water course. Owners and operators will already be familiar with the type and quantity of debris that occurs in their waterways and can use the knowledge to drive the way in which debris is dealt with.

The turbine control system will need to respond to head differences across the screens and reduce or even stop the turbine flow if the screens become blocked. Automatic raking machines can be used to keep the screens cleaned but these are expensive to purchase and require maintenance. Shutting the turbines down and allowing the natural flow of water to take the debris away can be effective as can manual raking at times of high debris flow.

Sediment transportation and redistribution

On navigation waterways, a small head hydropower plant can benefit from specific hydraulic conditions head created by other hydraulic structures built for waterway management purposes:

- Small head hydropower station to generate energy
- A weir or drain to control the water level in the system
- A fish passage system, to allow fish migration both upstream and downstream of the systems
- Navigation locks to manage the ships to pass through the system.

Especially for water level maintenance in a system, the link between the hydropower station and the weir or gate (fish passage) construction is important for water level management. The combined water discharge from a weir/drain/lock and a hydropower station should match the average system discharge. In this way, the water level in the system and all other purposes of the river can be maintained, e.g.

- Sufficient water to allow for navigation
- Sufficient water in the river for drinking water extraction
- Sufficient water for adjacent industrial processes and irrigation (agricultural purposes)
- Maintainable water level in order to avoid flooding's

The hydropower plant main characteristics (head and discharge range) have thus to be defined regarding the whole system requirements and features, and in particular the discharge balance. It is common to see hydropower plants on navigation waterways able to operate in both pump and turbine modes. As such, in periods of excess discharge, energy is produced while, in low flow periods, loss of water in upstream reaches because of locks operation is compensate by pumping.

In order to calculate the upstream water levels from the hydraulic structures, backwater curves can be calculated. These can be calculated both analytical and by means of numerical simulations.

Extreme events

During extreme events, water systems should be able to discharge the high-water discharge peaks in the system. This is generally done by means of weirs or adjustable draining channels, as the small head hydropower systems have a limited capacity in comparison to the flood flows. At specific locations, where the hydropower system is blocking a part of the waterway, these systems can be adjusted (hydropower stations with adjustable discharge levels), often or even lifted, in order to avoid any influence on the discharge of high water peaks. In some cases it is necessary to be able to react on a short term bases.

When a small head hydropower system is located in an artificial branch of the waterway, the influence on the water discharge of the system is generally limited. In such a case, the hydropower plant can remain in operation during an extreme event.

In case hydropower schemes are not able to be removed from a water system or cannot be adjusted, upstream flooding's might occur, or the small head hydropower system might be flooded.

Small scale

Near small scale power stations, small scale effects might be present. For most situations, a scheme consists of a weir, a hydropower station, navigation locks and fish passages. All these hydraulic structures have intake and outfall systems, which cause jets that might influence each other. In this section, more information is given on typical situations that might be present.

For an optimal operation of the hydropower station, little head losses upstream and downstream of the system should be present. For systems located in the waterway, this is generally the case, but for systems that are located in a side branch additional resistance can cause head losses, which affect the energy production. For this reason, the full hydraulic system together should be in harmony and controllable.

Detailed flow patterns

To have an optimal design of the hydropower plant, the approach flow towards the turbines should be optimal, with minimum hydraulic losses. Sharp bends or rapid changes in the flow should be avoided. To investigate the hydraulic losses upstream and downstream of the turbines, both numerical and physical modelling could be applied.

Impact on navigation

Hydrodynamic forces on a ship can be significant near small head hydropower stations, due to strong concentrated flows near the outflow of a power station, in particular for recreational and smaller ships.

The hydrodynamic forces exerted on the ship's hull result from all the water movements and pressure variations (e.g. pressure force due to differences in water level, velocity changes due to jet flows, drag forces caused by flow around the hull, turbulence force due to the energy dissipation in the lock chamber). The resultant sum of all hydrodynamic forces on the hull can be termed the 'ship force'.

These are the forces measured on the physical model, with two components: one longitudinal and one transversal. Their numerical prediction requires a sophisticated 3-D numerical model able to reproduce the movement of the ship, which means long and costly numerical calculations.

Morphology

Hydraulic structures have an impact on the waterway or channel flows. Weirs, locks and hydropower schemes can only transport limited amounts of sediment. If the sediment cannot be transported through a system, it might influence the approach flow patterns of a system. To investigate potential sediment accumulation near the intake of a power plant, numerical modelling is often applied, incorporating significant upstream and downstream regions, to model the total sediment balance of the system. Detailed nearfield models, incorporating all turbulent 3D flow patterns could indicated dead zones, which are susceptible for sediment accumulation.

Bed protection

Near intake and outfall systems of hydropower plants, flow acceleration is present, that might cause erosion near the structure. For this reason, bed protection is often applied, as erosion pits near a hydraulic structure can undermine the hydraulic structure. To design bed protection near hydraulic structures different guidelines exist, such as the Rock Manual, [CUR, 2007]. If no precautions are taken, the bed needs to be monitored and if necessary maintained (dredging, equalising, refilling).

Conclusions

Dealing with environmental regulators is an important aspect of constructing a hydro power plant on an inland navigation. The regulations vary from country to country and even from region to region. However, they are essentially related to the elements contained in this paper and they can, usually, be dealt with by design and planning in the initial stages of the project.

The owners and operators can view the environmental regulations and restraints as a necessary evil, or a more positive view can be taken where the environmental benefits and improvements are used as part of the justification for the scheme, possibly enabling environmental grants to be applied for and good will to be generated in addition to generating green energy.