ENVIRONMENTAL ISSUES AND MANAGEMENT FOR HYDROPOWER PEAKING OPERATIONS

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Abstract

Many hydropower plants are operated as peak generators or frequency controllers, because they can change their output quickly to follow the fluctuating power demand. When meeting peak load requirements, a power station is turned on at a particular time during the day, generates power at a constant load for a certain number of hours, and is then turned off or set to a different load for another time period, resulting in a high variability in flow discharges. Where reservoir hydro schemes are operated primarily to provide peak load services, there are particular environmental risks that should be considered in any environmental impact assessment. At a minimum these should focus on water quality, fluvial geomorphology, riparian vegetation, macroinvertebrate and fish communities underpinned by a sound hydrological analysis. Frequent temperature changes may occur downstream of a peaking power station; increased seepage-induced erosion of riverbanks due to frequent water level drawdowns; and impacts to macroinvertebrate and fish communities due to rapid and frequent in channel habitat conditions. With a sound understanding of the potential environmental issues, there are strategies that can be employed at the siting and design stage to minimise or mitigate these risks, including but not limited to minimum environmental flows, ramping rules, utilisation of a re-regulation storage and localised treatment works.

Keywords

hydropower, environmental, peaking, hydropeaking, mitigation

1 Hydropower peaking operations

Hydropower schemes are built on many scales, involve different project types, and play different roles in an integrated energy system. Operating patterns vary, and discharge patterns to the downstream river environment reflect whether the station is operating in base load, peak load or frequency mode.

When meeting base load requirements, a power station usually discharges a constant flow all day and can maintain this for days, weeks and even months depending on the scale of the scheme and the generation needs. When meeting peak load requirements, a power station is turned on at a particular time during the day, generates power at a constant load for a certain number of hours, and is then turned off or set to a different load for another time period, resulting in a high variability in flow discharges. Hydropower stations may also operate in frequency mode, where generators are brought on or off depending on the changing electricity demand throughout the day, essentially 'following' the load.

Many hydropower plants are operated as peak generators or frequency controllers, because they can change their output quickly to follow the fluctuating power demand. A hydropower generating unit can start up or stop within tens of seconds, which provides an important role in an integrated energy system where each type of energy source can be used to its best advantages. Because of its flexibility in generating patterns, hydropower can optimise the efficiency of less flexible fossil or nuclear generation options, and also offers a backup for other more intermittent renewable energy sources such as wind and solar.

Reservoir hydro schemes in particular provide considerable flexibility in energy provision, because with their larger storage they can be operated to provide either base load or peak load services. Run-of-river hydropower schemes provide base load options, but with less flexibility in their ability to provide peak power because of their smaller storage capacities. Pumped-storage plants are particularly well suited to meeting the peaks in electricity demand; they essentially work as a huge storage battery by charging or discharging power according to the system's demand.

2 Potential environmental issues with hydropeaking

Where reservoir hydro schemes are operated primarily to provide peak load services, there are particular environmental risks that should be considered in any environmental impact assessment. With a sound understanding of the potential environmental issues, there are strategies that can be employed at the siting and design stage to minimise or mitigate these risks.

With any hydro scheme, the downstream river environment has an altered hydrograph due to the curtailing of major floods and a flow range restricted to the turbine discharge capacity. For a peaking station, a typical hydrograph shows twice-daily fluctuations from off to full capacity discharges often with weekend shutdowns. A peaking station may show consistent daily to weekly patterns of discharge throughout the year rather than the strong seasonal pattern that might be shown for base load providers, and depending on the scale of the scheme inter-annual variability may be low.

Downstream effects on water quality depend on the storage configuration and offtake depth. If the storage is deep and stratifies and the offtake is low, the downstream environment may experience frequent temperature and dissolved oxygen fluctuations particularly during the summer period, with the power station injecting cold water from deep in the reservoir into the warmer waters of the receiving environment. In situations where there are downstream pollution sources draining into the river system, peaking power station discharges can cause pulses of polluted water downstream rather than a general dilution effect when operating to meet baseload demand.

Downstream effects on the fluvial geomorphology and dominant geomorphic processes differ if a power station is operating to meet base versus peak demand. Major issues with any hydro operations are with the reduced sediment supply to the downstream environment and the erosive capabilities of continuous larger than natural baseflows for baseload operations. With peaking operations, the significant flow discharge patterns affecting the channel form are the rate and frequency of water level rise, the time the station is at its maximum discharge level, and the rate and frequency of water level drop. A rapid increase in water level has considerable bank scouring capabilities. The amount of time the power station discharges at its full capacity influences the degree of saturation of the river banks, which in turn influences the degree of seepage-induced erosion that may occur when the power station turns off. Frequent and rapid drawdowns in water level result in considerable pore water pressures as the water drains out of the banks, so with peaking operations the frequency of seepage-induced erosion events increases, however the severity of any one event may be less than otherwise if the power station has not been on long because the banks will not be as saturated.

Downstream effects on riparian vegetation with any hydro operations can be a loss of species cover and diversity in the riparian zone due to waterlogging and inundation, lack of regeneration and recruitment, and habitat alteration due to bank erosion. Inundation is the submergence of vegetation that prevents gas exchange, and prevents plants carrying out photosynthesis and respiration through their leaves. Waterlogging is the submergence of the root zone, which causes depletion of oxygen in the soil and prevents respiration by plant roots. Light limitation is also a stress because plants require adequate daylight hours without inundation or waterlogging to acquire carbon through photosynthesis. With peaking operations there are reduced risks of impact due to waterlogging and inundation, as the riparian zone is drained and exposed to sunlight on a daily basis. However there is still the case of limited regeneration and recruitment, because seedlings can not establish on the banks where water levels rise rapidly several times per day and wash them away. Banks close to the power station may eventually end up with a high percentage cover of mineral substrates, and riparian tall woody shrub species may be replaced with ephemerals such as grasses, gramonoids (grass-like plants) and tolerant semiaquatic herb which may provide some structural stability to river banks.

Downstream effects on macroinvertebrates (e.g. aquatic insects and micro-crustaceans) for any hydro operations are often a reduction in species diversity and abundance, as well as loss of edge and snag habitat. The significant drivers of these impacts are that the water levels with the power station off are often lower than mean summer baseflows resulting in less habitat availability for colonisation, and water levels with the power station on are often higher than mean winter baseflows resulting in greater depths and current velocities than optimal for some species. With peaking operations, water levels change across this range several times per day, and frequent water level as well as temperature changes would cause high stresses on the instream biota. For example, high shear stresses, that is the force applied to the river bed from rapidly rising water levels, is associated with faunal displacement and possibly bed movement under rapidly varying flows.

Hydropower schemes can affect migratory aquatic species due to the physical barrier to upstream migration presented by the dam itself. Baseload discharge patterns can reduce fish populations in the downstream environment due to reduced macroinvertebrate food supplies, loss of snag habitat, and impacts on spawning and migration cues due to changes in the seasonality of flows (and in cases temperature). Where there are natural downstream obstacles to fish migration such as river gorges, baseload discharge patterns may cause fish migration difficulties due to sustained high flow releases, whereas peaking discharge patterns may provide more frequent opportunities for migration through these gorges.

Social issues can also arise due to peaking operations, for example human safety issues with rapidly changing water levels, risks of stock strandings, and issues with pump set-ups for landowners.

3 Investigating environmental impacts due to hydropeaking

Investigations of environmental impacts of hydropeaking operations must be underpinned by a sound analysis of operating patterns and downstream hydrology. The drivers of impact in the downstream environment are the rapid changes in flow, and at any given point in the system this will result in different water heights, current velocities, degree of backwater inundation or channel dewatering, ramp-up and drawdown rates. A detailed set of gauging sites and water level recorders will provide basic data that can then be fed into a hydrological model of the river system to assist in modelling of environmental impacts.

Because of the rapid changes in water level with peaking operations, water quality impacts are best assessed using sites that continuously record temperature, dissolved oxygen and conductivity, at several sites downstream of the power station. Sites should be in conjunction with a gauging or water level station so that readings can be related to flow/level changes, and ideally upstream and downstream of significant tributaries.

Investigations of the impacts of peaking operations on fluvial geomorphology require particular attention because the dominant geomorphic processes can vary considerably depending on the type of discharge regime from the power station. These investigations can employ a number of different approaches. Development of a sediment budget for the downstream environment provides a valuable framework for more detailed reach-specific assessments, as does mapping of riverbank and bed attributes using a hand-held GPS to identify those zones most susceptible to bank erosion. For existing schemes, broadscale geomorphic change in over time can be assessed using comparative aerial photography. Changes to channel profile, depth and channel geometry can be assessed using repeat survey cross-sections. Changes to bank stability and profile can be assessed using erosion pins and photo monitoring. Scour chains in association with erosion pins offer the ability to show maximum scour that occurred during the period between erosion pin measurements. Water samples analysed for suspended sediment concentrations at different points in the river, particularly with continuous autosamplers, are valuable where rivers transport fine-grained sediments.

Further techniques can be employed for predicting the fluvial geomorphic impacts of peaking operations for proposed hydropower projects. Sediment transport capacity of the flow regime can be assessed with dedicated experiments and hydraulic calculations requiring good particle size data and hydraulic characteristics at a cross-section. Penetrometer readings of sediment banks can provide an indication of bank cohesion and strength. Piezometers are a valuable tool to determine groundwater changes in the near river sediment banks in response to changes in river level, so that degree of bank saturation, pore water pressures and degree of risk of draw-down seepage induced erosion can be assessed, often with the aid of computer models (e.g. SeepW). Close investigation of the inter-relationships of riparian vegetation composition and cover with bank stability processes is essential in any investigations.

Investigations of the impacts of peaking operations on riparian vegetation require a basic broadscale mapping exercise of riparian plant communities, and more site-specific surveys of cover and abundance of plant species using a quadrant based approach. Quadrants need to be located in a profile up the bank so that they can be related to different water levels and inundation times. Additional riparian vegetation investigations should encompass assessments of recruitment within each survey quadrant, sampling and analysis of root mat densities in different bank sediment types, and assessment of the contributions of mosses or ground cover species to stream bank stability.

For assessment of hydropeaking impacts on macroinvertebrate populations, investigations should consider species presence/absence, species abundance, habitat availability and shear stress. Several techniques exist to obtain samples for identification. A rapid presence/absence assessment can be undertaken using kick-net sampling in riffles, with samples identified to the family level, and ideally this data would be fed into a predictive bioassessment model which can compare observed taxa to expected taxa and thus provide a rating of degree of impact. Considerable work must go into the development of a bioassessment model if no appropriate model exists. Macroinvertebrate abundance can be assessed using quantitative (‘surber’) samples that are typically identified to genus level, and in cases to species level to identify any threatened species. Habitat availability analyses requires two data sets – hydraulic data (e.g. velocity, depth, substrate characteristics) collected in field surveys from representative transects across the river under power station on and off conditions, and habitat preference data for key aquatic taxa derived from either the literature and/or from field sampling – to derive plots of ‘weighted usable area’ for different flow levels. Finally, shear stress analyses can be undertaken in the field by placing hemispheres of known densities on the stream bed and observing their movement under changing flow conditions, an exercise that requires diving and so safety is a prime consideration when considering this technique.

Assessment of the impacts of peaking operations on fish species are largely based on field fish surveys. Backpack electrofishing is often chosen as a standard sampling method. It allows for a repeatable approach with minimal mortality rates, has known biases, and offers a method of comparison between sites. Results can be standardised into a comparative Catch Per Unit Effort figure for each visit to each site, and site ordination, ANOVA and other statistical analyses conducted. Habitat availability and preference should also be undertaken as per the macroinvertebrate assessments. Site selection should include significant tributary streams as well as the mainstem river, and particular attention paid in sampling program design to upstream and downstream of natural flow obstacles to migration such as gorges. It can be valuable to dissect some fish to analyse their food sources, to better enable linkages in fish condition to be made with macroinvertebrate populations.

More specific assessments are likely to be required for significant species such as waterbirds or aquatic mammals, which would vary considerably in different parts of the world.

4 Environmental management and mitigation measures for hydropeaking

A range of management approaches and mitigation measures can be employed to address the potential environmental issues with peaking operations, and investigations of impacts should be directed at identifying and evaluating management options as much as assessing impacts.

4.1 Discipline-specific options and objectives

Water quality –

- storage siting and design should consider whether reservoir stratification is likely to occur, and whether a multi-level offtake may be required to ensure release of oxygenated and ambient temperature water.
- air injection in the turbines can ensure sufficient oxygenation of water releases.
- siting upstream of a significant tributary can ensure mixing of power station discharges with water of ambient temperatures to the further downstream environment.

Geomorphology -

- physical buttressing of riverbanks;
- reduction of the maximum power station discharge to reduce the phreatic surface gradient in the banks;
- minimising the duration of maximum discharges to reduce the extent of bank saturation;
- maintenance of a minimum environmental flow to lessen scour of the bank toes and reduce phreatic surface gradient; and
- measures that would increase the viability of riverbank vegetation.

Riparian vegetation -

- instigating low flow rates for three summer months every year to allow riparian plants to grow and reproduce and for recruitment to occur during the season of greatest metabolic activity;
- ensure 24-48 hour shutdowns on approximately a weekly basis to reduce stresses of waterlogging and inundation (note this would likely occur anyway with peaking operations);
- facilitate regeneration by direct-seeding of the river banks with local riparian species; and
- measures that would improve physical stability of the riverbanks.

Macroinvertebrates –

- a minimum flow to ensure that a proportion of the channel is permanently inundated, that snag habitats on the channel margins are inundated, and that the channel can maintain a constant macroinvertebrate community when the power station is not discharging;
- management of rates of increase and decrease of power station discharge can slow the rates of downstream river level changes, and thus reduce shear stresses on the bed particularly on the rising limb of the hydrograph by reducing water surface slopes, and reduce incidences of stranding of fish and macroinvertebrates.

Fish –

- a minimum environmental flows would benefit macroinvertebrate communities and so would indirectly benefit fish that feed on the macroinvertebrates;
- a partial or stepped ramp-down would provide cues to the fish of dropping flows before full dewatering of habitats occurred, hence reducing the potential for fish stranding under peaking operations; and
- restocking with native species.

4.2 Options assessment

A number of the management and mitigation options to address environmental impacts of peaking operations involve dedicated water release patterns. Water management options include minimum environmental flows, power station ramp-downs, power station rates of flow increase, reducing maximum discharges, and minimising durations of full gate discharges.

Controls on patterns of release to the downstream environment to address potential impacts to the downstream ecosystem can be provided either through the power station discharges, through a dedicated release valve, or by a re-regulating structure downstream of the power station.

In general, water management options constitute significant constraints on power station operations and can incur considerable losses in generating potential. Large generating turbines may not be able to generate small discharges required for minimum environmental flows, and many have rough running bands that should be largely avoided.

For delivery of an environmental flow, an upfront major capital cost may be preferable to ongoing constraints on discharge patterns. If the siting allows it and the cost-benefit analysis supports it, construction of a re-regulation storage to allow downstream release patterns to be dedicated to environmental management outcomes can be very successful. A re-regulating structure is a dam or weir that impounds the regulated flows from the power station, and allows control over release patterns to downstream of the structure. Mini-hydro turbines can also/alternatively be employed to recover generating capability with minimum flow releases.

A ramp-down or step-down rule for the power station could be compatible with peaking operations. This would be particularly of benefit in reducing seepage-induced erosion in riverbanks, and would also offer benefits to fish to reduce risks of fish strandings.

Ramping up constraints would not be desirable with peaking operations, as they would reduce the rapid start advantage that the hydropower station offers with the provision of peak load. The provision of a minimum environmental flow can lessen the need for a ramp-up rate, as it would ensure that shear stresses are reduced as water levels rise in the downstream river system.

Depending on the circumstances, it is likely that several of the options are utilised as a package. Water management options in combination with localised treatment works can be successful. Localised treatment options include bank protection works, bank revegetation works, local willow control, and fencing/stock exclusion. There may also be site-specific opportunities, such as diversion of part of the downstream flow to lessen the degree of water level rise and fall.

5 Conclusions

In summary, there are a number of potential environmental issues associated with hydropeaking operations, as well as a range of mitigation measures available to substantially address these issues. Potential environmental issues should be thoroughly assessed prior to finalising the siting and design for a proposed scheme, so that potential impacts can be minimised, and that the scheme can include any mitigation or management measures as part of its design. Many of these measures can also be employed to minimise impacts arising from peaking operations with an existing scheme. Assessment of management measures should consider any possibilities of trade-offs that might arise amongst the different ecosystem components, and should be subject to a thorough cost-benefit analysis.