Hydroecology in decision-making: balancing effort with outcome

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With or without climate change, meeting environmental goals whilst delivering a reliable and adequate water supply to a growing population provides considerable challenges. Ecosystems are complex; understanding the impact of abstractions and discharges on these is challenging. Certainty requires considerable study, which can be costly and often too protracted for decisions required within the Periodic Review cycle. Rules of thumb based on hydrological parameters — as in the UKTAG guidelines for Water Framework Directive implementation — are a cost-effective and pragmatic way for dealing with many situations. In some circumstances, adherence to these can lead to poor decisions. With relatively little effort, better-informed decisions are possible, which are robust and safeguard the needs of both the water industry and the wider environment. This paper explores the decision-making process, drawing on practical examples where carefully deconstructing pressures on the water environment has allowed investment decisions to be made with confidence.

The challenge

Across the UK, water companies are facing growing demands on their services: both increasing numbers of consumers and potentially increasing *per capita* demand. There is also unwavering demand to provide wholesome water without interruption in supply. Under such circumstances water utilities require efficient, cost-effective tools to address the environmental concerns which impact on their operations.

The environment, from which water is abstracted or to which utilities discharge, is also under stresses. Ecological systems are susceptible to changes in water quality and quantity associated with utilities' operations, as well as more general development pressures, and are in continual flux due to short and long-term climatic change. This variability, both natural and anthropogenic, means that water companies are operating in a changing system, which is unlikely to be in equilibrium with the prevailing hydroecological regime.

There is also pressure to improve the quality of water ecosystems, partially driven by legislation, such as the Habitats Directive and, looking to the future, the Water Framework Directive (WFD). The application of such legislation, as well as nationally generated laws, (for example, the Countryside and Rights of Way Act (CRoW) in England and Wales), has meant that water companies face considerable investment outlay if they are unable to demonstrate their activities are not doing harm. Consequently there is a present and growing need for water companies, along with many others with activities impacting on the water environment, to develop robust and cost-effective means of assessing the nature and severity of impact of activities on ecosystems.

Planning framework for water resources

Until recently, the water resources planning process was dominated by the short-term responses determined by the demands of the water utilities' five year Periodic Review process (six years for the equivalent process in Scotland). Whilst plans for the longer term have been an integral part of the business's management, generally these have required no more than high-level consideration of environmental matters. However, by sharing their longer-term plans through the 25-year Water Resources Management Plans and other mechanisms, the opportunity for planning environmental investigations ahead of project implementation is growing. This in turn may lead, in some situations, to investigations of several years' duration being undertaken in preparation for major investments. However, currently and for the foreseeable future, in the majority of instances water utilities are likely to need to assess their impacts on ecosystems rapidly, still within the framework of relatively short investment implementation programmes.

Often the dominating ecological issues that arise are local, associated with a particular source or discharge, and will not be easily embraced by a long-term strategic programme of investigations. Conversely, it is often only when long-term actions are being assessed that there is sufficient time to undertake an in depth study of the impacts of those actions.

Two consequences of this prevailing planning environment are:

- Assessments of ecological impact are made under considerable time pressure, whilst failure to reach definite conclusions can result in significant disruption

to investment plans.
- Where there is time to collect ecological data, this may not be done because the requirements or responsibilities are unclear.

The latter outcome may arise because the exact requirements of schemes are not developed sufficiently for potential impacts to be identified with the required clarity. Also, there is recognition that the environmental regulator's criteria may change over time, meaning that collecting data to meet current standards may not equate to the standards when a scheme is implemented. Finally, there may be debate surrounding whether it is a correct use of utilities' current funds to engage in a programme of data collection which may ultimately have no benefit to the utility.

Tools to aid pragmatic decisions

Over the years, there has been a search for effective methods for assessing hydroecological regimes, and the potential consequences of changes to these arising from anthropogenic activities. The main challenges continue to be:

- With some notable exceptions, very little is known about how individual species interact with their environment, so that identifying risks to viability in anything other than very crude terms is problematic. Indeed, for some species, knowledge of their lifecycle and interdependence with other organisms is close to non-existent. Moreover, individual species communities can adapt over time to prevailing conditions; therefore some communities will be more resilient to some forms of change than others. Consequently, this makes it difficult to apply lessons from one catchment, or one study, to another situation.
- The status of individual ecosystems, and the pressures on these, is not monitored on anything other than a very coarse scale. Typically there are insufficient data to assess the prevailing dynamics of the community which may be impacted. Considerable uncertainties therefore arise in projecting impact of change.
- The water environment's dynamics in individual catchments are poorly understood. Cost pressures result in data being collected at a few strategically selected sites. This may not be sufficient to properly assess the impact of prevailing utility practices or any proposed changes to these, or indeed the impact of other activities (farming, mineral abstraction and industrial operations) on the catchment. Moreover, the information that exists is often fragmented. In some circumstances one or two individuals may hold considerable insight, but even then this is rarely sufficiently comprehensive.

In short, the interaction between ecosystems and the water environment is extremely complex and is likely to continue to defy comprehensive understanding. Moreover, the data available on which to make an assessment are normally very limited.

This complexity and the associated uncertainty is recognised, for example in the UKTAG recommendations on standards for implementing the WFD (UKTAG, 2008). In particular, reference is made to the 'Indirect Model' in decision-making where "the scale of action is a balance of the confidence that the level of risk is real and the confidence that the action will help".

The UKTAG recommendations (UKTAG, 2007; UKTAG, 2008) nevertheless propose specific standards to promote good ecological status, creating the condition whereby a type of water is either compliant with the standard or it is not*.

Whilst compliance with prevailing WFD requirements is mandatory, assessing a utility's ecological impact solely at a given location against this current standard is likely to be insufficient as:

- The standards have been derived with considerable effort, but nevertheless are expected to be modified in the light of additional information on whether the standards protect the biology or whether they are too strict (UKTAG, 2008).
- The standards relate to a generalised notion of 'good condition'. There are many locations where past anthropogenic influences have given the opportunity for unexpected ecological communities to establish themselves. Rigid compliance with the standards could be detrimental to such communities. For example, the WFD's emphasis on aiming for near pristine conditions could place at risk the metallophytes found around some Cornish estuaries (e.g. Restronguet Creek) on sediments contaminated from the former tin mines (Smillie, 2004).

It is recognised that UKTAG standards may be a useful tool in some situations, as they provide pragmatic boundaries to hydromorphological, flow and water quality assessments which are moderately easy to investigate and can be readily used to predict whether impacts are acceptable. Consequently, where minor impact on the environment is expected, ensuring compliance with such standards may be sufficient. However, in all cases the appraisal chosen needs to be technically adequate while not being disproportionately costly. It needs to be recognised that different methods may be appropriate in situations that may initially be considered comparable, taking into account site location, available time, the impact being investigated, the ecology of interest and the available data, specialists and resources. Acreman and Dunbar (2004), in their review of the various methods available for defining environmental river flow requirements, recognised four broad approaches.

Look-up tables

This is the traditional rule of thumb approach based on indices in reference tables and is similar to the approach enshrined in the UKTAG's recommendations discussed above. Evaluations tend to be based on hydrological convenience, rather than having a particularly sound ecological justification.

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* Note that these standards are primarily focused on the boundary between good and moderate ecological status, and that under the Water Framework Directive (WFD) achievement of Good Ecological Status is not necessarily required before 2027, nor at all under defined circumstances where less stringent alternative objectives may be set.

The main advantage of this approach is in its simplicity, but given that little account is taken of site-specific conditions, the outcome tends to be precautionary. An example is the widespread use of Q_{95} (95% exceedance flow) as an indicator of low flows to guide the determination of abstraction and discharge consent volumes (Bragg *et al.*, 2005).

Arguably, the Dundee Hydrological Regime Alteration Method (DHRAM) (Black *et al.*, 2005) approach is one such approach. This application uses some 30 different flow parameters which seek to characterise a stream's hydrological flow regime through considering variables such as monthly mean flows, the magnitude of annual extremes, periods of rising and falling flow and the frequency/duration of high and low pulses. Hence the impact of anthropogenic interventions (abstractions and discharges) can be quantified and a statement made on the degree by which the flow regime is altered. However, in common with similar techniques, the approach gives limited insight into the impact on the ecology of interest. A similar approach is often used for making decisions about water quality impacts, with chemical concentrations rather than flow rates being used.

Desktop analysis

Links are investigated between existing hydrological and ecological data; the obvious problem being a lack of suitable data.

An example is the Lotic Invertebrate Index for Flow Evaluation (LIFE) (Extence *et al*, 1999) which uses data that can be routinely collected to assess the relationship between LIFE scores and river flow regimes. This technique can be used to support discharge and abstraction licensing decisions.

One of its main limitations (as with other similar approaches) is that the relationships established in the original river systems may not hold as true elsewhere. So whilst providing a tangible, quantifiable index, caution is required before making costly investment decisions on the basis of LIFE scores.

Functional analysis

These techniques attempt to more fully understand links between a multitude of aspects relating to the hydrology and ecology of the river system, such as aquatic ecology, hydrology, fisheries, hydrogeology and geomorphology. This is largely done through combining the extensive inputs of experts in these fields in a holistic way. This means more data are required and the decision-making process is more costly and takes longer.

Hydraulic habitat analysis and modelling

This approach uses parameters derived from hydraulic modelling (such as wetted perimeter, discharge, depth, velocity) and employs these as a function of ecological habitat by linking them to animal or plant species.

PHABSIM (Physical Habitat Simulation) was developed in the US to link parameters derived from one-dimensional hydraulic models to habitat preference to define how the useable habitat changes with flow (Acreman and Dunbar, 2004). This technique has been adapted for use in the UK, and has been applied to consider, among other things, the impacts of abstractions, reservoir releases and water transfers on fish habitats (Spence and Hickley, 2000).

In short, the approaches for appraising impact of anthropogenic influences range from the very simple to the highly sophisticated. The concern is ensuring that the most appropriate is adopted when decision-making.

The data and tools used in these approaches vary in complexity:

- Flow data are relatively commonplace.
- Water quality data – knowledge of primary parameters, for example, BOD, dissolved oxygen, orthophosphate nitrates / nitrites and ammonia can provide considerable insight without the need for a larger suite of analysis. Observing the presence of caffeine has some merit as a marker of sewage effluent, albeit somewhat imperfectly, while presence or absence of some metals can also aid understanding flow patterns.
- A suite of standard ecological tools has also been developed over the years to aid defining the status of water bodies, based on the species present. These include: mean trophic rank (MTR) for aquatic macrophytes; diatom quality index (DQI) for benthic diatoms; biological monitoring working party (BMWP), average score per taxon (ASPT) Lincoln quality index (LQI) and the lotic-invertebrate index for flow estimation (LIFE) covering various conditions as represented by the presence of certain aquatic macro-invertebrates.

Choice of approach

With the range of tools available it is possible to match level of investigative effort to the needs of individual situations. Where there are minor investment (or operational) costs at stake, an approach using look-up tables or a rapid desktop study may be appropriate. Even if the result is unfavourable for a scheme's proponent, it is not worth doing more. Where major investments are proposed, obtaining a commercially sensible outcome is important. In this case, if there are marked concerns over ecological impact, the costs of functional analysis or even modelling may be minor in comparison with the costs associated with adopting a less commercially sensible solution to the investment's driver. It is therefore worth doing such studies, provided there are sufficient data to give a reasonably high level of confidence in the conclusions.

There will be many cases lying between the two extremes outlined above. For these, even with the short timeframe of the AMP investment cycles, a flexible approach to evaluating the hydro-ecological relations makes sense as it allows expenditure on ecological and hydrological studies to be made as needed.

To do this well, evaluations on prevailing and potential future hydroecological links should be made by:

- Undertaking a through scoping evaluation
- Allowing plenty of time within any overarching constraint.

Time

The seasonality of biological processes means that identifying the status of a population of a species or community can generally only be undertaken in certain periods. Indeed, to allow comparison with data obtained through standard survey techniques, can require any fieldwork to be restricted to certain weeks of the year. This limitation is well understood by those involved in hydroecology and the sister disciplines; getting this across to investment programme planners with little appreciation of ecology is paramount. Where not achieved, the almost inevitable result is rushed field surveys, or fieldwork done at sub-optimal times and with the consequent risk that the resulting data are compromised. Application of the 'precautionary principle' in such circumstances has the potential to result in inefficient investment. (For example, the principle could lead to construction of a new water supply source elsewhere, given doubts over whether future abstractions might have a negative impact. The investment might be unnecessary, had a better-executed study adequately demonstrated concerns on impact to be unfounded.)

Scoping

Effective scoping is crucial to both good hydroecological evaluation and cost-effective investment. It is arguably best done as a two-stage activity, with the first stage determining the scope and amount of effort devoted to the second stage.

The first stage comprises identifying what ecological features might be impacted by proposed anthropogenic activities, and making a preliminary assessment on whether there will or will not be impact. The second stage is to look in some depth on the nature of the impact and to determine with some clarity what the source-pathway-receptor model is like.

In some quarters there is a tendency to support the first stage of scoping but not the second. In place of the latter, if there is an issue meriting further study, intensive investigations may ensue. This may be because of lack of time — if the biological survey windows are limited, the temptation is to sample even if the case for doing so is not established. This is not necessarily good for reaching a correct decision in a cost-effective manner.

Alternatively, an in-depth investigation may be commenced with a view to convincing an environmental regulator that the ecological impact is being taken seriously. There are undoubtedly many occasions when much measuring, observing and sampling is necessary to establish within acceptably narrow bands prevailing status and how this might change. However, a second stage to the scoping investigation can be an invaluable substitute (or, indeed, precursor).

For example, the specific geographic features of a site are invariably crucial to whether an impact may or may not arise. In one study in southern Britain, a project brief required assessing impact of discharges on a highly fragmented SSSI in a lowland marsh environment intersected by drainage ditches. The brief assumed that several parts of the SSSI could potentially be impacted, to the north, south-west and south-east of the discharge point. The flow directions were not apparent from an initial desk study and there was pressure to begin flow and water quality sampling immediately as there was limited time available. However, a thorough site reconnaissance and meetings with the local water level managers allowed, by a combination of slight variations in topography and the presence of water control structures, the flow direction of the receiving drainage network to be established. As a consequence, sampling effort was not wasted monitoring watercourses of no relevance to the study's objectives. Investing a few days in familiarisation with a site at an early stage can save thousands of pounds measured against a poorly designed appraisal.

It is similarly important to fully understand the basis of the findings of earlier investigations. A study during the current AMP period was concerned that certain fish populations were well below what would have been expected given the river's protected status. Various causes were postulated, including the activities of a water company. This resulted in a very concentrated study, with evaluation of existing information going in parallel with field investigations. However, as the study progressed, it became apparent that there was a major mismatch between what earlier data showed and how it had previously been interpreted. If this had been investigated before fieldwork commenced then it could have either negated the requirement for the field investigation or, perhaps more properly, resulted in others, not the water company, commissioning the investigation to clarify the protected species' status.

Finally, on the topic of scoping, there can be reluctance (outside academic circles) by those commissioning assessments and their contractors to engage in thorough literature reviews. Instead, the focus can be on learning about site-specific phenomena. However, literature reviews ahead of field studies and data analysis can provide considerable value. A mixture of formal sources and casual sources can shed considerable insight into possible causal relationships. Buried away there is a wealth of information published by universities through to local interest groups. It is all too easily overlooked.

Deconstructing pressures

Lack of long-term data, data with inconsistencies, conflicting information and poor understanding of ecological pressures, are the hallmark of many hydroecological investigations. However, like a post-impressionist painting, considerable sense can be obtained by standing back from the detail and taking a broad view of the available information. This is central to cost-effective decision-making as it can obviate the need for major programmes of data collection and analysis.

This is not, however, to suggest that data collection and in-depth analysis can be dispensed with. Rather through setting out to look carefully at available ecological and hydrological information, it is possible to avoid both commissioning surveys that are of limited value and the expense of the ensuing evaluations.

For example, in a study of a 20 ha wet grassland interspersed with drainage ditches, the concern was whether a ditch carrying effluent from a treatment works could be adversely affecting the designated species. A comprehensive network of flow and level gauges could have been installed, including shallow groundwater levels, with automatic logging of water chemistry undertaken at key locations. From this, an excellent understanding of the hydrology of the grassland would have been established. However, to provide insight into the biological status, aquatic invertebrate and diatom populations had to be assessed. Combining the information from the ecological studies (e.g. BMWP, ASPT and DQI scores) with information gained from a programme of periodic flow monitoring was sufficient. The flow monitoring showed the direction in which ditches flowed depended on whether the weather was dry or wet. Mapping grassland vegetation communities provided further insight into flow patterns, as did monitoring the incidence of seasonal standing water and shallow ground water.

Water quality data indicated high nutrient levels in the ditch flowing from the treatment works but elsewhere in the ditch system the data were somewhat ambiguous. BOD and dissolved oxygen observations indicated uniformly poor conditions except in one part of the site. This was broadly reflected in ecological parameters (BMWP and ASPT scores).

Overall no single parameter allowed any conclusions to be drawn; indeed it was all too easy to conclude that further study with a more intensive field investigation programme was the only means to reach firm conclusions. However, by constructing a conceptual model, based on all the parameters, the hydrological regime became very apparent. This was achieved by recognising that data obtained from different sources mutually reinforced the interpretation of the flow regime. For example, vegetation community classification and aquatic invertebrate scores gave confirmation of deductions made from flow data. As a consequence, using the available data (water chemistry, ecological indicators and community classifications as well as the modest flow records), it became possible to quantify the interactions between the treatment works discharges and the wet grassland and associated ditches with a level of confidence that was acceptable to the environmental regulator.

As many active practitioners will appreciate, by considering hydrology, water chemistry and ecological parameters together, a far better appreciation of the nature and magnitude of impacts can be determined than by looking simply at any one component. Moreover, by looking across disciplines, particularly developing conceptual models which combine disciplines, it is possible to reach conclusions on the relevance of pressures more quickly and more cost effectively than through resorting to numerical techniques for relating habitat analysis to hydrological parameters.

Conclusion

Understanding the impact of utilities' activities on the ecology of waterways and wetland can be extremely challenging given the vagaries of individual species and the relative sparseness of reliable information on responses to hydrological regimes. Decision-making often entails apparent precision through numerical values used for physical and chemical phenomena; however, flora and fauna are at best quantifiable only in statistical terms and at times races or isolated populations can behave contrary to the general species' or community's characteristics. This makes in-depth assessments demanding, and as scientific rigour grows, in many cases the perceived measure of uncertainty grows apace. This militates against making decisions within the timeframe which arise from the present periodic review framework.

It is, however, perfectly feasible to develop conceptual models which allow decision-making within the time constraints. This requires sufficient attention being given to preliminary scoping; going beyond the simple test of whether there might or might not be an impact. This scoping should allow rational, well-considered decisions to be made more rapidly and more cost effectively in some cases. However, in some instances the scoping will still indicate that an extensive field programme and detailed analysis is required; this should not be the default starting position.

Moreover, it is imperative that a cross-disciplinary approach is adopted to obtain specialist insight into the various physical, chemical and ecological characteristics. Constructing conceptual models with such a basis can provide a powerful means of identifying the sources of ecological pressures and allow quantification to occur. This can lead directly to transparent, defensible decisions.

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