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# Environmental Impact of Run-of-River Hydropower Schemes in Upland Rivers

## Ecological implications and the means available to assess individual sites

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R&D Technical Report W1

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# Environmental Impact of Run-of-River Hydropower Schemes in Upland Rivers

## Ecological implications and the means available to assess individual sites

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**Statement of use**
This report summarizes the findings of literature review of the environmental impacts of run-of-river hydropower schemes in upland rivers. The information in this document is for use by Environment Agency staff and others involved in the planning, development and development control of such schemes. The document should be used in conjunction with other relevant guidance on environmental assessment.

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# EXECUTIVE SUMMARY


1. As a result of the governments non-fossil fuel obligation scheme there has been increased interest in the development of small hydropower schemes.

2. It is likely that most schemes would be situated in upland areas where sufficient head is available.

3. This scoping study examines the literature on the effects of run-of-river schemes and collates information on the physical and ecological characteristics of upland streams.

4. It is clear that although there is a considerable body of work on the effects of flow regulation (through dams, water transfers, abstractions) there is very little information specifically on run-of-river hydropower schemes.

5. Ecological information on upland streams in Great Britain is fairly extensive but in general restricted to distributional and floristic/faunistic studies. There is a lack of information on the responses of biota to changing flow conditions and the relationship between habitat availability and discharge conditions in channels of differing morphology.

6. The efficient implementation of schemes requires cooperation and good lines of communication between developers, regulators and the public. Most importantly a comprehensive database of information on all aspects of the potential development area should be available.

7. This study identifies knowledge gaps and makes recommendations for future work. These include the establishment of a descriptive database for the area covering both physical and biological aspects; the implementation of a sampling programme which will provide both monitoring information and more detailed data on the functional responses of the biota in relation to modifications of the physical environment; and the establishment of a protocol for ensuring free flow of information between all interested parties.



**Key Words**

Environmental Impact, Environmental Assessment, Hydropower, Upland Rivers, Botany, Invertebrates, Fish, Birds, Mammals, Guidelines.

## ACKNOWLEDGEMENTS

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# 1. INTRODUCTION

The need for sustainable sources of "clean" power has of recent years focused attention on both wind and water. The generation of electricity from water has most often involved the construction of large reservoirs which power turbines downstream or provide water which is transferred elsewhere to drive the turbines. There is an extensive literature on the performance and ecological impact of such schemes but the often adverse effects of these methods of power generation have led to an increasing interest in small run-of-river schemes where water is taken directly from the stream or river and piped to the turbine before being returned to the watercourse. These schemes should not be confused with large scale projects involving massive transfers of water or micro hydroelectric power plants involving the use of stored water in reservoirs.

The Environment Agency is authorized to issue abstraction and related licences for run-of-river hydropower schemes. Recent technical and economic developments have encouraged commercial interest in their construction on upland rivers. Despite the potential of these schemes the Environment Agency information sources and modelling tools are relatively poorly developed for rivers suitable for use in run-of-river schemes. We do not know the extent of information available to assess their impact on the environment and to develop guidelines to aid decision making processes by both industrial and environmental groups regarding choice of site and operating procedures.

# 2. PURPOSE OF THIS REPORT

1. To provide a concise review (in general terms) of the hydrological and biological characteristics of upland streams and collate information on the environmental effects of stream flow regulation with reference to run-of-river hydropower schemes.

2. To describe the general characteristics of run-of-river schemes including their requirements and activities associated with their construction and operation.

3. To identify potential impacts of such schemes on river biota as a basis for Environmental Assessment guidance.

4. To recognize and catalogue those topics for which there is little information.

5. To make recommendations for future work and produce a framework for the subsequent development of guidelines for assessing and operating run-of-river schemes.

# 3. UPLAND STREAMS

## 3.1 Hydrological Characteristics

The mountainous regions of England and Wales are generally formed from old, hard rocks and the terrain characterized by thin soil cover, steep valley slopes and fast flowing rivers sustained by the abundant rainfall. These rocks cannot 'hold' water which would maintain river flow between rainfall events as younger aquifer rocks do in lowland areas. Combined with the other factors upland catchments exhibit rapid and extreme variations in flow, and rivers will go from frequent flooding in winter to become little more than a trickle in extended dry periods.

This is illustrated by the two annual hydrographs in Figure 3.1 for the River Lugg (a lowland catchment) and the River Conwy (an upland catchment). The characteristic of rapid response to rainfall is known as 'flashiness', and is evident from the abundant 'spikes' shown on the hydrograph of the River Conwy where river flow rises and falls rapidly following rainfall. In contrast, the lowland River Lugg shows significantly fewer, smaller spikes.

Further more detailed analysis of how flows are distributed can be obtained from analysing flow duration curves (Figure 3.2) derived from long term accurate flow measurement. For most catchments where hydropower schemes are proposed, however, this type of information is not available because of the remoteness of the sites, and other methods must be used. Some of the available techniques are discussed below.

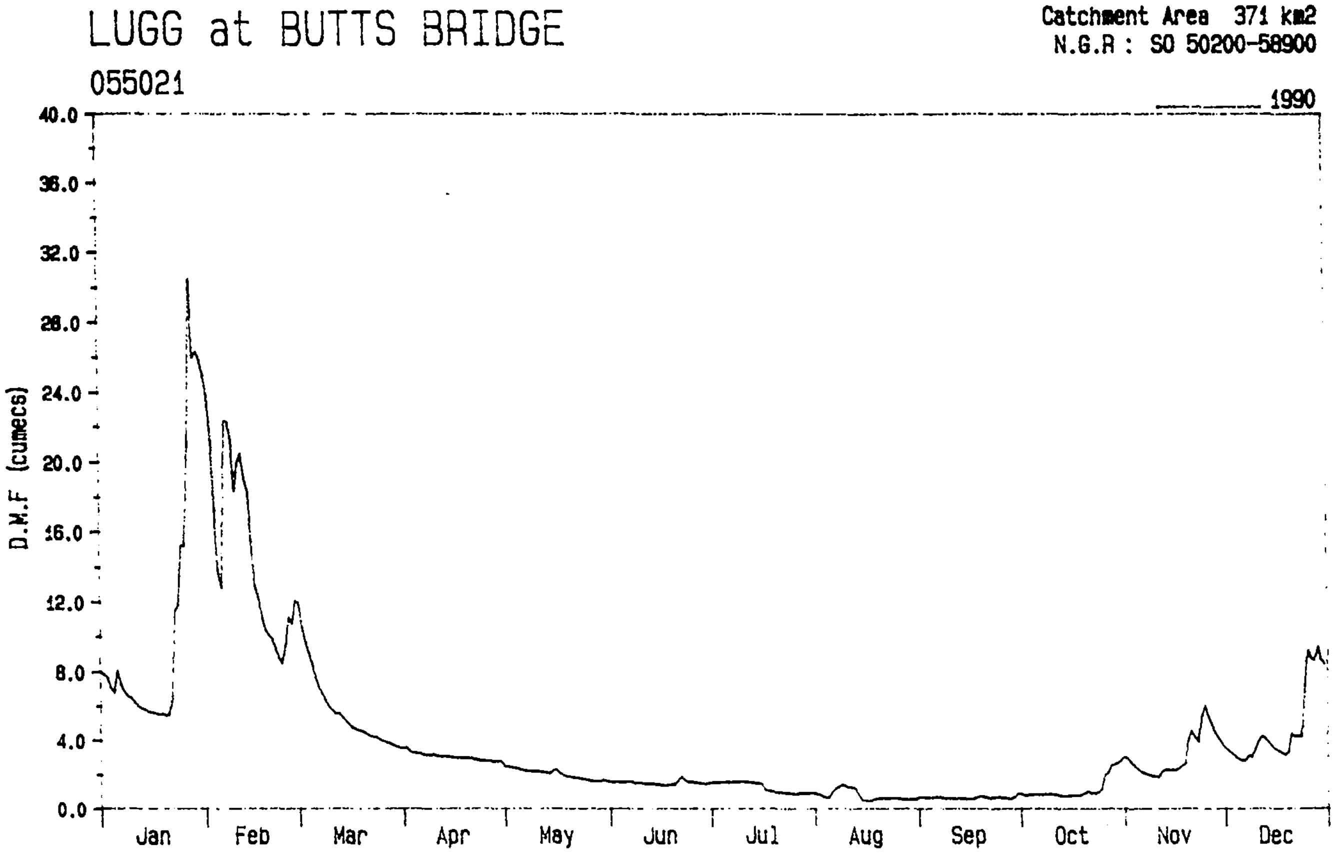
**Hydrological Assessments**

Proposed abstraction points almost invariably involve ungauged catchments in the remotest of locations, so that the most basic check - but that which matters greatly in subsequent work - is that of estimation of Average Daily Flow (ADF).

Three basic methods for assessing ADF are commonly used by the Environment Agency:

- the `Water balance' approach (see Journal of IWES, July 1977, Vol. 31);
- the Institute of Hydrology's Microlowflows method; or
- the relationship between rainfall and measured run-off. An example typical of most Gwynedd catchments is shown in Figure 3.3.

These and other hydrological techniques can be used to allow environmental scientists to appraise the effect that any abstraction will have on in-river interests and allow a judgment of the scheme's economic viability to be made.




**D.M.F. = Daily Mean Flow** **Cumecs = Cubic metres per second**

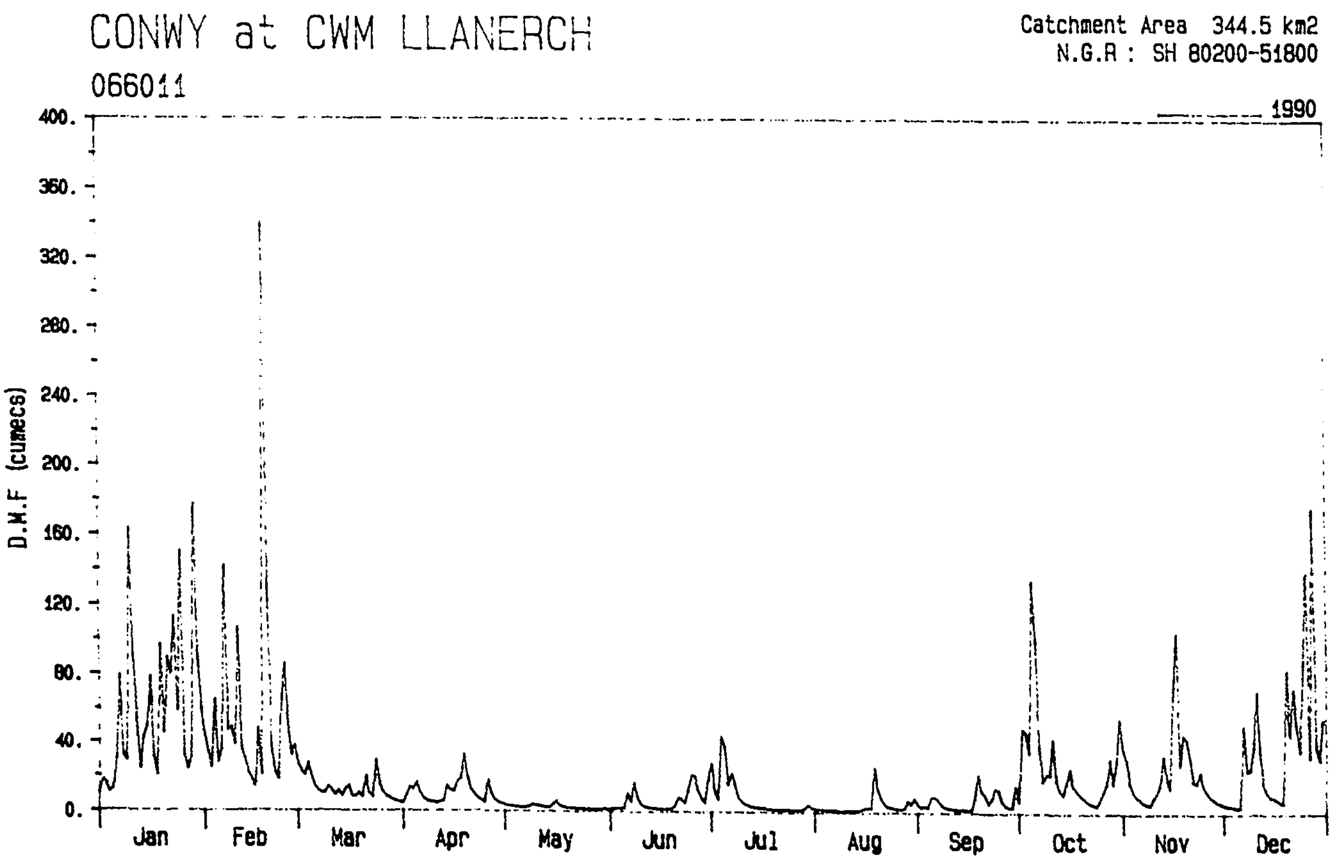
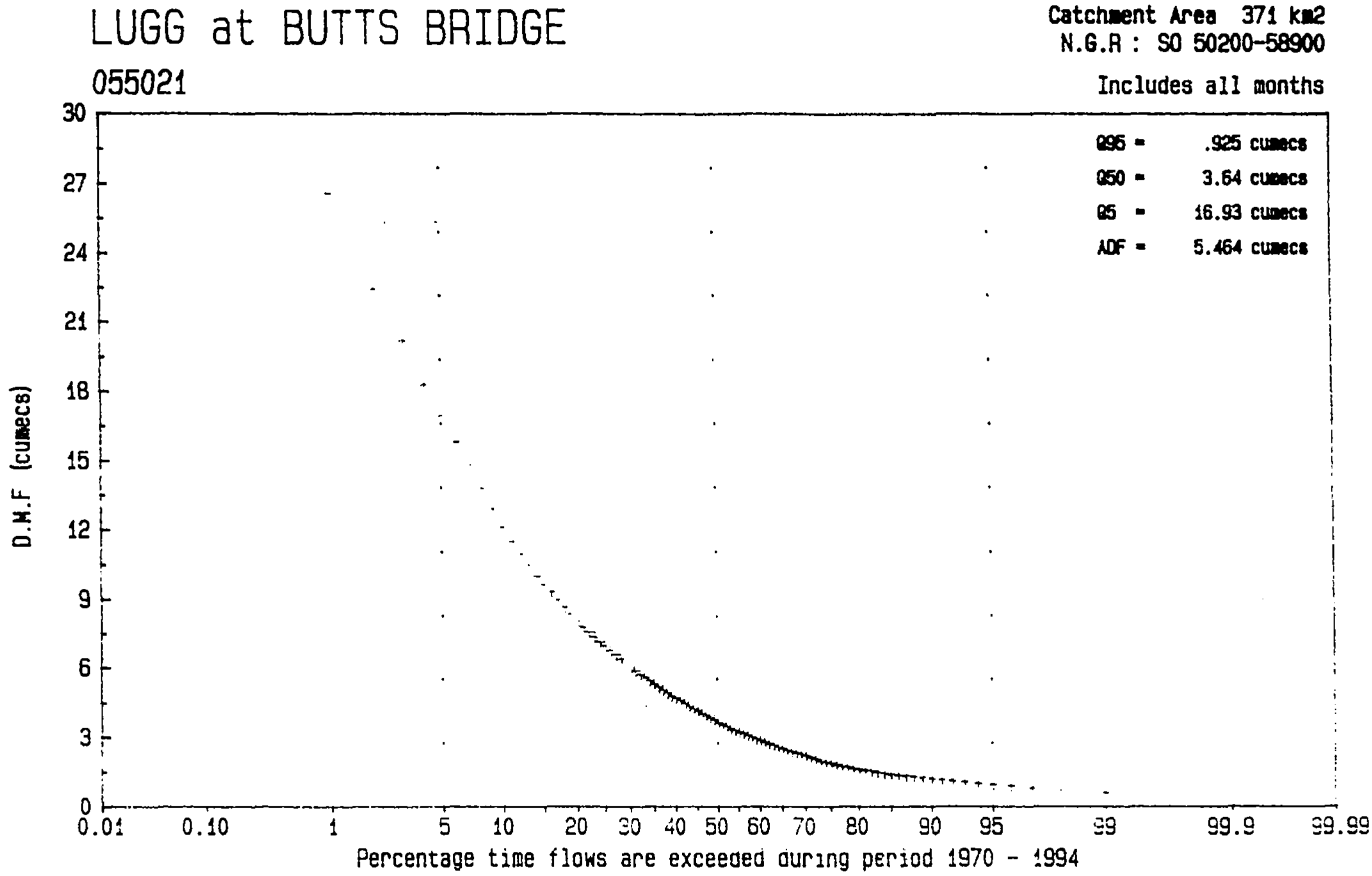



**Figure 3.1 1990 annual hydrographs for the Rivers Lugg and Conwy**




D.M.F. = Daily Mean Flow Cumecs = Cubic metres per second

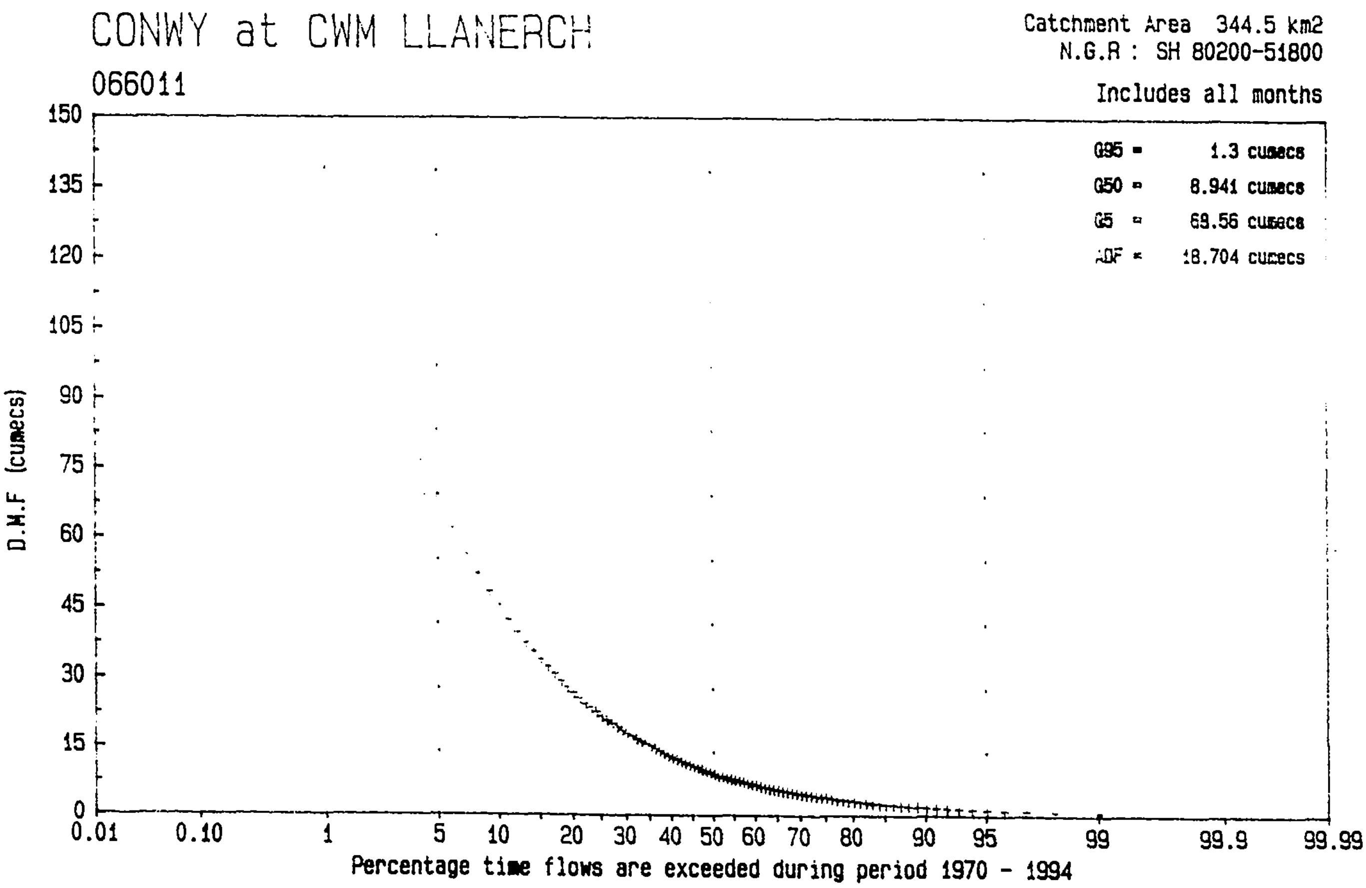



**Figure 3.2 Flow duration curves for the Rivers Lugg and Conwy**

Where the effects of a proposed abstraction are uncertain, the Environment Agency usually asks developers to provide an Environmental Report to assess the risks, which can then be audited by the Environment Agency. Some of the data used are supplied by the Environment Agency, Institute of Hydrology or the Meteorological Office, and are of dependable quality. Where developers need to supplement these basic data it is essential they must ensure that hydrological information is collected and processed to conform to established hydrometric principles and standards. The Environment Agency will reject information if it cannot be demonstrated that it has been collected and processed to standards approved by the Environment Agency.

**Upland hydrology and hydropower abstractions**

Non Fossil Fuels Objective (NFFO) contracts run on a fixed rate per unit of electricity generated. The objective is therefore to abstract at as high a rate from a river as turbine capacity will permit, through as much head as possible, and for as long as possible to maximize financial returns, in accordance with the energy formula:

$$\text{kWh} = \underset{(m^3/s)}{\text{flow rate}} \times \underset{(m)}{\text{head}} \times \underset{(hrs)}{\text{time}} \times \underset{(m/s^2)}{\text{gravity}} \times \underset{(\%)}{\text{efficiency}}$$

Schemes are typically submitted and considered in economic terms in relation to a catchment's mean flow duration curve, where a maximum turbine flow rate is chosen to correspond to ADF or more (up to 1.5 x ADF). Generation continues at variable rates leaving a small residual ($Q_{95}$ - $Q_{90}$), until a point is reached when turbines no longer respond to flow, normally 10 - 15% of maximum rate. (The term Q means flow, and when it is followed by a number it refers to a flow that is exceeded for a certain percentage of the time on average, thus $Q_{90}$ is the flow exceeded on average for 90% of the time). This information can be derived from flow duration curves mentioned earlier. Volumes potentially abstracted vary from between 40 - 80% of a catchment's annual run-off depending on the catchment hydrology and the type of turbine used.

Upland catchments are chosen for run-of-river hydropower schemes because they are the principal locations where sufficient head is potentially available to operate these high head abstractions (at least in comparison to lowland sites). The flashy nature of such catchments is however far from ideally suited to supporting hydropower abstraction. The range of flows within which the turbine can generate power is such that there is often either insufficient water, or more water available than the turbine can accept. The result is that to maximize economic returns hydropower abstractions 'cream off' a significant portion of the hydrograph above low flows and below very high flows (see Figure 3.4). This has a profound effect on the hydrograph of the reach between the points of abstraction and return, by eliminating many of the peaks in flow or greatly reducing their extent.

*Surface Water Abstraction Licensing Policy (SWALP)*

The importance of flow variability has been confirmed by a number of recent Environment Agency research projects, including a Surface Water Licensing Abstraction Policy (SWALP) development which suggests that variability of flow plays a key role in sustaining the ecological and fisheries characteristics of a river.

The new policy is currently being refined for implementation in North East Region and will subsequently be considered for introduction across the Environment Agency. The basis of SWALP is to reflect the sensitivity of individual rivers to abstraction by setting a series of 'hands off' flow levels (similar to a prescribed flow) between each of which there is a volume available for abstraction. The greater the sensitivity of the river, based on an environmental weighting, the lower the quantity that will be available. This will have the effect of preserving flow variability to leave a more natural flow regime in the reach deprived of water by abstraction. Generating capacity will be reduced, but not dramatically because winter generation (when most power is produced) should be affected relatively little. Although the policy is likely to be applicable in most situations, it will not replace the need for an Environmental Assessment where appropriate.

## 3.2 Biological Characteristics

The run-of-river schemes considered in this report as indicated above are most likely to be situated in upland regions of Britain. These areas have in the past been the subject of general surveys and ecological studies of both single species and assemblages of species. The sections below outline the information available and present some general features of instream and riparian biota in upland regions of Great Britain.

### 3.2.1 Botanical considerations

**Sources of information**

There have been few surveys of the distribution of lichens and bryophytes in British rivers. This does not necessarily mean that the distribution of riparian species is poorly known on a national or regional scale because records are incorporated into county floras and national atlases of distribution, and the introductions to floras may contain a few paragraphs on riparian species (Alan Orange (National Museum of Wales) pers. comm.). General surveys of this type are listed in the appendix together with references to work on riparian vegetation along Swedish rivers regulated for hydropower production. Other studies on the response of lichens and bryophytes to pollution are not relevant to this scoping study and are not listed.

## Habitat and zonation

Streams and rivers with rocky channels are often valuable habitats for lichens and bryophytes, creating a diversity of habitats; humid gorges provide shelter for drought-sensitive species. High flows reduce competition from vascular plants, and riversides are commonly relatively undisturbed by neighbouring land use, supporting fragments of woodland or other semi-natural vegetation no longer present on adjoining land.

Truly aquatic species, namely those which are rarely if ever exposed, are relatively few in number. Above the level of the lowest flows, the habitats available to mosses and lichens near a stream may be divided into two broad categories, namely those submerged during high flows and those which lie above the highest flows. These will be described here as 'riparian' and 'terrestrial', respectively.

The lichen and bryophyte vegetation on rocks next to the water often differs markedly in appearance and composition from the vegetation on rocks in adjoining habitats, and frequently shows some degree of zonation such that different species are most abundant at different distances from the water. Variations in water level are almost certainly the single most important factor affecting the riparian zone, for which the affected bank area experiences:

1. periodic submergence, of longest duration at its lowest levels in winter, and alternating with periods of exposure which are longest at its highest levels in summer;
2. action of moving water, especially at times of higher flow when a significant sediment load may also be present, causing drag and abrasion; and
3. a gradient of moisture from the lower to higher limits of the zone, maintained by groundwater, capillary action, splash and humidity.

Species found within the riparian zone may be divided into a number of categories:

1. those found exclusively beside rivers and on lake shores; these may be termed 'strictly riparian';
2. those also found in other habitats but which are more often found in the riparian zone; and
3. those found in many other habitats and only rarely in the riparian zone; these constitute the `terrestrial' species referred to above.

## Ecological requirements

Species growing in the riparian zone are diverse morphologically and taxonomically, and their ecological requirements are by no means necessarily identical, although all must be able to tolerate periods of submergence. The following factors may influence the small- and large-scale distribution of riparian species:

1. tolerance/intolerance of exposure and desiccation;
2. tolerance/intolerance of submergence;
3. competition from other species;
4. water chemistry;
5. degree of silting;
6. water running over bank from adjacent land;
7. inclination of the rock surface;
8. degree of shading (and aspect);
9. ability to withstand strong currents and abrasion;
10. substrate dependence.

Some species are able to tolerate both submergence and moderately strong currents yet do not have a particular requirement for submergence, and there are others characteristic of riparian rocks which can tolerate extended periods of desiccation. Another group appear to be tolerant of extended dry conditions.

Strong currents exert a powerful influence on the composition of riparian communities. Species which are not firmly attached or which do not have a sufficiently hydrodynamic colony shape will then be at a disadvantage. Current action and abrasion by mobile sediment loadings may maintain a bryophyte-free rock that can be occupied by crustose lichens, or may create gaps in bryophyte cover which can be colonized by weakly competitive species.

'Terrestrial' species are only influenced by the river according to its possible effects on humidity. The important dependence of this zone on water supply is more likely to be met by rainfall and releases from adjacent rock strata (hence their location), together with the effects of these sources on humidity. Sub-surface releases of water can increase the base-status of rocks and hence locally enrich the flora with associated species.

Variations in water level are therefore one of the major factors responsible for the existence of a distinctive riparian lichen and bryophyte flora. A regime in which there was no variation in level would be unlikely to support such diversity, and a reduction in the duration or frequency of immersion of drought-sensitive species is likely to create stress, leading to the downward relocation of the community and perhaps a narrowing of the riparian zone. However, the effects of varying the duration of each submergence event while largely retaining the same frequency and annual distribution of these events is not known.

It may, for example, be the case that drought-sensitive species require frequent rather than extended submergence, in which case shortening the duration of each event would not be significant. Indeed, reducing exposure to abrasive stress could reduce erosion and hence community loss. It is conceivable that 'drought-hardening' plays a part in the survival of some riparian species, such that drought-tolerance increases at the approach of seasonally drier conditions.

### 3.2.2 Invertebrates

**Sources of information**

Although the literature search (Appendix A.5) has revealed a dearth of information on the effects of run-of-river hydropower schemes on stream invertebrates a considerable amount of published data exist on faunal assemblages in the upland regions of Great Britain. Most of the general survey work was carried out in the 1960s and 1970s and some key references are listed in the appendix together with more recent references to work on Welsh streams. In addition to these published studies there are reports on the environmental impacts of road developments, dam construction, pipeline crossings etc, sponsored by civil engineers, oil companies and conservation organizations. Further information may be obtained from routine Environment Agency monitoring activities and the Institute of Freshwater Ecology database used in the development of RIVPACS which includes a number of upland sites throughout Great Britain.

All these sources of data provide information on the faunal composition of upland hill streams which can be used to place a proposed site in a national context, and studies which ran for more than one year provide data on the `natural' annual variability of faunal assemblages. Both aspects are important when assessing potential environmental impacts.

**The habitat**

Hill streams of the type suitable for run-of-river schemes are most numerous in Scotland, Wales and to a lesser extent in three areas of England (Lake District, Pennines, South West). The streams are characterized by gradients from 2 to $>20^{\circ}$ and typically with step-pool channels changing downstream to pool-riffle channels with predominantly boulder/cobble substrata but which may include beds of pebble/gravel in the lower reaches. The streams may flow through moorland, forests, and rocky gorges and experience a wide range of environmental conditions ranging from high flows which may occur at anytime of the year and low flows which although more common in the summer also occur in the wintertime. The faunal assemblages living in these habitats have adapted to the rigorous conditions which may result in sudden changes in velocity and movement of the substrate in spate conditions and reduction in available wetted habitat in dry periods.

**Ecological aspects**

There have been a large number of studies on hill streams and many of these are listed in the appendix. However it is not the object of this review to present an exhaustive account of these studies but rather to illustrate aspects of benthic invertebrate ecology which may have relevance to the assessment of run-of-river schemes. For this purpose recent data on Welsh streams are considered.

There has been a long history of research into the hydrobiology of Welsh hillstreams which had origins in part, in assessing effects of pollution from mining (e.g. Carpenter 1924), but also in fundamental studies of faunistics (e.g. Jones 1941, Hynes 1961). General areas of interest are listed, along with selected references, in Table 3.1.

Although assessments of effects by regulation have figured prominently in this Welsh work (Table 3.1), in all cases the rivers involved were large (> 4th or 5th order), such as the Elan, Wye and Tywi. These studies have limited relevance to understanding effects caused by regulation on **small** upland streams, but can provide information on general responses to flow regulation and the development of conceptual approaches to assessing environmental impacts (e.g. Figure 3.5).

In Scotland and in the Pennines and Lake District small low order streams have been studied in some detail (Egglishaw and MacKay 1967, Minshall and Kuehne 1969, Armitage *et al.* 1974, 1975) and this information includes data on seasonal and distributional aspects which will be of relevance in assessing the effects of run-of-river schemes.

More recent assessments of the invertebrate fauna of smaller upland streams have been made during studies of the effects of land use and acidification. They are useful in providing both a regional context for work on hydropower in Snowdonia (e.g. Wade *et al.* 1989), and in providing an indication of important attributes of communities at other upland locations.

Acidity has been repeatedly shown as a major influence on faunal community type and composition (Ormerod and Wade 1990). This is reflected in the limited fauna apparent at some of the sites where run-of-river schemes are proposed (see Brewin *et al.* 1994; reviewed below). In addition such studies have provided information on seasonal dynamics, fluctuations in density, habitat structure, conservation value of the fauna and persistence and resilience of the faunal assemblages. Low overall correlations in monthly densities between years were observed which will, if repeated elsewhere, have corollaries for our ability to detect year-to-year effects due to power generation. At the same time, assessments of the persistence and constancy of invertebrate communities show at least that classification and ordination of sites in relation to environmental factors are robust between years (Weatherley and Ormerod 1990a). However, persistence in community composition is less strong in margins than in riffles, while there is a tendency at some upland Welsh sites for long-term change in community type. The ability of investigations of run-of-river schemes to detect change will thus depend on the magnitude of effects relative to such unexplained, and perhaps natural, turnover from year-to-year. Stronger turnover in community composition in margins has particular importance since it is these areas that are likely to be most affected by altered flow patterns.

**Snowdonia**

A recent study by Brewin *et al.* (1994) investigated the invertebrate fauna of fourteen upland streams in Snowdonia typical of those at which run-of-river schemes might be

**Table 3.1 Selected studies of invertebrate communities in upland Welsh streams**

| Subject | River system | Reference |
|---|---|---|
| Density and dynamics (within and between years) | Wye | Brooker and Morris (1980a) |
| | Ystwyth, Rheidol | Brooker and Morris (1980b) |
| | Tywi | Weatherley and Ormerod (1990a) |
| | Tywi | Weatherley *et al.* (1989) |
| Habitat associations and habitat structure | Tywi | Rutt *et al.* (1989) |
| | Various | Ormerod *et al.* (1993) |
| Effects by forestry | Various | Ormerod *et al.* (1993) |
| | Tywi | Rutt *et al.* (1989) |
| | Wye/Severn | J.H. Gee (unpubl.) |
| | Tywi | Weatherley and Ormerod (1990) |
| Effects by acidity | Review | Ormerod and Wade (1990) |
| | Various | Rutt *et al.* (1990) |
| | Tywi | Stoner *et al.* (1984) |
| | Tywi | Ormerod *et al.* (1987) |
| | Various | Wade *et al.* (1989) |
| | Various | Weatherley and Ormerod (1991) |
| Effects by regulation | Elan/Tywi | Scullion *et al.* (1982) |
| | Wye | Brooker and Hemsworth (1978) |
| | Elan | Inverarity *et al.* (1982) |
| | Elan/Tywi | Scullion (1983) |
| Conservation | Teifi | Jenkins *et al.* (1984) |
| | Tywi | Ormerod *et al.* (1990) |
| | Review | Brooker (1984) |
| Effects by drought | Severn | Cowx *et al.* (1984) |
| Other ecological studies (Drift, production, vertical and zonal distribution, life cycles) | Wye | Brooker and Hemsworth (1978) |
| | Wye | Brooker and Morris (1978) |
| | Wye | Hemsworth and Brooker (1979) |
| | Usk | Hildrew and Edington (1979) |
| | Wye | Ormerod and Edwards 1987 |
| Invertebrates and birds | Wye | Ormerod and Tyler 1991 |
| Microcrustacean communities: | Tywi | Rundle and Ormerod 1991 |
| Links with floral communities: | Various | Ormerod *et al.* 1987 |

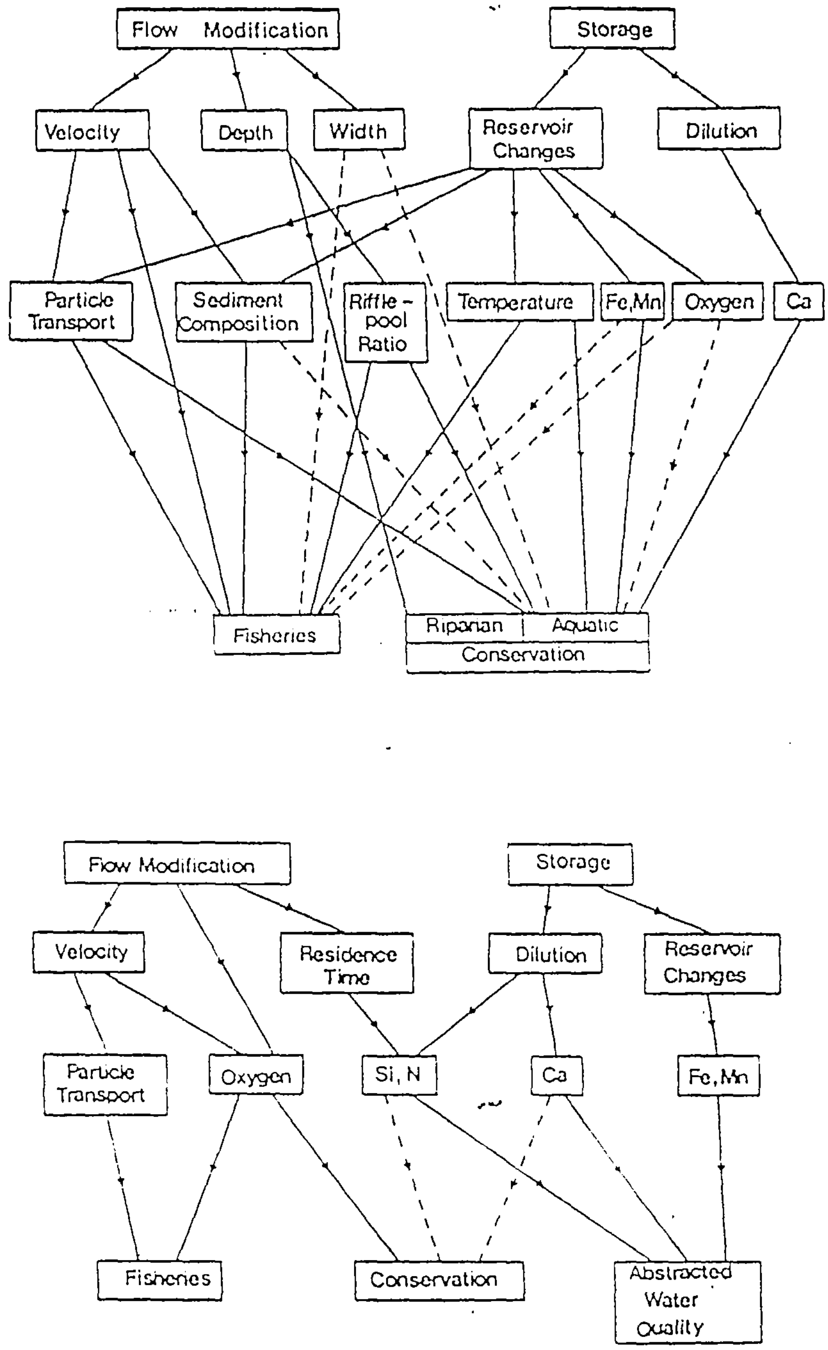



**Figure 3.5** **A conceptual model indicating the routes through which river regulation and storage might affect fisheries and conservation value in the upper Wye (after R. W. Edwards)**

developed. Communities were typical of those found across large, soft water areas of upland Wales (cf Wade *et al.* 1989). None of the sites were particularly diverse, holding only 5-28 invertebrate families, and were usually dominated by Plecoptera from the Nemouridae, Leuctridae and Chloroperlidae, which were all widespread.

Using a key to classify the invertebrate fauna of upland British streams developed by Rutt, Weatherley and Ormerod (1990), ten of the fourteen streams were typical of sites characterized by low pH ($<$ mean pH 6; aluminium $>$ 0.1 mg/l), differences supported by spot chemistry. These ten had significantly fewer taxa, significantly lower total abundances and significantly lower abundances within 14 families that the remaining four sites. One inference is that at least some of the Snowdonia sites at which run-of-river schemes are planned already have invertebrate communities limited by, and probably damaged by, acidification.

Because associations between invertebrates and certain habitat types are germane to understanding how flow modifications might affect communities, the habitat affinities of each invertebrate family was assessed during the survey. Twelve families were significantly more abundant in some habitats than others, while some numerically scarce taxa were only ever recorded from the stream margins. Thus, emphasis should be placed on habitat-specific sampling when monitoring effects by run-of-river schemes.

In addition, faunal comparisons at the sites were made which compared downstream and upstream reaches. On average, there were no significant differences in total abundances, taxon richness or family-specific richness between upper and lower reaches. However, some sites showed strong differences which would have ramifications for the design of a monitoring programme because the upper site could not be used as a control for the downstream regulated site. Moreover, because effects by downstream reaches on upstream reaches cannot be excluded (for example through affecting the movement of organisms), this type of survey design was not recommended.

### 3.2.3 Fish

#### Sources of Information

A number of surveys of fish populations have been made in upland streams in Great Britain and key references are listed in the appendix. Fish have been the subject of much study in relation to regulated flow and the Proceedings of the Symposium on Small Hydropower and Fisheries (May 1985, Colorada) includes a variety of studies on the effects of habitat loss in relation to discharge and the effects of screens at infall and outfall points. This work is listed in the appendix together with other sources of information. In addition, the Environment Agency as part of their monitoring programme regularly survey a large number of sites within England and Wales. These data can be found in unpublished NRA/Environment Agency reports and environmental impact assessments or by contacting the local Environment Agency fisheries officers.

**The habitat**

It is not unusual for the upper reaches to be inhabited by residential brown trout and possibly also salmon and sea trout, in which case the river downstream is likely to hold some specimens displaced from the main population which are prevented from returning upstream by falls, and which in time are progressively displaced further downstream. Though there may be suitable sites for upland run-of-river schemes which migratory salmonids will not be able to negotiate, they may penetrate past outfalls and into the lower reaches of these schemes as far as the most downstream waterfall or cascade.

There will be certain sites, those characterized by steep gradients and torrential flow regimes, even at times of low flow, in which the currents are extremely fast, making them unsuitable as nursery areas for fry. Only small numbers of parr and older fish are found over much of these reaches, and the absence of fry suggests that these fish are in passage rather than residents.

As for invertebrates the fish populations have adapted to a rigorous regime of spates and very low flow conditions which have major influences on wetted available habitat, dissolved oxygen concentrations and water temperatures.

**Ecology**

While recognising that there are many studies of fish in upland streams (see Appendix) this account will consider recent comprehensive data on salmonid densities obtained from Welsh streams. This work has arisen from studies into effects of surface water acidification in Wales. They include one-off surveys of density and distribution (e.g. Milner and Varallo 1990, Turnpenny *et al.* 1987, Ormerod *et al.* 1988) with more detailed production studies at a small number of locations in the Wye Catchment (e.g. Gee *et al.* 1978, Milner *et al.* 1978). Year-to-year changes in density at fixed locations were made at Llyn Brianne (Ormerod unpubl.), while repeat surveys of 88 upland sites initially made in 1984 will go ahead in 1995 along with assessment of habitat character using HABSCORE.

Some of the important corollaries from this work in the present context are that:

1. Upland Welsh streams can be important nurseries for salmon and sometimes sea trout. Densities of salmon recorded during the 1984 acid waters survey of Wales were 0-216 fry per $100m^2$, with salmon recorded at 16 out of 88 sites.

2. While habitat structure and the size of the spawning stock are important influences on salmonids in upland Welsh streams, other factors include acidity, and particularly aluminium concentration. It is therefore possible that hydropower schemes in acid locations typical of Snowdonia could be sited without major impacts on current stocks. Typical densities of brown trout from acid and circumneutral locations are given in Table 3.2.

3. There were large year-to-year changes in trout density in tributaries at Llyn Brianne (Figure 3.6). If they were matched in other upland locations, they would have ramifications for both stock assessment and for the detection of effects due to hydropower schemes.

**Table 3.2 The percentage frequency of occurrence of different trout densities at 89 sites in upland Wales during 1984**

Sites have been divided into acid (n = 42 sites) and circumneutral (n = 47) at a mean annual pH of 6.

| Density class (per 100m$^2$) | Acid sites | Circumneutral sites |
|---|---|---|
| 0-49 | 79 | 47 |
| 50-99 | 14 | 13 |
| 100-149 | 2 | 17 |
| > 150 | 5 | 23 |
| Mean density (with SD) | 29.6 (49.9) | 104.2 (98.6) |

### 3.2.4 Mammals and Birds

Many birds and mammals are at the top of riverine food webs and are consequently good indicators of the general `health' of a river. River corridors along upland streams provide mixed habitat `passageways' for riverine birds such as dipper, grey wagtail and kingfisher and mammals such as otters, water voles, water shrew and mink.

**Birds**

The principal bird species present along upland British streams will be aquatic insectivores such as the dipper and riparian insectivores such as the grey wagtail. The occurrence of other species will depend on stream character in any particular instance, but might include common sandpiper, kingfisher, goosander, sand martin, although all are less likely on the sites currently under consideration for hydropower development. Any effects are thus likely only on the periphery of their normal range. Similarly, species more casually associated with rivers, such as pied wagtail and pied flycatcher, are liable to be affected only at the periphery of their niche space, hence effects will be marginal in the extreme. These species are not considered further here.

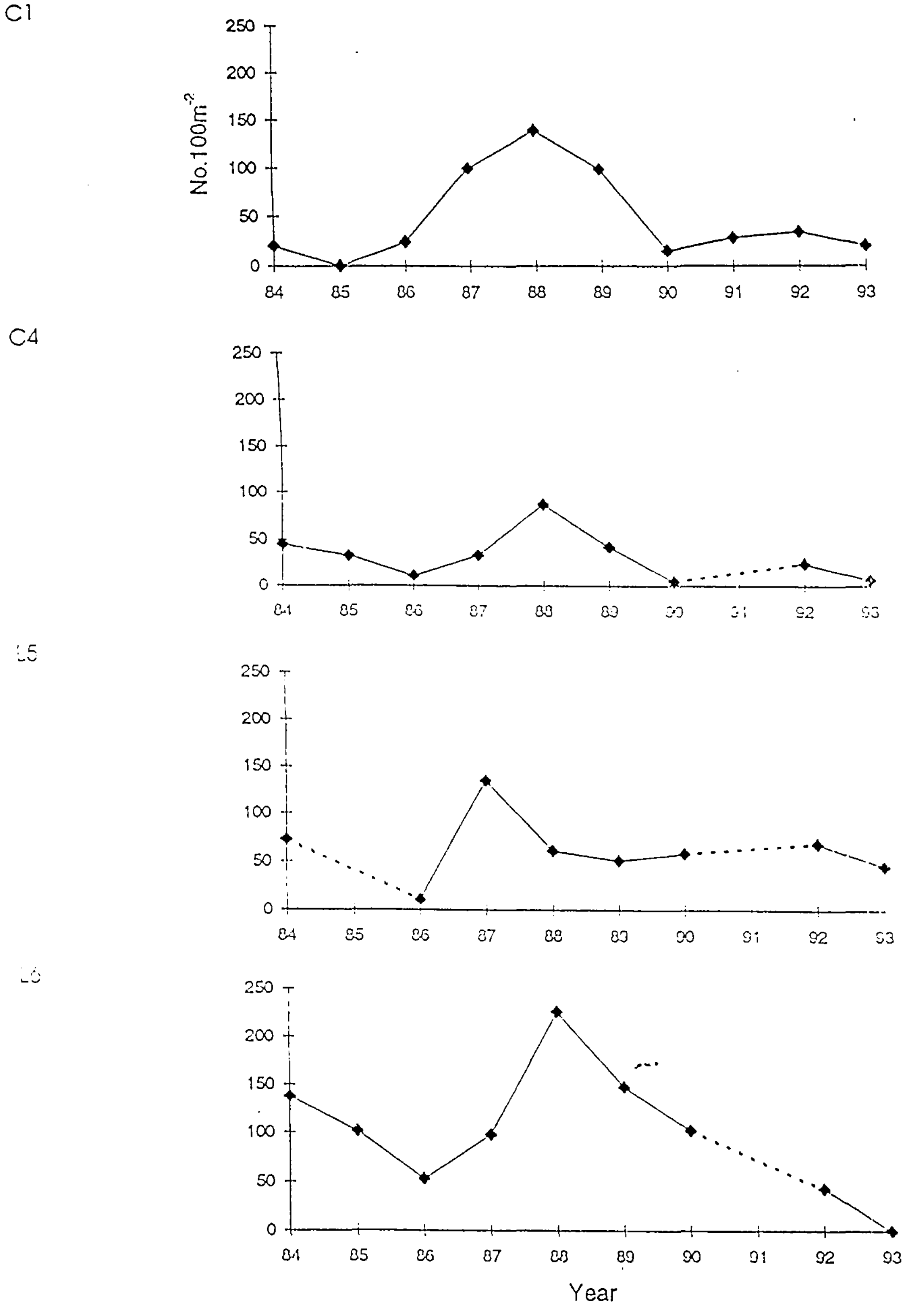



**Figure 3.6** **Year-to-year variation of trout densities in four upland streams at Llyn Brianne, mid Wales**
All sites were unmanipulated references (Ormerod unpubl. data)

At present, understanding the effects on river birds of hydropower schemes depends largely on surmise and qualitative prediction. Basic ecological information is available (see Appendix) but has not been tested in relation to run-of-river schemes.

Questions that will be germane in any hydropower schemes which go ahead, and in monitoring work involving birds, are:

i) Are the direct and indirect changes in river bird habitat that are predicted here borne out in reality?

ii) Are there gains in habitat quality which offset losses?

iii) If losses occur are they sufficient to affect important population parameters, such as density, territory length, breeding performance and survival?

iv) Are any of the changes which occur in important population parameters likely to be important in conservation terms?

These points are considered in detail in the full text of this section which is given in the Appendix.

Effects can arise either directly through alterations in discharge, current velocity, substratum character and wetted perimeter, or indirectly by alterations in food supply and available habitat. Key questions for monitoring will be to assess whether any detrimental effects are sufficient to affect important population parameters such as density, territory length, breeding performance or survival.

**Mammals**

**Otters**

Principal interest in mammals in upland riverine environments centres on otters, one of the species protected under the Wildlife & Countryside Act 1981. It is well established that this species frequents the territory to which run-of-river schemes are suited.

The most sensitive requirements of otters relate to their feeding and breeding habits. These respectively hinge on fish/amphibians and dense thickets of any type of vegetation located close to rivers and which are free from human interference.

Dense vegetation is a common feature in some catchments, more so in lower reaches than on high ground but nevertheless available at all elevations at which run-of-river schemes are likely to be developed. Since otter breeding most commonly occurs in the spring and the habitats so favoured are occupied by the bitch and her young for up to three months, upland sites will normally be accessible throughout. Such locations are, of course, better suited to the pools and marshy ground needed to support amphibians and which will therefore attract otters who will time the arrival of their families to match the presence of this food supply.

The home run or hunting ground of an otter may cover several kilometres, this extending both along an individual river and possibly to those in adjacent valleys. Suitable resting places will be visited regularly, these often comprising cavities within piles of large rocks and around the roots of established trees from which soil has been eroded by strong river flows. These habitats should not be adversely affected by run-of-river schemes, indeed they may become marginally more accessible by the earlier lowering of higher water levels after storms.

Construction work could disturb otters, especially if it involves work in well vegetated areas and close to marshes. There is a case for timing such activities to avoid the Spring period. Frequent visits to an installation could continue to disrupt established otter habits, but occasional visits, which should normally be sufficient for inspection and maintenance purposes, should not be disruptive.

**Other mammals**

Water shrews have been recorded from a wide range of habitats including mountain burns at altitudes of 230m in Scotland and 420m in Wales and have an extended breeding season from April to September. Water voles also occur in a wide range of habitats ranging from headwaters (to 620m) to slow-flowing lowland ditches. They have a similar breeding season with up to 5 litters averaging six young. Construction work at the run-of-river site may temporarily disturb populations of these small mammals but the effects are likely to be short term and very localized.

The American mink, *Mustela vison*, an escapee from fur farms and a relative newcomer to Europe, is often associated with river corridors. In Scotland they may be found up to 717m O.D. Breeding occurs in the late winter and four to six young are born in the spring after a variable period of delayed implantation. Current opinion suggests that mink is not in direct competition with otter but it is unlikely that there will be a strong lobby to protect this species.

# 4. RUN-OF-RIVER SCHEMES IN GREAT BRITAIN

The economic viability of such schemes is dependant on particular physical requirements. An optimal area would have a catchment without large groundwater flows, be situated in a part of Britain with high annual rainfall (>2000-2500mm) and possess streams with an average gradient of at least 1 in 10. In addition access should be good to facilitate construction and connection to the National Grid. Hill streams suitable for run-of-river schemes are most numerous in Scotland, Wales and to a lesser extent in three areas of England (Lake District, Pennines, South West).

## 4.1 Features of Run-of-river Schemes

The construction of a run-of-river hydropower scheme requires the following:-

- an intake;
- a pipeline to transfer the water;
- a turbine or power house;
- an outfall to return the water to the stream;
- access roads to service stages in the construction which may involve building temporary or permanent bridges;
- connection of power lines between powerhouse and the nearest National Grid powerlines.

### 4.1.1 The intake

In the high head run-of-river schemes considered in this report, the direct abstraction of water from watercourses, while excluding entrainment of fish, sediments, organic debris and air, necessitates the design of structures on an individual basis to suit local conditions. The preferred option is a fully submerged intake arrangement. Low head systems (not considered here) will require a dam or weir to raise the level of the water flowing into the feed-pipe. A primary requirement of the intake design is that it guarantees that a specified flow shall continue downstream past the intake whenever abstraction is taking place; this is usually designated the `Residual Flow'.

### 4.1.2 The pipeline

A major factor is often the detailed alignment of the pipe route, having regard for the implications of its construction and that no parts of it should operate at sub-atmospheric pressures. It is not unusual to site intakes well upstream of changes in land gradient in order to secure a satisfactory route. The pipe itself is likely to be between 250 and 500mm in diameter and will be buried for the majority of its length. By the nature of the terrain in which the pipeline has to be laid, it is not unusual for some localized use to be made of explosives to break up particularly hard rock outcrops lying across the pipe route. The size of the trench to be formed is usually not more than about 800mm wide and 1m deep. This is an operation involving `stitch' drilling and rock `popping' along the strip of interest.

### 4.1.3 Powerhouse

The location selected for a powerhouse needs to balance a number of economic and aesthetic factors, and ecological considerations may also apply. Primary factors are access for construction and maintenance, also ease of connection to the grid and a ready route for discharge back to the river. Powerhouses tend to be fairly standard, small, single-storey barn-like structures, with plan areas of 35-50m$^2$ and conventional pitched roofs. They can be constructed to any acceptable style, stone and slate exteriors being used where planning regulations so require.

### 4.1.4 Outfall

The main criterion for the design of the outfall is that it must release water back into the river with minimum disturbance to the nearby river regime. This means that the outfall diffuser must reduce the flow velocity to an acceptable level and that the release shall always be at, rather than above, river level. These criteria are usually not difficult to achieve, though it may be necessary to locally deepen the river by lowering the bed level, the reduced depth being kept clear manually should stone be moved into it at times of higher river flow. Outfall structures can be largely or totally submerged.

### 4.1.5 Connection to the National Grid

It is common for the established electrical network to exist in valleys, where it is needed to supply at least small nearby communities and, in some cases, to serve as a feeder to more distant consumers. The option of routing power lines over mountains is less favoured than following the line of the valley on aesthetic grounds because they then stand out against the skyline. Local powerlines operate at 11,000 volts (11kV) and may comprise either three wires (three-phase) when carrying more power, or two wires (single-phase) when feeding a small number of domestic and farming consumers. Both of these electrical systems are carried on single wooden poles. If a run-of-river scheme is not able to secure ready access to an electrical network, it is likely that the cost of connection will rule against its commercial viability.

### 4.1.6 Access roads

Construction activities will necessitate good access for installation of the components described above. This may involve making new tracks capable of accommodating heavy plant and new stream crossing points. After construction run-of-river schemes should not require more than regular maintenance visits comprising essentially people but not heavy equipment. Only when the pipeline needs to be cleaned will it be necessary to bring in more than easily portable plant to the intake area Servicing and repair of the generator following a wiring fault, may require a hoist and ready access for a suitable vehicle.

Maintenance of the intake and outfall will generally not require heavy plant and can be carried out manually but the servicing of the ultrasonic flow recorder, which the Environment Agency now require shall be installed on the pipeline close to the intake, may require some form of lifting gear and transport. It will therefore usually be necessary to have a permanent track to the powerhouse and an access route to the intake and outfall.

### 4.1.7 Operation

Excluding environmental/ecological considerations, the operation of run-of-river schemes will be controlled by the *specific* physical characteristics (head of water, total discharge, seasonal discharge trends, and flood hydrograph) of the site. Thus, this section will address in general terms only the features involved in run-of-river operation.

The main characteristic of high head run-of-river schemes is that they do not require storage of water. Although the design of water turbines has not changed radically this century the complexity and cost of their associated control equipment has been reduced by direct connection to an electrically strong grid and improved electronic methods of control. This means that run-of-river schemes can operate to match the availability of water and their outputs will vary in response to `real-time' variations in run-off.

As stated above, operation of any individual scheme will be determined by local conditions but the basic principle of operation is that water is abstracted into a pipeline to a turbine from whence it is returned to the river. It is in some cases topographically preferable to locate the outfall of a run-of-river scheme on another river from that which supplies it.

The main features associated with operation are:

- lower flows persist for more of the time;
- peak flows are little changed; and
- flow rates corresponding to former average annual flows occur less often.

# 5. POSSIBLE IMPACTS AND KNOWLEDGE GAPS

The purpose of this section is to identify impacts associated with the construction and operation of any small run-of-river scheme in upland areas, and to relate these to biota and identify areas which require more information. The overall aim is to produce a framework for future action.

## 5.1 Impacts on the Environment

Table 5.1 identifies the main impacts associated with the implementation of a run-of-river scheme and considers the potential effects these may have on the stream and surrounding landscape. In some cases judgement as to whether an impact is negative or positive will be influenced by the assessor. According to the table most of the impacts appear to be negative however it is possible that for some people, improved access to remote areas would increase their enjoyment. The provision of electricity poles, bridges and buildings as perching and nesting sites may represent increased habitat for birds (whinchat, wheatear, pied wagtail) and reduced flows may allow the dipper to feed in an increased number of locations for longer periods.

## 5.2 Sensitivity of Biotic Elements

Table 5.2 illustrates the potential sensitivity of biota and landscape features to aspects of the implementation of a run-of-river hydropower scheme. It must be stressed that this is a gross simplification of the possible sensitivities and the main purpose of the table is to identify those features which are most sensitive to this type of development.

Construction effects are likely to have most impact on landscape features (aesthetics) and possibly on local drainage which may reduce wetland areas of high ecological interest. There may also be some local disturbance of birds and mammals. The generation of sediments from instream building activities is a potential source of trouble to many of the biota. However, siltation problems in rivers with high slopes are not usually long lasting provided that the sediment generation through disturbance is not a continuous process. Any sediment is likely to accumulate further downstream in areas with reduced slope and has the potential for blanketing areas of stream bed if large quantities are involved.

Operation procedures are clearly most likely to affect instream biota which are adapted to the particular flow regime of upland streams. Increased access for maintenance may increase disturbance of birds and mammals.

## 5.3 Effects on Biota

Table 5.3 identifies the main disturbances which could arise from run-of-river schemes and their potential effects on instream and outstream biota. It is important to stress that these

**Table 5.1 Possible impacts of run-of-river schemes on the physical environment**

| ACTIVITY | | IMPACTS | SUBSIDIARY EFFECTS |
|---|---|---|---|
| CONSTRUCTION | Instream | Disturbance of bank | Destruction of vegetation<br>Siltation of stream bed |
| | | Disturbance of substrate | Local siltation<br>Minor changes in substrate |
| | | Local diversion of flow<br>(to facilitate construction activity) | Reduction of wetted habitat<br>Change in flow patterns |
| | | Oil and other pollutants from heavy plant | Contamination of substratum and submerged plants |
| | Outstream | Access roads | Scarring of landscape, disruption of natural drainage<br>Increased disturbance to remote areas |
| | | Bridge building | Generation of sediment<br>Oil pollution |
| | | Burial of pipeline | Scarring of landscape<br>Disruption of natural drainage<br>Destruction of wet flushes |
| | | Powerhouse<br>Connection to grid | Scarring of landscape |
| OPERATION | Instream | Intake from and outfall of water to the stream | Entrainment of fish at intake<br>Rapid dewatering of local area subject to channel morphology<br>Changes in water chemistry in pipe following periods of disuse |
| | | Changes in flow regime | Lower flows for longer periods<br>Floods with reduced peaks<br>Flows equivalent to former mean annual Discharge will occur less of the time<br>Reduced flows over waterfalls/chutes/cascades |
| | Outstream | Increased visitor pressure<br>Noise | Increased use of access tracks for maintenance of equipment and by tourists<br>Turbine noise |

**Table 5.2** **The potential sensitivity of instream and riparian biota, and landscape features associated with the construction and operation of small upland run-of-river hydro schemes**

X low, XX moderate, XXX high, XXXX very high. Note that this table presents an "average" view based on available information and that individual sites will vary in their sensitivity to construction and operation components.

| ACTIVITY / BIOTA / LAND | CONSTRUCTION | | | | | | OPERATION | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Intake | Pipeline | Powerhouse | Outfall | Access | Nat. Grid | Intake | Pipeline | Powerhouse | Outfall | Access | Nat. Grid | Flow changes |
| Algae | XX | - | - | XX | - | - | X | - | - | X | - | - | XX |
| Bryophytes | XX | - | - | XX | - | - | X | - | - | X | - | - | XXXX |
| Invertebrates | XX | - | - | XX | - | - | X | - | - | X | - | - | XXXX |
| Fish | XX | - | - | XX | - | - | X | - | - | X | - | - | XXXX |
| Birds | X | X | X | X | X | - | - | X | X | - | X | - | X |
| Mammals | X | X | X | X | XX | - | - | - | - | - | XX | - | X |
| Riparian and wetland plant | - | XXX | - | - | XXX | X | - | X | - | - | XX | X | - |
| Landscapes/Aesthetics | - | XXX | X | - | XXXX | XX | - | X | X | - | XX | XX | X |

## Table 5.3 Potential effects of run-of-river schemes on biota

| TYPE OF DISTURBANCE | CONSEQUENCES | BIOTIC EFFECTS | MITIGATING FACTORS |
|---|---|---|---|
| DISTURBANCE ON LAND DUE TO CONSTRUCTIONS AND MAINTENANCE | Earth movement<br>Drainage changes<br>Permanent tracks<br>Electric lines | Disturbance of birds and mammals during construction<br>Local alterations to drainage pattern - reduced diversity of wetland<br>Local damage to stream bank | Major construction of short duration (5m)<br>Statuatory controls |
| SILTATION | Clogs interstices<br>Reduces surface area | *Major changes to benthic fauna and flora - reduction in abundance and diversity*<br>Reduced niche diversity<br>Spoiling of salmonid spawning gravels | *High Slope* |
| POLLUTANTS ASSOCIATED WITH CONSTRUCTION (Oil, hydraulic fluid, cement) | Direct toxic effects and habitat change<br>Stored water in pipe | Fish ,invertebrate, and algae/bryophyte kills<br>Reduction in habitat availability | No natural factors but colonization from upstream |
| REMOVAL OF RIPARIAN VEGETATION | Reduced shading<br>Reduction in ambient humidity | Changes in bryophyte composition<br>Reduction in habitat for birds and mammals | No natural factors |
| REDUCED FLOW | Reduction of wetted perimeter<br>*Slower velocities*<br>Reduced depths<br>Reduced humidity and *abrasion*<br>Reduced power of waterfalls | Reduction of living space - decreases in standing crops of instream biota<br>Changes in faunal and floral composition<br>*Isolation of fish to small pools and general reduction in movement*<br>Increased water temperature range of water<br>Changes in zonation pattern of bryophytes and encroachment of riparian *vegetation and increases in terrestrial bryophytes*<br>Reduction in torrential habitat | Channel morphometry<br>Most abstraction in winter |
| CHANGES IN FLOW REGIME | Peak flows insufficient to maintain channel features<br>Sudden changes in flow at intake and outfall | Gradual armouring of stream bed and reduction of habitat diversity<br>Reduced effects of winter floods on reset mechanisms for stream ecology<br>Entrainment of fish and other biota<br>Local scouring of stream bed | Run-of-river schemes mirror natural flow pattern<br>Intake and outfall rates are controllable |

are potential effects and the present state of knowledge of the impacts of run-of-river schemes does not enable predictions of the amplitude and direction of these effects to be made.

## 5.4 Assessment of Available Information

### 5.4.1 General

It is clear from this report that there is considerable amount of information available in the literature which will be of relevance in assessing the impacts of run-of-river hydropower schemes. However it has also become clear that there are specific areas where information is lacking. The whole area of conflict resolution and communication pathways seems to be of major importance. It is interesting that in NRA Handbook Volume 027 on hydropower only the relationship between developers and the NRA is considered. A protocol should be developed (if it does not exist already) to ensure that **all interested parties** can make their views known and most importantly be told precisely what will be involved in the development. It is this precision which is presently lacking and this report has identified a number of features which will require more study before all major points can be answered. The main points are listed in Table 5.4.

### 5.4.2 Physical Environment

There are much background data but not much information on the relationship between discharge and available habitat in channels of differing geomorphometry. The `waterfall' environment and its seasonal variation in size and aesthetic appeal have not been quantified. The relationship between waterfalls/splash zones and local humidity are possibly important features particularly for bryophytes and lichens. The hydrology of upland rivers and the requirements of their ecosystems have hitherto received much less scientific attention than corresponding lowland regimes. Moreover, the two appear to have relatively little in common, hence extrapolation based on existing information would have to be heavily qualified. The Environment Agency's River Habitat Survey (RHS) scheme (Raven *et al.* 1996) is helping to expand appreciation of the variability of upland habitats, however, that survey is not intended to provide the depth of insight into river-related ecosystems which assessment of the implications of run-of-river schemes requires.

### 5.4.3 Biology

Again there is much background information and there are means available to place sites in a national context and assess their conservation value. However most of these data are simply descriptive and we have little information on the response of faunal assemblages to temporary or unseasonal reductions in depth/wetted perimeter. We do not have sufficient information on the `natural noise' in river systems - without this it is not possible to attribute impact to anthropogenic causes. Basic information on the resilience and stability

**Table 5.4 Identification of knowledge gaps**

| | Knowledge gap | Action |
|---|---|---|
| **General** | Measures of the uniqueness/rarity of reaches which are suitable for run-of-river schemes | Classify upland streams using all available techniques(SERCON, RHS, RIVPACS) |
| **Hydrology** | 1. Detailed information on flow regimes of small upland streams<br>2. Relation between flow and stream topography and geomorphometry<br>3. Effect of reduced flow on ambient humidity | 1. Installation of water level recorders<br>2. Possible use of some PHABSIM programs<br>3. Installation of humidity recorders |
| **Biology** | 1. Behavioural responses of biota to altered flow regime<br>2.Effect of altered flow regime on standing crop, biomass, and productivity of instream biota<br>3. Relationship between flow/channel geomorphometry and mesohabitat availability<br>4.The effects of "disturbance" on bird and mammal populations<br>5. The effects of altered flow regime on ambient humidity and concomitant effects on bryophyte zonation<br>6. Long-term effects of altered flow regime<br>7. Differentiate between natural and anthropogenically induced changes in biotic parameters | 1. Cause and effect studies<br>2. Experimental manipulations of flow regime<br>3. Identify faunal assemblages of mesohabitats<br>4. Census of breeding populations - counting/trapping<br>5. Study composition and distribution of bryophytes in impacted and carefully selected control zones<br>6. Instigate survey<br>7. Investigate the annual and seasonal variation in biotic parameters and physical characteristics (substrate, velocity distribution) of upland streams |
| **Aesthetics** | Perception of change due to constructions and increased access by tourists and other recreational users of the environment | Social surveys, questionnaires etc |

of upland hill streams is required to assess properly the possible risks of implementing modifications to the flow regime. This requires a programme of longterm monitoring. So basically we have descriptive biological data but we need information on community functional response (all biotic elements) to disturbance. This can be achieved by experimentation or detailed impact assessment before, during and after implementation of run-of-river schemes. The literature searches have shown that detailed impact assessment of the effects of run-of-river schemes are not generally available because small schemes have not been considered to have an adverse effect on the environment. However, this is a point which needs clarification.

### 5.4.4 General issues

Construction activities will lead to disturbance of the land - it is important that we can answer the question `how long will it take to recover?'. The implementation of a scheme may have ecological gains (for example, bridge sites are frequently optimal nesting sites for grey wagtails). Construction tracks may improve access to remote areas for the public (a feature of the development of the Cow Green Reservoir).

A difficult aspect is that we do not have a measure of the extent of any disturbance, that is to say, what is acceptable and what is not. For example, if only a small reach of the river is affected - how important is this, balanced against the gain of relatively cheap clean power? For this reason it is probably advisable to always consider the worst case scenario where, as in many early hydropower schemes in Europe and the USA, the reach in question is dewatered sometimes for extended periods. Would this be acceptable if it could be shown that the reach prior to regulation had only poor fish stocks or an unremarkable bryophyte community? In intensively used lands this sort of question will become increasingly important.

The concept of cumulative impact is also of relevance to possible flow regulation of upland streams. Some impacts may have repercussions in different areas. An obvious example is altered flow regime reducing salmonid spawning grounds and thereby affecting local angling and tourist interests. This is an extreme case for illustrative purposes and cumulative biological impacts may be more subtle and hard to quantify. The public's perception of a cumulative impact is likely to be more clear; for example one run-of-river scheme in an area may be acceptable but the aesthetic and/or perceived ecological impact of three may be unacceptable.

### 5.4.5 Summary

In this report we have reviewed the information available on aspects which may be affected by development of run-of-river schemes in upland regions of Great Britain. It is clear that much background information exists on the general floral, faunal and physical characteristics of these regions. What are missing are data on the functional responses of biota to changes in the environment and a means of separating anthropogenically induced responses from `natural' fluctuations in biotic assemblages. Although there are lists of species and some data on annual changes in densities and occurrence, there is no information on the effects of discharge fluctuations on habitat availability and its effects on biotic communities. This is the most crucial area of ignorance because it is the flow regime that will be altered by run-of-river schemes.

# 6. RECOMMENDATIONS FOR FUTURE WORK

## 6.1 General

The Environment Agency has produced a variety of guidance on environmental assessment (e.g. NRA 1995a, 1995b and EA 1996) which contain information relating to specific development types including hydropower. The earlier, but more detailed, NRA Handbook (Volume 027) on hydropower was produced to help Environment Agency staff deal with proposals for development. This document presents an overview of the salient features to be considered in the granting of licences for the generation of hydropower and outlines the importance of Environmental Assessment (EA). EA has a legal basis and if properly done can be of benefit both to developers and the environment. It is useful to present a summary of the steps involved in carrying out an EA.

**Screening the proposal.** *"Is it possible in principle, to have a hydropower development there?"*
**Scoping the assessment.** *"If you want to build works there, you will need to address these concerns."*
**Baseline studies.** *"What will be the main environmental impacts and what will cause them?"*
**Impact prediction.** *" A development there will have these impacts".*
**Choice of option.** *"If you build it here you will make this level of profit and have minimum impact on the river"*
**Mitigation measures.** *"How can we reduce the impacts which we know will occur to a minimum?"*
**Decommissioning and restoration.** *"What will happen when the scheme comes to an end?"*
**Responsibilities.** *"Who will be responsible for what?"*

All these pointers require answers which are not always readily available. Some information may be inferred from previous studies but as this report has revealed there are many areas where specific information is sparse. Knowledge gaps are found particularly in "Baseline studies" and in "Impact of prediction" and these key issues await the findings of specific monitoring programmes and professional expertise. It is suggested that the apparently least sensitive schemes (with available information) could be promoted with detailed monitoring programmes to help assessment of schemes in the future. Certainly it will be difficult to make authoritative statements on impacts before such schemes are monitored!

## 6.2 The Development of Guidelines

The formulation of further guidelines depends on having the right sort of information/framework. The first requirement is that the parameters which are likely to be affected by any run-of-river scheme are listed, ranked and classified according to their potential for change and impact on biota associated with the river. Such information would form the basis for assessing any flow-related impact on a river system and as such would have a wide appeal to water resource managers and developers. This should form part of a package on offer to interested parties and the information would be obtained from surveying and collating data from previous studies on the effects of flow-regulation.

Thus the main parameters to be considered are:

**The flow regime pre- and post-abstraction including assessments of both hydrological and hydraulic characteristics.**

**The distribution and characterization of instream and riparian habitat.**

**The composition of assemblages of instream and riparian biota (including algae, bryophytes, macrophytes, macroinvertebrates, fish and birds).**

**The conservation "value" of the site (geological, biological etc).**

The steps which need to be considered could be used to develop an expert system with a series of questions, the answers to which lead the operator down a route which will eventually identify important areas for investigation and an appropriate sampling regime. This would be linked to a means of putting the site under investigation into some national context. Points would be checked off and eventually a statement of the conservation value would be arrived at together with the factors which are most likely to change the status of the site. This information would then form the basis for subsequent monitoring. Elements which could be linked into this are SERCON, RIVPACS and the River Habitat Surveys presently in progress. SERCON is probably at too early a stage to be of direct use but SERCON assessments of similar streams, in a catchment where several options for a proposed development are available, could provide a useful means of highlighting areas where development would detract from conservation value. RHS would have immediate use as would RIVPACS for the placement of sites in a national context.

This initial phase is envisaged as a desk study backed up with some very basic monitoring to provide preliminary data for decision making. This would provide a modular structure for monitoring which would help target specific objectives and facilitate costing and planning.

Assuming the above has taken place, the next stage is the development of a monitoring programme.

It is important that surveys of the targeted stream(s) are carried out at least one year before the construction of the scheme. These should include as basic data, descriptions of the following.

1. The macroinvertebrate fauna and bryophyte and algal communities at least above and below the abstraction and input points (but where these sections are very different carefully selected controls in adjacent streams should be employed). These data to include information on relative abundance or % cover (plants).
2. The fish community and identification of critical life-history stages.
3. The flow regime.
4. The channel morphometry with data on the effects of natural changes in discharge on available wetted area (photography at different stages) and information on stream substrate.
5. Instream and riparian habitat (with associated biota- mammals, birds);
6. Water quality (standard anion/cation analyses plus oxygen concentration to monitor differences between stored water in the pipe and stream water).

In addition further aspects of importance are:

7. the placing of the sites in some national context (for example by using SERCON, River Habitat Survey, and RIVPACS);
8. the prediction of the effects of the discharge changes on the wetted area of the streams ( by using IFIM with PHABSIM, or photography, or some other method - to be determined);
9. the use of information on the fidelity of communities to particular habitat types to extrapolate the effects of possible loss of wetted area on the stream communities (Armitage *et al.* 1995).

The RIVPACS predictions and site classification can be carried out as soon as the relevant physical and chemical data are collected. The PHABSIM methodology however requires intensive surveys of hydraulic parameters at periods of contrasting flow. This has the effect of increasing costs and where fish stocks are considered to be poor it may not be worth carrying out the IFIM/PHABSIM methodology.

## 6.3 Frequency of Monitoring

For macroinvertebrates it is important that the stream is monitored over a range of flows. Spring, summer and autumn usually cover this. Single sets of samples are of little use because they give no idea of the natural variation experienced by the system throughout a year. In studies carried out at the IFE a 20% fluctuation in faunal parameters such as richness, biotic score etc. has been noted in `unimpacted' streams. For other biota, less frequent sampling may suffice but a seasonal element would have to be incorporated into the sampling regime.

For fish it may be necessary to determine distribution at high and low discharges in order to observe how habitat utilization varies. Obviously any loss of wetted area is particularly important for fish populations and it would be necessary to identify critical periods where flow reductions might have the most impact, for example during spawning.

Very often major changes in channel morphometry and in biological characteristics may be rather subtle and may remain unobserved in short term studies (1-2 years) because of natural "noise" in the data. It is a question of scale - looked at over short periods the stream is seen to fluctuate in physico-chemical and biotic parameters but within certain boundaries. Only long-term study will reveal any major shifts in the character of the river. That is why it is important than any monitoring effort is continued for a number of years after the initial post-impact study. A comprehensive long-term survey (> 5 years post implementation) will provide data which will have relevance to future schemes for development of hydropower and will be cost effective because developed sampling logistics and familiarity with the system will increase the speed of sample and data processing.

## 6.4 The Number of Streams to Monitor

An initial low cost extensive survey of possible sites would indicate whether they belonged to a single group regarding their physico-chemical and biological characteristics. If this was found to be so in general terms then intensive survey need only be carried out at those sites most likely to be used for hydropower generation. If on the other hand likely sites varied in their environmental characteristics then representatives of each type would need to be surveyed.

"Reference" sites for comparison with areas of possible impact would have to be selected at this time. The choice of such sites may be difficult where there are major differences between upstream and downstream sections. It has been suggested that surveys of sites already used for hydropower generation will be useful pointers to the expected impacts of run-of-river schemes. It is extremely unlikely that this will be so. Run-of-river systems are radically different to conventional hydropower generation techniques and any results from these latter systems are likely to be extreme values.

## 6.5 Experimental Studies

It is has been noted in this report that survey/monitoring data are important in assessment, but these alone will be insufficient to identify the specific effects which may arise from alterations in the pattern and quantity of flow in small steeply sloped streams. Cause and effect studies are noticeably lacking from studies in these streams with the possible exception of liming experiments in upland Britain.

Experimental studies of flow pattern alterations would be relatively simple to set up in small streams. A temporary pipe can be used to siphon or pump water from upstream to a downstream location. The changes in wetted perimeter, depths etc would mimic the situation which is likely to occur in the run-of-river scheme and provide an opportunity to study relatively cheaply the reactions of the instream biota to flow changes over periods of days and at different seasons. A set of data from a number of reaches may provide useful site specific information for developing guidelines relatively rapidly (within one year) as against conventional surveys. However as stressed above some of the effects may be very subtle and may be detectable only after a period of years.

## 6.6 Summary

Points which should be considered:

1. Place site in national context.

2. Assess conservation value (in general habitat terms).

3. Identify impact areas of scheme.

4. Define existing physico-chemical conditions.

5. Define post-impact physico-chemical conditions.

6. Monitor biota over at least one year pre-impact. If impact effects are likely to be gross, family level data are often sufficient to detect changes. More subtle effects are better shown with species data but it is important to note that species level data are frequently more `noisy' and may require more replicates (which will increase costs).

7. Continue monitoring of physical and biotic elements for at least 5 years (at reduced intensity?) and subsequently every 5 years to detect longterm changes.

8. At the earliest opportunity set up a series of experiments to determine empirically the effects of discharge changes on the availability of habitat and behaviour and distribution of instream biota.

# 7. CONCLUSIONS

The information gleaned from published and unpublished literature has provided clues to possible effects of abstractions for hydropower on physico-chemical and biotic features of rivers. However, none of this information has directly concerned run-of-river schemes. Such schemes differ radically from the methods of generating hydropower which involve storage of water in reservoirs and/or transfer from other catchments. The environmental impact of these two different types of abstractions varies significantly.

The implications from previous studies on regulated streams indicate that the particular flow regime employed in the run-of-river schemes in question are unlikely to cause major adverse effects on the instream and riparian biota. There are however dangers in extrapolating impoundment-based information into a radically different situation and that is the reason why in this case a comprehensive pre- and post-survey are needed to monitor carefully any changes which may arise as a result of the altered flow regime.

If run-of-river schemes are to become more common then it is important that a good database be developed which contains all necessary descriptive features and documents all known impacts. Such information will facilitate the implementation of future schemes. For this reason it would be reasonable to expect funding from prospective developers in addition to statutory environmental organizations. While a reliable database of information on streams which are probable candidates for small hydropower development is essential, it is also necessary to have knowledge on the functional aspects of the communities of biota. Without this information it may not be possible to associate particular impacts with disturbances caused by anthropogenically induced flow regulation. Such a database would have a very wide application far beyond the environmental assessment of run-of-river schemes. The relative importance of the various elements in the database can only be judged on a site specific basis, it is not possible to have rules which will apply to all locations.

Although this study has concerned itself with upland streams it is possible that low-head systems may also prove attractive as power sources and perhaps future studies should address the particular problems which such developments may cause in lowland streams.

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# APPENDICES

## A.1 Literature Review

A number of sources were searched for information on small run-of-river hydropower schemes. These included direct communication with workers in Scandinavia, France and Spain, examination of numerous published studies dealing with the effects of power generation throughout the world and computer searches of the literature.

The results were on the whole rather disappointing. Correspondents from Norway and Sweden indicated that studies on the biological effects of such schemes were rare since most research effort has been placed on the effects of larger schemes involving reservoirs or massive transfers from one catchment to another. None of the French scientists responded but information from the computer search on French work showed that some work had been carried out on small-scale hydropower plants but most of these involved the use of reservoirs and were not *sensu stricto* run-of-river schemes. Spanish work has concentrated on technical papers and the contact has indicated that there are no noteworthy studies on the biological effects of `mini' hydropower schemes. In South America there seems to be a growing interest in such schemes but the emphasis is again on technical not environmental aspects.

The computer search of world literature in the past 10 years revealed only a few studies concerned mainly with legislative and design aspects of small-scale hydropower plants some of which are run-of-river schemes with additional studies concerned with the setting of minimum flows for rivers with stocks of anadromous fish. The table below summarizes the findings of this search. Two reviews on the effects of small scale schemes were found from the USA but these and other impact assessments were generally based on general knowledge of stream ecology, etc, not on the results of actual impacts.

| Subject | References | Countries |
|---|---|---|
| Design and Planning | 9 | Canada,France,New Zealand,Pakistan,USA,"USSR", |
| Legislation | 3 | USA |
| EIA General | 4 | USA,Canada |
| EIA Dams and Reservoirs | 6 | Canada,France,USA |
| EIA Run-of River | 2 | Austria,USA |
| Chemical aspects | 4 | USA |
| Fish | 3 | France,USA |

This lack of success in finding directly relevant works is not surprising in view of the preponderance of information on the effects of large dams and transfers on the receiving rivers. These projects have understandably been the subject of much detailed study because of their greater environmental impact and smaller plants have not received much attention. This is partly due to the emphasis on construction of large scale plants (see Background) and the perceived reduced impact of small schemes but an additional factor is the relative newness of small run-of-river schemes and hence lack of associated biomonitoring studies.

Flow regulation is the common feature to both large and small schemes. It has the potential to alter instream habitat characteristics and consequently the structure of biotic communities and there is a large body of work which addresses the problems associated with the regulation of flow for abstractions, storage, transfer, irrigation, and power generation (large schemes).[*see appendix for source data*]. Such information together with general data on the `natural' ecology of river biota will be of direct use in assessing possible environmental effects of risks associated with run-of-river schemes.

## A.2 General Source References to the Effects of Flow Regulation

**Proceedings of regulated Stream Symposia** (chronological order)

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Craig, J.F. and Kemper, J.B. (Eds) (1987) *Regulated Streams - Advances in Ecology*. Plenum Press, New York, 431pp.

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Stanford, J.A. and Hauer, F.R. (Eds) (1993) Proceedings of the Fifth International Symposium on Regulated Streams. *Regulated Rivers: Research and Management,* **8(1-2)**, pp 209. Wiley & Sons, Chichester.

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Wright, J.F., Furse, M.T. and Armitage, P.D. (1993). RIVPACS - a technique for evaluating the biological quality of rivers in the U.K. *European Water Pollution Control*, 3, 15-25.

## A.3 Impacts of Small Hydro-power Installations (Literature Search)

TI: Dissolved Oxygen in Streams and Reservoirs.
AU: Gordon,-J.-A.
SO: Research Journal of the Water Pollution Control Federation RJWFE7, Vol. 63, No. 4, p 550-552, June 1991. 38 ref.
MNDE: Biochemical-oxygen-demand, Hydroelectric-power, Model-studies, Transfer-dynamics, Urban-runoff
AB: Recent literature on dissolved oxygen in streams and reservoirs has been reviewed, and includes studies concerned with stream processes and hydropower. One case study presents findings on urban runoff from a reservoir near Calgary, Alberta; urban runoff had little effect on the dissolved oxygen in the adjacent Bow River. Other studies address models to predict the impact of small impounding dams on the remaining free-flowing river; a design for an in situ sediment oxygen demand respirometer; and a tailwater ecology workshop that covered reservoirs, technical issues, management issues, and case histories of hydro-relicensing. In the area of lake and reservoir processes, studies were done that provided a detailed review of DO dynamics in impoundments, and revealed unusual temperature and DO profiles in an ice-covered Wyoming lake. A formula for the determination of the saturation concentration of DO in both seawater and freshwater was determined; equations for predicting liquid-phase and gas-phase parameters for volatilization of organic solutes from streams was developed; details of surface transfer mechanisms with a gas microprobe using the polarographic principal for measurement of DO was studied; and, models were developed for biochemical oxygen demand-DO processes. In addition, aquatic effects of DO changes and remedial measures for low DO conditions were examined. (White-Reimer-PTT)

TI: Development of Small Hydro for Remote Areas of Northern Pakistan.
AU: Riaz,-R.-A.; Ali,-N.
SO: International Water Power and Dam Construction IWPCDM, Vol. 43, No. 5, p 24-26, May 1991. 1 tab.
MJDE: *Hydroelectric-plants, *Hydroelectric-power, *Pakistan-, *Turbines-, *Water-resources-development
AB: The Northern Areas of Pakistan, a remote region characterized by difficult terrain, could not be economically connected to the country's national grid. Small hydro schemes therefore have a particularly important role to play in providing much needed supplies of electricity for the local population and stimulating the overall development of the area, particularly with regard to light industries and tourism. At present 48 stations operate to provide electricity for a third of the population. Work on another 30 stations is in progress and more are being planned. The development of small hydro schemes has changed the socioeconomic pattern of these areas and positive effects on the environment and ecology can be expected soon. Of the two types of turbines already in use (crossflow and Francis), experience has shown that the crossflow runners wear out relatively quickly. Frequent breakdowns are caused by poor metallurgy in the manufacture of guide vanes and runners. This experience has led to a tendency to prefer Francis runners. Recently, growing populations and an increasing demand for electricity have forced planners to choose high-capacity (625 kVA to 1250 kVA) Francis or Pelton turbines. (Rochester-PTT)

TI: Future Directions for Water Resources.
AU: Whipple,-W.
SO: IN: A 25th Anniversary Collection of Essays by Eminent Members of the American Water Resources Association. AWRA Special Publication No. 89-2. American Water Resources Association, Bethesda, Maryland. 1989. p 9-13.
MJDE: *Clean-Water-Act, *Flood-control, *Future-planning, *Hydroelectric-power, *Water-resources, *Water-resources-management
MNDE: Environmental-effects, Irrigation-, Storm-water-management, Waste-disposal, Water-conservation, Water-law, Water-pollution-control, Water-resources-development, Water-supply
AB: The great era of water resources got well underway with the passage of the Flood Control Act of 1936. For the next 30 years large Federal programs featured flood control, navigation, hydroelectric power, and irrigation. The environmental movement of the 1960's and the Clean Water Act of 1972, created a basic shift

in national priorities. As the nation urbanized, environmental pressures became more acute. Water resources development started involving community life. In addition, waste control and disposal programs became ranking activities in the environmental field, encompassing air, land and water environments. As fossil fuels become scarcer in the future, the value of hydroelectric power will increase. Few new projects will be built, however, because the best sites remaining cannot be used without unacceptable economic, environmental and social dislocation. Navigation improvements will be maintained and some channels deepened; but few new systems will be built. The planners of flood control will find it ever more difficult to find acceptable new reservoir sites. Further general increases in flood damages appear inevitable, especially along the smaller rivers and streams. Growth in flood damages due to new development can be precluded on small streams, and minimized on larger streams, by programs of stormwater management. As water shortages due to drought become more serious, water conservation will increase in popularity and practicality. By far the greatest change comes with the increasing importance of pollution control. A major technological change in the treatment of water for potable uses will be made when the EPA finally publishes new standards for trihalomethanes. Regional water management plans will be increasingly applied. Urbanization ups the pressures for better planning and more effective environmental protection. Despite our best efforts, a new generation of planners and analysts will have their hands full. (See also W91-11206) (Mertz-PTT)

TI: Water-Quality Impact Assessment for Hydropower.
AU: Daniil,-E.-I.; Gulliver,-J.; Thene,-J.-R.
SO: Journal of Environmental Engineering (ASCE) JOEEDU, Vol. 117, No. 2, p 179-193, March/April 1991. 6 fig, 1 tab, 19 ref.
MJDE: *Dam-effects, *Data-acquisition, *Environmental-effects, *Hydroelectric-plants, *Water-quality, *Water-quality-management, *Water-resources-development
AB: Studies to evaluate the impact of hydropower facilities or downstream water quality, are frequently mandated for hydropower licensing by local, state and/or federal agencies. Negative impacts can result from the substitution of discharges aerated over a spillway, with minimally aerated turbine discharges that are often withdrawn from lower reservoir levels where dissolved oxygen is typically low. Historic data are used to establish the probability of low dissolved oxygen occurrences. Synoptic surveys, combined with downstream monitoring, give an overall picture of the water quality dynamics in the river and the reservoirs; spillway aeration is best determined through measurements and adjusted for temperature. Theoretical computations of selective withdrawal are sensitive to boundary conditions, such as the location of the outlet relative to the reservoir bottom, but withdrawal from the different layers can be estimated from measured upstream and downstream temperatures and dissolved oxygen profiles. Downstream water quality under hydropower operation is predicted based on field measurements. Improving selective withdrawal characteristics or diverting part of the flow over the spillway provides a cost-effective mitigation solution for small hydropower facilities (15 MW) because of the low capital investment. (Brunone-PTT)

TI: Methodological and Organizational Characteristics of Surveys for Small Hydroelectric Stations.
AU: Skiba,-S.-I.
SO: Hydrotechnical Construction HYCOAR, Vol. 24, No. 2, p 69-72, 1990. 3 ref.
MJDE: *USSR-, *Project-planning, *Hydroelectric-plants, *Surveys-, *Hydraulic-design
MNDE: Hydraulic-engineering, Design-criteria, Geological-surveys, Mountain-streams, Environmental-impact, Reservoir-siting, Baseline-studies, Engineering-geology, Estimated-costs
AB: Increasing development of small hydroelectric power engineering projects requires reexamination of the main methodological and organizational techniques of surveys for small hydrostations (characterized by capacities from 0.5-1.0 to 30 MW, and small and comparatively simple structures such as arch dams with a height up to 60 m, channels on slopes, tunnels under complex geological conditions, aqueducts, sag pipes, etc.). The majority of small hydrostations will be examined anew by the All-Union Planning, Surveying, and Scientific-Research Institute. Some general principles which should be considered during the survey include the following. Unpredicted processes complicating construction or operation and often leading to failures are known precisely for small hydraulic structures, and must be recognized. Practice has shown the error of 'a priori' assignment of estimated survey costs for hydropower facilities. Engineering-geological substantiations for small hydrostations at the development stage should be realized without the difficult exploratory works. The main design and construction stages are the most important ones for small hydrostations because the design stage, as a rule, is absent and the working design begins at the next stage. Mountain rivers, where concentrated falls and the possibility of creating reservoirs with minimum flooding and subirrigation areas are combined, are most prospective for constructing small hydrostations. Some unpopulated stretches of the valleys of mountain rivers have favorable natural conditions for creating seasonal reservoirs which increase

the efficiency, capacity, and production. Under current conditions it is necessary to find new ways to organize surveys for small hydrostations, with mobile, economically-independent parties. (Fish-PTT)

TI: Small hydroelectric plants and environmental protection.
OT: Petite hydraulique et protection de l'environnement
AU: Henry,-J.P.; Monition,-L.
CO: 128. Session du Comite Technique de la Societe Hydrotechnique de France, Paris (France), 12 Jun 1986 SOME-CHARACTERISTICS-OF-HYDROELECTRIC-MINIPOWER-PLANTS-AND-STUDIES-ON-TRANSIENT-PHENOMENA - CERTAINS -ASPECTS- DE - L'-HYDROELECTRICITE -DE -FAIBLE -PUISSANCE.-QUELQUES-ETUDES-DE-CAS-DE-TRANSITOIRES-HYDRAULIQUES.-Societe-Hydrotechnique-de-France,-Paris-France.-Com.-Technique1986. no. 1-2 pp. 87-94
LA: French
AB: The environment must be given sufficient consideration when developing small hydroelectric plants. In France, the law relative to the protection of nature (1976) and its application decree relative to impact studies (1977) set the legal framework for evaluating all types of effects of a plant (impact on the watershed, the aquatic ecosystem, the landscape, social and economic impact, etc.). The law also requires considering measures designed to eliminate, reduce and, if possible compensate for the damageable consequences of the projects. The recent law relative to fresh water fishing and management of piscicultural resources (June 1984) mentions that conservation of the aquatic environments and protection of the piscicultural resources are of general interest. In this respect, it sets forth new obligations concerning the reserved flow in the bed of a waterway and the passes for fish. In many cases, accompanying solutions can be suggested and implemented under technical and financial conditions that are acceptable to the operators and other users of the river and water.
DE: hydroelectric-power-plants; environmental-protection; environmental-impact; watersheds-; ecosystems-; sociological-aspects; economic-analysis; freshwater-fish; fishways-; fish-culture

TI: Repercussion of small hydroelectric power stations on populations of brown trout (Salmo trutta ) in rivers in the French Massif-Central.
AU: Demars,-J.-J.
CO: Symp. of the European Inland Fisheries Advisory Comm. on Habitat Modification and Freshwater Fisheries, Aarhus (Denmark), 23 May 1984 HABITAT-MODIFICATION-AND-FRESHWATER-FISHERIES.-PROCEEDINGS-OF-A-SYMPOSIUM-OF-THE-EUROPEAN-INLAND-FISHERIES-ADVISORY-COMMISSION. Alabaster,-J.S.-ed. 1985. pp. 52-61
LA: English
AB: An overall description is given of 10 small hydroelectric stations situated in a medium-altitude mountain zone. The populations of the main fish species (Salmo trutta ) were assessed by electric fishing at each of the 10 sites. Comparisons are made between the stocks in a sector of river from which water is abstracted for the power station, and those in a sector not so affected. Correlations are given between the apparent status of the stock in the diverted sector as compared with the control sector, the volume of water abstracted for the station, and the discharge reserved for the river. The wide variety of results indicated that the effects depend on the particular characteristics of each station. Shortcomings of the study are noted and prudence would have to be shown in applying the results elsewhere.
DE: hydroelectric-power-plants; environmental-impact; river-engineering; stock-assessment; population-dynamics; Salmo-trutta; France,-Massif-Central

TI: Study, Use, and Protection of Small and Medium Rivers.
AU: Altunin,-V.-S.; Dmitruk,-V.-I.; Pankratov,-V.-F.
SO: Hydrotechnical Construction HYCOAR, Vol. 22, No. 9, p 542-547, March 1989. 1 fig, 12 ref.
MJDE: *Environmental-protection, *Dam-effects, *Rivers-, *Water-resources-development, *Hydrologic-data-collections, *Discharge-measurement
MNDE: Annual-runoff, Hydroelectric-power, Streamflow-, Water-management, Hydrologic-models, Gaging-stations, Meteorological-data-collection, Water-potentials, USSR-, Environmental-impact, Fish-hatcheries, Regulated-flow
AB: Insufficient knowledge about the channel regime of rivers makes it difficult to rationally use rivers as sources of water supply, irrigation, and for construction of hydraulic structures for hydroelectric power.

Rivers are classified as small and medium according to their drainage area, length, and runoff. These properties can differ for rivers in arid and semiarid regions. In the absence of observations of the runoff characteristics of a river, it is necessary to substantiate water management construction on the basis of indirect methods of calculation by hydrologic models and interpolation. An increase of the accuracy of the methods used depends on the number of hydrometric observation stations and an improvement of their spatial distribution. The volume of available information on runoff can be substantially increased by using extensive meteorological and physiographic data in addition to the available hydrometric data. These factors were taken into account when creating an improved method of calculating the characteristics of the annual runoff of rivers, namely the indicator of potential water resources of a territory. The developed methods are being used for substantiating water management projects in the European USSR. To improve the methods of estimating the hydropower potential of small and medium rivers, small hydrostations can be constructed to perform ecological impact studies. To improve the schemes of streamflow regulation and hydropower use of the runoff of medium rivers and small river tributaries the construction of small reservoirs (with the installation of small hydrostations) in the upper reaches of reservoirs is recommended, primarily on stretches without a floodplain. It is also advisable to construct fish nurseries for breeding and rearing commercial fish. (Geiger-PTT)

TI: Saint Aignan: a Demonstration Siphon Plant in Brittany.
AU: Pontier,-R.; Donot,-A.; Petillon,-C.
SO: International Water Power and Dam Construction IWPCDM, Vol. 41, No. 9 p 45-49, September 1989. 2 fig.
MJDE: *Siphons-, *Turbines-, *Hydraulic-turbines, *Concrete-dams, *Hydroelectric-power, *Siphon-turbines, *Water-resources-development, *Rural-areas, *Developing-countries
MNDE: Dam-effects, Hydraulic-design, Tunnel-construction, Costs-, Maintenance-, Environmental-protection, France-
AB: Modern engineering and project management techniques, giving optimum low-head generation economics, are being utilized in a new hydropower station in Brittany, France. This demonstration siphon plant will be opened to visitors beginning the summer of 1989, and is of particular interest for rural areas and developing countries. The siphon turbine concept is particularly suitable for areas where run-of-river plants can harness rivers having wide seasonal variations. It is suitable for heads of between 1 and 4.5 m. The siphon water passage is primed using a vacuum; when generation is no longer required, air-break valves stop the flow. The concept offers the advantage, apart from a cost gain over other low-head units (such as pit or bulb units), of keeping the electromechanical equipment above the tailwater level. This enables easy access for maintenance. Other interesting features for regions where environmental aspects are important are the small disturbance and impact on the surroundings, the relatively small excavation required for the installation, and the usual ecological advantage of Kaplan turbines over other types for fish protection. The future potential of the siphon technique can already be seen; during a recent project bid, three siphon units were seen to be about 30 percent cheaper (on first electromechanical price comparison) than two right-angled drive units of equivalent installed capacity. (Ence-PTT)

TI: Environmental Benefits of Further US Hydro Development.
AU: Rogers,-W.-L.
SO: International Water Power and Dam Construction IWPCDM, Vol. 41, No. 8, p 10-11, August 1989.
MJDE: *Hydroelectric-power, *Electric-power-production, *Environmental-policy
AB: Further development of the substantial remaining hydro resources in the USA has the potential to reduce carbon dioxide emissions by more than 220 Mt/year (or approximately 5 per cent of the country's total emissions). Current energy and environmental policies in the USA, however, are severely restricting progress in developing the resources available, at a time when concerns about global warming are underlining the important role which hydropower could play. Small hydro plants have almost been regulated out of existence. The environmental impacts of hydro plants can be greatly reduced through careful planning and mitigative measures, such as the construction of fish ladders or the provision of minimum flows. However, hydroelectric plants, unlike fossil fuel and nuclear fuel plants, are required to pay the full, life-cycle environmental impact costs at the outset which leaves hydropower at a disadvantage. Hydropower should be compared in the light of the true life-cycle costs to society of nuclear or fossil generation. The Electric Consumers' Protection Act needs significant amendments to ensure that the Act is living up to its name. This legislation has had the greatest detrimental effect on hydropower. Well planned hydropower development is an activity to be encouraged, and not regulated out of existence. (White-Reimer-PTT)

TI: Local (Small-scale) Hydroelectric Resources.
AU: Stewart,-R.-E.
SO: IN: Aquatic Biology and Hydroelectric Power Development in New Zealand. Oxford University Press, New York. 1987. p 18-27, 1 fig, 2 tab, 2 plates, 4 ref.
MJDE: *Hydroelectric-power, *Water-resources-development, *Environmental-impact, *Management-planning, *New-Zealand
AB: Local hydroelectric development, and how it fits into the overall picture of hydroelectric development in New Zealand, is described. The background and definition of local hydro-schemes, their evolution and current position are detailed together with indications of where such development is headed. The essential physical elements of a local hydro-scheme are common to all hydro-schemes. A flow of water must be diverted through a turbine. The turbine drives a generator whose output is then carried to the user or users. To this end the following identifiable components of a scheme are needed: a water diversion structure; an intake structure; an overflow structure (for surplus or flood flows); a penstock or pressure pipe system; a turbine; a generator; a transmission system. In addition the following components are also commonly used: a water storage structure (normally a dam); a water transfer structure such as a canal or tunnel; and a surge chamber to reduce water hammer pressures on penstocks when the turbines are shut down. Every year the Electricity Sector Planning Committee (Ministry of Energy) publishes a report which gives details of current local hydro-schemes and estimates of their generation for the following 15 years. Because this is based on government policy at the time and a local hydro-scheme could be built within five years from inception, these estimates are increasingly inaccurate towards the end of the 15-year period. This aspect affects all attempts to predict the future development of local hydro-schemes, but it is likely that for the next 15 to 20 years, provided financial and legal obstacles do not increase over those of the early 1980s, there could be some two to four stations being constructed at any one time with a further three to six being investigated, but this will depend on the circumstances of the time. (See also W89-01871) (Lantz-PTT)

TI: Standardization and Layout of the River Murz Cascade Scheme.
AU: Krauss,-H.; Burger-Ringer,-E.
SO: International Water Power and Dam Construction IWPCDM, Vol. 40, No. 7, p 26-31, July 1988. 5 fig, 1 tab.
MJDE: *Austria-, *Water-resources-development, *River-Murz, *Hydroelectric-power, *Hydroelectric-plants, *Design-criteria
MNDE: Construction-, Standardization-, Planning-, Engineering-, Austria-, Electric-power, Environmental-impacts, Cascades-, Run-of-river-plants
AB: In total, 27 small hydro sites have been identified on the River Murz in Austria. To date, 11 plants are in operation, four are under construction, seven more are under consideration, and studies are being carried out on the remaining five. The capacities of the individual run-of-river plants range from 0.5 to 2 MW, and the combined generation of the completed cascade scheme would be 133.25 GWh/year. The authors comment on 18 of these projects in which they are directly involved, and devote particular attention to environmental impact and the standardization of the equipment and civil works. (Author's abstract)

TI: Effects of Variable Discharge Schemes on Dissolved Oxygen at a Hydroelectric Station.
AU: Mathur,-D.; McClellan,-E.-S.; Haney,-S.-A.
SO: Water Resources Bulletin WARBAQ, Vol. 24, No. 1, p 159-167, February 1988. 9 fig, 3 tab, 2 ref.
MJDE: *Discharge-flow, *Dissolved-oxygen, *Hydroelectric-power, *Water-quality, *Chemical-properties, *Water-temperature
MNDE: Meteorological-factors, Oxygen-depletion, Peaking-plants, Run-of-the-river-plants, Susquehanna-River, Maryland-
AB: The effects of variable discharges during the summer on the dissolved oxygen (DO) content and water temperature upstream and downstream of the Conowingo Hydroelectric Power Station (Susquehanna River, Maryland) were investigated. The DO dynamics are controlled primarily by meterological factors that are independent of the mode of hydrostation operation. DO stratification occurred during the summer in Conowingo Pond, but thermal stratification was not observed. The magnitude and duration of off-peak discharges including a run-of-the-river operation did not affect DO stratification in Conowingo Pond; little vertical mixing occurred. However, strong winds and/or high river flows temporarily destroyed DO stratification. The run-of-the-river operation or off-peak continuous discharge schemes did not provide better DO conditions downstream of the hydrostation than the peaking operation with intermittent off-peak releases. (Author's abstract)

TI: Alternatives for reducing the impacts of regulated lake levels on the aquatic ecosystem of Voyageurs National Park, Minnesota
AU: Kallemeyn,-L.W.; Cole,-G.F.
CA: Voyageurs National Park, International Falls, MN (USA)
SO: 1990 112 pp
NT: NTIS Order No.: PB91-163253/GAR.
LA: English
AB: With the establishment of Voyageurs National Park in 1975, the National Park Service became one of many interest groups concerned with the regulation of Rainy Lake and the Namakan Reservoir lakes, which are a part of the larger Lake of the Woods watershed. Lake levels in these bodies of water are controlled by a single hydropower facility and two small regulatory dams that are located outside Voyageurs' boundary. The research program at Voyageurs consisted of two principal components. The first assessed the effects of the present water management program on the park's aquatic ecosystem. The second developed a hydrological model to assess the effects of alternative regulatory programs on power generation or other public purposes. Research studies were conducted on: aquatic vegetation and benthic organisms; the fish community, particularly walleye, yellow perch, and northern pike; shore and marsh nesting birds, particularly the common loon and red-necked grebe; beaver and muskrat; osprey; river otter;primary production; archeological resources; and the relationship between lake levels and boat docks, navigation, flood control and power production.
DE: hydroelectric-power-plants; dams-; watersheds-; environment-management; research-programs; benthos-; freshwater-fish; aquatic-birds; aquatic-mammals; primary-production; environmental-impact; flood-control; navigation-; recreational-waters; USA,-Minnesota,-Voyageur'-s-Natl.-Park; Pisces-

TI: National Perspective on Environmental Constraints to Hydroelectric Development.
AU: Hildebrand,-S.-G.; Sale,-M.-J.; Cada,-G.-F.; Loar,-J.-M.
SO: IN: Perspectives on Nonpoint Source Pollution, Proceedings of a National Conference, Kansas City, MO. May 19-22, 1985. Environmental Protection Agency, 1985. p 301-303, 12 ref.
MJDE: *Environmental-effects, *Hydroelectric-power, *Water-resources-development, *Water-quality
MNDE: Hydroelectric-plants, Dissolved-oxygen, Tailwater-, Fisheries-, River-basins, Ecological-effects
AB: The U.S. Department of Energy (DOE) initiated a hydropower development program in 1977 to promote small-scale (< or = MW) hydroelectric projects across the country. Consistent with DOE's support of research on environmental aspects of energy production, it was recognized that analysis of potential environmental constraints should be an integral part of the DOE program. The Environmental Sciences Division of Oak Ridge National Laboratory implemented studies on the environmental effects of hydropower development in 1978 in support of the DOE effort. Problems associated with the concentration of dissolved oxygen in tailwaters below dams and instream flow requirements for fisheries are analyzed. The need for, and technical challenges related to, assessment of the environmental effects of multiple-project developments in river basins are discussed. Although the focus of the DOE program is on small-scale hydroelectric development, the issues discussed are applicable to large-scale facilities as well. (See also W88-01083) (Lantz-PTT)

TI: Status of DOE Small Hydropower Research and Development Projects.
SO: Available from the National Technical Information Service, Springfield, VA 22161, as DE83 001353, A03 in paper copy, A01 in microfiche. EGG-HYD-6024, September 1982. Edited by E. H. Magleby, B. N. Rhinehart and J. R. Chappell. 26 p, 23 fig, 2 tab. Contract No. DE-AC07-76IDO1570.
MJDE: *Hydraulic-machinery, *Turbines-, *Hydroelectric-power, *Electric-power
MNDE: Dams-, Electrical-equipment, Fish-passages, Environmental-effects
AB: The status and results of Department of Energy small hydropower research and development projects is summarized. Projects include use of a scroll motor as a turbine, cross-flow turbine, diffuser optimization with water jets around the draft tube entrance, free stream turbines, Schneider engine, modular hydro-dam, variable speed synchronous generator, hydraulic air compressor, marine thruster turbine, low-cost fish passages, pumps as turbines, modular float-in powerhouses, powerhouse gates, and turbine index tests. The report also presents a bibliography of completed reports and ordering information. (Cassar-PTT)

TI: Repurcussion of Small Hydroelectric Power Stations on Populations of Brown Trout (Salmo trutta) in Rivers in the French Massif-Central.
AU: Demars,-J.-J.

SO: IN: Habitat Modification and Freshwater Fisheries, Proceedings of a Symposium of the European Inland Fisheries Advisory Commission, Aarhus, Sweden, May 23-25, 1984. Butterworths, London, England. 1985. p 52-61, 4 fig, 2 tab, 2 ref.
MJDE: *Trout-, *Hydroelectric-power, *Environmental-effects
AB: An overall description is given of 10 small hydroelectric stations situated in a medium-altitude mountain zone. The populations of the main fish species (Salmo trutta) were assessed by electric fishing at each of the 10 sites. Comparisons are made between the stocks in a sector of river from which water is abstracted for the power station, and those in a sector not so affected. Correlations are given between the apparent status of the stock in the diverted sector as compared with the control sector, the volume of water abstracted for the station, and the discharge reserved for the river. The results suggest the fixing of the reserved discharge as a percentage of the mean annual flow, bearing in mind the size of the station in question. Under these conditions, and while maintaining the seasonal water levels, the values of the reserved discharges for spring and summer should be 20% greater than the mean annual value within the limit of the natural yield; those for autumn and winter would be between 10 and 15% of the annual average flow, given that as a result of the overflows from the dam the residual discharge would be greater, depending on the circumstances. (See also W87-09036) (Lantz-PTT)

TI: Small Scale Hydropower and Anadromous Fish: Lessons and Questions From the Winchester Dam Controversy.
AU: Blumm,-M.-C.; Kloos,-B.
SO: Environmental Law, Vol. 16, No. 3, p 583-637, Spring 1986. 279 ref.
MJDE: *Hydroelectric-power, *Federal-Energy-Regulatory-Commission, *Water-law, *National-Marine-Fisheries-Service, *National-Environmental-Policy-Act
AB: The authors use the authorization of the controversial Winchester project on Oregon's North Umpqua River as a case study to examine federal and state regulatory schemes governing small-scale hydropower. Between 1982 and 1985 this 1.5 megawatt project received state and federal approvals, was constructed, and experienced two years of troubled operation before it was shut down. The authors show how the project led the Oregon Legislature to reform the state's standards for hydroelectric permits, and how it induced the Federal Energy Regulatory Commission to interpret away the ability of the National Marine Fisheries Service to prescribe binding conditions on projects qualifying for exemptions from federal licenses. They also explain why FERC's failure to satisfy the requirements of the National Environmental Policy Act caused the project to shut down in December 1985, and they make detailed recommendations as to how the federal program authorizing small hydroelectric projects can comply with NEPA. The authors argue that federal and state fishery agencies should insist the Winchester project not restart until FERC prepares an environmental impact statement on the effects of the project and a proposed replacement dam on the North Umpqua's anadromous fish runs. (Author's abstract)

TI: Small Hydroelectric Plants and Environemental Protection, (Petite Hydraulique et Protection de l'Environment).
AU: Henry,-J.-P.; Monition,-L.
SO: La Houille Blanche, No. 1/2, p 87-94, 1986. 5 ref.
MJDE: *Hydroelectric-plants, *France-, *Powerplants-, *Legal-aspects, *Environmental-protection, *Regulations-
MNDE: Fish-, Fish-farming, Economic-impact, Social-impact, Ecosystems-, Environmental-impact-statement
AB: The environment must be given sufficient consideration when developing small hydroelectric plants. In France, the law relative to the protection of nature (1976) and its application decree relative to impact studies (1977) set the legal framework for evaluating all types of effects of a plant (impact on the watershed, the aquatic ecosystem, the landscape, social and economic impact, etc.) The law also requires considering measures designed to eliminate, reduce, and if possible compensate the litigible consequences of the projects. The recent law relative to fresh water fishing and management of piscicultural resources (June 1984) mentions that conservation of the aquatic environments and protection of the piscicultural resources are of general interest. In this respect it sets forth new obligations concerning reserved flow in the bed of a waterway and passes for fish. A number of such passes are described. In many cases, solutions can be suggested and implemented under technical and financial conditions that are acceptable to the operators and other users of the river and water. (Author's abstract)

TI: Hydropower's Newest Generation.

AU: Smallowitz,-H.
SO: Civil Engineering, Vol. 55, No. 8, p 46-49, August, 1985. 3 Fig.
MJDE: *Water-resources-development, *Hydroelectric-power, *Canals-
MNDE: Small-hydropower, Planning-, Dam-construction, Dams-, Enviromental-effects, Hydroelectric-plants
AB: The Great Falls, Paterson, NJ project is based on a system of canals constructed in the late 1700s to spur small industry in the fledgling US, and develop independence from the economy of Great Britain. While the mills and factories the canals once powered have long since closed, the waterways are still capable of producing 4900 to 11000 Kw. The city of Paterson hopes to make use of this energy source in the future. In North slope, Alaska, the Susitna project is actually made up of two major developments on the Susitna River, some 180 mi North and East of Anchorage. The Eldred L. Field Project, in Lowell, Massachusetts is on a canal system that dates back to 1792. Efforts to make use of this system in modern times necessitated making certain that historical and environmental factors were considered. In Bumcombe County, North Carolina, near Ashville, developers are bringing out of retirement an abandoned hydroelectric plant. The Craggy Dam was originally constructed in 1904. A proposal to tap electricity from the flow of water to Jersey City, New Jersey's water taps is beset with regulatory problems. Plans call for two small hydroplants to be installed at the Boonton Reservoir, 25 mi west of the city. An innovative use of existing mud gates in the reservoir will also make it cost effective to generate 2 Mw more from the facility. (Baker-IVI)

TI: Small Hydroelectric Stations and the Environment (Environment et petites usines hydroelectriques).
AU: Cuinat,-R.; Roussel,-Ph.
SO: Houille Blanche, No. 4/5, p 243-247, 1981. 2 Fig.
MJDE: *Hydroelectric-plants, *Environmental-effects, *France-
AB: In France, due to the increase in the price of oil, the value of other energy sources, such as small hydroelectric plants, has increased. The placement of new small hydroelectric plants in certain mountainous regions may lead to the destruction of the last natural zones in those regions. Thus the lasting effects of these structures may be out of all proportion to the power derived from the installation. The effects of small hydroelectric power stations on the environment are not significantly different from those of larger installations. The current regulations which deal with such installations do provide for a number of constraints on operators which are based on the size of the project and the quality of the environment. These constraints give priority to protecting the aquatic environment, and particularly the aquatic fauna as well as the countryside. A program has been established for the use of the waters in each hydrographic basin, to ensure balanced energy development that enables other uses of water to be preserved. (Baker-IVI)

TI: Small Scale Hydroelectric Development and Federal Environmental Law: A Guide for the Private Developer.
AU: Burke,-S.-H.
SO: Boston College Environmental Affairs Law Review, Vol 9, No 4, p 815-861, 1981. 315 Ref.
MJDE: *Hydroelectric-power, *Legal-aspects, *Federal-jurisdiction
MNDE: Electric-power-generation, Regulations-, Reviews-, Licensing-, Planning-, Water-use, Water-resources-management, Environmental-effects
AB: This article provides a general guide to the major federal environmental laws affecting the planning and construction of hydroelectric facilities and shows how the federal licensing process has been affected by these laws. Each statute is described in sufficient detail to familiarize the reader with the scope and purpose of the law and to allow him to predict generally its impact on a particular proposal. The article is divided into three broad areas: disclosure and consideration of environmental impacts, which describes the role of federal regulatory agencies in the evaluation of the general and resource-specific environmental impacts of proposed hydroelectric facilities before authorizing their construction; federal resource management, which provides for the protection, conservation, and management of particularly sensitive resources; and compliance with licensing procedures to ensure environmental protection. While the development of the hydroelectric potential of the country's rivers and streams will continue to be strongly influenced by the wealth of federal environmental legislation passed in the last two decades, regulatory agencies may not authorize a project before the environmental effects of the facility have been identified and considered. Special attention must be given to preservation of endangered species, fish and wildlife resources and historic resources. Proponents of hydroelectric development should be familiar with the requirements of federal environmental law and should consult with appropriate federal agencies to identify environmental impacts of such facilities. (Baker-FRC)

TI: Draft environmental impact analysis of small-scale hydroelectric development in selected watersheds in the Upper San Joaquin River Basin, California, FERC No. 5248-999.
CA: Federal Energy Regulatory Comm., Washington, DC (USA)
SO: 1984. 253 pp
NT: NTIS Order No.: DE84015549/GAR.
RN: FERC/DEIA-0001 (FERCDEIA0001)
LA: English
AB: Twelve unconstructed hydroelectric projects on ten sites located on Sand and Browns Creeks, Whisky Creek, Willow Creek, Jose and Mill Creeks, Nelder Creek, and the Lewis Fork of the Fresno River in California, are evaluated with respect to their anticipated impacts on selected target resources. The 12 projects would be operated as run-of-river projects. Each would require the installation of a diversion structure, a penstock, a powerhouse containing turbine-generators, a switchyard, transmission lines, and access roads. The total installed energy capacity of all the projects is 32 megawatts, while the average annual energy produced is estimated at 103 gipawatt hours.
DE: hydroelectric-power-plants; environmental-impact; construction-; nature-conservation; Salmonidae-; USA,-California,-San-Joaquin-R.-basin

TI: Three Case Studies of Small Scale Hydro in Newfoundland and Labrador.
AU: Bursey,-B.-W.
CS: Newfoundland and Labrador Hydro, St. John's.
SO: Canadian Water Resources Journal, Vol 6, No 3, p 163-177, 1981. 1 Fig 3 Tab, 9 Ref.
MJDE: *Hydroelectric-plants, *Environmental-effects, *Newfoundland-, *Labrador-
AB: Case studies of three small scale hydroelectric plants in Newfoundland and Labrador are presented, with emphasis on environmental concerns. These plants are designed to replace oil-based generators in areas remote from accessible fuel supplies. The Roddickton Project in Newfoundland incorporated water quality sampling, a survey to determine possible effects on Atlantic salmon upstream migration, use of untreated wood to protect a downstream municipal water supply, and stream flow regulation to protect fish habitats. At the Pinware River plant in Labrador $800,000 was spent over three years to study possible impacts on fisheries, wildlife, archeological sites, forests, a provincial recreational park, and socioeconomic aspects. The probable costs of mitigating these impacts caused indefinite postponement of this project. The Dry Pond Brook project was expected to have major impacts on fisheries and wildlife and minor impacts on recreation, historic resources, aggregate resources, and socioeconomics. Three conclusions were drawn, based on the experiences gained from these studies. Small-scale hydro projects have all the elements of larger scale projects with respect to environmental concerns. Impacts are site specific. Costs of environmental surveys are proportionately larger than in large scale projects. (Cassar-FRC)

TI: Provision of Energy Requirements for Remote Communities by Small-Scale Hydro Development.
AU: Everdell,-R.-A.; Near,-F.-M.
SO: Canadian Water Resources Journal, Vol 6, No 3, p 143-162, 1981. 7 Fig.
MJDE: *Hydroelectric-plants, *Environmental-effects, *Ontario-, *Remote-communities
MNDE: Water-resources-development, Dams-, Powerplants-, Small-scale-hydroelectric-plants
AB: Small prefabricated hydroelectric generating stations have been installed at two sites in Ontario. The Mini Hydel stations are designed to operate at heads from 3 to 8 meters. Water is delivered to turbines via open flumes at lower heads and pressure casings at higher heads. Plant outputs are 100-400 kw. Francis turbines are used with a speed increaser gearbox and a standard generator. Generally, small hydro projects are compatible with the environment. Air quality and noise effects are negligible. Water quality is affected considerably during construction but minimally in the long term. The projects produce little impact on fish, wildlife, society, or esthetics. The Wasdell Falls Project and the Sultan plant are described in detail. Future developers of small hydro plants are advised to select sites needing minimal civil work, bypass excess flows, conduct thorough preconstruction surveys, seek permits a year before planned construction, schedule construction for a single summer season, choose easy-to-build designs, minimize custom modifications, and accurately estimate required resources and work schedules. (Cassar-FRC)

TI: Aquatic ecosystem response to flow modification: Overview of the issues.
AU: Sale,-M.J.
CA: Oak Ridge Natl. Lab., TN (USA)
CO: Symposium on Small Hydropower and Fisheries, Denver, CO (USA), 5 May 1985

SO: 1985. 24 pp
NT: NTIS Order No. DE85016740/GAR.
RN: CONF-8505147-4 (CONF85051474)
LA: English
AB: Lotic ecosystems respond to modified flow regimes through changes in physical habitat availability, water chemistry and temperature, nutrient cycling, biomass/energy relationships, and the population and community dynamics of aquatic biota. A systems perspective is therefore essential in understanding flow-related impacts and in making water management decisions. More retrospective studies and experimental management are needed to provide the necessary design information for environmentally sound hydropower development. The responsibility for these studies must be shared among developers, regulators, and natural resource managers. (DBO)
DE: water-currents; fluid-flow; fishery-industry; aquatic-communities; ecosystems-; hydroelectric-power; lakes-; hydrology-; environmental-impact

TI: Legal Obstacles and Incentives to the Development of Small Scale Hydroelectric Power in Virginia.
SO: Department of Energy Report DOE/RA/04934-15, May 1980. 50 p, 1 Fig, 43 Ref.
MJDE: *Hydroelectric-power, *Institutional-constraints, *Legal-aspects, *Regulations-, *Virginia-
AB: The state laws and regulations affecting hydroelectric power development are reviewed in the context of Federal regulations and the power of the Federal government to pre-empt state regulations. The Public Utility Regulatory Policies Act of 1978 is expected to remove some hydroelectric projects from Federal jurisdiction, and also from state law. The theory of riparian rights follwed in Virginia is one of reasonable use, to the mean low-water mark on navigable waters. The Milldam Act allows a riparian owner to build a dam across non-navigable waters. Only public utilities may use the power of eminent domain. Before constructing a dam for hydroelectric power generation, a developer must obtain a license from the State Corporation Commission, and if the developer is a public utility, a certificate of convenience and necessity. Public utilities are subject to the Commission for rate setting. Numerous state regulations have an indirect impact on hydroelectric power projects because of the impact of the project on the environment, as do the Potomac River Basin Compact, the Ohio River Valley Water Sanitation Commission, and the Ohio River Basin Commission. A negligence theory has been followed, but there is a trend toward use of the strict liability theory for dam breaches. Taxing of a small-scale hydroelectric project depends on its classification as a public service corporation or as a private business enterprise. Financial incentives include the availability of loans from the division of Industrial Development and the Virginia Industrial Building Authority. (Brambley-SRC)

TI: Environmental Readiness Document, Small Scale Low Head Hydro, Commercialization Phase III Planning.
SO: Available from the National Technical Information Service, Springfield, VA 22161 as DOE-ERD-0009, Price codes: A03 in paper copy, A01 in microfiche. Report No. DOE/ERD-0009, September 1978. 28 p, 2 fig, 5 tab, 2 append.
MJDE: *Hydroelectric-power, *Turbines-, *Environmental-effects, *Research-and-development
AB: The uncertainties concerning small scale low-head hydropower technology which remain to be resolved through research and development are discussed. The characteristics of the technology are examined; status information on the technical and environmental research and development program is provided; the relationship between a considered commercialization schedule and relevant environmental research and development is charted; and environmental concerns significant to the technology are reviewed. There are three major environmental concerns associated with the retrofitting and management of low-head hydropower dam impoundments: (1) impacts on aquatic and semi-aquatic organisms; (2) effects on the downstream environments and organisms of the release of impounded chemicals and silt; and (3) use conflicts. The numerous major uncertainties associated with commercialization of low-head hydropower are represented in a diagram. Availability of sites suitable for either retrofitting old dams or building new dams is the major environmental constraint on the development of low-head hydropower. The likelihood and consequences of adverse findings, problems and uncertainties generated from current or anticipated environmental controls are examined. An assessment is made on the basis of this of the existing or potential barriers to commercialization. All conclusions are probable and based on the uncertainties which were diagrammed. There is only a low probability that an adverse finding will be determined in environmental research and development; probability is medium for technology program delays in the event of an adverse finding; and it is highly probable that energy costs will increase 10% in the event of an adverse finding. (Division-IDA)

TI: Prediction of effects of daily flow fluctuations on stream biota.
AU: Hooker,-F.F.; Otter,-D.R.
C: Mucigen State Univ., East Lansing (USA). Inst. of Water Research
SO: TECH.-COMAL.-REP.-M.-INST.-WATER-RE. EAST-LANSING,-M-USA-MS 1982. 50 p
NT: NATIS Order No.: PB83-19454; W83-02480; Contract DI-14-34-0001-1124.
RN: OWRT-A-113-MICH(1) (OWRTA113MICH1)
LA: English
AB: The short-term effects of regulated daily discharges on benthos communities were examined in a small Michigan trout stream. Flow regulation designs simulated fluctuations produced by storage and release for hydroelectric generation, as well as different constant daily stream diversions. Impacts on the dynamics of micro-distribution, species diversity, and behavior were evaluated on stable artificial substrates. Invertebrate drift rates were measured at different discharges during light and dark periods. The caddisfly Goera nigrior became less active and oriented downstream when exposed to high discharge, and underwent movements to protected substrate faces. The mayfly Baetis vagans also changed micro-positioning in response to flow fluctuations, but total density changes generally were more pronounced. There was evidence for increased species diversity during low discharges.

TI: Methodologies for assessing the cumulative environmental effects of hydroelectric development on fish and wildlife in the Columbia River Basin: Volume 2. Example and procedural guidelines: Final report.
AU: Stull,-E.A.; LaGory,-K.E.; Vinikour,-W.S.
CA: Bonneville Power Adm., Portland, OR (USA). Div. of Fish and Wildlife
SO: REP.-U.S.-DEP.-ENERGY. 1988. 62 pp
NT: NTIS Order No.: DE89007437/GAR. Contract AI79-84BP19461.
RN: DOE/BP/19461-4 (DOEBP194614)
LA: English
AB: A hypothetical example of multiple hydroelectric development is used to demonstrate the applicability of the integrated tabular methodology (ITM) that was recommended for cumulative effects assessment in Volume 1. The example consists of an existing mainstem dam and four proposed small hydroelectric developments in a small river basin containing elk summer and winter range and chinook (Oncorhynchus tshawytscha ) salmon spawning areas. Single-project impact assessments are used collectively in the methodology to estimate the cumulative effects of the projects on elk and salmon. (Portions are illegible in microfiche.)
DE: development-projects; hydroelectric-power-plants; freshwater-fish; environmental-surveys; Oncorhynchus-tshawytscha; USA,-Oregon,-Columbia-R.
ID: environmental-impact

TI: Swimming upstream: FERC's failure to protect anadromous fish.
AU: Bodi,-F.L.; Erdheim,-E.
SO: ECOL.-LAW-Q. 1986. vol. 13, no. 1, pp. 7-50
LA: English
AB: This article describes and analyzes FERC's (Federal Energy Regulatory Commission) regulatory program for hydroelectric development and operation in terms of its effect on anadromous fish. Section I describes the FERC regulatory process. Section II evaluates FERC's reluctance to comply with the statutory standards for protecting anadromous fish when FERC issues exemptions for small hydropower projects, preliminary permits, and licenses for major hydroprojects. Section III discusses FERC's troubled relationship with federal and state fish and wildlife agencies. Section IV analyzes how the Federal Water Pollution Control Act and the National Environmental Policy Act affect FERC's regulatory process. Finally, Section V briefly describes FERC's approach to the issuance of exemptions for small hydroelectric projects.
DE: government-policy; anadromous-species; freshwater-fish; marine-fish; hydroelectric-power-plants; population-dynamics; USA-

TI: Effects of variable discharge schemes on dissolved oxygen at a hydroelectric station.
AU: Mathur,-D.; McClellan,-E.S.; Haney,-S.A.
SO: WATER-RESOUR.-BULL. 1988. vol. 24, no. 1, pp. 159-167
LA: English
AB: The effects of variable discharges during the summer on the dissolved oxygen (DO) content and water temperature upstream and downstream of the Conowingo Hydroelectric Power Station were investigated. The

DO dynamics are controlled primarily by meteorological factors that are independent of the mode of hydrostation operation. DO stratification occurred during the summer in Conowingo Pond, but thermal stratification was not observed. The magnitude and duration of off-peak discharges including a run-of-the-river operation did not affect DO stratification in Conowingo Pond; little vertical mixing occurred.
DE: DO-; water-quality; electric-power-plants; temperature-; meteorology-; dissolved-oxygen; hydroelectric-power-plants; power-plants; USA,-Maryland,-Susquehannah-R.

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## A.9 Potential Effects on Birds.

**Summary**

The principal river birds in upland locations likely to be the sites of hydropower schemes are dippers and grey wagtails.

Effects can arise either directly through alterations in discharge, current velocity, substratum character and wetted perimeter, or indirectly by alterations in food supply and available habitat. All these ideas are currently based on surmise and qualitative prediction, and no real data are available.

Key questions for monitoring will be to assess whether any detrimental effects are sufficient to affect important population parameters such as density, territory length, breeding performance or survival.

**Introduction**

The principal bird species present along upland British streams will be aquatic insectivores such as the dipper and riparian insectivores such as the grey wagtail (Table A1). Typical densities of both are 2-10+ pairs per 10km, and there are respectively 7-21,000 and 34,000 pairs currently breeding in Britain (Gibbons *et al.* 1993, Tyler and Ormerod 1994). The occurrence of other species will depend on stream character in any particular instance, but might include common sandpiper, kingfisher, goosander, sand martin, although all are less likely on the sites currently under consideration for hydropower development (Table A2). Any effects are thus likely only on the periphery of their normal range. Similarly, species more casually associated with rivers, such as pied wagtail and pied flycatcher, are liable to be affected only at the periphery of their niche space, hence effects will be marginal in the extreme. These species are not considered further here, although the conceptual model given below can act as a guide for predicting any effects.

At present, understanding the effects on river birds of hydropower schemes depends largely on surmise and qualitative prediction. A conceptual model is shown in Figure A1. It displays potential routes through which changes in discharge, current velocity, hydraulics and wetted perimeter might affect birds either directly, or indirectly through changes in habitat character and/or food supply. Note that changes in some instances will be highly interdependent (e.g. boxes 1-3), so that their influences cannot be separated in any straightforward fashion, and they are considered here to act in combination.

**Table A1 Typical bird species which breed along British rivers**

Little Grebe
Great Crested Grebe
Heron
Mute Swan
Canada Goose
Mandarin[2]
Mallard
Tufted Duck
Goosander[1]
Red-breasted Merganser[2]
Moorhen
Coot
Oystercatcher
Lapwing
Curlew
Redshank
Common Sandpiper[1]
Little Ringed Plover[2]
Kingfisher[2]
Yellow Wagtail
Grey Wagtail[1]
Pied Wagtail[2]
Dipper[1]
Sedge Warbler
Whitethroat
Reed Bunting
Sand Martin

Notes: Those marked [1] and [2] are most likely in upland and river mid-reaches, respectively.

**Table A2 Bird Species encountered at 74 sites along upland Welsh Rivers in the Cambrian Mountains and Snowdonia during surveys in 1995**
The results are from the first of three repeat surveys over 2 km at each location.

| | Number of sites | Number of individuals |
|---|---|---|
| Grey Heron | 1 | 1 |
| Teal | 1 | 2 |
| Goosander | 5 | 14 |
| Red-breasted Merganser | 1 | 2 |
| Kingfisher | 1 | 1 |
| Dipper | 23 | 44 |
| Grey Wagtail | 31 | 83 |

Questions that will be germane in any hydropower schemes which go ahead, and in monitoring work involving birds, are:

i) Are the direct and indirect changes in river bird habitat that are predicted here born out in reality?
ii) Are there gains in habitat quality which offset losses?
iii) If losses occur are they sufficient to affect important population parameters, such as density, territory length, breeding performance and survival?
iv) Are any of the changes which occur in important population parameters likely to be important in conservation terms?

**Changes in discharge, hydraulics and velocity**

Direct effects

Changes in discharge, velocity and hydraulics will have direct effects on the dipper through changing foraging behaviours and hence energetic cost. In general diving activity declines with decreasing average velocity and water depth (O'Halloran *et al.* 1990). As an example, reduction in diving (energy cost c 219 J/g/h) as a foraging method will result in reduced energy expenditure since normal foraging is less energetically expensive (64 J/g/h); in summer diving occupies almost none of the active day, but in winter can occupy up to 20-40 % (or 2 - 4 h out of a total time spent foraging of up to 8 hours on base-poor streams). Total elimination of diving during winter could thus result in actual energy savings of 18,600 - 37,200 J per 60g individual per day, around 10 - 15 % of typical daily energy expenditure at this time. This extreme saving is unlikely given that pronounced increases in discharge will still occur in hydropower schemes despite water abstraction.

Habitat selection is also important in foraging dippers in ways that vary through the annual cycle. Any change in discharge that results in alteration in average depth might give advantages at certain times. For example, recently fledged and inexperienced birds perform best in shallower, slow-flowing water (Yoerg 1994). Moulting adults (in July-September) also experience temporary flightlessness, due to simultaneous loss of 4 inner primaries, and might gain foraging opportunity where discharge declined.

Indirect effects

Indirect effects from changes in velocity through food supplies will depend on the mix of velocities which result, on the response of particular key prey, and on other confounding effects such as siltation, retention of organic matter and altered temperature regimes. Prey organisms sensitive to current velocity include those important to the dipper such as mayfly nymphs, net-spinning caddis and fish (Table A3). Increase in the retention of organic matter along stream reaches might be expected to favour leaf shredders at the expense of epibenthic grazers (Dobson *et al.* 1995), a change liable to increase the density of some organisms avoided by dippers (e.g. stoneflies), but some also which are favoured (e.g. caddis larvae).

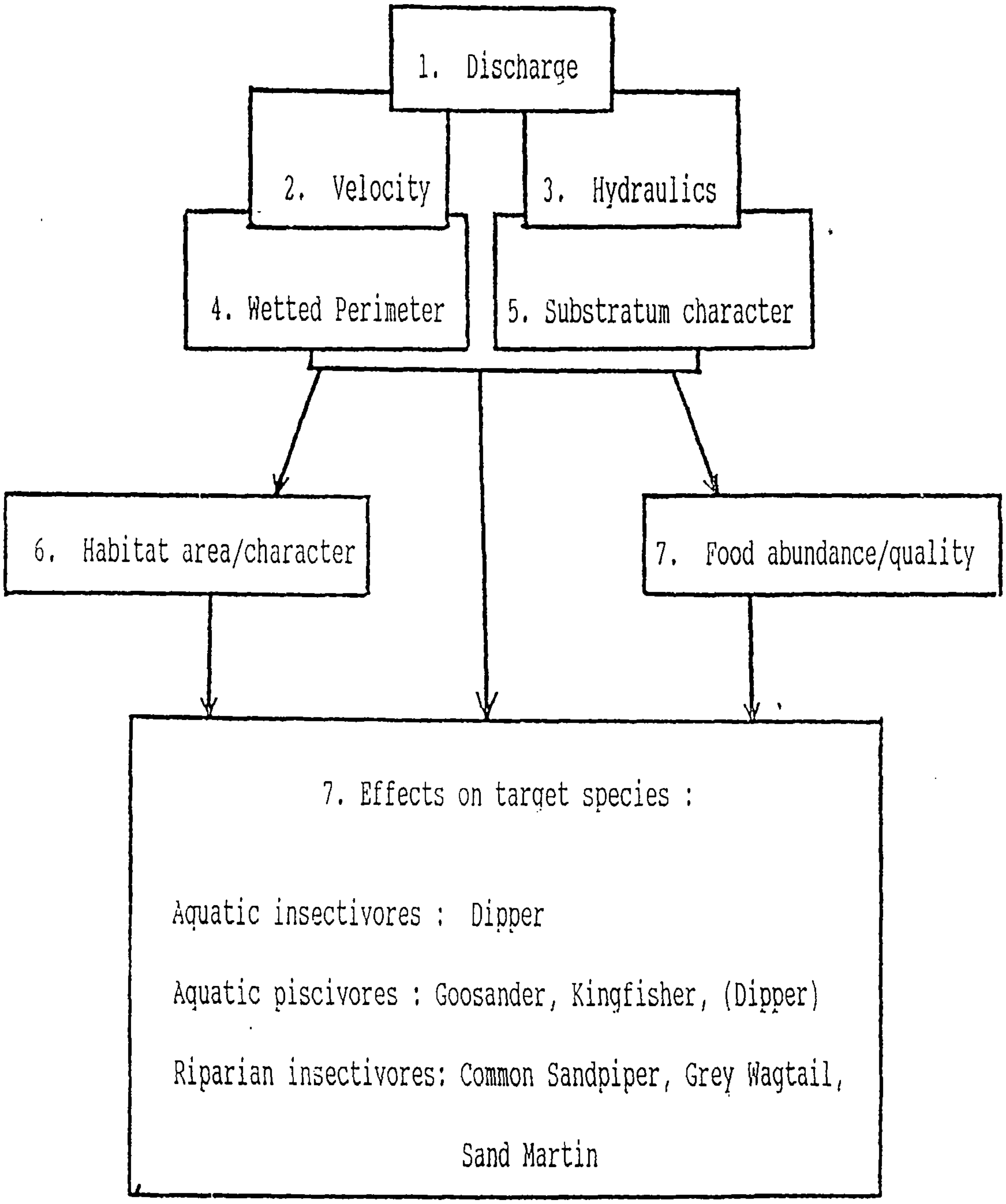


**Figure A1** **A conceptual model indicating routes through which river birds might be influenced by run-of-river hydropower**

**Table A3** **The estimated percentage contributions (by weight) to the diets of dippers on acidic and circumneutral streams in Wales at different times of the year (from Ormerod and Tyler 1991)**
Breeding is taken as April - June inclusive, Moult as July - September inclusive, and Winter as October - March. No data were available from acidic streams during moult. Data from the breeding season have been combined for nestlings > 5 days old (O.N.) as opposed to those < 5 days old (Y.N.).

| | Circumneutral streams | | | | | | Acid streams | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Breeding | | | | Moult | Winter | Breeding | | | | Winter |
| | Y.N. | Adults | O.N. | Adults | | | Y.N. | Adults | O.N. | Adults | |
| Molluscs | 0 | 0 | 0 | 0 | 0 | 6.1 | 0 | 0 | 0 | 0 | 0 |
| Crustacea | 0 | 0 | 0 | 0 | 0 | 3.2 | 0 | 0 | 0 | 0 | 0 |
| Mayflies | 35.3 | 19.6 | 3.8 | 17.1 | 7.3 | 3.2 | 6.1 | 0 | 0.2 | 1.3 | 0 |
| Stoneflies | 18.8 | 4.9 | 0.8 | 1.7 | 0.7 | 1.3 | 20.2 | 33.5 | 4.2 | 36.3 | |
| Caddis | 45.7 | 75.4 | 80.9 | 51.4 | 69.4 | 19.3 | 73.6 | 64.6 | 95.5 | 61.3 | 60.1 |
| True-flies | 0.2 | 0.1 | 0.1 | 0.8 | 3.4 | 3.1 | 0.1 | 1.9 | 0.1 | 0.8 | 7.7 |
| Others | 0 | 0 | 8.5 | 1.6 | 0.1 | 0.3 | 0 | 0 | 0 | 0 | 0.1 |
| Fish | 0 | 0 | 5.9 | 27.4 | 19.1 | 63.8 | 0 | 0 | 0 | 0 | 0 |

Detailed predictions are not possible without further information, and demonstrate the need to account for changes in prey abundance if ornithological studies are carried out during hydropower schemes.

## Changes in wetted perimeter

Direct effects

Reductions in discharge might be taken up by reduced velocity and/or reduced wetted perimeter in combinations which will vary between and within stream reaches. Much will depend on the physiography of the river in question, but any direct loss of riffle habitat for dippers will be matched by gain for grey wagtails. While dippers for much of the year feed from shallow shingle and pools, grey wagtails feed predominantly from riverside shingle (Ormerod and Tyler 1991a), but are also highly flexible in exploiting rapidly changing foraging opportunities.

For the dipper, reductions in wetted perimeter are potentially more profound. Pairs crop a substantial biomass from rivers annually (0.9 - 2.3 g dry mass per sq metre per year; Ormerod and Tyler 1991b) which for some food groups represents a substantial proportion of the total produced. The defence of large territories is a necessity to provide such production, and territory lengths in upland Wales range from around 0.4 to 2.5 km with lengths greater along base poor streams. Territory areas here exceed 10,000 sq m, so that dippers along a stream of 5 m width would occupy a length of 2 km. Progressive reductions in wetted perimeter, say to 4 m and 3 m, might lead to a need to increase territory length to 2.5 or 3.3 km. Territory defence might become uneconomic, or alternatively reduction in breeding productivity or body condition might decline as in the case of acidification (Ormerod *et al.* 1991).

Reduction in wetted perimeter might also lead to the exposure of nest sites to access by ground predators, usually excluded from dipper nests by their inaccessible position over water.

Indirect effects

Indirect effects on dippers of alterations in stream wetted perimeter might be mediated by alterations in food supplies and habitat structure. Much will depend on the specific habitats affected and on the prey they contain. For example, cased caddis from the Limnephilidae are particularly important to dippers in feeding growing young, and occur predominantly in shallow habitats at the stream margins (Ormerod 1988). Any reductions in the availability of this habitat would have ramifications if prey density declined, and if similar habitats were not available under the new flow regime.

**Changes in substratum character**

Direct effects

Direct changes in substratum character, such as alterations in bryophytes cover or particle size structure, have potential ramifications for river birds if preferred feeding habitats are affected. Little quantitative information on the choice of substratum types by foraging dippers is available, although casual observation suggests they use riffles where substrata of pebble to cobbles are present. Occasional foraging over bedrock or sand occur if epibenthic prey such as caddis larvae are present.

Changes in substratum character, such as increased deposition by fine material, might affect preferred habitats.

Indirect effects

As with changes in wetted perimeter, any effects of altered substratum character through altered food abundances will depend on habitat type and prey type.

**Monitoring needs**

The fundamental requirements of a research programme for birds are for pre- and post-scheme monitoring at a replicated series of sites, matched to adequate reference sites. Effects parameters include territory size, breeding performance, nest survival, time-activity pattern, energetics, food availability, nest provisioning, diet and adult condition. Among these parameters, some will be recorded sufficiently at a small number of sites (e.g. energetics, time-activity). Others would accrue only from extensive numbers (e.g. quantifiable breeding performance).

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