Case study project on Heavily Modified Waters in Scotland – Case Study on the River Dee

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Executive Summary

This study arises in the context of the Water Framework Directive (2000/60/EC), brought into force on 22 December 2000. Its focus is the identification and designation of Heavily Modified Water Bodies (HMWB), a mechanism by which the normal requirements of the Directive may be altered on account of environmental, practical or economic considerations in relation to the present uses of water bodies. In a Heavily Modified Water Body, the normal standard of Good Ecological Status is replaced by a locally adapted standard of Good Ecological Potential.

The research comprises three case studies – for the Forth Estuary, the River Tummel (Perthshire) and the River Dee (Galloway). The purpose of the studies has been to trial the process of identifying water bodies which may require designation under the terms of the Directive, and to trial the designation process.

The study areas for Scotland were chosen to focus on the hydro power industry and "transitional" (estuary) waters, as part of a co-ordinated United Kingdom effort. More widely, the studies contribute to a total of 32 studies undertaken across Europe, covering a broad range of water body types and major water body uses, and across the diversity of social, economic and cultural conditions encompassed within the European Union. At the time of writing this Executive Summary, the Scottish studies had already made a substantial contribution to the formulation of pan-European guidance, which will ultimately be issues to all Member States and used to help deliver effective and appropriate implementation of the Directive.

Each of the three Scottish reports follows a common format. After a brief Preface and summary of key statistics (Chapters 1 + 2), an Introduction (Chapter 3) provides local background specific to the study. A Description of the Case Study Area (Chapter 4) provides a broadly-based context covering physical characteristics of the water bodies, land and water use of the study area, and relevant socio-economic descriptions. Chapter 5 deals with the Physical Alterations to water bodies in the study area, including hydrological and morphological changes. Such information is vital since designation applies only to physically altered water bodies. Chapter 6 addresses equally important assessments of Ecological Status. The Identification and Designation of HMWBs is reported in Chapter 7, along with the appropriate justifications, following the rubric of the Directive. For those bodies designated, Chapters 8 and 9 respectively outline the Definitions of Maximum and Good Ecological Potential and their justifications. These are key to the establishment of management objectives which will form an important part of the implementation of the Directive. Finally, Chapter 10 provides Conclusions, Options and Recommendations.

The reports each provide insight and recommendations for the future application of the Directive – both in the study areas and more widely. They consider the basis on which water bodies may be identified. They indicate the results of ecological status assessments – water bodies classified as less than "Good" on account of physical alterations must be

considered for designation. Alternative means of achieving the ends presently supported by the water bodies are considered, along with their likely costs, benefits and viability in order to identify optimum environmental solutions. The results of designation testing are presented, and in most cases involve HMWB status being awarded.

Keywords

Heavily Modified Water Body, Water Framework Directive, ecological status, physical alteration, pressures and uses, identification, environmental options, designation, Maximum Ecological Potential, Good Ecological Potential

PART I

1 Preface

On 22nd December 2000, the Water Framework Directive (WFD) was adopted. The WFD is a major legislative initiative, which is intended to resolve the piecemeal approach to European water legislation, which has developed since 1975. The overriding goal of the Directive is that Member States should aim to achieve "good status" in all bodies of surface water and groundwater, and also to prevent deterioration in the status of those water bodies.

Under the agreed common strategy for implementation of the Directive, a number of working groups have been established to “develop informal guiding and supporting documents on key aspects of the WFD”. There will be at least 10 working groups, Project 2.2. is the working group to develop guidance on the designation of HMWBs.

The EU Project 2.2 will co-ordinate *Case Studies* in a number of member states for the identification and designation of Heavily Modified Waters and the identification of good ecological potential under the proposed requirements of the Water Framework Directive (Article 4(3)). The EU project will produce a synthesis of experience from member state case studies and will identify best practice, consensus or differences in approach taken by member states in the case studies. The case studies chosen from all member states include riverine and estuarine/coastal areas and represent a range of modifications (navigation, flood defence, coastal defence, hydropower, agriculture/forestry, water supply, urbanisation etc) and size of catchment area (small-large).

The output from the EU project (with special reference to the UK case-studies) will be used to help develop technical guidance for the identification and designation of heavily modified water bodies in the UK.

This project represents part of the Scottish contribution to the EU HMWB project, and in particular to the work of the hydropower sub-group of case studies. The work is sponsored by the Scotland and Northern Ireland Forum For Environmental Research (SNIFFER).

2 Summary Table

	Item	Unit	Information
1.	Country	text	UK
2.	Name of the case study (name of water body)	text	River Dee
3.	Steering Committee member(s) responsible for the case study	text	Martin Marsden
4.	Institution funding the case study	text	SNIFFER
5.	Institution carrying out the case study	text	Contractor
6.	Start of the work on the case study	Date	January 2001
7.	Description of pressures & impacts expected by	Date	June 2001
8.	Estimated date for final results	Date	December 2001
9.	Type of Water (river, lake, AWB, freshwater)	text	river
10.	Catchment area	km^2	1050
11.	Length/Size	km/ km^2	78.5 km river; GIS estimates: 588 km river channel; 33 km^2 standing waters
12.	Mean discharge/volume	m^3/s or m^3	$41.7m^3$ /s
13.	Population in catchment	number	4500
14.	Population density	Inh./km^2	23
15.	Modifications: Physical Pressures / Agricultural influences	text	Hydropower
16.	Impacts?	text	construction of dams, cross catchment transfer
17.	Problems?	text	Variation of lake levels, artificial river flow regimes & low flows
18.	Environmental Pressures?	text	
19.	What actions/alterations are planned?	text	
20.	Additional Information	text	
21.	What information / data is available?	text	Flow data, biological survey data.
22.	What type of sub-group would you find helpful?	text	Hydropower
23.	Additional Comments	text	

3 Introduction

3.1 Choice of Case Study

The Dee study area is one of two chosen in the UK as examples of water bodies affected by hydro power development. Approximately 20% of the land area of Scotland contributes water to hydro power schemes (and further areas in England and Wales), so trials of the HMWB designation process are clearly important in a UK context. The Dee study area has been chosen as an example of one of the earliest major hydro schemes developed in the UK (1930s), and one in which most of the runoff harnessed originates directly within the controlled catchments (rather than in adjacent areas). These characteristics contrast with the Tummel case study, the other UK hydro study, so that two substantially different types of scheme are investigated. Findings from the two studies are therefore complementary.

3.2 General Remarks

This case study focuses on the River Dee catchment in Galloway, southwest Scotland (Figure 1). It deals with the impacts of the Galloway hydro-electric scheme and contributes to the outputs of the Hydropower sub-group.

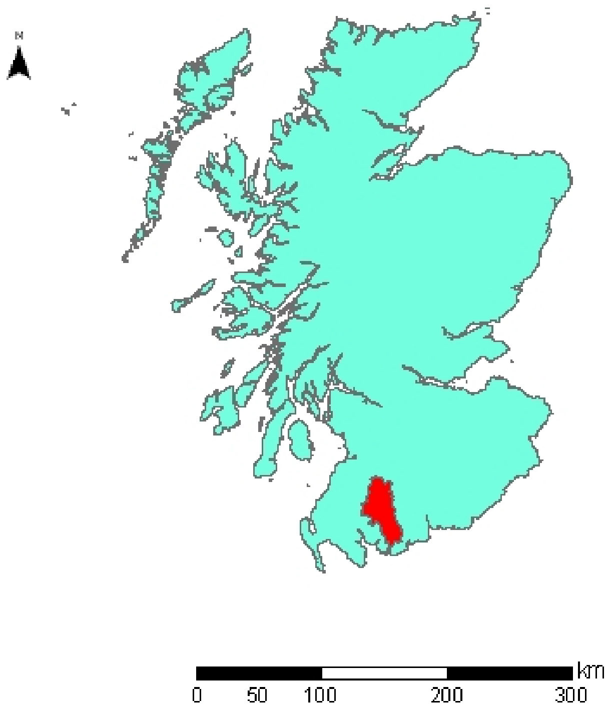

Figure 1 Location of the Dee (Galloway) catchment (red) within Scotland.

The project has been conducted against the background of the 2001 outbreak of Foot and Mouth Disease in the U.K., which affected Galloway particularly seriously. As a result, visits to the area by the contractor's research team were severely restricted, with repercussions for the way in which the work was achieved. It was not practical for the team to undertake the planned programme of fieldwork, and local staff of the Scottish Environment Protection Agency (SEPA) were able, late in the season, to carry out only the portion of the targeted biological sampling programme that could be achieved without crossing agricultural land. As a result the work has relied heavily on published literature, information from SEPA, local authority archives and invaluable advice and assistance from local experts.

In spite of these limitations, the exercise has produced useful results. A clear framework has been developed for discretizing the catchment into constituent water bodies and this provides the basis for subsequent appraisal of ecological status. A typology has been developed in concert with the companion Tummel Report that will be used for establishing the ecological potential of water bodies ultimately designated as heavily modified.

Primary data from previous surveys, including invertebrate and RHS work, is available but not always easy to interpret without reference standards, and comprehensive fisheries data are available due to the on-going research activities of the West Galloway Fisheries Trust.

4 Description of Case Study Area

4.1 Geology, Topography and Hydrology

The catchment of the River Dee (Galloway) is situated in the Southern Uplands of Scotland. It covers an area of 1021 km^2 (Sinclair and Ribbens 1996) and reaches a peak altitude of 814 m above sea level (a.s.l., equivalent to U.K. Ordnance Datum) at Corserine in the Rhinns of Kells range of hills. Deformed, principally argillaceous, sedimentary rocks of marine derivation underlie most of the area. The northern part of the catchment is dominated by rocks of Ordovician age (c. 440-505 Ma), while younger, Silurian (c. 410-440 Ma) sequences are prevalant in the south. Both these formations, which are distinguished on the basis of their fossil content, are dominated by sequences of interbedded black shales and greywackes, together with local conglomerates, sandstones, impure limestones and tuffs. Outcrops of two major Caledonian age (c. 400 Ma) granite intrusions are important lithological features in the western sectors of the catchment. These are the Merrick pluton emplaced into the Ordovician rocks and the Cairnsmore of Fleet pluton emplaced into the Silurian rocks, respectively to the north and south of Clatteringshaws Loch (Figure 2). There are also numerous outcrops of minor associated intrusions throughout the area. Pleistocene till mantles much of the catchment, with valley floor alluvium and peat being of local importance (Figure 3).

The Galloway Dee is a freshwater system made up of a network of rivers[1], streams and lakes[2] (Figure 4), the main rivers extending to 78.5 km (Sinclair and Ribbens 1996), with 588 km of river/stream channel and 33 km^2 of standing waters included in the Ordnance Survey Meridian digital dataset. The upper part of the catchment is drained by the Carsphairn Lane and the Water of Deugh which join at Kendoon Loch and continue as the Water of Ken, becoming the River Dee at the confluence with the Black Water of Dee. The River Dee continues through Tongland Loch whose lower end is close to the tidal limit, and then through a *ca*. 8 km long estuary before discharging into Kirkcudbright Bay. The catchment area of the Glenlochar gauging station, 20 km upstream of the tidal limit, is 809 km^2. The annual mean discharge was 41.46 m^3s^{-1} during the 18-year period ending in 1995. Additional flow statistics are shown in Table 1.

[1] For the purposes of the Water Framework Directive, “River“ means a body of inland water flowing for the most part on the surface of the land but which may flow underground for part of its course. The same definition is adopted here for streams, which differ from rivers in that their catchments are smaller. Following HMW paper 7 ver 2, rivers and streams are taken to include the bed, channel and any part of the adjacent land which is clearly influenced by the water regime (restricted riparian zone); the latter is generally very limited within this particular system.

[2] Defined for the Directive as “bodies of standing inland surface water“; generally known in Scotland as “lochs“.

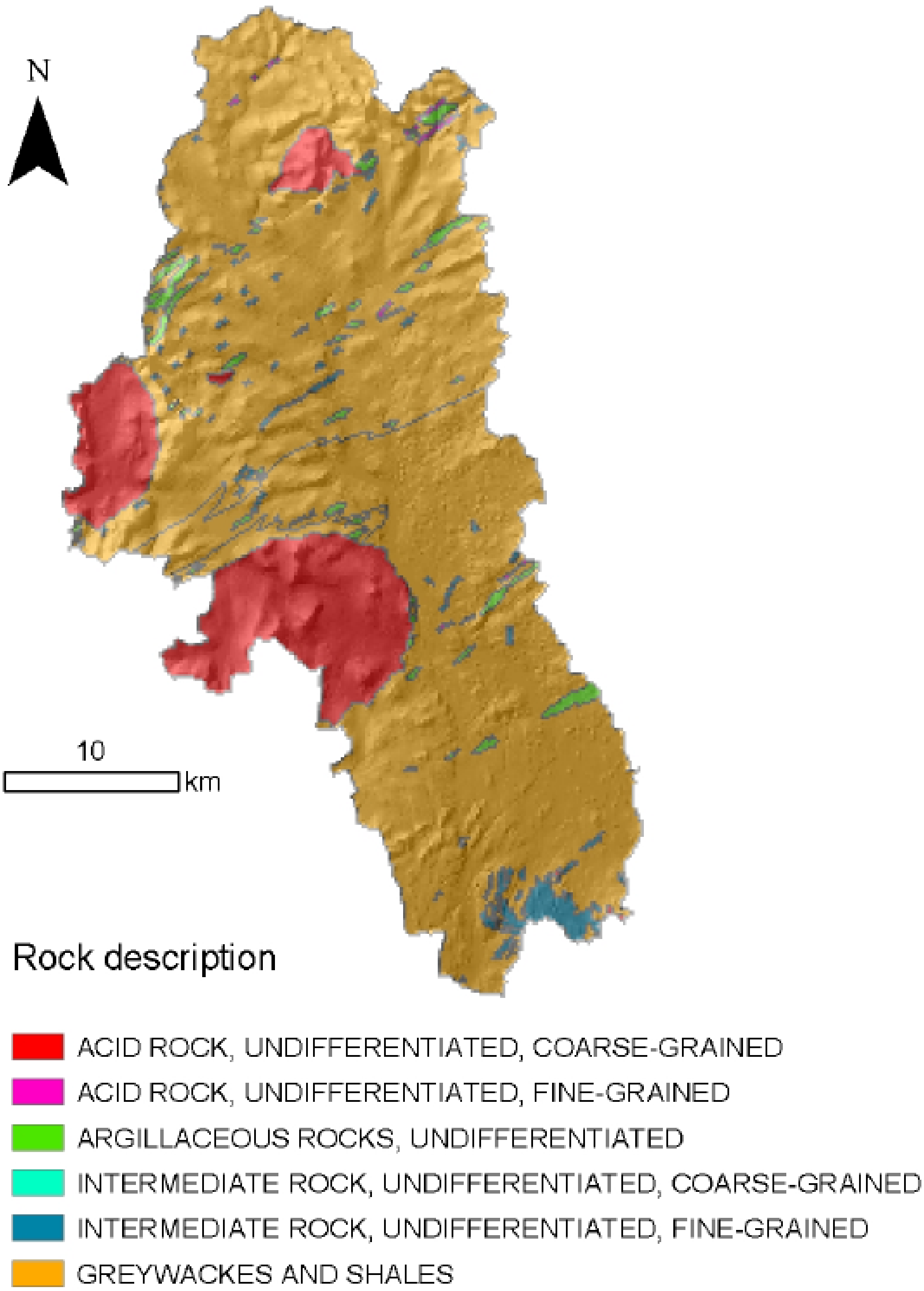

Figure 2 Solid geology of the River Dee (Galloway) catchment.

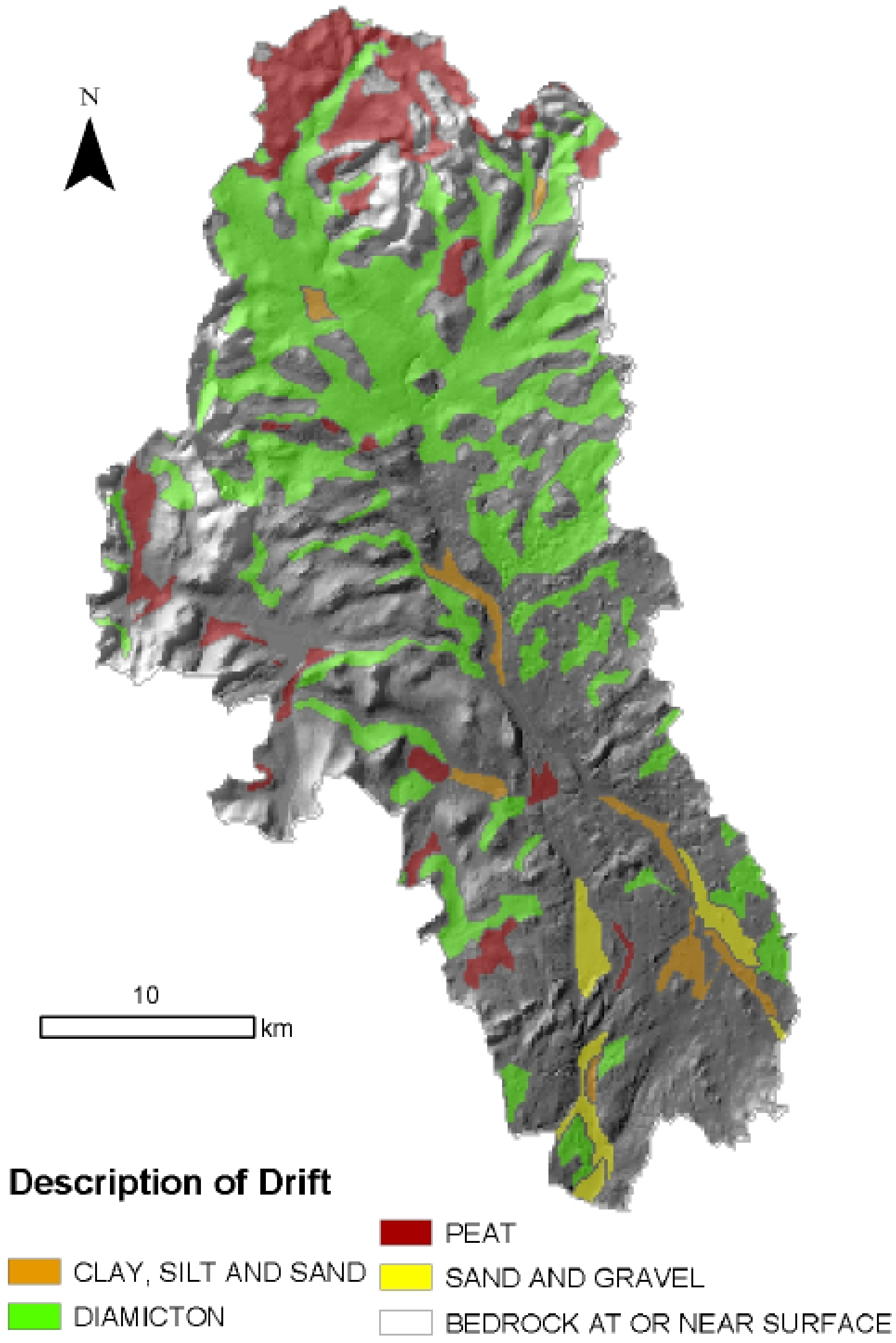

Figure 3 Drift geology of the River Dee (Galloway) catchment.

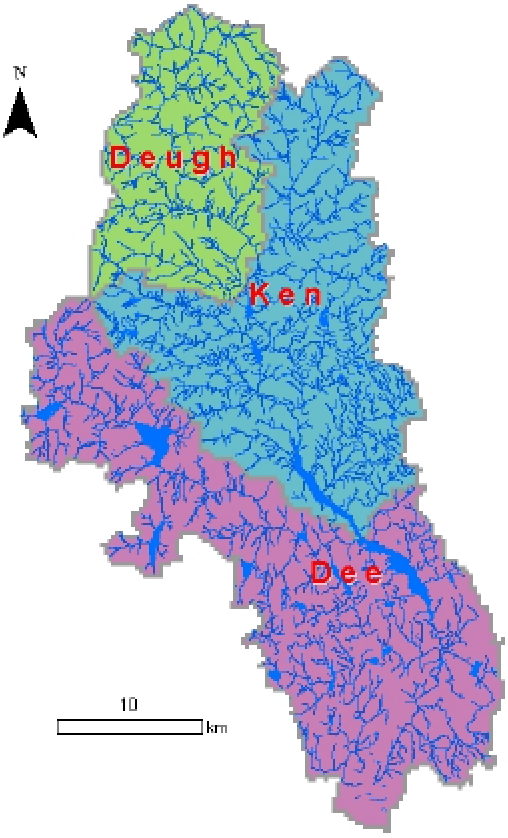

Figure 4 Principal sub-catchments of the River Dee (Galloway) system.

Table 1 Flow statistics for the River Dee at Glenlochar (gauging station 080002). From Marsh and Lees (1998).

Period of record	1977 to 1995
Mean annual rainfall (mm)	1888
Mean annual runoff (mm)	1616
Maximum annual runoff (mm) ; *year*	1874 ; *1982*
Minimum annual runoff (mm) ; *year*	1368 ; *1978*
Minimum monthly flow ($m^3 s^{-1}$) ; *month, year*	2.06 ; *08, 1984*
Base Flow Index*	.40
10 percentile ($m^3 s^{-1}$)	102.7
95 percentile ($m^3 s^{-1}$)	3.38

* Base Flow Index (BFI) is the fraction of total runoff occurring in slow-flow periods.

4.2 Socio-Economic Geography and Human Activities in the Catchment

The Dee catchment area[3] has a low population density close to the figure for Dumfries and Galloway region as a whole (0.23 persons per hectare). Most people live in the only urban settlement in the area, Castle Douglas, whose 1999 population was estimated by the General Register Office Scotland to be 4070 people. Only a few hundred people are found in the rest of the catchment. Minor settlements include St John's Town of Dalry, Balmaclellan, Crossmichael and Rhonehouse. One major artery (the A75 Stranraer to Dumfries road) traverses the catchment, but much of the traffic on this route simply passes through the region without stopping.

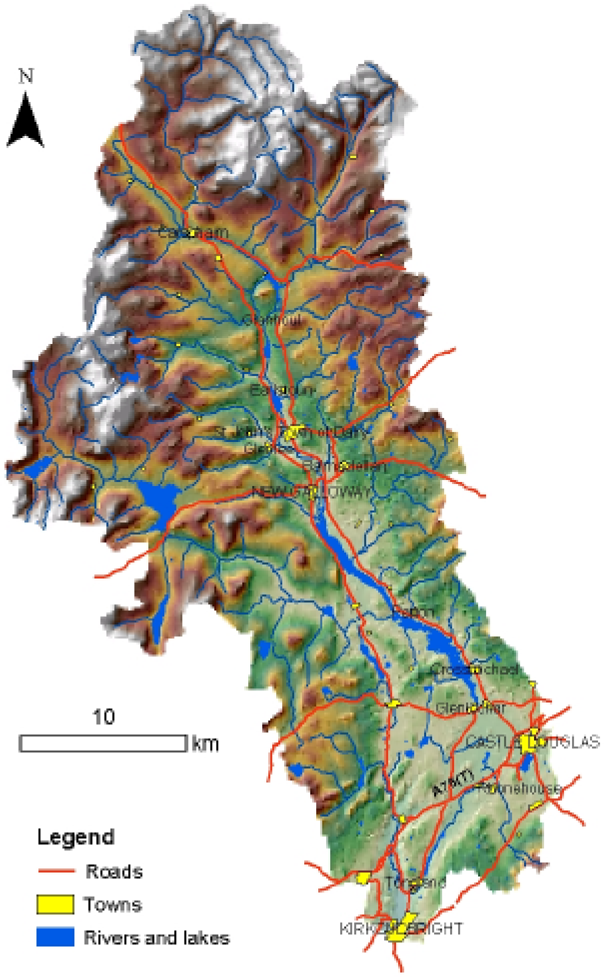

Figure 5 Settlements and roads of the Dee (Galloway) catchment.

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[3] The census geography of the catchment as reported in the main text was based on two postcode sectors (DG 7.2 and DG 7.3). Excluded from the analysis were the census output areas in DG 7.2 relating to the town of Kirkcudbright and its immediate hinterland. The census data reported in the text therefore relates to DG 7.3 and output areas 5810AH06, 5810AH09, 5810AH10, 5810AH11, 5810AH12, 05810AH13, 05810AH14a and 5810AH14b.

As for other parts of rural Dumfries and Galloway, the population has risen only slowly over the last decade (1991-99 population growth rate of 0.04 per cent) as a result of net-in migration. Unlike rural areas which are more accessible to urban Scotland, the Dee catchment has only attracted a modest level of retirement net in-migration.

The 4368 people recorded in the 1991 census exhibited an atypical age structure. In terms of household composition, 23.0 per cent of residents were of pensionable age compared with only 17.5 per cent across Scotland as a whole. Like many other parts of rural Scotland, the Dee catchment experienced the inverse effect of having a population with fewer dependent children (19.0 per cent) than the Scottish average (22.0 per cent).

Some 19.4 per cent of households have only one person, considerably fewer than the Scottish average (28.2 per cent). The stereo-typical family of two adults and dependent children make up a further 23.1 per cent of households. In terms of housing tenure, the 63.2 per cent of households which are owner occupied place the area well above the Scottish average (52.1 per cent). The housing stock is made up almost exclusively (96 per cent) of low rise, detached and semi-detached properties.

The most recent reliable migration figures remain those provided by the 1991 census (based on migration in the previous 12 months). At the time, the Dee catchment area had a mobility rate (10.9 per cent) that was only slightly higher than the national average. Population estimates for the 1990s suggest that net in-migration has continued, although at a slower pace than in the 1980s. A large proportion of movers were migrants from other regions of Scotland or from outside Scotland (27.2 per cent in the Dee catchment, compared with an average of 8.0 per cent for Scotland as a whole). The area therefore experiences moderate levels of population turnover involving migration from further afield than would be expected in a typical Scottish region.

In terms of the economically active cohorts, the area has an activity rate (89.6 per cent) that is slightly below the Scottish average (90.9 per cent). Agriculture and forestry account for 28.2 per cent of those over the age of 16 in active employment - farming is the dominant player in the area’s rural economy with 27.0 per cent of economically active persons working as farmers or agricultural employees (Scottish average = 2.5 per cent). Outside the agricultural sector, the single largest occupational category is 'employers and managers' (14.3 per cent). Many of these are small business people engaged in the tourist industry or related tertiary activities (22.2 per cent of employment is in the distribution and catering sector). Castle Douglas is undoubtedly the main focus of tourist activity, although clearly other minor nodes exist along Loch Ken and in relation to the National Trust's Threave Gardens, south of Glenlochar. Clearly both sectors of the rural economy discussed above have suffered much during recent months from the effects of the foot and mouth outbreak.

4.3 Identification of Water Bodies

Development of the approach to identification of water bodies is described in the companion report on the River Tummel (Black *et al*. 2002). It is based principally on recognition of "hydromorphological" and "effective management" units. Although moving and standing waters are generally regarded as separate segments of the system, the distinction between them assumes subsidiary importance.

The network of rivers and streams was first divided into primary hydromorphological units (segments), namely:

- Carsphairn Lane / Water of Ken main stem
- Black Water of Dee / River Dee main stem
- Tributaries to the main stems

The watercourses that are affected by hydro-power generation were readily identified because they contain structures such as dams and weirs. Since each obstruction has upstream as well as downstream impacts, the whole of any segment containing such a structure was considered. Mitigation is likely to be directed at the structures which might, therefore, be placed at the centres or at the boundaries of effective management units (Wimmer *et al*., 2000). The second option was adopted for two reasons: (a) because different reference criteria would apply upstream and downstream of impoundments constructed at the outlets of previously existing lakes, and (b) because this would result in definition of units that might later be combined to yield a scheme equivalent to the first option if desired. The units so defined were further subdivided on hydromorphological grounds, principally at any boundary between river/stream and standing water. Several additional boundaries were deemed useful at the confluences of the main channels with particular tributaries. On the other hand, several sets of unimpacted tributaries and segments of tributaries upstream of "farthest-upstream" structures were grouped, on the basis of similar impacts, to form large composite water bodies.[4] Once defined, the water bodies were grouped according to the structure from which their modification arises, and finally according to the highest power station of the cascade at which the water collected by the structure(s) is used. A link between hydrological/ecological impact and generation of electricity (and therefore of revenue) is thus established.

Figure 6 shows the extent of each group of water bodies, and the detailed composition of each group is shown in Figures 7 to 11.

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[4] For example, Water Body K07 (Figure 9) includes at least 8 tributaries of the Carsphairn Lane, the Water of Deugh and the Water of Ken. The only impact of hydro-power generation on these tributaries is that structures downstream may compromise their connection to the sea and thus disrupt river continuity especially with regard to access by migratory fish.

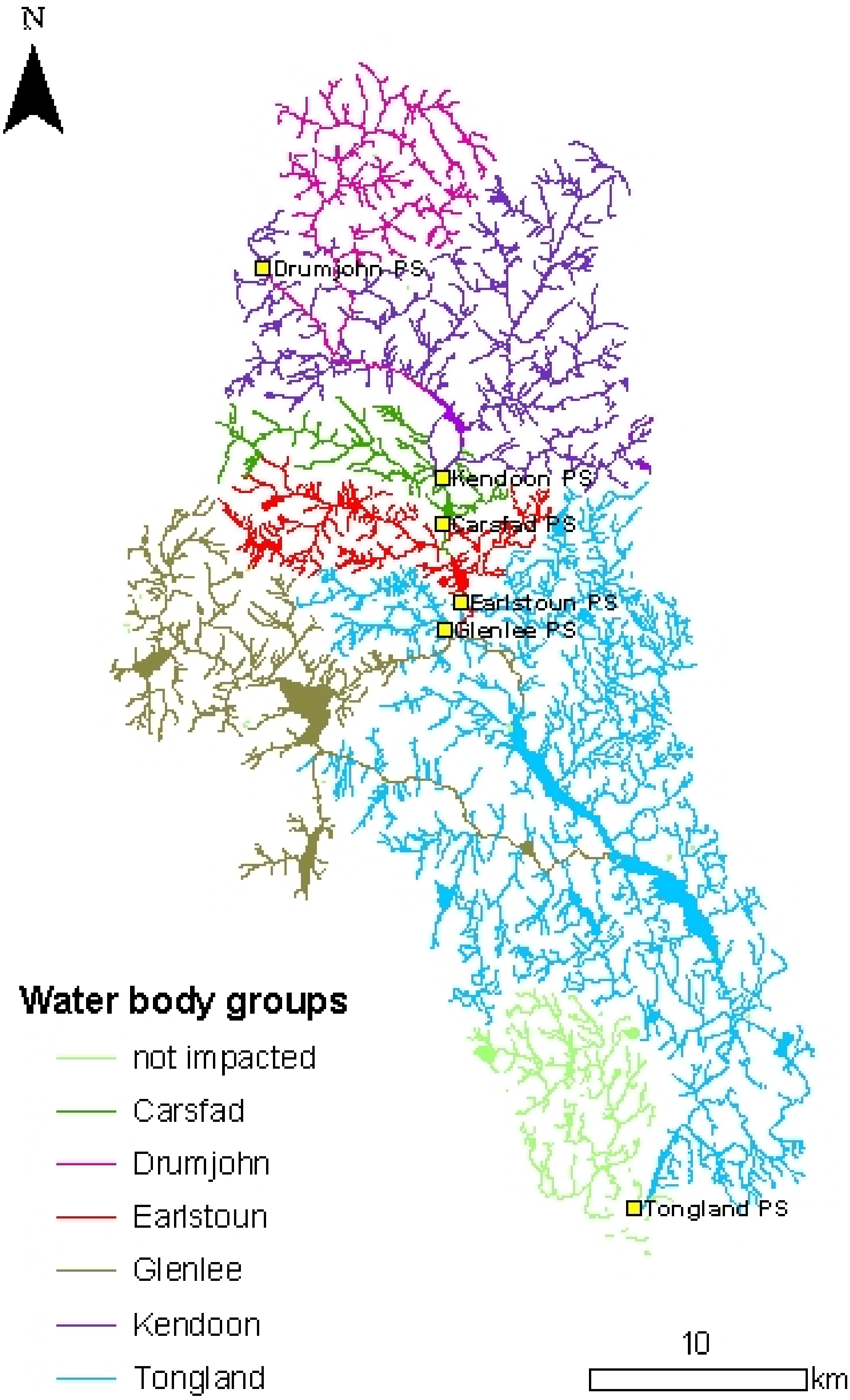
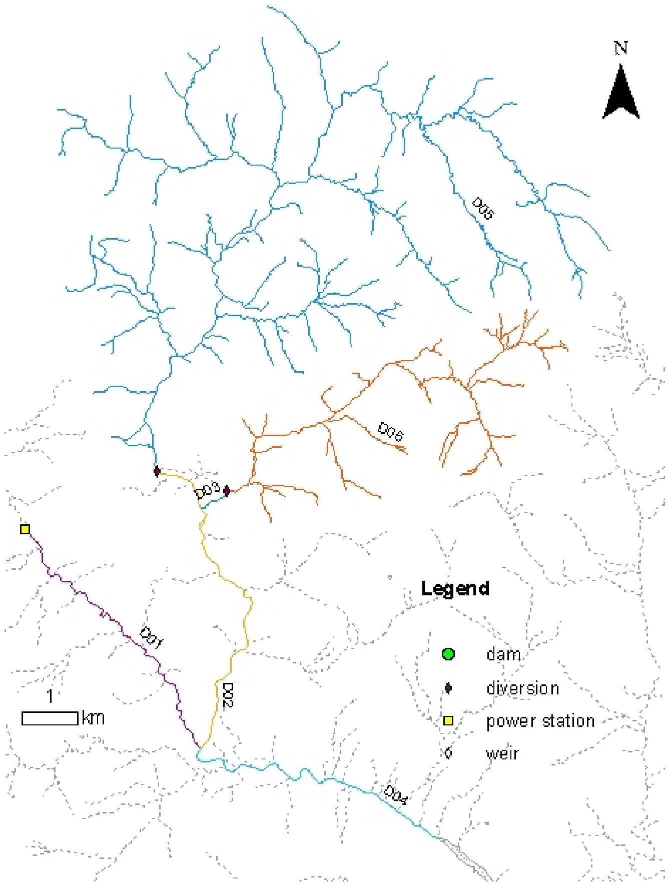
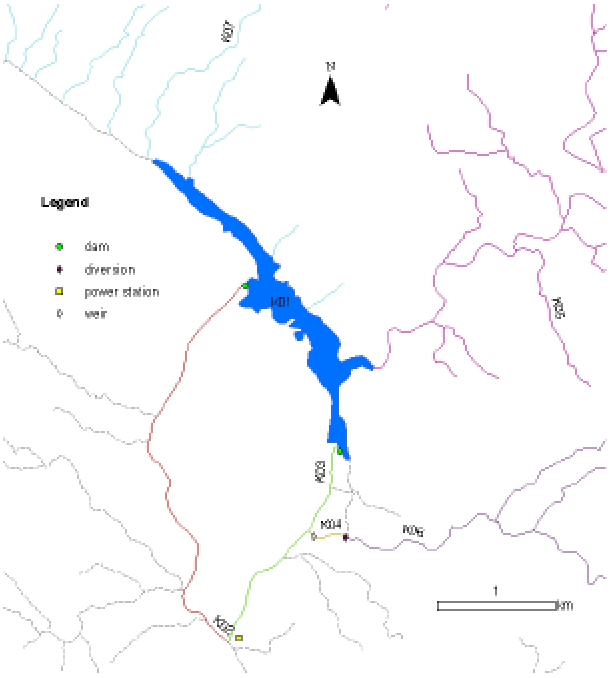


Figure 6 Water body groups defined within the Dee system.



Group	Water bodies
Drumjohn	D01 Carsphairn Lane, Drumjohn p/s to Water of Deugh confluence
	D02 Water of Deugh, intake to confluence with Carsphairn Lane
	D03 Bow Burn, intake to confluence with Water of Deugh
	D04 Water of Deugh, Carsphairn Lane confluence to Kendoon Loch
	D05 Water of Deugh, intake to headwaters
	D06 Bow Burn, intake to headwaters

Figure 7 Drumjohn group water bodies.



Group	Water bodies
Kendoon	K01 Kendoon Loch K02 Water of Deugh, Deugh dam to confl. with Water of Ken K03 Water of Ken, Ken dam to confluence with Water of Deugh K04 Blackwater Burn, Water of Ken to Blackwater Burn dam K05 Water of Ken, Kendoon Loch to headwaters K06 Black Water, Kendoon aqueduct to headwaters K07 All streams (8+) upstream of Black Water dam

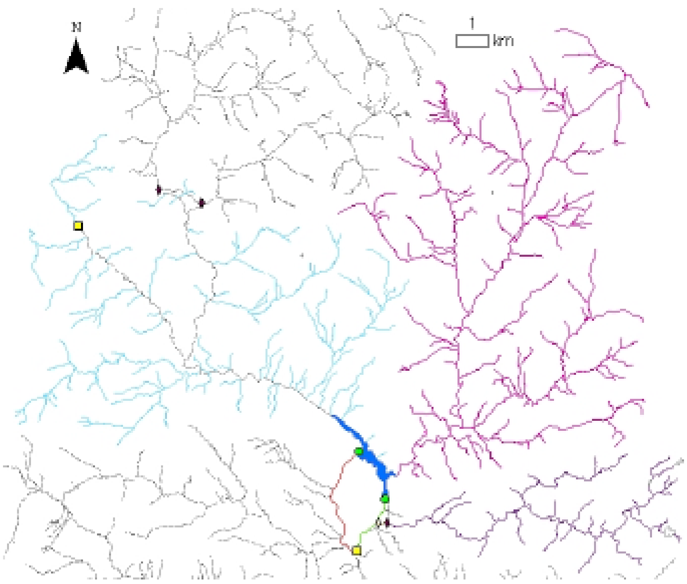
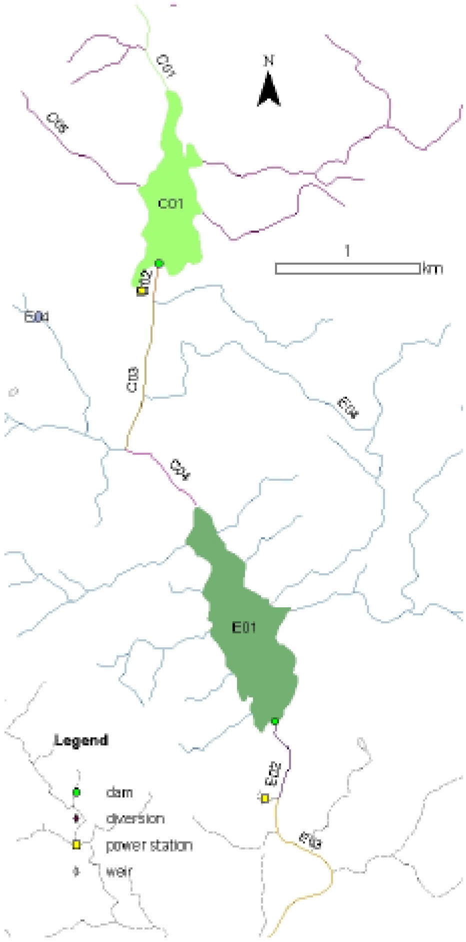


Figure 8 Kendoon group water bodies.



Water bodies
<u>Carsfad group</u>
C01 Water of Ken/Carsfad Loch, Water of Deugh confluence to Carsfad Dam
C02 Water of Ken, Carsfad dam to Carsfad tailrace
C03 Water of Ken, Carsfad tailrace to Polharrow Burn confluence
C04 Water of Ken, Polharrow Burn confluence to Earlstoun Loch
C05 Unmodified tributaries, Carsfad dam to Kendoon Loch dams
<u>Earlstoun group</u>
E01 Earlstoun Loch
E02 Water of Ken, Earlstoun dam to Earlstoun tailrace
E03 Water of Ken, Earlstoun tailrace to Coom Burn confluence/ Glenlee tailrace
E04 Unmodified tributaries, Earlstoun dam to Carsfad dam

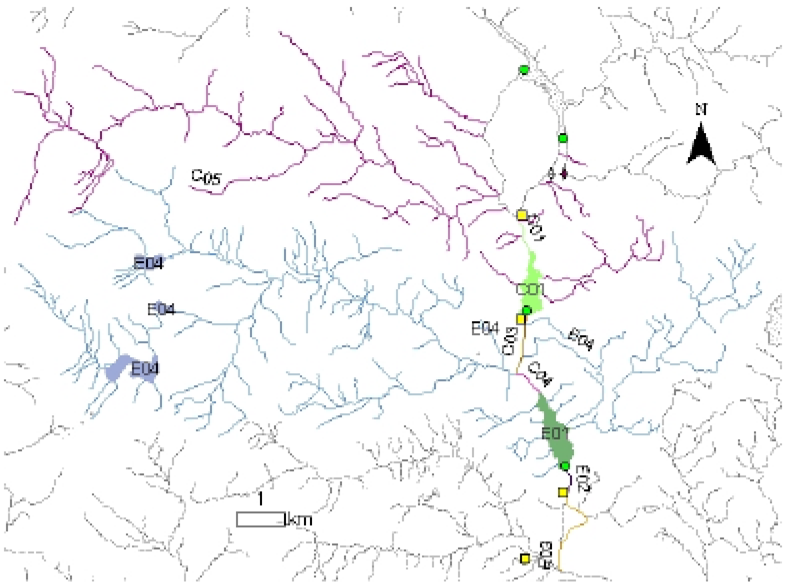
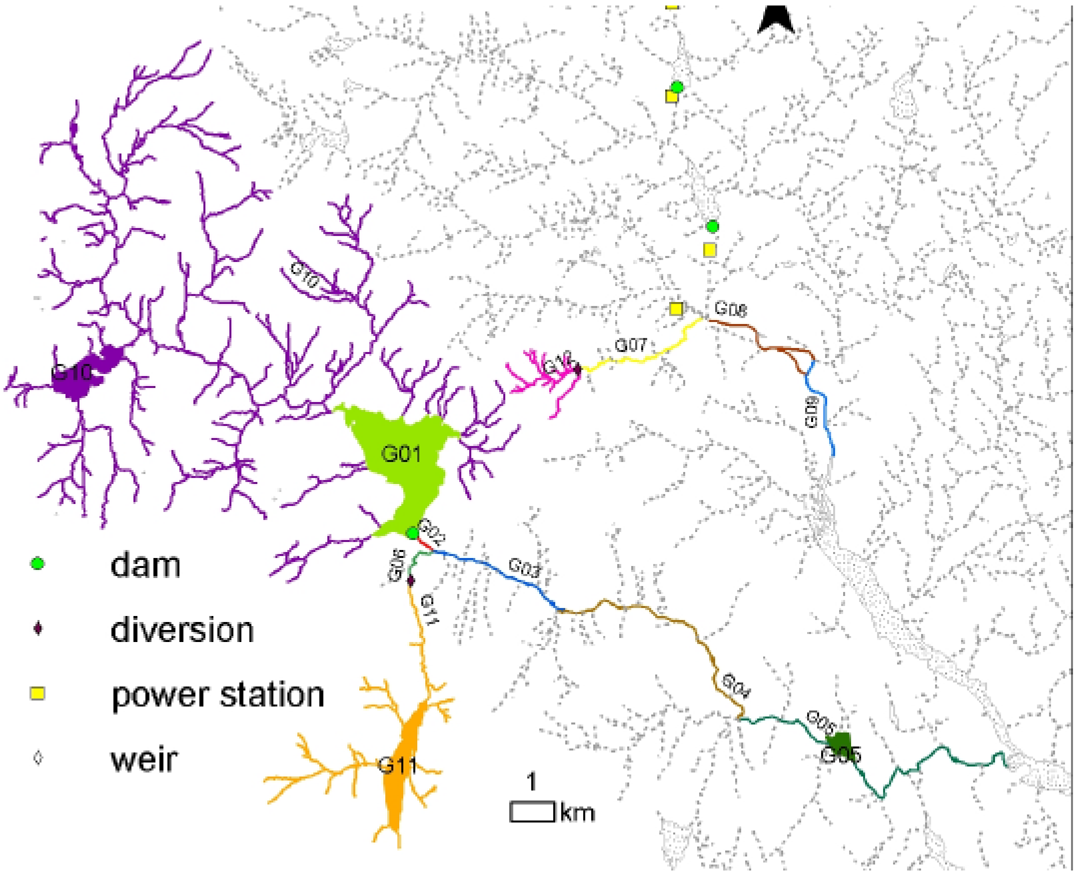


Figure 9 Carsfad and Earlstoun group water bodies.



Water bodies
G01 Clatteringshaws Loch
G02 Black Water of Dee, Clatteringshaws Dam to Pullaugh Burn confluence
G03 Black Water of Dee, Pullaugh Burn confluence to White Burn confluence
G04 Black Water of Dee, White Burn confluence to Glengainoch Burn confluence
G05 Black Water of Dee, Airie Burn confluence to Loch Ken
G06 Pullaugh Burn, Black Water of Dee to aqueduct intake
G07 Craigshinnie Burn, offtake to Glenlee tailrace channel
G08 Water of Ken, Glenlee tailrace to Garple Burn confluence
G09 Water of Ken, Garple Burn confluence to head of Loch Ken
G10 River Dee and other tributaries u/s Clatteringshaws Loch
G11 Pullaugh Burn u/s intake
G12 Craigshinnie Burn u/s intake

Figure 10 Glenlee group water bodies.

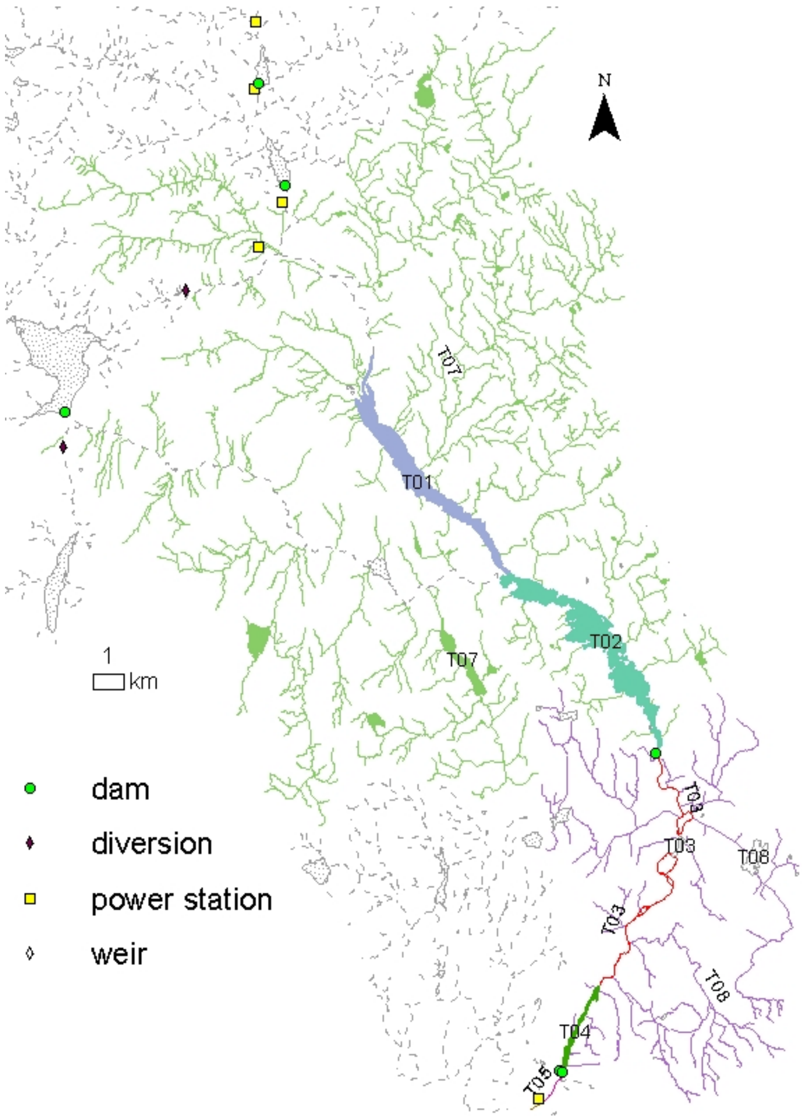


Figure 11 Tongland group water bodies.

Group	Water bodies
Tongland	T01 Loch Ken, head to River Dee confluence T02 Loch Ken (River Dee), River Dee confluence to Glenlochar barrage T03 River Dee, Glenlochar barrage to Tongland Loch T04 Tongland Loch T05 River Dee, Tongland dam to Tongland tailrace T06 River Dee, Tongland tailrace to tidal limit T07 Unmodified tributaries, Glenlochar Barrage to head of Loch Ken T08 Unmodified tributaries, Tongland dam to Glenlochar barrage

Typology

The Water Framework Directive suggests distinct but similar typological systems, at two levels (A and B) for rivers/streams and for lakes. The principal factors included in both System A and System B typologies are geology and altitude, together with size/catchment area for rivers and size/surface area plus depth for lakes. In the absence of ecologically calibrated typologies for Scotland, systematic typologies are unlikely to be useful for the individual study areas of this project (Black *et al*. 2002). However, an implicit typological system is adopted for use as necessary during development of this project. The three principal divisions of solid geology within the Dee catchment (Ordovician, Silurian and granite, see Figure 2) are all composed of silicious rocks, although the distinction between granite and the other deposits is significant in relation to acidification; thus two divisions of solid geology are appropriate. Of the drift deposits (Figure 3), peat is probably the most important in relation to water quality. Only the highest (800-814m a.s.l.) peaks of the Dee catchment lie outwith the Directive's lowland and mid-altitude altitude classes (high >800m / mid-altitude 200-800m / lowland <200m) and a compatible sub-division into 200m altitude classes is implicitly adopted.

4.4 Discussion and Conclusions

Using the criteria developed within this study a total of 42 individual water bodies were identified within the Galloway Dee system. A feature of the channel network in a hydro power scheme is the multitude of small component reaches and artificial segments such as tail races and aqueducts. Consequently, many of the water bodies identified were smaller than the 1 km channel length ($1km^2$) area threshold suggested in HMW Paper 5. As a pragmatic solution to undertaking the ecological assessments and subsequent designation tests for HMWB, these constituent water bodies were grouped by power station, or power station cascade (c.f. Ken cascade). This approach was also adopted in the companion report for the River Tummel. Due to difficulties of access to the study area during the summer of 2001 (Section 3.2), this was necessarily achieved by desk study only, using published maps and literature in conjunction with advice from the staff of SEPA (Dumfries), the West Galloway Fisheries Trust and Scottish Power plc. The result is felt to be satisfactory, but it must be noted that fine details of the most useful divisions of river segments did not emerge until an advanced stage of consideration of impacts.

PART II

5 Physical Alterations

5.1 Pressures and Uses

The principal pressure on the River Dee is hydro-power generation. The Galloway Water Power Company was incorporated in1929, with the objective of exploiting the area for hydro-power despite its relatively gentle relief and remoteness from markets. The project had become viable – and indeed almost essential - with establishment of the National Grid (U.K. electricity distribution network) and the initial selection of exclusively base-load coal-fired power stations to supply it, in 1927. The so-called “Galloway Scheme“ could be operated to cope with the peak loads. When the last turbine was brought into service in October 1936, it was the largest integrated hydro-electric development in the United Kingdom (Payne 1988).

The scheme imports water from Loch Doon into the Carsphairn Lane, a headwater tributary of the River Dee. Supplemented by local runoff, the water is used to generate electricity in a cascade system during its comparatively slow descent to the sea near Kirkcudbright – a fall of little more than 200m in a distance of some 64km. During this journey, the water passes first through a sequence of four power stations situated on the main stem of the river at Drumjohn, Kendoon, Carsfad and Earlstoun. A fifth power station, Glenlee, uses water from a major tributary, the Black Water of Dee. All the water then converges in Loch Ken before continuing to the sixth power station at Tongland (Figure 13). The total installed capacity is 109 MW.

The Galloway Scheme is now operated by Scottish Power Plc from a central (remote) control room at Glenlee power station. It is designed for peak operation at an average load factor of 21%, the bulk of the output (60%) being derived from run-of-river flows and the remainder (40%) from controlled storage. In practice, generation patterns aim to use the available water to maximum economic benefit (by generating at times of high demand) on both daily and seasonal timescales, whilst accommodating water and plant management considerations. Actual average load factors calculated from commissioning to the present day are 23.2% (annual), 33.2% (November to March) and 37.9% (December/January). Generation statistics are summarised in Table 2.

Table 2 The Galloway Scheme: summary of power station capabilities.

Power station	Head (m)	Generators	Capacity (MW)	Time to full load (minutes)
Drumjohn	-	1 x 2MW	2	5
Kendoon	46	2 x 12MW	24	8–10
Carsfad	20	2 x 6MW	12	15
Earlstoun	20	2 x 7MW	14	15
Glenlee	112	2 x 12MW	24	5
Tongland	32	3 x 11MW	33	8-10

In addition to the direct benefits of hydro-power generation, the extensive hydrometric network enables the Galloway Scheme to play an important role in flood prevention. Strict management protocols for water diversion and power generation are in place to control flooding on the lower Dee as well as in the River Doon which flows northwards from the natural outlet of Loch Doon.

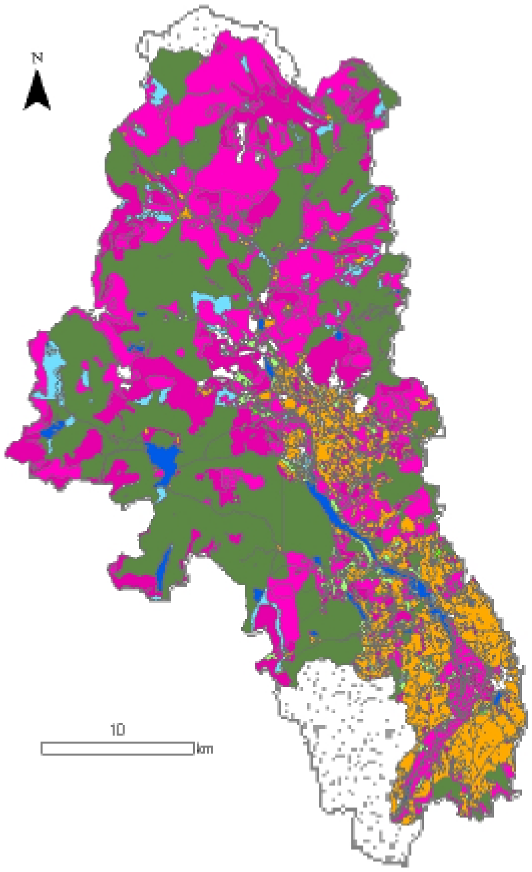


Figure 12 Map showing land cover of most of the Dee catchment (stippled underlay).

The main categories of land cover are: agriculture (orange); grassland/heathland (pink); forestry (dark green); woodland (pale green); open water (dark blue); peatland (pale blue).

The dominant land uses in the Dee-Ken catchment (Figure 12) are agriculture (predominantly livestock rearing) and forestry, which involve abstractions and drainage operations respectively. Public water supplies are obtained from Loch Doon (Scottish Water, *ca*. 4500 $m^3 d^{-1}$) which is outside the Dee-Ken catchment, and from Lochinvar, with potential impact on a sub-catchment with area less than 10 km^2. There is a private small hydro-power installation at Loch Dungeon, also with potential effect on a catchment area smaller than the limit set in HMW paper 5 ver 3. Recreational activities (angling, aquasports & ecotourism *via* RSPB conservation activities) are of major economic significance on Loch Ken and the Dee-Ken system has important salmon and trout fisheries. In 1986, Kenmure Fisheries Limited were pumping water from the northern end of Loch Ken for circulation through trout rearing tanks at Kenmure Holms, and planned to double their production of around 200 tonnes of table trout *per annum*. This activity has now ceased but there is currently a large cage trout farm (Glenkens fish farm) at Kendoon Loch.

5.2 Physical Alterations

The Galloway Scheme draws water from two catchments i.e. the Dee-Ken (894 km^2) and the catchment for Loch Doon (130 km^2).

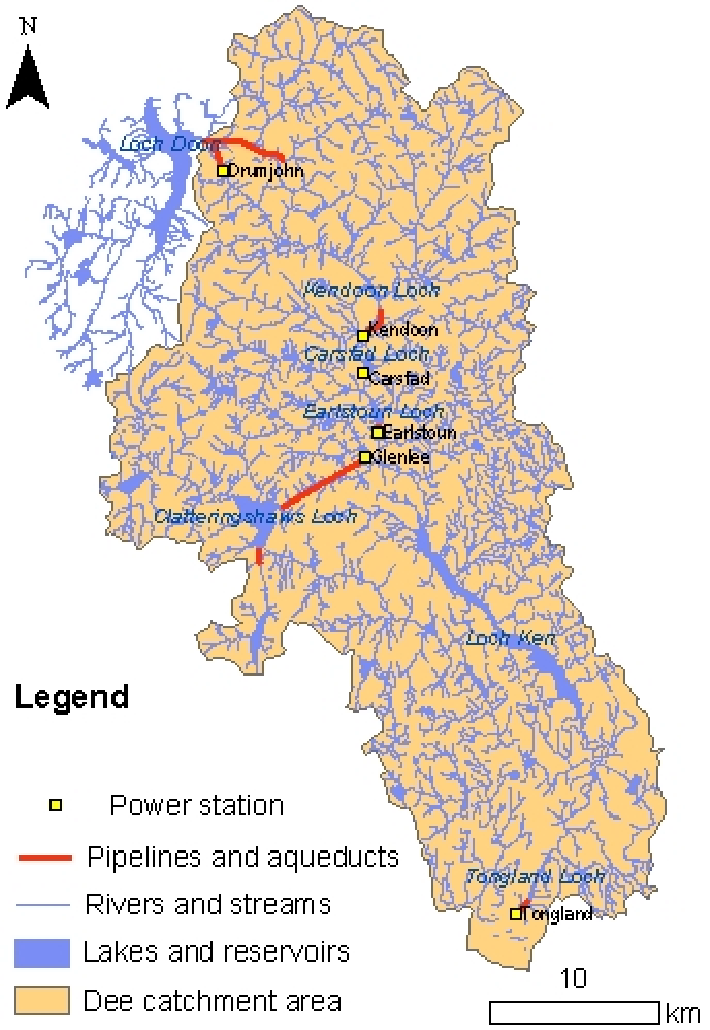


Figure 13 Main features of the Dee (Galloway) hydro-power scheme

Water from Loch Doon[5] enters the Dee catchment by tunnel and discharges into a

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[5] This water constitutes a cross-catchment transfer. Such arrangements feature widely in the hydro-electric power schemes of Scotland, so that the ecological impacts of power generation in one natural catchment are not restricted to that catchment. Implementation of the Water Framework Directive is to be achieved on the basis of natural catchments, so that a consistent policy is necessary to ensure that the effects of cross-catchment transfers will be properly accounted within this organisational framework. In the work reported here, imports are taken into account in assessing hydrological impacts within the Dee system (DHRAM methodology) but the consideration of other physical impacts is restricted to the natural catchment area of the Dee. Subsequent assessment of ecological status in the Doon catchment should thus include full consideration of the physical impacts of the transfers on Doon watercourses, counting the transfers as exports in calculations of hydrological impact.

headwater stream called the Carsphairn Lane at Drumjohn. During periods of high runoff, flow from the Water of Deugh and the Bow Burn (78 km^2) is diverted *via* a system of catch-water weirs, conduits and an open aqueduct into Loch Doon pressure-tunnel for storage in Loch Doon. When required, this flow can be reversed, and water can be drawn from Loch Doon and discharged into the Carsphairn Lane through Drumjohn Power Station (constructed in 1984) or the adjacent needle valve.

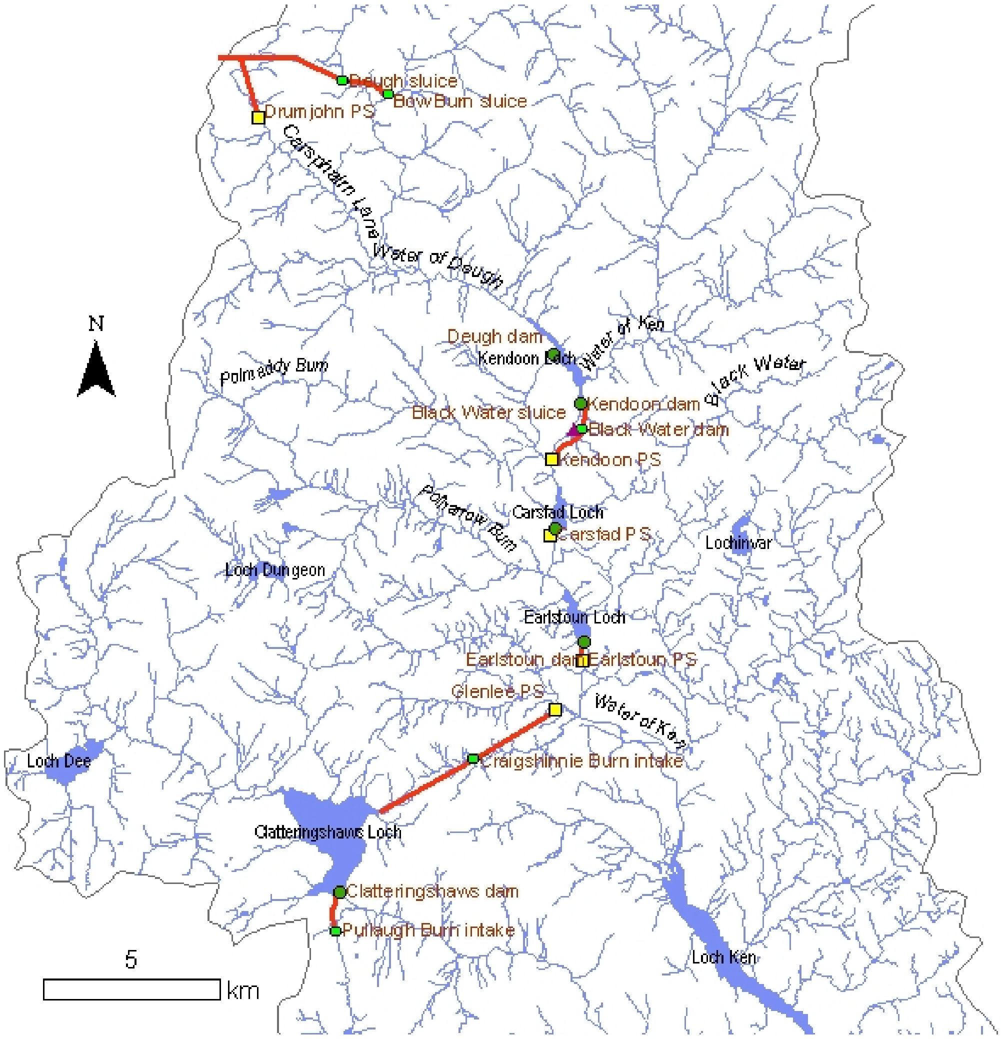

Figure 14 Hydro-power structures in the northern part of the Dee cathment. See Figure 15 for Legend.

Kendoon Reservoir is situated 14.5 km downstream of Drumjohn power station. Dams were constructed on both the Water of Deugh (Deugh Dam) and the Water of Ken (Ken Dam), effectively impounding the saddle between the two valleys. A cut was made through the hill in order to allow water imported upstream to reach the Ken dam in times of extremely low flow. Water from Kendoon is routed along a canal 12-13 m wide, 4 m deep and 760 m long to the Blackwater Burn Dam intake, which is provided with a one-way fish pass to enable juvenile fish to move downstream. Carsfad dam is 3.2 km downstream of Kendoon and the backwater extends to 0.3 m below the Kendoon tailrace (103 m OD). The fish pass has 35 steps divided by resting-pools into four flights and it discharges into the Water of Ken near the tailrace, 250m downstream of the dam. Earlstoun dam (365 m) is of concrete gravity arch design (75 m OD). The intakes, fish-ladder and turbine pipes are similar to those at Carsfad.

Clatteringshaws reservoir is impounded by a gravity dam, 450 m long with no fish pass. The foundation rock was granite and minor excavation was necessary. Glenlee power station draws water from Clatteringshaws reservoir *via* the 6 km Glenlee Tunnel whose intake is screened to exclude stocked trout. The tunnel also collects water from the Craigshinnie Burn *via* a shaft. The power station discharges into an 800m artificial tailrace channel which joins the Water of Ken at a weir fitted with a low screen to prevent entry of salmonids.

Loch Ken receives and regulates the varying discharges from all the power stations upstream, including Glenlee. It is impounded by the Glenlochar barrage which was designed to raise the loch's water level to 45.1 m, the upper 1.2 m providing 9.1 Mm^3 of additional storage. The dry-weather level of the loch is 43.3 m. The barrage is 103 m wide and has six gates that can be controlled to release water into the river to feed Tonglands power station; it also has a vital flood control role. A fish pass has been incorporated into the centre of the barrage to facilitate fish movements when the gates are closed.

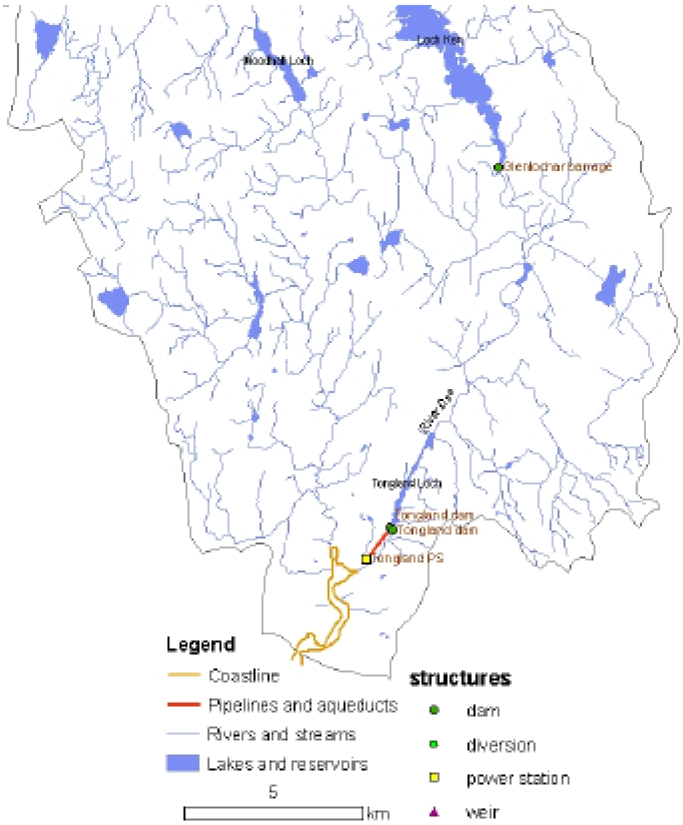

Figure 15 Hydro-power structures in the southern part of the Dee catchment.

At Tongland, a horizontal arch dam impounds the main channel of the River Dee. Water is drawn from the reservoir by an aqueduct running 1.2 km downstream to the power station. There is a fish pass with downstream entrance immediately below the dam.

The principal physical impacts of these alterations are summarised in Table 3.

Table 3 Summary of major physical impacts on the Galloway Dee.

Disruption of the river continuum	There are 7 obstructions (6 dams and one barrage/weir) on the system, of which 4 are provided with two-way fish passes; although the Earlstoun and Tongland passes are cited as poorly functioning (J. Ribbens *pers. comm.*). Kendoon Reservoir has a fish pass for the descent of salmon smolts only (Hill, 1984) and Clatteringshaws dam has no fish pass
Changes in river profile	No significant work has been identified in this area other than the effects of installing the reservoirs
Channelisation	This is limited because of the bedrock nature of the channel system. Only one major area of resectioning and reinforcing has been noted, on the Carsphairn Lane downstream of Drumjohn power station (Water Body D01); although possible concrete lining of the bed of Water of Ken in Glenhoul Glen (Water Body K03) has also been reported. Each of the power stations has an intake linked to a tunnel which bypasses a section of the main channel and discharges *via* the turbines at a mill race
Mechanical damage	Mechanical damage to aquatic fauna occurs at mill races, although these are typically screened

5.3 Changes in the Hydromorphological Characteristics of the Water Bodies and Assessment of Resulting Impacts

Operation of the Galloway scheme as a low-load peak-demand provision involves the movement about the catchment of large volumes of water at irregular times, governed by demand for electricity and the operator's trading arrangements. For the river system, the significant hydromorphological impacts are:

- Change in the total water supply to individual segments of the drainage network; both augmentations and reductions are evident.
- Changes in hydrological regime.
- Disruption of sediment transport; in general, sediment accumulates upstream of obstructions and channel morphology alters downstream.

<u>Change in water supply</u>

Overall, two-thirds of the water used for electricity generation in the Galloway Scheme is natural run-of-river flow, and the remaining one-third is drawn from storage in Loch Doon. Thus, a quantity of water equivalent to 33% of the total natural discharge from the whole Dee-Ken catchment is imported *via* the Carsphairn Lane, which was originally a small headwater tributary; and the quantity of water moving through the central axis of the entire river system is significantly augmented. At Glenlee, additional water from the Black Water of Dee is introduced into the channel of the Water of Ken upstream of the natural confluence, further enhancing total flow through this section (Water Bodies G08, G09 and T01). Nonetheless, diversions, tunnels and pipelines (Figures 13-15) bypass some stretches whose total water supply is consequently less than it would be under natural conditions.

Change in hydrological regime

A recently-developed method for assessment of the severity of anthropogenic alterations to the hydrological regimes of rivers and lakes awards a (DHRAM) score between 1 (natural) and 5 (severely impacted) (Black *et al*. 2000). It follows the approach of Richter *et al*. (1996) in assessing changes in 32 hydrological variables that are known to influence aspects of ecology. In order to explore the types of regime changes encountered, DHRAM scores were calculated for a number of example water bodies within the study area. A full report of the analysis undertaken is provided in Annexes A and B.

RIVERS

Flow regimes are altered downstream of dams, weirs/barrages and power stations, due to the effects of impoundment and generation. Catchwater intakes normally direct all flow to the diversion until the capacity of the intake structure or the diversion structure is exceeded, creating a highly artificial flow regime downstream, with no flow except in periods of high runoff (generally estimated to be no more than 10-15% of an average year). Some examples of flow modifications below the various power stations and dams of the Galloway Scheme and at the catchwaters on the Water of Deugh and the Bow Burn are given in Tables 4 and 5.

Table 4 Examples of flow modifications at catchwater structures.

Water body	DHRAM Score	Impact points	Description of situation and/or flow characteristics
D01	5	20	Downstream of Drumjohn power station; substantial imports to a headwater tributary, temporal distribution governed by demand for electricity at peak times and especially during he summer season to augment natural run-of-river flows. At other times flow in this reach is curtailed by diversion of tributaries to Loch Doon.
D02	4	17	Water of Deugh intake weir
D03	4	18	Bow Burn intake weir

Table 5 Examples of flow modifications at dams and weirs.

Water body	DHRAM Score	Impact points	Description of situation and/or flow characteristics
K03	5	16	Stretch of Water of Ken bypassed by aqueduct and pipeline connecting Ken dam to Kendoon power station; tributary (Black Water) is also intercepted.
C01	5	11	Downstream of Kendoon power station, whose tailrace discharges into the Water of Ken 0.3m above the spillway level of Carsfad dam. Therefore this stretch is effectively a standing water body, with rapid throughflow during generation and transmitting only compensation for Carsfad fish ladder for the remainder of each day, except in times of spate.
C03	5	21	Downstream of Carsfad dam and tailrace; flow varies daily from that associated with generation to Carsfad fish ladder compensation.
C04	(4)-5	12	As C03 with addition of water from a significant natural tributary.
E03	(4)-5	16	Downstream of Earlstoun dam and tailrace; flow pattern similar to C03.
G08	(4)-5	12	Downstream of Coom Burn confluence and Glenlee tailrace. Flow pattern is further distorted by input of water diverted from the Black Water of Dee, but this appears to compensate for some of the extant flow distortion.
G09	(4)-5	12	Downstream of Ken Bridge; flow regime as for G07 with addition of natural tributary (Garple Burn).
G02	5	25	Black Water of Dee below Clatteringshaws dam. Compensation flow only.
G04	3	6	Black Water of Dee 4km downstream of Clatteringshaws dam; receives spillage from Pullaugh Burn when in spate and inflow from a number of natural tributaries including the White Burn.
G05	2	3	River Dee 10 km downstream of Clatteringshaws dam; further input from natural tributaries.
T03	2	3	River Dee immediately downstream of Glenlochar barrage. Flow regulated to achieve relatively stable water levels in Loch Ken and optimal generation at Tongland
T06	(4)-5	13	Downstream of Tongland tailrace; flow governed by generation at Tongland and compensation for Tongland fish ladder

RESERVOIRS

The 6 dams of the Galloway scheme impounded sections of river, transforming them into standing waters. Of these, Kendoon, Carsfad, Earlstoun and Tongland Lochs are small (areas around 0.5 km^2); indeed they were originally referred to as “headponds”. Clatteringshaws reservoir is, on the other hand, substantial (413 ha).

Only one natural lake, Loch Ken, has been incorporated into the Galloway Scheme. It was impounded in 1935 when the Glenlochar Barrage was constructed. This raised the water level by 2.5m and incorporated into the loch the stretch of the River Dee upstream from the barrage to its confluence with the Water of Ken. This stretch is, therefore, treated as a separate water body from the original loch which lay upstream of the Ken/Dee confluence. The whole loch is now 14.9 km long, its mean width is 0.5 km, the water area is approximately 846 ha and the circumference 53 km at spillway level. In 1986, operation of the barrage was managed to draw down the water level in wet weather and allow storage to build up in dry periods. Although compensation water was released upstream, the level of the water could fall to 43.2m a.s.l., equivalent to its unimpounded level. The spillway limits the upper level to 45.7m a.s.l. (range 2.5m), but the normal operating range was 1.2m (43.9 to 45.1m a.s.l.) (Dumfries and Galloway Regional Council 1986). This regime modification was established in consultation with RSPB to minimise disruption to wildfowl breeding in the marginal zone (Scottish Power, 2000). Such locally negotiated arrangements are indicative of best practice reconciling hydro power generation with wider environmental considerations.

Clatteringshaws Loch (and Loch Doon[6]), on the other hand, are used for seasonal storage, being drawn down in summer by as much as 12m and replenished in winter. Details of all the Dee-Ken reservoirs, obtained from Scottish Power plc, are listed in Table 6. Changes in area and perimeter of each of the reservoirs within the natural catchment area of the Dee due to impoundment are shown in Figure 16 and Table 7. The latter set of data are GIS calculations derived from the digital outlines used to construct Figure 16.

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[6] In addition to its role as a water supply reservoir, Loch Doon provides the main seasonal storage for Drumjohn, Kendoon, Carsfad and Earlstoun power stations; therefore data on the impacts of hydro-power generation will be pertinent to eventual assessment of the status of the River Doon catchment for the purposes of the Water Framework Directive. The water level of the natural loch was raised by 8.3 m to 214 m a.s.l. by the construction of the Loch Doon dam (300 m wide) across the natural outlet at the northern end of the loch. Compensation flow is provided from a culvert at the base of the dam. A low saddle on the eastern side of the loch was also closed, by the Muck Burn dam (150 m). Loch Doon has available capacity of 83 Mm^3 and a total drawdown of 12 m (Hudson and Hunter, 1938). As of 2001, Scottish Power propose a target water level range of 6 m. In practice, the annual range is considerably greater; in the two year period 1999-2000 the water level varied by 9.1 m. A new minimum water level target of 207m a.s.l. is to be implemented because this was recently discovered to be a threshold for effective operation of the existing fish pass.

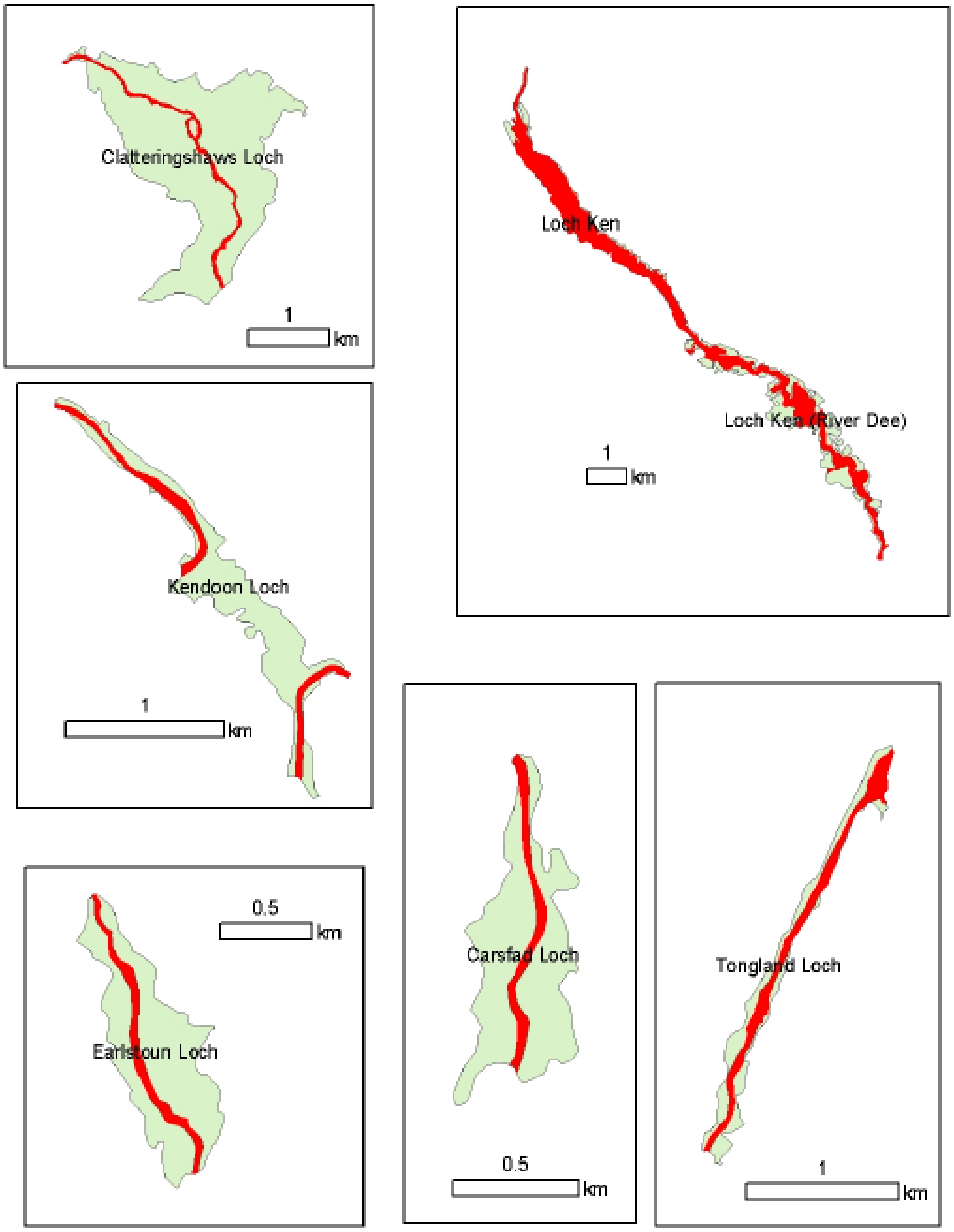

Figure 16 Comparisons of the present shapes of the Dee hydropower reservoirs (pale green) with their shapes before closure of the dams (red).

Modern outlines derived from Institute of Hydrology Digital Loch Boundaries dataset with modifications based on current Ordnance Survey 1:50,000 coverage. "Pre-Hydro" outlines derived from UK Ordnance Survey Popular Edition sheets 83, 87 and 92 (pre-1930 revisions) at scale 1" to 1 mile.

Table 6 Details of reservoirs in the Dee system.

Water Body	Reservoir	Catchment area (km^2)	Reservoir area (ha)	Annual water level range (m)	DHRAM score
-	Loch Doon	130	874	9.1	4
K01	Kendoon Loch	393	60	2.9	3
C01	Carsfad Loch	442	41	2.6	3
E01	Earlstoun Loch	502	54	3.5	4
G01	Clatteringshaws Loch	123	413	9.2	5
T01, T02	Loch Ken		846	1.9	3
T04	Tongland Loch	1023	43	3.9	5

Table 7 Changes in area and perimeter of the 7 Dee reservoir water bodies due to impoundment. Derived by GIS (ArcGIS 8.1) analysis of the digital data used to construct Figure 16.

LOCH	AREA (km^2)			PERIMETER (km)		
	pre-Hydro	now	% increase	pre-Hydro	now	% increase
Loch Ken	2.87	3.12	8.7	20.66	21.69	5.0
Loch Ken (River Dee)	1.95	4.10	110.3	24.08	29.73	23.5
Tongland Loch	0.14	0.32	127.4	6.09	6.87	12.8
Kendoon Loch (total)	0.10	0.53	412.2	5.23	8.30	58.9
Earlstoun Loch	0.07	0.51	670.5	3.52	4.22	20.0
Carsfad Loch	0.04	0.33	757.8	2.67	3.92	46.7
Clatteringshaws Loch	0.16	3.88	2361.1	9.48	13.19	39.0

The independent estimates of reservoir areas shown in Tables 6 and 7 agree reasonably well, although those shown in Table 6 must remain the official estimates. The changes to Loch Ken itself (Water Body T01, upstream of the Ken-Dee confluence) due to impoundment amount to increases of 5% in its perimeter and of less than 10% in its area. These changes are well within the thresholds for significant morphological change[7] that were (tentatively) employed for the Tummel system reservoirs (Black *et al*. 2002). Thus, no significant morphological alteration is indicated for Water Body T01. The areas of all the other Dee reservoirs at least doubled at impoundment, and the perimeters of all but one (Tongland Loch 12.8%) increased by 20% or more; thus all are judged to have undergone significant morphological change amounting to changes in character from moving to standing waters. The DHRAM estimates of regime change shown in Table 6 were calculated using natural lochs as standards, and so do not employ the standards that are appropriate for assessment of alteration from the natural states of any of the impounded river sections. However, Water Body C01 has also been assessed using DHRAM river criteria and scored 5 (Table 5). Therefore, alteration in hydrological regime is assumed to be significant for all such water bodies. The regime of Water Body T01 is, however, sufficiently natural to warrant "good" ecological status.

<u>Sediments</u>

River Habitat Survey (RHS) was undertaken on three 500m stretches of the Black Water of Dee, one upstream and two downstream of Clatteringshaws reservoir. The flow types and depositional features recorded in two of the surveys are summarised in Table 8. The data show a slight decline in depth of water and fast flow types downstream of the dam, even though the slope of the bed is similar. Depositional features, in the form of unvegetated (mobile) point bars, side and mid-channel bars are significantly less extensive downstream of the reservoir than they are upstream. It is noteworthy that a significant effect in channel morphology has been demonstrated here, since the DHRAM assessments indicate that the flow in the river has recovered to an acceptably natural regime at this point (DHRAM score 3; Table 5).

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[7] 20% change in perimeter biologically significant, 100% change in area indicates a change from moving to standing water.

Table 8 Summary of flow types and channel features recorded in RHS survey of two 500m stretches of the Black Water of Dee, upstream and downstream of Clatteringshaws Reservoir. Data collected by Alison Bell and Dave Rendall (SEPA Dumfries), 17 July 2001.

Water body	G10	G04
Location (UK National Grid Reference)	Downstream of Loch Dee (NX485794)	Downstream of Clatteringshaws Loch, near Tannoch Burn confluence (NX602733)
Distance from Clatteringshaws	5 km u/s	6 km d/s
Slope	7m km^{-1}	7m km^{-1}
Water depth (m)	0.25	0.22
FLOW TYPES		
Waterfalls/Cascades/Rapids	- / E / P	- / P / -
Number of riffles	8	9
Runs/Boils/Glides	E / P / P	- / - / P
Pools/Ponded reaches/Marginal deadwater	- / - / -	- / - / P
DEPOSITIONAL FEATURES		
point bars	unvegetated (1)	
side bars	Unvegetated (7sc)	Unvegetated (2sc)
mid-channel bars	Unvegetated (2sc)	Unvegetated (0sc)
mature islands	P (2sc)	P

Notes: "Spot-check" records relate to transects at 50m spacing; data are indicated by (*n*sc) where *n* is the total number of spot-check records of a particular feature. "Sweep-up" information relates to the stretch as a whole, indicated by E:extensive; P: present.

5.4 Discussion and Conclusions

The ‘Foot and Mouth’ outbreak of 2001 made field access to the catchment impossible throughout the Stage 1 research phase. The consequence was that the nature of hydromorphological change was assessed almost entirely on the basis of literature, maps and aerial photography. Nonetheless, it has been possible to demonstrate the nature of some of the physical changes which result from hydro-power operation in the Dee study area, including alterations in sediment transport, loch/reservoir levels and the flow regimes of streams and rivers.

The planned programme of RHS analysis was curtailed due to access difficulties (Foot and Mouth disease) which totally prevented fieldwork in parts of the study area that are used for agriculture. However, forestry land was re-opened towards the end of the field season, enabling RHS survey of the Black Water of Dee which afforded some insights into changes in sediment dynamics, water depth and vegetation attributable to the presence of Clatteringshaws dam and the Pullaugh Burn offtake.

However, this problem was mitigated by the nature of the fluvial geomorphology of the Galloway Dee system. The dominance of bedrock channel features means that physical modifications to the channel, beyond the obvious changes associated with dams and power stations, were relatively minor. Thus, it is clear that the principal issue influencing the system is modification of the hydrological regime. Until development of standards against which existing and future biological data can be assessed in the context of physical alteration, heavy reliance must unavoidably be placed on abiotic methods for assessment of ecological status. The Dundee Hydrological Regime Alteration Method (DHRAM) presently represents the best available means of assessing hydrological change. Especially for bedrock-dominated systems such as the Dee, this has proved to be an essential element in the analysis. The DHRAM methodology has been used to assess the severity of hydrological change at many sites across the river/stream network, using observed and synthetic data to describe daily mean river flows under unimpacted and impacted conditions. It reported high levels of change at most of the sites at which it was applied. It is recognised that some uncertainty must result from the application of the underlying modelling and it is important to acknowledge that calibration of the DHRAM scoring system requires to be undertaken. However, the method does allow differentiation between different degrees of alteration of the hydrological regime, and will provide a basis for further development of methods in the future.

Five of the reservoirs have undergone hydromorphological alterations sufficient to change their character from river to lake. The northern part of the sixth reservoir (Loch Ken), which was originally a standing water, has been shown to be within the acceptable limits set by the DHRAM methodology for standing waters, but its southern part was inundated and thus also hydromorphologically changed at impoundment. For such an elongated standing water comprising two parts of similar size with dissimilar impact levels, which also spans a confluence of major branches of the river system, it seems expedient to define two separate water bodies, T01 and T02.

6 Ecological Status

6.1 Biological Quality Elements

The Water Framework Directive defines ecological status in terms of biological quality elements. For rivers and lakes the pertinent quality elements are the taxon composition and abundance of phytoplankton; macrophytes and phytobenthos; benthic invertebrate fauna; and fish fauna, judged against standards defined by the biota of water bodies belonging to the same typological group that have not been disturbed by human activity, termed "type-specific communities". The division between "good" and "moderate" status[8] is critical in that ecological status below "good" is unsatisfactory. A practical interpretation is that species composition and/or abundance of individual species in the water body under consideration exhibit demonstrable differences from the standard; a judgement of the level at which differences are significant is required, however. Thus, the prerequisites for rigorous assessment of ecological status of each water body are data on species composition and abundance for all four biological groups or an appropriate subset, and the corresponding typological standards. The latter are yet to be developed, precluding a rigorous assessment at this stage. However, relevant biological information is reviewed below, and assessed against a natural standard of some type if possible.

<u>Phytoplankton</u>

The only information located indicates effects on the fish farms in Kendoon Loch and Loch Ken arising from occasional algae problems (Section 6.2).

<u>Macrophytes</u>

At the sites of RHS survey (Section 5.3) on the Black Water of Dee, the main macrophyte cover of the river bed was an unidentified moss. Vascular species noted, probably at a spot observation, were *Isoetes lacustris*, *Carex rostrata*, *Caltha palustris*, *Juncus effusus* and *Deschampsia cespitosa*. The presence of the last 3 of these species indicates consistency of the flora with rivers of group C (generally occurring on non-calcareous shales) and D (on hard rocks e.g. granite) of the classification of Holmes *et al*. (1998) but these represent only 10% of the *ca*. 30 species characteristic of either group. The discrepancy may indicate macrophyte species impoverishment in the Black Water of Dee but this cannot be confirmed without standard macrophyte data, based on survey of 1 km of river.

Macrophyte survey data were available for a number of lochs in the area including Loch Ken.

[8] At "moderate" ecological status, the biological quality elements are moderately distorted due to human activity.

Table 9 shows a comparison of the edge flora at Loch Ken with that of the adjacent Woodhall Loch (Figure 15). Woodhall Loch is not impacted by hydro-power operations and, notably for this area, is also not acidified. 29 of 37 species were common to both lochs. The occurrence of submerged and floating species is compared in Table 10. Only 60% of the 25 species recorded were common to both lochs. Moreover, the vegetation does not fit readily into the classification prepared by Palmer *et al.* (1992); there are affinities with Types 3 and 5. One interpretation is that Loch Ken belongs to Type 5A (although it lacks *Elodea canadensis*) and Woodhall Loch is the species-poor variant of this (Type 5B), dominated by *Potamogeton natans* and *Nymphaea alba*. Another interpretation is that Loch Ken belongs to Type 3 (the larger, rockier lakes of base-poor rocks) and Woodhall Loch to Type 5 (typical of slightly base-rich rock). Adding Stroan Loch (located on the Black Water of Dee; part of Water Body G05) to the comparison enables no further clarification of the class affinities of any of the lochs.

Table 9 Comparison of edge flora of Loch Ken with that of Woodhall Loch (unimpacted).

Scores based on DAFOR scale: Dominant; Abundant; Frequent; Occasional; Rare. (l) indicates local occurrence, e.g. O/F(l) = Occasional, locally Frequent. Source: SNH, 1996.

EMERGENT AND EDGE SPECIES	Loch Ken	Woodhall Loch
Agrostis stolonifera	F	F / A(l)
Alisma lanceolatum		O / F(l)
Alisma plantago-aquatica	O	F(l)
Baldellia ranunculoides	R	
Caltha palustris	O	O
Carex aquatilis	A(l)	
Carex lasiocarpa		R / D(l)
Carex nigra	F (l)	F / A(l)
Carex rostrata	R / F(l)	O / D(l)
Carex vesicaria	A(l)	O / F(l)
Eleocharis acicularis	F(l)	R
Eleocharis multicaulis		R / F(l)
Eleocharis palustris	O / F(l)	F / A(l)
Eleocharis quinqueflora		
Equisetum fluviatile	O / A(l)	F / A(l)
Eriophorum angustifolium		
Glyceria declinata	O / F(l)	

Glyceria fluitans	O	R / F(l)
Hydrocotyle vulgaris	O / F(l)	F (l)
Juncus acutiflorus	O / F(l)	A
Juncus articulatus	O / F(l)	F(l)
Juncus bulbosus	F / A(l)	O(l)
Juncus conglomeratus		O
Juncus effusus	O / F(l)	F / A(l)
Limosella aquatica	O(l)	
Littorella uniflora	D(l)	O / A(l)
Lythrum portula	O / A(l)	
Lythrum salicaria	O / F(l)	R
Mentha aquatica	O	F / A(l)
Menyanthes trifoliata	O / F(l)	O / F(l)
Montia fontana		R
Myosotis laxa	O	F
Myosotis scorpioides	O	R
Oenanthe crocata		O
Persicaria amphibia	O(l)	
Persicaria hydropiper	F(l)	O
Phalaris arundinacea	F / D(l)	F / D(l)
Phragmites australis	O / A(l)	A / D(l)
Potentilla palustris	O	O / F(l)
Ranunculus flammula	O(l)	F
Ranunculus hederaceus	O(l)	
Rorippa palustris		O
Schoenoplectus lacustris	A(l)	A / D(l)
Sparganium emersum	O(l)	F(l)
Sparganium erectum	O(l)	R / F(l)
Veronica beccabunga	O(l)	
Veronica scutellata		R
Number of species	37	37

Table 10 Comparison of submerged and floating vegetation at Loch Ken, Woodhall Loch and Stroan Loch (source: SNH 1996), and characteristics of U.K. Class 3 and Class 5/5A vegetation (Palmer *et al*. 1992).

Scoring as in Table 6.1. Constancy classes: V:80-100%; IV:60-80%; III:40-60%; II: 20-40%; * indicates cover value high (F to A); after Palmer *et al*. (1992).

SUBMERGED AND FLOATING SPECIES	Loch Ken	Constancy for Type 3	Constancy for Types 5(5A)	Woodhall Loch	Stroan Loch
Apium inundatum	A			O / F(l)	R
Callitriche hamulata	A	II	II		R
Callitriche hermaphroditica			II		
Callitriche stagnalis	R	II		R	
Chara spp.	-		III*	-	
Elatine hexandra	F / A(l)				
Eleogiton fluitans	R			O / F(l)	
Elodea canadensis			IV*	O / F(l)	
Elodea nuttallii	F/A(l)				
Fontinalis antipyretica	F / A(l)	III	II	F	O
Glyceria fluitans		III			
Isoetes lacustris	A	III		F	O(l)
Juncus bulbosus	A	V*	III	R	O / F(l)
Lemna minor	O(l)			O	
Lemna trisulca				A(l)	
Littorella uniflora	A (l)	V*	V*	F / A(l)	F
Lobelia dortmanna	F(l)	III	II	O	F / A(l)
Lythrum portula	F(l)				
Myriophyllum alterniflorum	A(l)	IV	V*	R	O
Nitella spp.:		II	IV*		
Nitella flexilis agg.	F(l)			R	
Nitella opaca	F(l)				
Nitella translucens	A (l)				
Nuphar lutea	F / A(l)		II	F / D(l)	F / D(l)
Nuphar pumila					O / D(l)

Nuphar x spennerana				F	
Nymphaea alba			III (V*)	F / A(l)	F / D(l)
Persicaria amphibia	R / F(l)				
Pilularia globulifera	O / F(l)				
Polyganum amphibium			II		
Potamogeton alpinus			II	O / F(l)	
Potamogeton berchtoldii			IV		
Potamogeton crispus			II		
Potamogeton gramineus			III	O(l)	
Potamogeton natans	R	III	III (IV*)	F / D(l)	R / F(l)
Potamogeton obtusifolius			III	F / A(l)	
Potamogeton perfoliatus		II	III		
Potamogeton polygonifolius	R	III		O(l)	
Potamogeton pusillus		II			
Sparganium angustifolium	F	III		R	
Sparganium emersum	F(l)			F	
Sparganium minimum			II		
Sparganium natans				O(l)	
Subularia aquatica	O / F(l)	II			
Utricularia stygia					O / F(l)
Utricularia vulgaris/australis agg.	F(l)				F
No. species (average for class)	25	(9)	(13)	24	16
PH	6.9			6.6	5.7
Alkalinity (meq/l)	0.14			0.28	0.06
Conductivity (µS/cm)	53			95	44

Phytobenthos

No reports of diatom distributions in the streams and rivers of the Dee catchment were located.

Macroinvertebrates

The factors associated with abstractions that can affect the benthic invertebrate fauna of rivers are listed by Castella *et al*. (1995) as: threshold changes of hydraulics exceeded, channel bed dewatered, sedimentation of fine particulate matter, compaction of substrate sediments, development of periphyton and macrophytes and changes in water quality. Whilst these authors were unable to demonstrate any coherent faunal changes across a sample of 22 abstracted streams and rivers, comparison of paired samples upstream and downstream of individual abstractions revealed clear effects at four sites. For one of the comparisons, the downstream samples showed marked reductions in total fauna and increases in Caenidae and Ceratopogonidae. Other taxa that increased in some downstream samples were Brachycentridae, Gammaridae, Lymnaeidae, Limnephilidae and Chironomini. These changes were observed in locations where a 1.5 m section of the channel had mean flow velocity less than 0.05 m s^{-1} and mean depth less than 10 cm.

Cortes *et al*. (1998) attributed a substantial decrease in invertebrate diversity downstream of a small hydropower dam on the River Poio in northern Portugal to transportation of fine sediments that fill interstitial spaces, and to substratum instability associated with discharge variability. Conversely, on the River Rheidol in Wales, more taxa were found in the regulated reach below the Nant-y-Moch dam than in unregulated reaches, and the greatest number of taxa was recorded below a tributary where availability of sediment facilitated changes in channel morphology (Greenwood *et al*. 1999). Almodovar and Nicola (1999) noted no marked differences in benthic invertebrate communities upstream and downstream of a small hydropower plant on the River Hoz Seca in Spain and concurred with Armitage (1989) and Petts *et al*. (1993) in the conclusion that regulation did not impoverish the invertebrate fauna but induced subtle changes in faunal composition. Downstream recovery in macroinvertebrate communities is gradual, probably occurring completely over distances in excess of 10 km (Pozo *et al*. 1997).

Some very recent work on the River Lyon, a tributary of the River Tay in eastern Scotland, indicates clear differences in presence and abundance of invertebrate species between the regulated main stem and unregulated tributaries; although there are other potential contributing factors such as differences in detritus levels (Summers 2000).

Benthic invertebrates are sampled systematically within the Dee catchment by SEPA. These data are used to derive BMWP scores (Armitage *et al*. 1983) which are intended to relate species complement to chemical conditions rather than to physical modifications. Moreover, since the “kick-and-sweep” sampling method used is at best only semi-quantitative (number of each species collected from wetted channel during a standard time interval) we cannot anticipate that the effects of quantitative physical alterations, for example to wetted area and interstitial living space, can be assessed adequately from such data. Thus, although considerable quantities of invertebrate data are available, it is not clear how they should be assessed for present purposes.

An interpretation of some existing invertebrate data in terms of water quality is available from the SEPA Web site, as follows. The ASPT scores at Water of Deugh near Carsphairn and Water of Ken at High Bridge are typical of sites with Good/Excellent water quality. At Polharrow Burn, and the Black Water of Dee downstream of Stroan Loch the range of ASPT values again indicates Good/Excellent water quality, but the invertebrate faunas are typical of moderately acidified sites. The Water of Ken near New Galloway and the River Dee at Glenlochar give ASPT scores indicating Fair to Good quality although no pollution problems are suspected; the poor scores are attributed to flow control resulting from hydro-electric generation.

Fish

The fish populations of the River Dee system are affected by a combination of influences that tend to distort their composition. Those which have received most attention are acidification and access limitations due to hydro-power structures; but predation, fish farming, fisheries stocking, habitat availability and modification, the extent of forestry and forest practices also affect the situation.

Acidification is regarded as most severe in the Black Water of Dee and the Water of Deugh where acid events related to snowmelt have caused fish kills. The Black Water of Dee lacks acid-sensitive species including salmonids, minnows and stone loach (the latter also avoid the headwaters of the Polharrow and Polmaddy Burns) but appears to be preferred by perch. When the Blaree Burn (at the top of the Polmaddy Burn) was electrofished in 1996, it was found to contain no fish species at all (Sinclair and Ribbens, 1996).

The non-native signal crayfish has been introduced for its culinary properties and as food for large trout; unfortunately this voracious carnivore consumes juvenile salmonids. Clatteringshaws Loch is stocked with brown trout, and escaped rainbow trout (an alien species believed to be unable to spawn in Scottish waters) can be found in the vicinities of fish farms. Game fishing in Loch Ken is considered to be poor and this has been attributed to hindrance to the passage of fish by the hydro-power scheme, infestation of the loch by pike and other predators, acid rain, netting of salmon on the lower stretches of the Dee and artificial stocking of the loch with trout, one of the main predators of salmon fry (Dumfries and Galloway District Council 1986). Roach are abundant in the Loch.

The main salmon spawning grounds are in the Shirmers Burn on the east side of Loch Ken and in tributary burns higher up the Water of Ken. There is also a salmon hatchery (West Galloway Fisheries Trust) on the Garple Burn and fry have been released to the river since 1996 (Sinclair and Ribbens, 1996). Fish released as fry have passed the most vulnerable life stage with respect to acidification, and it is also intended that stocking will enable salmon to exploit good juvenile fish habitat that is inaccessible to adult migratory fish. Extensive studies of juvenile fish (by electro-fishing) and their habitats have been carried out by the West Galloway Fisheries Trust since 1996. Downstream of the Glenlochar barrage, the only samples (in 1996) contained 19-308 salmon fry, 1-4 salmon parr, abundant roach parr, perch which often form large shoals in that location and do consume salmon fry, and no trout. No habitat data were collected, but this part of the river is reported to be deficient in habitat suitable for salmon once they have developed into parr. The Tarff Water, which is accessible without passage through Tongland Dam, had smaller numbers of salmon but also trout in 2000. All of the tributaries of Loch Ken and the Water of Ken between its confluences with the River Dee and the Water of Deugh were sampled. At least small numbers of trout were present in most streams in most years. Juvenile salmon were scarce or absent before 1998. Large numbers of fry appeared in 1998 due to stocking of 5 streams. Small numbers of parr remained in 1999, but these had left all but two of the streams by 2000, and there had been no further recruitment. The Water of Dee was not stocked. One salmon parr was recorded here (in 1996), downstream of Woodhall Loch. Trout were present a little upstream of the Tannoch Burn, but above this the river (sampled only on its main stem between the Tannoch Burn and Clatteringshaws dam) was devoid of juvenile fish throughout the study. Juvenile fish counts and habitat data for selected sites are summarised in Table 11.

Table 11 Summary of electro-fishing and fish habitat information. The sites are located downstream of Glenlochar barrage and on the Black Water of Dee (the Tannoch and Glengainoch Burns are tributaries 3 km apart within water body G04). Finer substrates, especially gravel, are suitable for spawning and coarser substrates offer cover to older fish.

SITE	River Dee d/s Glenlochar (3 sites)	Tarff Water	Tannoch Burn	Glengainoch Burn	Black Water of Dee (3 sites)
SUBSTRATE (%)					
Silt/sand		10	35		
Gravel		10	40	10	5-10
Pebble		20	5	20	10-15
Cobble/boulder		60	20	70	80
YEAR(S)	1996	2000	1996, 2000	1998, 1999	1996,1998, 1999,2000
Salmon fry	19-308	42	0	0	0
Salmon parr	1-4	15	0	0	0
Trout fry	0	17	20-50	0	0
Trout fingerlings	0	4	0	0-1	0

Eels are unable to negotiate the fish pass at Tongland, and so have no access to the system. From elsewhere in Scotland, it seems that sea lamprey may also be significantly impeded in their progress up-river by dams, even if these are fitted with salmon ladders. However, it is the system's accessibility to salmon that has received most attention, initially as a result of their fisheries value but now also because salmon are protected under the EU Habitats Directive. The legal background to the debate is that the Galloway Scheme is still governed by the Act of 1929 and is exempt from the Salmon (Fish Passes And Screens) (Scotland) Regulations of 1994 (Sinclair and Ribbens 1996).

Prior to hydropower development (1920s), low numbers of salmon were caught in Loch Ken and the New Galloway stretch of the Water of Ken. Sinclair and Ribbens (1996) report observations that local people watched salmon leaping over the Earlstoun Linn and that in a single day up to 5 salmon were taken from the Polmaddy Burn. There are records of salmon ascending annually to the headwaters of the Water of Deugh, even though the 12 m (40 ft) Tinkersloup Falls that now lie beneath Kendoon Loch were passable only under certain conditions. On the upper Water of Ken there is evidence of a seasonal salmon fishing camp dating from Mesolithic times (7-8,000 years ago); a substantial annual run occurred in the 1920s and up to 5 salmon per day could be caught during the 1930s. There are also historical records of moderate salmon catches in the higher reaches of the Black Water of Dee; only 11 fish were caught between 1908 and 1924 but their average weight was greater than that for fish caught in the remainder of the Dee system (Sinclair and Ribbens 1996).

Prior to the construction of the Galloway Scheme, many of the salmon entering the Dee were captured at the Doachs of Tongland where a combination of the natural rock channels of the river bed and artificial obstructions called “hecks” effectively prevented the passage of fish, allowing them to be netted in large numbers. Since the tailrace of Tongland power station would discharge into the Doachs and render them ineffective as a fish trap, the proposed Galloway Scheme was expected to improve the fishing in the remainder of the river. This was an important aspect of planning for local landowners; the provisions required were stipulated within the Galloway Water Power Act and established under the supervision of the current Inspector of Salmon Fisheries as well as his predecessor who was engaged as a consultant to the power company. Under the Act, upstream and downstream movement of fish was to be secured as far as the Ken and Deugh dams on the Water of Ken and up to Clatteringshaws dam on the Black Water of Dee. Accordingly, power station intakes were generally screened and each dam was equipped with a fish ladder of the latest design.

The Earlstoun and Carsfad fish ladders are of similar “pool-and-orifice” design, each with 35 pools, and the centre of the Glenlochar barrage incorporates a small fish pass for use when the gates are closed. Although not stipulated by the Act, there is also provision at Kendoon for juvenile salmon (smolts) from a planned (but never established) hatchery upstream to achieve their first migration to the sea. Fine screens inserted seasonally at the Blackwater Burn dam were to prevent smolts from entering the turbines, which are of small dimensions and operate at relatively large head. Instead, they would descend *via* an overspill pass that is entered through a hinged chute whose position adjusts to variations in water level (Hudson and Hunter 1938).

When commissioned, the passes at Tongland (21.3m), Earlstoun (21.5m) and Carsfad (22.6m) were amongst the highest ever to have been constructed and concern was expressed as to whether the fish would use them. They were judged to be successful

(Hudson and Hunter 1938, Hill 1984) although there is a report of fish massing at the bottom of the Carsfad dam in 1942/3 (Sinclair and Ribbens 1996). Much more recently Carnie (2001) identified and addressed problems at Earlstoun and Tongland (work by Fisheries Research Services is also in progress). At Earlstoun it emerged that the flow in the fish pass was more than double the optimum for upstream passage of adult salmon. At Tongland, fish using the conventional overspill fish pass (36 pools) had difficulty in ascending through the top five pools which lie inside the dam, due to eddy currents caused by the edges of the sluice valves that regulate the (variable height) entry to the reservoir; in November 1995 large numbers of fish appeared to have been trapped in these pools for so long that they were on the point of spawning. Diagonal timber walls were fitted to the pools concerned, and easier passage by fish was observed as a result (Gordon Ross, Scottish Power, pers. com.).

The arrangements for fish passage at Tongland are pivotal, since there is no habitat suitable for spawning below the dam. Here, descending smolts are admitted to the turbines since experiments indicated that they suffered few injuries in taking this route, despite the fact that they would be subjected to pressures ranging from 9 to 45 psi during the process. The fish pass is provided for use in both directions by larger and less adventurous fish; although some do leap out of its pools onto dry land. However, the lower entrance to the fish pass lies upstream of the power station tailrace discharge which, at full generating power, is much greater than the compensation flow emerging from the fish pass so that fish experience difficulty in locating the route upstream. Whilst the timing of the annual salmon run has changed since the 1930s, some accommodation has been achieved by adding an extra month to the period over which compensation flow is provided each year (now April to December). Other issues at Tongland are the vulnerability of fish to poaching from the pools of the fish pass, the smallness of its upper entrance/exit which causes problems to fish moving both upstream and downstream, and strandings below the dam after debris-flushing at times when fish are moving up the river.

Historically, salmon catches in the River Dee have varied widely. The catch increased rapidly after 1952, reaching a peak of 800+ in 1967. Thereafter, numbers crashed, following the national outbreak of 'salmon disease' UDN (Ulcerative Dermal Necrosis), reaching a low of 18 in 1979. Through the 1980s and 1990s numbers rose slightly but have only once exceeded 200 salmon per season. A contributing factor may be sea lice, which have caused much greater problems to salmon on the west coast of Scotland than in the east during recent years. Another factor may be the effects of afforestation, since the Dee catchment has been heavily afforested through the 20th century, and much of this before the establishment of good practice for the protection of watercourses. Sea trout catches have always been low, ranging from 2 to 77 fish per year but normally not exceeding 20. The highest-ever count of fish moving through Tongland was 16,000 in 1964 and the lowest count, in 1976, was 923 fish. (Sinclair and Ribbens 1996). Counts of fish ascending and descending through Tongland in 2000 are shown in Table 12.

Thus, the ecological status of the fish of the River Dee system is generally below "good". However, only some aspects of the problem can be attributed to the hydro-power scheme, and those that relate to accessibility have been addressed in part by stocking with salmon. The lack of eels and various effects of flow regulation including sediment re-distribution remain un-tackled. It is unlikely that good status can be restored through remediation of hydro-power-related problems alone, since the effects of acidification (Section 6.2) and predation by alien and unnaturally abundant species, especially in Loch Ken, appear to exert overruling constraints on biological quality.

Table 12 Patterns of fish movement through the Tongland fish pass during 2000.

Month	Ascending	Descending	Net number ascending	Ascending (cumulative)	Descending (cumulative)
Jan				0	0
Feb				0	0
Mar				0	0
Apr				0	0
May	62	6	56	62	6
Jun	322	24	298	384	30
Jly	511	13	498	895	43
Aug	86	2	84	981	45
Sep	259	5	254	1240	50
Oct	169	9	160	1409	59
Nov			0	1409	59
Dec			0	1409	59

6.2 Physico-Chemical Elements

The Dee/Ken system marks the boundary between the acidified rivers of Galloway and the largely unaffected rivers to the east, and its upper catchment has been extensively studied in this context. The waters in the west of the catchment are acidic with low dissolved salt concentrations. Loch Dee is affected by acidification; the pH of the Black Water of Dee at the Loch's outlet remained almost steady at 5.50 from 1990 to 1998. Forestry is the main land use in the headwaters with a gradual transition to pastoral farming in the south. The Water of Ken and other tributaries flowing from the east are more alkaline (e.g.Crae Lane, a stream draining through calcareous strata). Whilst it is only the sub-catchments of the Black Water and Deugh that regularly fail the pH requirements for salmonids of the EC Freshwater Fisheries Directive, the entire catchment is designated under the Directive due to the impact of acid rain input and extensive afforestation[9]. Sinclair and Ribbens (1996) give the following prognosis:

> "Given that the hills of Galloway receive some of the largest loadings of acid precipitation in Scotland, combined with base-poor underlying geology and widespread coniferous forestry plantings (which exacerbate the acidification problem *via* the scavenging of airborne pollutants), it may be some considerable time before the acidification problems of the Dee are significantly reduced, even with expected future reductions in acid emissions and the improved design of the forestry plantings of today in comparison to those of the 1940s – 1970s".

Discharges of settled sewage occur at Carsphairn, New Galloway, Crossmichael, Bridge of Dee and Kirkcudbright. Full treatment is provided at Dalry, Balmaclellan, Laurieston, Twynholm and Castle Douglas. Monitoring in connection with sewage discharges indicates that the biological quality is mostly satisfactory. However, the water treatment works at the top of the Garple Burn catchment has been responsible for several pollution incidents during the 1990s; the Burn discharges into the Water of Ken downstream of Glenlee power station (Water Body G09). A single pollution incident at Shirmers Burn (discharges into Loch Ken, T01) in 1990 was attributed to agricltural pollution; other pollution incidents involving sheep dip have been recorded in the catchment.

Kirkcudbright Creamery releases effluent twice daily on the ebb tide to maximise dilution and dispersal. Water quality is not compromised by these discharges. Direct inputs of trade effluent come from two monitored fish farms at Kenmure Holms (discharging into Loch Ken; now ceased operation) and Glenkens (Kendoon Loch). The results of annual testing are mainly satisfactory although there is evidence of organic enrichment directly below the cages at Glenkens. Occasional algae problems causing temporary tainting of trout have been recorded at both fish farms.

Since 1986, BOD in the catchment has steadily decreased. BOD levels in the Water of Ken have remained stable at 2mg l^{-1}. BOD deceases at the railway viaduct in Loch Ken and remains low down to the sampling site at Glenlochar. BOD increases again as the river approaches the Solway Firth. NH_3-N levels are generally low (<0.1 mg l^{-1}) throughout the river. Since 1980, NH_3-N concentrations have consistently been < 0.2 mg l^{-1}. Levels of PO_4-P have dropped since the mid 1980s. The phosphate peak was probably due to fertilisers used by foresters. Concentrations are usually < 0.02 mg l^{-1}. However, Loch Ken attains only Class 2 within the UK Standing Waters Classification Scheme (Table 6.5) due to high phosphorus levels. Although the point input from the Kenmure fish farm has now ceased, diffuse inputs from forestry continue, and the

[9] The freshwater fish Directive (78/659/EEC) lays down quality requirements for freshwater fish. It was adopted in 1978/9 and implemented in Scotland through the Control of Pollution Act 1974 and the Water Resources Act 1991. It is to be replaced by the Water Framework Directive. Designation under Directive 78/659/EEC implies a need for protection or improvement of the water, in terms of a number of defined physical and chemical parameters, in order to enable it to support fish. In 1995, about 97% of the total length of designated rivers in the UK complied with the standards set out by the Directive. (Dumfries Biology Laboratory, unpublished).

situation is not expected to improve in the near future.

Table 13 Water quality classification for some locations within the Dee-Ken system. (Dumfries Biology Laboratory, unpublised data)

Location	Water Body	Chemical quality
Water of Deugh at A713 road bridge	D04	A2
Water of Ken at Earlstoun power station	E02	A2
Water of Ken at Ken Bridge	G09	A2
Dee at Glenlochar	T03	A2
Black Water of Dee at railway viaduct	G05	B
Dee at Clatteringshaws draw-off tower	G01	B

In general, the overall water quality in the Dee-Ken catchment can be classified as Fair to Good. No pollution problems have been associated specifically with the hydro-power scheme.

Nonetheless, various effects on water quality likely to affect living organisms have been associated with hydropower operation. The effects centre around the fact that turbine intakes are often near the bottom of the reservoir where conditions of aeration and temperature may differ from those at the surface. Such effects are particularly marked when the reservoir is stratified; the water below the surface mixed layer is then relatively cold and dense with low DO concentration. If DO is below 2 mg l^{-1}, nutrients, metals and toxins may be released from sediments as they are ionised by bacteria seeking oxygen (Danill *et al*. 1991). Some literature indicates that detrimental DO effects are restricted to large facilities (Cada *et al*. 1983), although an analysis has been carried out in the context of “small hydropower” developments (Thene *et al*. 1989). Mitigation usually involves spilling water over the dam bulkheads, although this may introduce the antagonistic risk of forming nitrogen-supersaturated air bubbles below the spillway, which can be fatal to fish.

The spray valve at Drumjohn is probably an effective aerator when used, but oxygen levels might fall under low flow conditions and temperature effects seem possible. Kendoon power station is fed through a 1km aqueduct giving some opportunity of aeration and temperature equilibration of water which may well, in any case, be taken from near the surface of the reservoir. Similarly, the water from Loch Ken flows for several kilometres through the river channel before entering the Tongland headpond and in any case discharges just above the tidal limit. The most likely locations of such effects are, therefore, in compensation water below Clatteringshaws dam and at the Earlstoun and Carsfad tailraces where water is stored during each day then released in the evening; although the “run-of-river” emphasis in operation and the small size of the headponds should make for less significant impacts than those recorded in the literature. No data on water temperature and DO collected specifically to investigate these effects in the Dee catchment have been located.

6.3 Definition of Current Ecological Status

In conducting the review above, it was possible to attempt a direct assessment of ecological status for only one of the 42 water bodies (Loch Ken), and then only for one of the quality elements; partly because comprehensive biological data are not available but more significantly due to lack of appropriate standards against which any data may be judged. Until typological standards are developed, the Directive allows "rough assessments" of ecological status (HMW paper 6 ver 2) using physical surrogates for the biological quality elements. The surrogates are the hydromorphological and physicochemical quality elements, which should be "consistent with the achievement of the values specified for the biological quality elements" for each level of ecological status. For rivers, the hydromorphological quality elements are hydrological regime, river continuity and morphological condition, and the physicochemical quality elements are general conditions (nutrient concentrations, salinity, pH, oxygen balance, acid neutralising capacity and temperature), synthetic pollutant levels and non-synthetic pollutant levels. The elements listed for lakes are similar except that river continuity is omitted.

A systematic approach to the assessment of ecological status, based on the information reviewed above, was attempted and summarised in Tables 14 - 19. The general principles that are applied in making the assessments are that:

(a) where good ecological status may be compromised, only those effects that can be attributed to the large-scale hydro-power scheme are taken into account, and

(b) it is assumed that quality is at least good unless there is evidence to the contrary.

For each water body, the existence of direct evidence for distortion of any of the biological quality elements that was not assessed relative to a suitable standard, is indicated by a cross. For Loch Ken, where assessment of the macrophyte flora relative to standard floras was possible (although it indicated that ecological quality was compromised), the assessment **M** is shown in the appropriate box of the Table.

As already noted, the direct biological assessments are far from comprehensive. On the other hand, an almost-complete (see next paragraph) assessment of the "physical surrogate" quality elements is presented on the basis of the information reviewed in Section 5 and its inferences for water bodies in similar situations to those for which direct information is available. Where a risk of distortion to biological quality elements due to a hydromorphological or physicochemical distortion resulting from hydro-power operation is inferred, a flag (?) is inserted in the appropriate box.

Potential distortion of the hydrological regime is assessed mostly on the basis of the example DHRAM scores listed in Tables 4 – 6, with a score of 3 or less being regarded as consistent with at least “good” ecological status. However, significant distortion of the hydrological regime is assumed automatically for the all of the reservoirs except for the northern part of Loch Ken (Water Body T01) (Section 5.3). No DHRAM calculation was completed for Water Body D04, but from the fact that it is formed by the confluence of two streams (D02 and D03) with scores of 4, it is judged to be unlikely that any resultant hydrological amelioration will be sufficient to raise the value to 3.

River continuity is assessed at two levels. Since there is some evidence that Tongland dam represents a sufficient obstacle to movement of at least two fish species (salmon and eels) to distort the composition, abundance or age structure of the fish populations everywhere upstream (Section 6.1), a continuity risk is flagged for all water bodies above Tongland. A second flag is applied if continuity is interrupted by a structure at the downstream end of the individual water body. At this stage no judgement is applied as to whether access of fish to the water body would be precluded by natural features such as waterfalls in the absence of hydro-power structures. Although the Directive does not require assessment of river continuity for lakes, it is considered relevant to the lochs of this particular system, since they form integral segments of its main branches.

The most pertinent aspect of morphological quality for moving waters is sediment supply and dynamics, for which distortion is inferred in all water bodies that lie downstream of impounding structures. In the few locations where they have been identified, re-sectioned and reinforced channels (Section 5.2) are also counted as being morphologically degraded. For lochs, the principal indicators of morphological alteration employed are changes in area and perimeter (Section 5.2).

The only evidence for alterations to physicochemical quality that can be attributed to hydro-power activities, and then only from elsewhere in Scotland, are water temperature and associated quality effects below dams where compensation or generation water may be drawn from the hypolimnion. The effects appear to persist for considerable distances downstream. Whilst there is currently no evidence of such effects in the Dee catchment, and although no data on compensation regimes have yet been obtained, it must be noted that consideration of this aspect will be pertinent to any proposals to introduce new compensation regimes at such locations, and to good practice in general. Where a risk of temperature or water quality effects on biota has been invoked (Section 6.2), a flag (?) is placed in the appropriate “general” box.

In Section 6.2, a number of physicochemical influences that can readily be attributed to causes other than hydro-power generation were also identified. Within the “general” category these include elevated phosphorus / unsatisfactory DO levels and, significantly, acidification. There are also indications of pollution by organic material, sewage and sheep dip. Where the evidence suggests that such influences are chronic rather than due to isolated incidents, an asterisk (∗) was entered in the appropriate box of the Tables.

The principal impacts of hydro-power generation operate on the reservoirs and the main stem rivers that connect them. These are considered on an individual basis. The remaining water bodies can each be assigned to one of three categories according to the different sets of physical influences acting on them. The potential biological consequences of each set of physical influences and their interpretation within the terms of the Water Framework Directive and HMWB designation are explored below.

1. Main stem tributaries without physical modification

(C05, E04, G10, K05, K07, T07, T08)

These water bodies cannot be considered for HMWB designation since there are no physical modifications. Also, the catchments of some of their elements may be too small (<10 km^2) to warrant their inclusion in the assessment process. The only prejudice to biological quality arising from use of the catchment for hydro-power generation operates through the river continuity criterion, in that the opportunity for access by migratory species is governed by their ease of passage along the main stems of the system. In some cases, this passage is precluded by obstructions whilst in others it is governed by the ability of individual species to negotiate one or a series of salmon passes. The final criterion in determining ecological status is that of natural accessibility. If unobstructed main stem passage were to be provided, the use of individual tributaries by different migratory species would be governed by their respective abilities to negotiate any steep sections of channel (whose accessibility may now even be eased by inundation), so that the degree of prejudice to high ecological status indicated by their absence is tributary-specific. These issues can be addressed systematically only through direct observation followed by application of ecological standards and species access criteria such as those already derived for salmon by the Centre for Ecology and Hydrology (CEH), Banchory. Such an exercise would be worthwhile only if the potential prejudice to biota would be sufficient to reduce ecological status to a level that is below “good”, and the appropriate action if access to the entrance of a theoretically accessible tributary could (justifiably) not be achieved would be derogation / application of “less stringent objectives” to take this into account.

Although there are clear historical indications that natural access to large parts of both the Black Water of Dee and Ken/Deugh catchments has been curtailed by construction of the hydro-power scheme, a systematic treatment has not been attempted; first because these issues are not the most significant to the exercise in hand, and secondly because they cannot be addressed on the basis of present knowledge and without fieldwork. Direct prejudice to only one of the biological quality elements (fish) is indicated, and indirect prejudice to other biological quality elements is not anticipated[10]. Thus, “good” ecological status is awarded to these water bodies, with the proviso that the issue of fish access to these water bodies from downstream will be flagged for further consideration when addressing river continuity as an aspect of ecological potential.

[10] Predation by fish is not considered to be a significant influence on invertebrate community structure in Scottish rivers and streams (Fozzard *et al*. 1994).

2. Tributary headwaters

(D05, D06, G11, G12, K06)

The small number of water bodies in this category belies their extent, since each includes a number of individual stream sections and, together with those included in Category 1, they represent most of the length of the catchment's water courses. All lie upstream of "farthest-upstream" structures associated with hydro-power generation and these structures offer no facilities for fish passage. In general, they differ from Category 1 water bodies in that they have been physically altered insofar as their downstream ends are closed by catchwater dams, and each of these dams impounds a small pond, typically *ca*. 100m across although more extensive ponding may occur above the Blackwater dam (K06). These can probably be regarded as insubstantial physical changes, so that the only prejudice to ecological status is, once again, due to interruption of river continuity. The appropriate natural analogue water body is, in all cases, a stream segment that lies above a natural waterfall and all of the water bodies in the category would qualify for at least "good" status if judged in this way. Whether or not there is a case for derogation depends, once again, upon natural accessibility. Therefore, good ecological status is assumed for these water bodies; although they may feature in river continuity recommendations that will be incorporated in the definitions of high and good ecological potential; and direct biological assessment of segments where natural accessibility seems questionable might be considered when standards become available.

3. Main stem tributaries downstream of catchwaters

(D02, D03, G06, G07, K04)

Only five catchwater structures have been identified within the Dee study area, so that this water body type is relatively scarce. The example calculations of DHRAM scores for such situations (Table 4) returned scores of 4 or 5, indicating significant disruption to the hydrological regime. Although no RHS survey was carried out at these water bodies, sediment "starvation" and changes in vegetation are anticipated by analogy with sites elsewhere. Therefore, the ecological status for such water bodies is likely to be less than "good".

Having clarified the interpretation of impacts on the water bodies that are peripheral to the main branches of the system, it is now possible to complete a systematic interpretation of hydromorphological and physicochemical impacts that are attributable to hydro-power activities in terms of their potential influence on biota, and thus to arrive at rough assessments of ecological status in this context. The latter are shown in the final row of each table, and are initially based on the number of flagged (?) boxes in each column (boxes containing double flags counted once only) as follows:

Number of flagged boxes (“Risk Score”)	Ecological status
1	**G**ood
2-3	**M**oderate
4	**P**oor

This approach recognises that the hydromorphological and physicochemical impacts have not been calibrated in terms of impact on biota, but incorporates the view that although alteration of a single physical attribute may be sufficient to introduce significant effects on biota, the risk of ecological distortion can be expected to increase with the number of different sources of physical change; this principle is embodied in the “risk score” shown in the second-last row of each of Tables 14 - 19.

The final stage of ecological assessment should involve reference to the assessments of biological quality elements; however the latter are, unavoidably, extremely sparse. Moreover, direct assessments of ecological quality can be expected to be useful in the present context only in the absence of extraneous chemical effects. For nearly all the water bodies for which there is evidence of biological degradation, physicochemical influences that are not attributable to hydro-power operations are superposed on physical impacts so that the relative significance of the two types of effects in creating any observed consequences for biota are not immediately deducible. Indeed, for many catchments, this would seem to be the principal challenge to the stated intention that physically-based ecological assessments will eventually be “improved” through direct observation of biota, since it incorporates a requirement for biological indicators of physical impacts to be insensitive to extraneous chemical influences. The exceptions are Water Bodies G08, G09 and T03, for which there is some evidence of biological distortion and none relating to chemical influences. However, since these water bodies attain “less than good” status on hydromorphological grounds alone, there is no case for alteration of the assessments.

Thus, the physically based assessments of ecological status were adopted as the best estimates that are possible at this stage. The distribution of ecological status thus derived for the entire Dee catchment, in the context of hydro-power impacts only, is shown in Figure 17.

Table 14 Assessment of ecological status of Dee water bodies: Drumjohn group.

ELEMENT Water Body	D01	D02	D03	D04	D05	D06
BIOLOGICAL						
Phytoplankton						
Macrophytes and phytobenthos						
Benthic invertebrate fauna						
Fish fauna						
HYDROMORPHOLOGICAL						
Hydrological regime	?	?	?	?		
River continuity (connection to d/s waters)	?	?	?	?	??	??
Morphological conditions	?	?	?			
PHYSICOCHEMICAL						
General	? *	*	*		*	*
Synthetic pollutants						
Non-synthetic pollutants						
Risk Score	**4**	**3**	**3**	**2**	**1**	**1**
OVERALL	**P**	**M**	**M**	**M**	**G**	**G**

Table 15 Assessment of ecological status of Dee water bodies: Kendoon group.

ELEMENT Water Body	K01	K02	K03	K04	K05	K06	K07
BIOLOGICAL							
Phytoplankton	✕						
Macrophytes & phytobenthos							
Benthic invertebrate fauna							
Fish fauna							
HYDROMORPHOLOGICAL							
Hydrological regime	?	?	?	?			
River continuity (connection to d/s waters)	??	?	?	?	?	??	?
Morphological conditions	?	?	?	?			
PHYSICOCHEMICAL							
General							
Synthetic pollutants							
Non-synthetic pollutants	∗						
Risk Score	**3**	**3**	**3**	**3**	**1**	**1**	**1**
OVERALL	**M**	**M**	**M**	**M**	**G**	**G**	**G**

Table 16 Assessment of ecological status of Dee water bodies: Carsfad group.

ELEMENT Water Body	C01	C02	C03	C04	C05
BIOLOGICAL					
Phytoplankton					
Macrophytes and phytobenthos					
Benthic invertebrate fauna					
Fish fauna					
HYDROMORPHOLOGICAL					
Hydrological regime	?	?	?	?	
River continuity (connection to d/s waters)	??	?	?	?	?
Morphological conditions	?	?	?	?	
PHYSICOCHEMICAL					
General		?	?		
Synthetic pollutants					
Non-synthetic pollutants					
Risk Score	**3**	**4**	**4**	**3**	**1**
OVERALL	**M**	**P**	**P**	**M**	**G**

Table 17 Assessment of ecological status of Dee water bodies: Earlstoun group.

ELEMENT Water Body	E01	E02	E03	E04
BIOLOGICAL				
Phytoplankton				
Macrophytes and phytobenthos				
Benthic invertebrate fauna				
Fish fauna				
HYDROMORPHOLOGICAL				
Hydrological regime	?	?	?	
River continuity (connection to d/s waters)	??	?	?	?
Morphological conditions	?	?	?	
PHYSICOCHEMICAL				
General		?	?	
Synthetic pollutants				
Non-synthetic pollutants				
Risk Score	**3**	**4**	**4**	**1**
OVERALL	**M**	**P**	**P**	**G**

Table 18 Assessment of ecological status of Dee water bodies: Glenlee group.

Water Body **ELEMENT**	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11	G12
BIOLOGICAL												
Phytoplankton												
Macrophytes and phytobenthos												
Benthic invertebrate fauna								×	×			
Fish fauna		×	×	×								
HYDRO-MORPHOLOGICAL												
Hydrological regime	?	?	?			?	?	?	?			
River continuity (connection to d/s waters)	??	?	?	?	?	?	?	?	?	?	??	??
Morphological conditions	?	?	?	?		?	?					
PHYSICO-CHEMICAL												
General	∗	? ∗	? ∗	∗		∗				∗	∗	
Synthetic pollutants												
Non-synthetic pollutants												
Risk Score	**3**	**4**	**4**	**2**	**1**	**3**	**3**	**2**	**2**	**1**	**1**	**1**
OVERALL	**M**	**P**	**P**	**M**	**G**	**M**	**M**	**M**	**M**	**G**	**G**	**G**

Table 19 Assessment of ecological status of Dee water bodies: Tongland group.

ELEMENT Water Body	T01	T02	T03	T04	T05	T06	T07	T08
BIOLOGICAL								
Phytoplankton	✕							
Macrophytes and phytobenthos	**M**	**M**						
Benthic invertebrate fauna			✕					
Fish fauna								
HYDROMORPHOLOGICAL								
Hydrological regime		?		?	?	?		
River continuity (connection to d/s waters)	?	??	?	??	?		?	?
Morphological conditions		?	?	?	?	?		
PHYSICOCHEMICAL								
General	∗	∗						
Synthetic pollutants								
Non-synthetic pollutants								
Risk Score	**1**	**3**	**2**	**3**	**3**	**2**	**1**	**1**
OVERALL	**G**	**M**	**M**	**M**	**M**	**M**	**G**	**G**

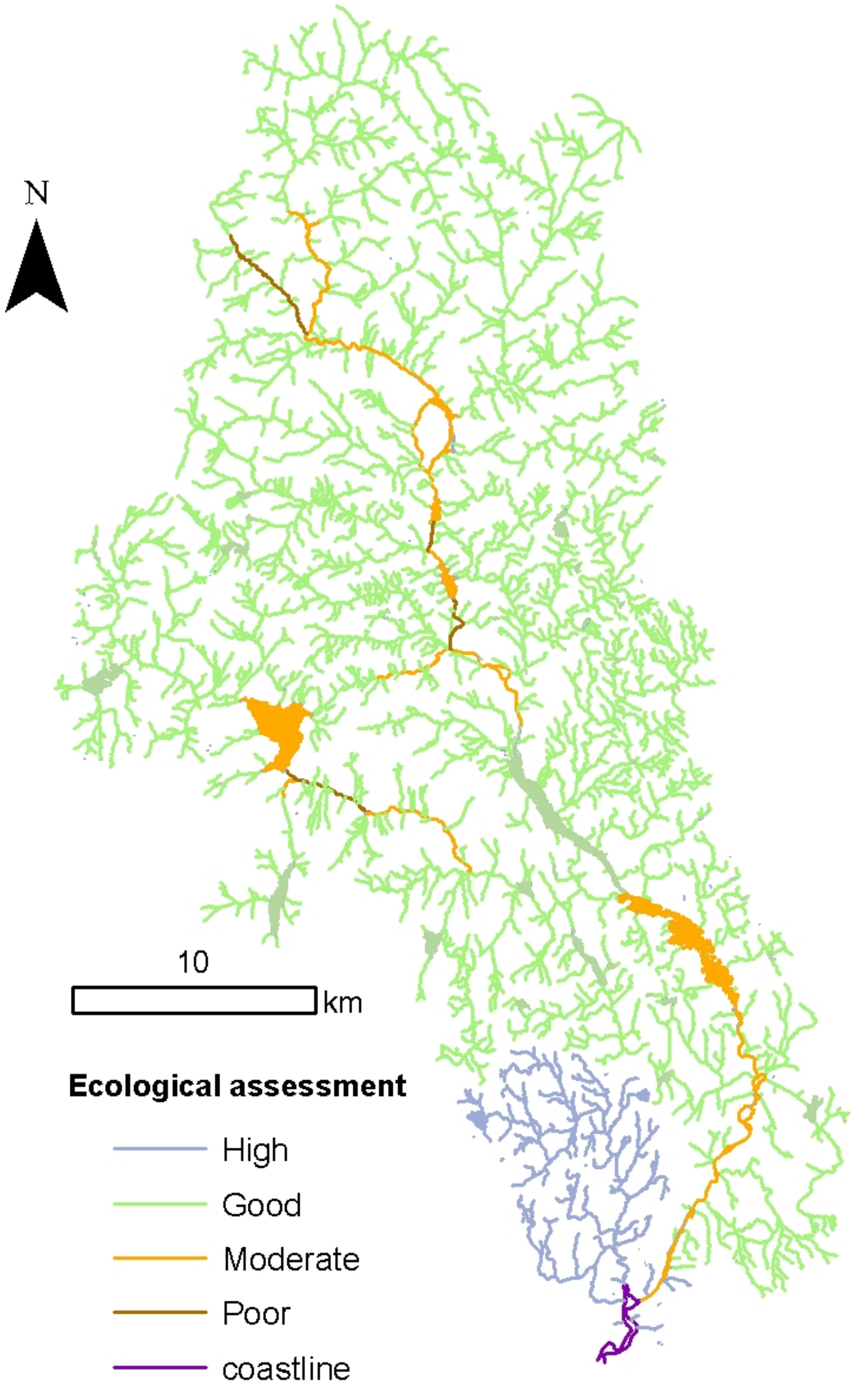


Figure 17 Ecological assessment of the Dee water bodies.

6.4 Discussion and Conclusions

The main sources of biological data identified for the Dee catchment were the West Galloway Fisheries Trust, the SEPA water quality monitoring programme, and the SNH lochs survey. Although much valuable information for this and for Stage 2 of the project was collected and reviewed, much of it proved difficult to use for systematic assessment of ecological status due to the non-availability of reference standards. However, the information obtained from literature, discussion with experts and a small part of the archive of existing data (Section 6.1) is useful in that it tends to focus attention on problem areas, and it is probably reasonable to assume that the most severe shortfalls in ecological status have been identified.

The overriding feature of the system in terms of ecological potential is the acidification of the Black Water of Dee. This is not, however, a criterion for HMWB designation and the Directive expects that the situation will show gradual improvement between 6-yearly quality reviews. Moreover, acidification is not a consequence of hydro-power generation except insofar as the problem might be lessened if Europe were to increase its production of hydro-electric power at the expense of generation that involves burning fossil fuels.

The attention afforded here to the Dee salmon fishery reflects the focus of current biological knowledge, which is driven by interest in the fishery. Issues of fish pass location and function have been considered in great detail, despite the fact that good provision for salmon passage is not the only issue relevant to effective reinstatement of river continuity for the whole biota. Nonetheless, this slant may be justifiable in view of the conservation importance of *Salmo salar*.

The ecological assessments are based primarily on hydromorphological information, which can be collected fairly easily at whole catchment scale even if site reconnaissance is impractical. In one way, this is indeed a “rough assessment” approach (HMW paper 6 ver 2). On the other hand, it seems debatable whether biological data could offer clear indications of physical problems in a catchment such as this, where the performance of biota is also prejudiced by water quality problems. Moreover, in view of the time-consuming nature of biological sampling and data analysis, it seems that an ability to make quick physical assessments of ecological status throughout catchments will always be of use in targeting biological effort.

The “river continuity” criterion is a composite concept. It affects several factors related to ecological status:

(a) the ability of fish to gain access to the water body;

(b) their ability to move upstream from its upper limit;

(c) their ability to move downstream from its lower limit;

(d) the supply of sediment to the stretch of river in question;

(e) trapping of sediment and sediment starvation of the reach downstream.

Thus, a single structure can have multiple and differential effects. For example, an impoundment provided with a fish pass at the upstream end of the water body in question may afford acceptable quality in respect of (b) but be unacceptable in terms of (d), whilst a "farthest-upstream" impoundment without a fish pass will influence factor (a) for water bodies upstream. The latter consideration has significant implications for the definition of water bodies. In terms of all other criteria, it is necessary to consider impacts only on those sections of streams and rivers that lie downstream of artificial structures. The "upstream continuity" factor requires consideration of the whole river network upstream of any structure, although there is potential for its demotion from high ecological status on the grounds of only one biological quality factor, namely distortion of the composition of the fish population, and then only if it can be proved that the fish impeded by the structure would use the river upstream under natural conditions. Moreover, if the upstream section is physically unmodified it cannot be considered for HMWB designation.

To some extent, these issues have been evaded in the approach adopted here, but this seems reasonable in view of the fact that the river continuity question will be re-visited in defining ecological potentials. Consideration of these issues has, however, made it clear that Scottish lochs form inherent parts of the river network to which continuity considerations are relevant despite the fact that they are hydromorphologically standing waters for which the Directive appears, at first sight, not to set continuity requirements.

Another point of difficulty related to the Dee reservoirs was that the guidance offered by HMW paper 3 ver 3 (page 2) for ecological assessment of lakes that were created anew by impoundment of rivers (as opposed to those that have simply been enlarged) was ambiguous in terms of whether these should be dismissed as artificial, or whether their assessment as river segments should the first step in the designation procedure. The point has now been clarified and is consistent with the spirit of the Directive in that a first assessment as river is required, leaving open the prospect of removal of a dam should it be shown to serve no useful purpose.

The outcome of the assessment exercise is that most of the water bodies that lie between the farthest-upstream and the farthest-downstream structures of the hydro-power scheme have been shown to be at risk of biological degradation through physical modification. However, there are are segments within these limits that attain good ecological status despite the use that is made of them. None of the "main stem" water bodies from Drumjohn power station to the point where the Water of Ken enters Loch Ken attain good ecological status, but it seems that all the flow modifications upstream are "absorbed" at Loch Ken. On the other hand, recovery of good ecological status in the Black Water of Dee occurs upstream of its confluence with Loch Ken, only to be impacted again due to the modifications associated with power generation at Tongland (Figure 17).

7 Identification and Designation of Water Bodies as Heavily Modified

7.1 Provisional identification of HMWB

The ecological assessments (Section 6.3) indicate that some of the physically modified water bodies in each power station group do not achieve good ecological status, and thus are candidates for HMWB designation. These water bodies are listed in Table 20.

Table 20 Provisional identification of HMWBs, based on the criteria described in Section 6.3.

PS group	Water bodies	No. of water bodies	Description
Drumjohn	D01-04	4	Carsphairn Lane d/s of Drumjohn p/s, Water of Deugh intake to Kendoon Loch, Bow Burn d/s of intake
Kendoon	K01-04	4	Kendoon Loch, Water of Deugh and Water of Ken from Kendoon Loch to their confluence, Water of Ken d/s Blackwater Burn dam
Carsfad	C01-04	4	Water of Ken from Water of Deugh confluence to head of Earlstoun Loch, including Carsfad Loch
Earlstoun	E01-03	3	Water of Ken, head of Earlstoun Loch to Coom Burn confluence/Glenlee tailrace
Glenlee	G01-04; G06-09	8	Clatteringshaws Loch, Black Water of Dee from Clatteringshaws Loch to Glengainoch Burn confluence, Pullaugh and Craigshinnie Burns d/s of their respective intakes, Water of Ken from Glenlee tailrace to head of Loch Ken
Tongland	T02-06	5	The main channel of the River Dee, including the flooded areas contributing to the enlarged Loch Ken

7.2 Necessary Hydromorphological Changes to Achieve Good Ecological Status

For most of the catchment, re-instatement of high ecological status would require removal of all the hydro-power related structures and extensive restoration of streams, rivers and lochs. However, there is no guarantee that such a programme is technically feasible, and such action would involve loss of artificially created environmental assets such as the wetland nature reserve near Glenlochar. Moreover, even total hydromorphological re-instatement would be insufficient alone to restore good ecological status to the Black Water of Dee and the Water of Deugh, where acidification is an issue. Here, removal of forestry might lead to improvements in water quality, but airborne inputs from fossil fuel combustion (including the products of thermal electricity generation) might still preclude a successful outcome.

At a more pragmatic level, it is possible that an approach to good ecological status could be attained in many instances in conjunction with hydro-power generation, by modifying structures and practice to provide appropriate compensation flows and to enable the passage of fish at some dams and catchwater structures. Some suggestions follow.

The status of Water Body T03, near the bottom of the system, appears to be capable of restoration to good ecological status simply through solution of the reported problems remaining at the Tongland fish pass. For the remainder of the system, however, more far-reaching alterations are required.

The flow regime in the whole length of river from the upper reaches of the Carsphairn Lane to the confluence of the Coom Burn with the Water of Ken is governed by the schedule of generation at Drumjohn power station. This schedule might be modified to yield more equitable river flows. The naturalness of any parts of the river system above Kendoon Loch that were inaccessible to fish before dam construction would not be improved by installation of fish passes. Moreover, attempts to introduce salmonids to the Water of Deugh may well be confounded by acidification. However, the arrangements for fish passage at least at Earlstoun and Carsfad might be improved by arranging more suitable flows in the fish ladders and releasing additional compensation water from the dams. Alternatively, an artificial “roughened channel” (Carnie 2001) bypassing both dams might be installed.

Below the Coom Burn, the flow regime of the Water of Ken is further influenced by discharges from Glenlee power station. Complementary scheduling of electricity generation in the main cascade and at Glenlee could be arranged to avoid simultaneous discharge into the Water of Ken from both branches of the system. This would have ramifications for potential improvement of the hydrological regime throughout the lower part of the system, to the reach below Tongland power station.

The impact associated with the diversion of the Craigshinnie Burn into the Glenlee Tunnel might be reduced either by decommissioning the tunnel offtake altogether, or by providing compensation flow and a fish pass.

Establishment of “closer-to-natural” hydrological and fish access conditions on the Black Water of Dee would also require a fish ladder and a more natural compensation regime at Clatteringshaws Dam. Similar provision might be made at the Pullaugh Burn diversion, or the catchwater could be decommissioned altogether. However, in view of the additional problem of acidification here, a more effective route to replacement of spawning ground lost through construction of Clatteringshaws Dam might be to provide a two-way fish pass at Kendoon, thus opening up the headwaters of the un-acidified Water of Ken to fish. It is not clear whether the Directive would regard such a "catchment-wide" approach to reinstating the total length of river that is easily accessible to salmonids as an approach to good ecological status or as a criterion for definition of ecological potential.

The principal cost implications of such measures would be the capital cost of physical modifications to structures; "wastage" of compensation water; and the potential loss of revenue incurred in imposing limitations on the power generation schedule that may prevent the operators from taking full advantage of the price incentives of peak-time provision. It will be demonstrated in the following sections that these implications amount to significant adverse impacts on the use of the water for hydro power generation.

7.3 Assessment of Other Environmental Options

The beneficial objectives served by the modifications in the Dee case study are the production of electricity from hydro power. This has a market value which varies greatly according to demand, but which averages around £23/MWh. The alternatives to this current modification are to either (i) shut down all hydro operations and generate electricity some other way; or (ii) change the way in which the catchment is modified, to reduce environmental impacts whilst retaining some or all of the valuable electricity output from the schemes. Both of these constitute a significant impact on current use.

With regard to (i), costs of decommissioning the dams and associated structures must be taken into account (see below). These are likely to be large, although in some cases simply ceasing operations (as distinct from dismantling structures) may be sufficient. However, the electricity short-fall must be made up. Hydro is used to generate peak load electricity, rather than base load. This means the alternative source must be capable of meeting peak load demands at short notice. For the UK, this implies in the long run the construction of new oil, gas or coal-fired stations, although in the short run this loss in power could be made up by increased generation from existing fossil fuel stations currently running below capacity. On environmental grounds, this is unlikely to be a better environmental option than hydro, due both to increased CO_2 emissions and increased acid emissions, neither of which are consistent with the UK's international obligations.

It would thus seem that the only potentially better environmental option than the current situation is to reduce the environmental impacts of the modifications, while avoiding or minimising costs in terms of reduced power production. A package of sample measures designed to achieve good ecological status was identified for four sections of the Dee system, corresponding to individual or aggregate power station groups, as summarised in Table 21.

Table 21 Summary of hydromorphological mitigation measures: Dee system.

"Drumjohn Group"
(i) increase compensation in Carsphairn Lane (D01), naturalise heavily engineered channel banks
(ii) increase compensation in Water of Deugh (D02) and Bow Burn (D03).
"Ken Cascade Group": aggregate of Kendoon, Carsfad and Earlstoun power station groups)
(i) re-naturalise flow in Water of Ken (C03)
(ii) improve Earlstoun fish pass, i.e. decrease fish pass discharge and enhance compensation flows (E02, E03)
"Glenlee Group"
(i) improve compensation regime in Black Water of Dee (G02 + G03)
(ii) install fish ladder at Clatteringshaws Dam (G01)
(iii) stop utilising storage function of Clatteringshaws Reservoir, in addition to installation of fish pass (G01)
(iv) remove Clatteringshaws Dam (G01)
"Tongland Group"
(i) improve fish ladder at Tongland Dam (T05 + T04)

All of these are technically feasible. The costs of the four options are set out in Table 22. Where costs of lost water are cited, these represent lost generation (in annual MWh) valued using a standard figure of £23/MWh to represent typical values for the Dee catchment. This value is somewhat higher than that provided by the operator on the Dee (Scottish Power), but somewhat lower than that provided by the operator in the Tummel case study (Scottish and Southern Energy). Where capital costs are cited, these are annualised at 6% over a 10-year time period. Total annualised capital + running costs are added to lost generation revenue: only this total is then reported, in order to protect operator confidentiality.

Table 22 Costs of measures necessary to achieve Good Ecological Status.

	Annualised capital + running costs, £k
Drumjohn (i)	142.2
Drumjohn (ii)	19.9
Ken (i)	2180.9
Ken (ii)	2.03
Glenlee (i)	145.5
Glenlee (ii)	72.0
Glenlee (iii)	1359.2
Glenlee (iv)	2038.7
Tongland (i)	2.03

Table 23 Annual benefit estimates related to improved salmon fisheries.

	km of length improved	***benefits per annum, £k***
Dumjohn (i)	11.4	45.3
Drumjohn (ii)	7.2	28.6
Ken (i)	17 river + 6.5 reservoir	93.4
Ken (ii)	18	71.7
Glenlee (i)	10	39.8
Glenlee (ii)	31	121.2
Glenlee (iii)	41	163
Glenlee (iv)	41	163
Tongland (i)	150 salmon	30

Benefits from these improvements will be likely felt over a range of ecological parameters. However, the only empirical estimates of value relate to welfare measures for salmon fishing. These are estimated by predicting the change in salmon fishings in the affected areas, and valuing these using estimates of current rents (i.e. producers surplus) for privately-owned beats, based on an average value per km, an estimate of the length of river where improvements would occur, and the assumptiopn of one angler per day per beat. Salmon angling beats currently charge £5/day, which over the season equates to £2650/km/yr; increasing this to reflect a crude estimate of consumers surplus implies a figure of £3975/km/yr. This is a very low estimate of value if compared with "industry standard" figures, such as Environment Agency (1998), which cites a value of £24,000/km/yr for creation of a migratory salmonid fishery. Our values are thus best viewed as underestimates. Estimates per Section are given in Table 23. However, current low pH levels (pH dipping as low as 3 at Clatteringshaws relative to around 5.5 tolerated by salmon) may prevent salmonid recovery despite hydro-geomorphological enhancements, implying that the figures in Table 23 are over-estimates. In the case of the improvements to the Tongland fishpass it has been assumed that the measures will enhance salmon survival by 10 % i.e. 150 fish. The economic benefits of this to the catchment as a whole have been estimated using a value of £200 per salmon per year, which was derived from consultation with fisheries officers and hydro-operators, and is consistent with values used in the companion Tummel Report (Black *et al*. 2002). Note, however, that simply removing hydo-related modifications may not be sufficient to allow salmon recovery if other factors such as acidity levels would still prevent recovery. Also, further complications may characterise the fisheries response to the changes outlined above, e.g. a decrease in coarse fishing revenue associated with an increase in salmon numbers. It is not possible to quantify this effect or estimate the likelihood of such an occurrence; the economic estimate proposed above must therefore be regarded as approximate only, and is best interpreted in the context of wider benefits.

Ecological benefits will exceed those simply related to salmon, and include enhancements to populations of other fish species and invertebrates in the area. However, converting these into economic benefits is difficult, due to a lack of useful estimates in the literature. On these grounds, the benefits figures must therefore be viewed as lower bounds.

7.4 Designation of Heavily Modified Water Bodies

The results of the economic analysis as a key stage in the designation process are shown in Table 24. As may be seen, the only modifications which come out with positive net benefits on this basis are the fish pass improvements at Earlstoun and Tongland, the fish ladder installation at Clatteringshaws, and increased compensation flows in the Water of Deugh and Bow Burn. On the whole, these are relatively minor changes to the way in which the catchment is currently used. More radical changes clearly equate to considerable net losses.

Overall findings regarding designation are presented in Table 25. Here, “better environmental options” is taken to mean a more environmentally-friendly hydro power system, which is consistent with meeting Good Ecological Status. What emerges is a pattern where, although some options in constituent water bodies have positive net benefits, are technically feasible and environmentally-preferable, for the water body group the decision may still be to designate as HMWB. This type of aggregation effect seems very likely to be met in other situations too. Note that the above designations are on the basis that the changes described do represent a possible better option. This view can only be reached if the changes described do not result in any significant increase in atmospheric emissions, a point which requires value judgements which should be made through the democratic process.

Table 24 Net benefits/costs of modifications.

	Benefits (£k p.a.)	***Costs (£k p.a.)***	***Net benefits, + or -***
Drumjohn (i)	45.3	142.2	-
Drumjohn (ii)	28.6	19.9	+
Ken (i)	93.4	2180.9	-
Ken (ii)	71.6	2.03	+
Glenlee (i)	39.8	145.5	-
Glenlee (ii)	121.2	72.0	+
Glenlee (iii)	163.0	1359.2	-
Glenlee (iv)	163.0	2038.7	-
Tongland (i)	30.0	2.03	+

Table 25 Overall findings on designation.

Water Body Group	***Better environmental options?***	***Technically feasible?***	***Disproportion-ately costly?***	***Designate as HMWB?***
1:Drumjohn	Yes	yes	with option 1: yes with option 2: no. with both: yes	Yes
2: Ken	yes, unless option (2) implies need for additional fossil fuel power	yes	with option1: yes with option 2: no with both: yes	Yes
3: Glenlee	yes, unless option (4)	yes, although uncertain if	Yes, except if option 2	Yes

	implies need for additional fossil fuel power	option (4) taken	undertaken alone	
4: Tongland	Yes	yes	no	No

Costs and benefits of reversing all of the physical modifications identified for the water bodies of the Tongland group (Table 19) were not included in the economic analysis, however. Reversal of the modifications to morphology and hydrological regime of the lower part of Loch Ken (T02) and Tongland Loch (T04) would involve loss of their functions as reservoirs and thus significantly impact operation of the hydro-power scheme. Re-naturalisation of the flow regimes downstream of Tongland dam (Water Bodies T05 and T06) is, by analogy with the other examples, likely to fail the cost-benefit test. For Water Body T03, however, the only additional measure required to re-instate good ecological status is an adjustment to its sediment supply, should further study indicate that this is a significant problem for biota. Since this is technically feasible and a relatively low-cost measure that would not affect hydro-power operation, HMWB designation is not justified. Thus, within the Tongland group, only Water Bodies T02, T04, T05 and T06 qualify for HMWB designation.

7.5 Discussion and Conclusions

1. Although an average figure of £23/MWh has been used to value lost electricity production, it should be noted that the marginal value of hydro power on the Balancing Market can be much higher: up to £1,000/MWh. This market might make up around 5% of total output for a typical hydro station in this catchment.

2. In this case, it is debatable whether any alternative option for electricity generation with lower environmental impacts exists, due to the role of hydro power in the national grid (i.e. providing peak load power), since all alternatives involve increased combustion of fossil fuels which would be counter to government commitments on global warming and reducing acid deposition. Reductions in hydro power generation to achieve ecological objectives can only be justified if balanced against atmospheric pollution – which should ultimately be a responsibility for national governments and their energy policies.

3. It is not clear how much over-lap and double counting is present in the calculation of the lengths of river where salmon fishing is improved for each option within a water body: can options really be treated as separate, or should they be considered in combinations?

4. However, the benefits of changes in hydro operations will be more widespread than simply changes in salmon fisheries. General increases in ecological quality (for example, in terms of aquatic plants, bankside vegetation, insects and birds) may occur,

which may be valuable to fishermen and the general public. Currently, there is a lack of existing suitable studies to place adequate monetary values on these kinds of ecological improvements, although work currently underway for DEFRA may rectify this situation at least partially. This work estimates the values of improving water quality from "fair" to "good" status on three criteria: river ecology, river appearance, and bankside vegetation. These values, shortly to be published by DEFRA, exist for two rivers, the Clyde (Scotland) and the Wear (England), and can be converted to a set of per-km measures. However, the transferability of these values to other rivers has not been tested.

5. Dam removal, if it means the loss of a reservoir/artificial loch, will also incur lost recreation values where the loch/reservoir is currently in use for boating, fishing etc.

6. Finally, our overall findings were that all of the example catchment sections except one should be designated as HMWBs. However, technically feasible and environmentally beneficial improvement options exist for all water bodies designated which generate benefits in excess of costs. These options all relate to rather minor investments in fish ladders and passes (Drumjohn (ii), Ken (ii), Glenlee (ii)), and could all form part of a River Basin Management Plan, although who would pay for them is a moot point. While these investments may be minor in comparison with the costs of major structures, they may nevertheless represent locally important costs.

8 Definition of Maximum Ecological Potential

The Water Framework Directive (Annex II, 1.3) stipulates that type-specific hydromorphological and physicochemical conditions shall be established for each surface water body type at high ecological status, and that the corresponding biological reference state shall be described. This requirement is not to be met until 2015, so that reference standards are not yet available and shall not be available for use during the first phase of designation. For heavily modified water bodies, the parallel concept of maximum ecological potential (MEP) applies. At maximum ecological potential, the values of relevant biological quality elements reflect as far as possible those associated with the closest comparable surface water body type, given the physical constraints imposed (only) by the use in respect of which the “heavily modified” designation is awarded. MEP should incorporate all possible mitigation measures, at least to ensure the best approximation to ecological continuum, but these must not detract from the use for which the designation applies.

For the River Dee (Galloway) system, HMWB designations are based principally on the premise that the changes to the hydrological regime that would be necessary for achieving good ecological status would have significant adverse effects on power generation, and that hydro-power cannot be replaced by a better environmental option (Art 4.3a and b; Section 7). A strict interpretation of the guidance that “mitigation measures considered in setting MEP must not impact on the use for which the water body was designated HMWB” (HMW paper 12 ver 3) means, in effect, that no water can be directed away from reservoirs/power stations in order to provide additional compensation flow in river channels, since this would result in loss of generating capacity. Even within this strict interpretation, the possibility of identifying any wastage of diverted water might be explored. A more constructive approach in the spirit of the Directive would embrace a principle of water trading. Possibilities for improving hydrological conditions for biota without impact on electricity generation schedules might then be explored in terms of temporal or spatial variation of compensation provisions, or even substitution of water sources at individual power stations.

For all aspects of ecological quality, the preferred ameliorative measures are those which simply involve changes in existing practice. As a second resort, measures with capital cost implications are considered to be admissible. Finally, measures with small effects on generation of electricity (and therefore of revenue) are not ruled out at this stage, in order to cover the possible outcome that the only constructive way forward for surface water quality would be to amend the guidance to read “mitigation measures … must not impact significantly on the (designated) use”, *impacts on use* being read as *impacts on electricity generation capacity*.

8.1 Determining Maximum Ecological Potential

Maximum ecological potential (MEP) is set in terms of high/good ecological status (HES/GES) for the closest comparable reference category of surface water body (river, lake, transitional water or coastal water) and type (based on the typological criteria listed in Section 4.3 but according to a typology that is yet to be established). The relationships between MEP and ecological status (HMW paper 12 ver 3) anticipated for the Dee (Galloway) water bodies are as follows:

For the 6 reservoirs, the relevant reference category is “lake”. This implies no change in category for the northern part of Loch Ken. The morphological modification resulting from impoundment of this part of the loch is minor, so that no change in type (e.g. “small shallow lake to large deep lake”) is inferred. Thus,

MEP = to << GES .

For all the other reservoirs and the southern part of Loch Ken, the category has changed from “river” to “lake”; for these,

MEP = to << HES for lakes of the appropriate types.

For all remaining water bodies the reference category is “river”. In general, there has been no change in type for these water bodies (geology and altitude unaltered; modifications to effective catchment areas insufficient to alter classifications), so that

MEP = to << GES.

For any river/stream water bodies whose type had changed, e.g. “wide shallow river to narrow deep river”, the criterion for definition of MEP would be

MEP = to << HES for a river of the new reference type.

The process for deriving MEP is summarised in Figure 18. MEP is expressed in terms of the potential conditions of relevant / “most sensitive” biological quality elements derived by two independent routes which amount, essentially, to modelling procedures. The first route (upper part of Figure 18) predicts effects on the extant biota of eliminating the effects of non-physical pressures and applying appropriate mitigation measures. The second route (lower part of Figure 18) examines the deviation of the biological condition of the HMWB from that of a biological reference standard, then adjusts to MEP. Approaches to the first route will be discussed in Section 8.2, and to the second route in Section 8.3.

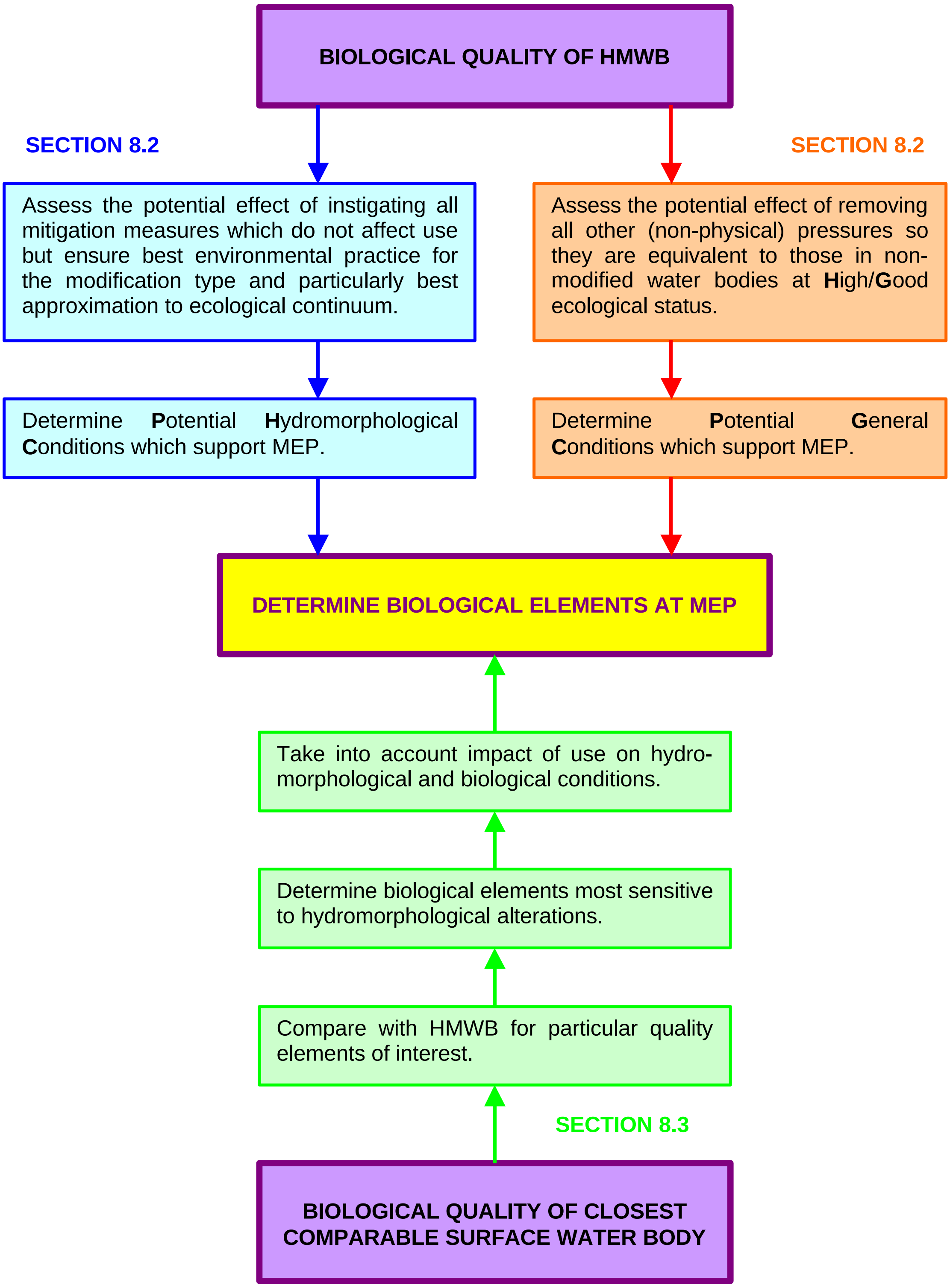


Figure 18 Sequence of actions for deriving MEP (after HMW paper 12 ver 3).

8.2 Measures Required for MEP

Apart from isolated pollution incidents, the non-physical pressures on the Dee system are acidification of the Water of Deugh and the Black Water of Dee, eutrophication of Loch Ken and organic enrichment at Kendoon Loch (Section 6.2). Temperature distortions may also occur below dams, particularly Clatteringshaws, Carsfad and Earlstoun, along with associated water chemistry changes, although there have been no direct observations of such effects in this catchment. On the other hand, known and implied alterations of all three hydromorphological quality elements (hydrological regime, river continuity and morphological conditions) are widespread. Three of the problems – sediment supply, temperature/stratification effects and acidification – will be explored generically prior to detailed examination of mitigation possibilities for the designated HMWBs, considered in four groups.

Sediment starvation has been flagged as a risk downstream of catchwaters and dams throughout the system. The severe limitation of fieldwork opportunities means that only brief impressions have been formed of the extent of bedrock relative to sediments in the river channels now, and it is unclear how widespread mobile sediments such as gravel, sand and silt would be under natural conditions. On the other hand, there is some evidence of reduction in depositional features in the Black Water of Dee (Table 8). Thus, more detailed geomorphological study is necessary to determine all the locations where mitigation would be appropriate.

For catchwaters, the principal possibility for mitigation is to modify clearing practice so that some material is placed in the river channel downstream of the structure, rather than on the bank. The proportion transferred in this way should be related to the amount of flow remaining downstream of the catchwater, and the condition of the channel should be monitored from year to year. Such practice would be subject to regulation under s49 of the Control of Pollution Act 1974.

If lack of sediment should be identified as a problem below any of the reservoir dams, it will presumably be necessary to import suitable material from elsewhere; this could be an appropriate use for any excess material cleared from catchwaters. In both cases, practical issues will be important in ensuring that such activities are indeed beneficial and not damaging to downstream reaches; a code of best practice would be needed, built on appropriate research. In some cases, practical issues may prevent the possibility of any beneficial measures being implemented.

Temperature/stratification effects have been investigated elsewhere in Scotland, in the River Lyon (a tributary of the River Tay). Automatic temperature loggers were installed at three locations in the early spring of 2000, and data from the spring/summer periods of two years are now available (Summers 2001). Between March and July 2000, the water temperature below the Lubreoch hydro-power dam was more stable and consistently lower than temperatures downstream. By May 2001, it had reached only 8^{o}C despite warm weather which raised downstream temperatures as high as 15^{o}C. In general, the pattern of temperature variation below Lubreoch, where the flow regime is governed directly by the generation pattern at Lochay Power Station, was consistent with stratification of the reservoir during warm weather and intermittent mixing during cool spells. Impacts on ecology in the Lyon are severe, with proliferation of algae, changes in invertebrate fauna and poor performance of juvenile fish. Factors other than temperature may or may not be implicated; in particular, the origin of a precipitate containing iron and manganese on stones in the river, which is reminiscent of a precipitate reported from the Elan Valley in Wales, remains to be clarified. Nonetheless these very recent observations from another Scottish hydro-power scheme indicate a risk of similar effects in the Dee system, calling for vigilance or even a targeted field investigation.

Should any impacts be confirmed, mitigation would involve modification of the arrangements for release of water from the reservoir to draw as much as possible from the epilimnion rather than from the base of the dam, at least during periods of stratification; this would, presumably, require installation of a multi-level or adjustable draw-off facility (perhaps following the Temperature Control Devices developed by the US Bureau of Reclamation (Vermeyen, 2000)). For the present, however, the locations at which such effects are most likely to arise will simply be noted.

Acidification poses difficulties because, although the procedure prescribed for deriving MEP indicates that the "potential effect of removing all non-physical pressures" should be assessed (Figure 18), it is not realistic to expect that the acidification in the Dee catchment can be reversed in the near future (Section 6.2). Thus, if acidification is to be eliminated theoretically before defining the MEP biota, unattainable biological targets will be set, e.g. for benthic invertebrates. Moreover, since some migratory fish species, notably salmon, cannot breed successfully in acid conditions, there are obvious implications for the utility of adding fish passes in acidified sub-catchments.

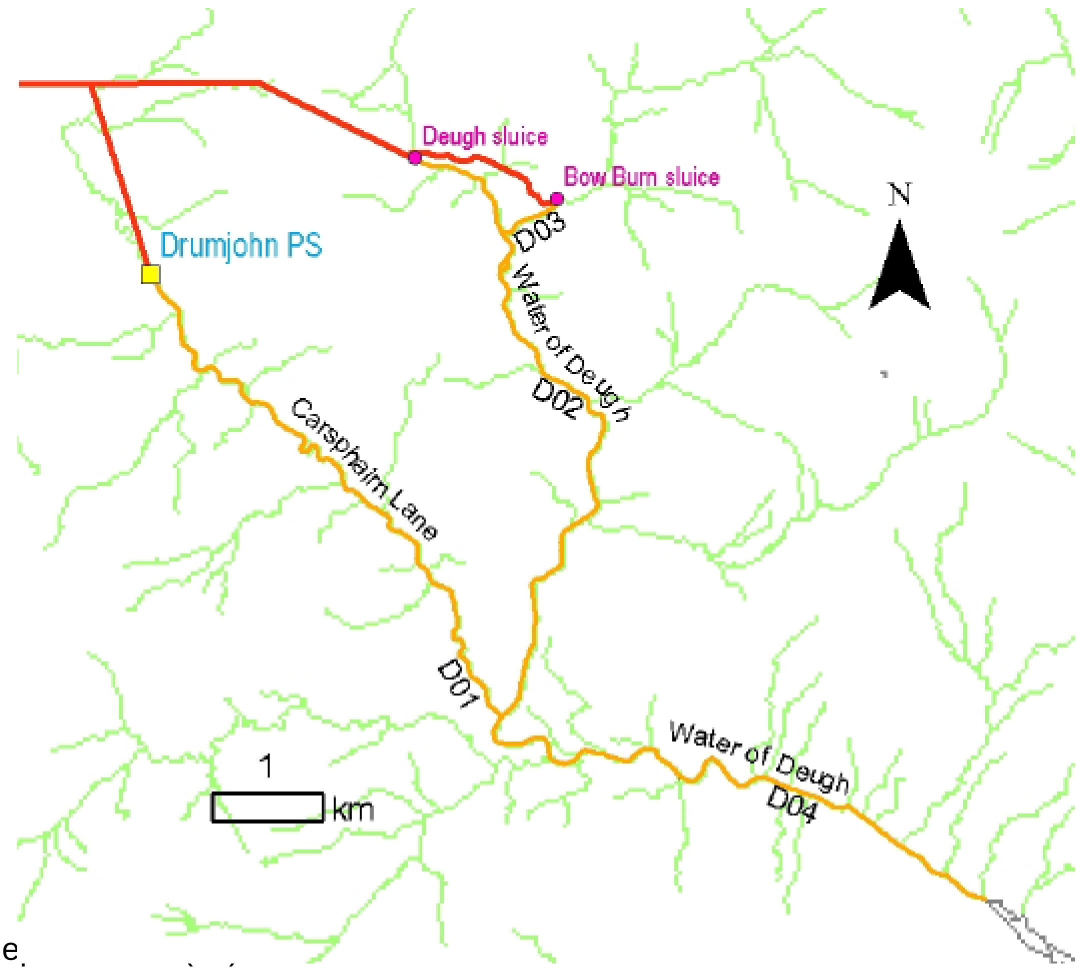
Article 4 of the Water Framework Directive separates the two issues. Designation as HMWB can be justified only in respect of hydromorphological distortions that are necessary for the hydro-power scheme to function, and the need to maintain these must be reviewed every 6 years (para. 2). HMWBs, like all surface water bodies, must be protected and enhanced with the aims of achieving good ecological potential and good surface water chemical status within 15 years (para. 1). If achievement of good status is infeasible due to impacts whose nature is such that they could not reasonably have been avoided, less stringent environmental objectives may be set. These must, however, represent the highest ecological and chemical status that is possible given the unavoidable impact (acidification); no further deterioration in the status of the affected water body is allowed; and the objectives must be reviewed every six years (para. 5).

Thus, Potential General Conditions for MEP (Figure 18) should incorporate theoretical resolution of acidification as well as other chemical problems. Good ecological potential (GEP) should then be defined as the acceptable level of approach to MEP, and less stringent environmental objectives (e.g. "benthic invertebrate fauna typical for good water quality at low pH within the RIVPACS scheme") applied subsequently. Such steps should be approached with care, recognising the specific local causes of acidity problems, e.g. acid deposition associated with metal (Al) toxicity.

In defining practical requirements to meet "less stringent environmental objectives", there would indeed seem to be little point in retaining any MEP requirements for construction of new fish passes if no migratory species would benefit from having access to the waters upstream. However, it is important that the whole biota, and not only salmonids, should be considered in this respect. There are fish species that tolerate higher acidities than do salmon, and there are species that do not migrate to sea whose natural movements along the river may still be impeded by physical obstructions. Thus, before a decision to delay construction of passage facilities can be taken on grounds of acidification, the passage needs of the whole of the MEP/GEP species complement should be taken into account. Moreover, since it seems that not all of these species are able to traverse conventional salmon ladders, it may be necessary to consider alternative designs (see, e.g. Carnie 2001) and this aspect may require research.

Since it seems likely that both MEP and "less stringent environmental objectives" will be reviewed together at 6-yearly intervals, a pragmatic approach would be to set the acidity objective at either the current or a realistic 6-year target pH, to define biota consistent with this acidity level, and then to decide whether the construction of a fish pass at a particular location would be useful, taking into account the potential movements of all species that might pass the location in its absence, given the acidity objective. In future iterations of the River Basin Management Planning process, reductions in acid loadings, coupled with the effects of improved Forests and Water Guidelines, may allow reductions in acidity to occur, such that fish pass construction in the Dee system may need to be considered.

Drumjohn HMWBs: Potential effects on biota of all mitigation



Re

Figure 19 Drumjohn HMWBs (gold) and structures (red lines, cyan and mauve labels).

Mitigation for some of the factors that compromise ecological status in the Drumjohn group of water bodies (Table 14) was considered in Section 7. There, it was concluded that it would be disproportionately costly to increase compensation in the Carsphairn Lane (D01) and naturalise its channel, but it would be feasible to increase compensation flow in the Water of Deugh (D02) and Bow Burn (D03). All of these options were technically feasible. However, costs were attached to the compensation releases even at the Water of Deugh and Bow Burn sluices, perhaps suggesting that they cannot be achieved without loss of some ability to generate electricity that can be sold at peak-time prices. Nonetheless, it would seem worth investigating further the possibility that some increase in compensation flow in all three water bodies could be provided without prejudice to the total annual capacity for peak-time electricity generation.

Re-naturalisation of the channel of the Carsphairn Lane would not prejudice electricity generation, so although it appears already to have been ruled out on economic grounds, it is still regarded as a possible mitigation measure.

Table 26 lists all mitigation measures appropriate to the identified non-physical pressures and to the physical quality risks flagged in Table 15. For measures marked with asterisks, further investigation will be necessary to confirm any need for mitigation (see above and early paragraphs of this Section).

<u>Ken (Kendoon/Carsfad/Earlstoun) HMWBs: Potential effects on biota of all mitigation</u>

Possible measures for mitigation for the various quality risks identified for the Kendoon group in Table 15 are shown in Table 27; Table 28 applies to the Carsfad group (Table 16) and Table 29 to the Earlstoun group (Table 17). For measures marked with asterisks, further investigation is necessary to confirm either a need for mitigation or its practicality (see above and early paragraphs of this Section).

The present arrangements (Figure 20) preclude fish access to the Black Water, as well as to Kendoon Loch and thence to all waters upstream. The latter include the Water of Ken, which is not acidified and was definitely accessible to salmonids prior to impoundment. It is possible that a fish pass at the Black Water dam could be arranged to give access to Kendoon Loch as well as to the Black Water itself; otherwise fish could be directed away from the aqueduct by providing separate passage facilities at one or other of the Deugh and Kendoon dams.

It appears that the fish access issues at Carsfad and Earlstoun dams might be solved quite simply without using extra water by altering the balance between flow in the fish ladder and the rate of compensation release from the dam (Section 6.1).

Again, some mitigation of the various distortions to hydrological regimes may be achievable through small changes in practice. However, further hydrological analyses would be necessary to explore means by which improvements to the water level regimes of lochs and increases in compensation flow in river sections could be achieved without prejudice to the total annual capacity for peak-time electricity generation.

Table 26 Potential effects of all mitigation at Drumjohn HMWBs.

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES			
Mitigation	Carsphairn L.	Deugh/Bow B.	Deugh	Upstream waters
	D01	D02 / D03	D04	D05 / D06
Provide facilities for unimpeded passage of fish at the Deugh and Bow Burn sluices	None	None	None	F: Given free access to Water of Deugh, some salmonid habitat utilized
Naturalise channel of Carsphairn Lane	MP: favoured BIF: favoured F: increased spawning	None	None	None
Reverse acidification of Deugh sub-catchment.	BIF: Replacement of acid-tolerant by acid-sensitive community. F: Inccreased survival of juvenile salmonids		None	BIF: Replacement of acid-tolerant by acid-sensitive community. F: Increased survival of juvenile salmonids
*Draw water from Loch Doon at ambient temperature/from epilimnion	None	MP: reduced algal growth BIF: increase F: re-synchron-ised spawning, inc. juv. salmon growth	None	None
*Import appropriate sediment to Water of Deugh and Bow Burn	None	(b) BIF: increase F: increased spawning	None?	None

*Provide feasible compensation flow &/or more equitable hydrological regimes below all structures (without prejudice to generation capacity)	BIF: favoured F: access eased; increased spawning and feeding	F: Given free access to waters upstream of Deugh and Bow Burn sluices, all potential fish habitat utilised

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate that further survey is necessary to confirm any actual need before application of measures.

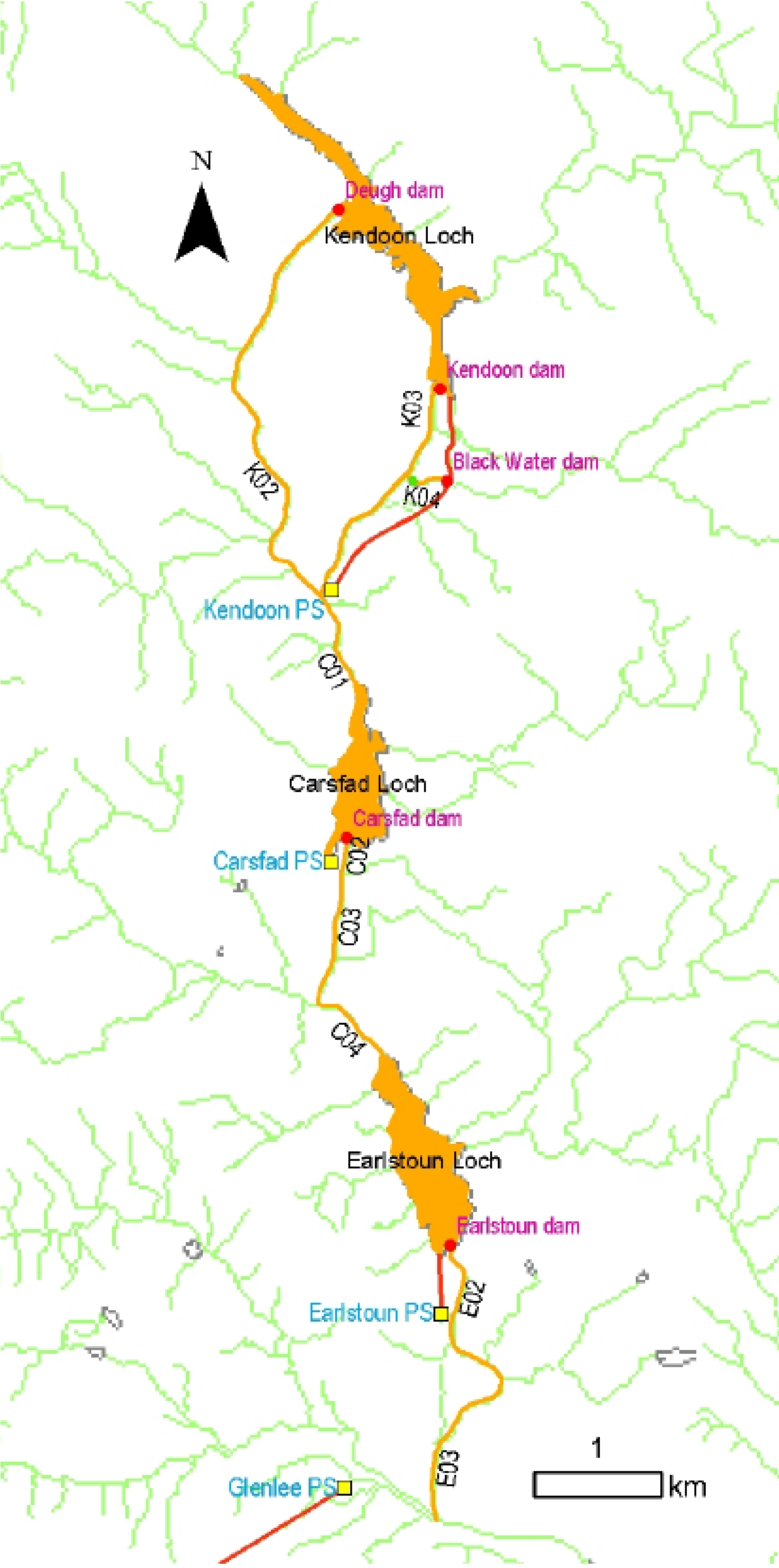


Figure 20 Ken (Kendoon/Carsfad/Earlstoun) HMWBs (gold) and structures (red lines, cyan and mauve labels).

Table 27 Potential effects of all mitigation at Kendoon HMWBs.

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES			
Mitigation	Kendoon Loch	Deugh/ Black Water	Water of Ken	Upstream waters
	K01	K02 (K04)	K03	
*Provide facilities for unimpeded passage of fish at Black Water dam and into Kendoon Loch	F: Migratory fish admitted	None	None	F: Migratory fish admitted
Reduce organic enrichment below cages at Glenkens fish farm	MP: reduced algae; changes towards typical aquatic flora BIF: favoured	None	None	None
Naturalise reinforced channel section in Water of Ken	None	None	MP: favoured BIF: favoured F: inc. spawning	None
*Import appropriate sediment to river channels below dams	None	BIF: favoured F: increased spawning density		None
*Provide any feasible compensation flow for more equitable hydrological regimes (without prejudice to generation capacity)	None	BIF: favoured F: access eased; increased spawning and feeding		F: Given free access to the Black Water & Kendoon L., all potential fish habitat utilised

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate that further survey is necessary to confirm any actual need before application of measures.

Table 28 Potential effects of all mitigation at Carsfad HMWBs.

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES			
Mitigation	Carsfad Loch	Water of Ken		Upstream waters
	C01	C02/C03	C04	
*Provide facilities for unimpeded passage of fish at Carsfad dam	F: increase in migratory species	None	None	F: Access established or eased for migratory species
*Import appropriate sediment to river channel below dam	None	BIF: favoured F: increased spawning density		None
*Provide more compensation flow and/or more equitable hydrological regimes from dam and fish ladder (without prejudice to generation capacity)	F: increase in salmonids	BIF: favoured F: access eased; increased spawning and feeding		F: Salmonid access eased
* Draw water from Carsfad Loch at ambient temperature/from epilimnion	None	MP: reduced algal growth BIF: favoured F: synchronised spawning, increased growth of juvenile salmonids	None	None

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate that further survey is necessary to confirm any actual need before application of measures.

Table 29 Potential effects of all mitigation at Earlstoun HMWBs.

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES		
Mitigation	Earlstoun Loch	Water of Ken	Upstream waters
Water Body	E01	E02/E03	
*Provide facilities for unimpeded passage of fish at Earlstoun dam	F: increase in migratory species	None	F: Access established or eased for migratory species
*Import appropriate sediment to river channel below dam	None	BIF: favoured F: increased spawning density	None
*Provide more compensation flow and/or more equitable hydrological regimes from dam and fish ladder (without prejudice to generation capacity)	F: increase in salmonids	BIF: favoured F: access eased; increased spawning and feeding	F: Salmonid access eased
*Provide more equitable hydrological regime in Earlstoun Loch (without prejudice to generation capacity)	MP: alter towards typical edge flora. BIF: increase in littoral zone F: increased spawning	None	None
*Draw water from Earlstoun Loch at ambient temperature/from epilimnion	None	MP: reduced algal growth BIF: favoured F: synchronised spawning, increased growth of juvenile salmonids	None

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate that further survey is necessary to confirm any actual need before application of measures.

Glenlee HMWBs: Potential effects on biota of all mitigation

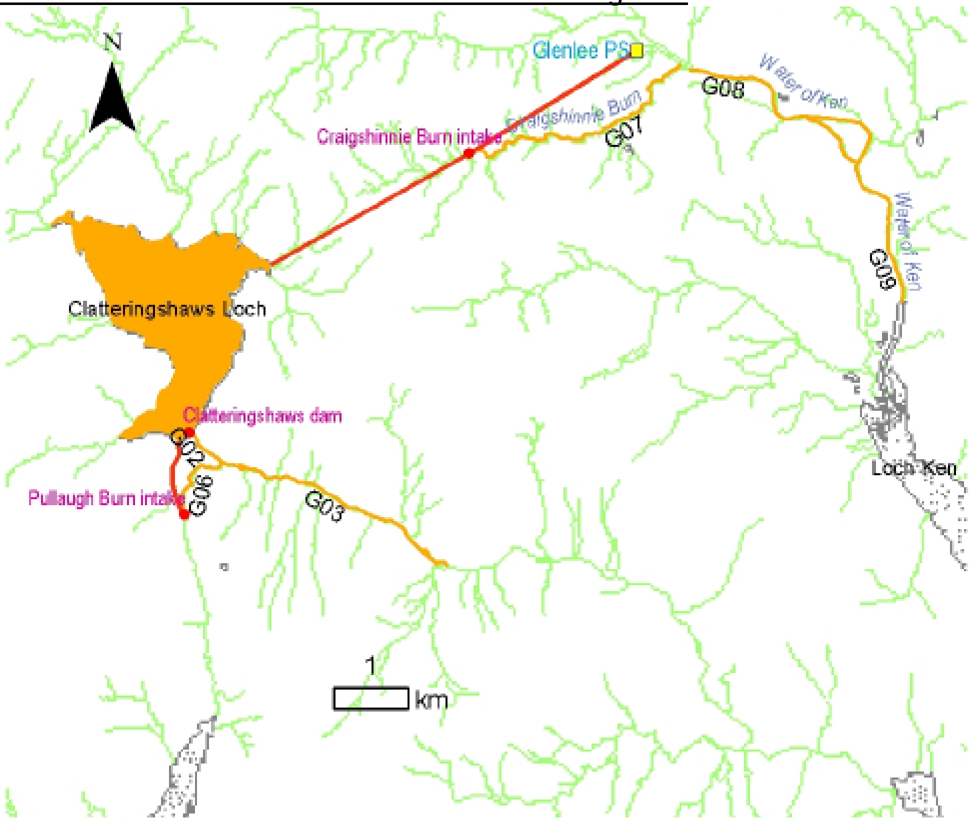


Figure 21 Glenlee HMWBs (gold) and strucutres (red lines, cyan and mauve labels).

The data shown in Table 18 for Water Body G04 are interesting in that the hydrological regime appears to be satisfactory, and yet there is evidence for downgrading of ecological status on the basis of fish data. Only sediment effects (Table 8) and/or acidification are implicated as the cause(s) and since mitigation will not affect the use of the catchment for hydro-power generation, HMWB designation is inappropriate.

An interesting possibility for flow regime mitigation is offered by the arrangement at the Pullaugh Burn intake. At present, this intake intercepts all flow up to the (unknown) capacity of the relatively short pipe or channel connecting it to Clatteringshaws Loch, before spilling into the lower part of the Pullaugh Burn and the Black Water of Dee. It would seem to be worth examining the feasibility of replacing the pipe with a larger flood diversion channel. The lowest flows in the Pullaugh Burn would not be intercepted and would, in effect, provide compensation flow to the Black Water of Dee. The diversion channel would begin to take water at some predetermined flow rate (e.g. Q_{90}) and its design capacity should be such that it would collect the same quantity of water as delivered by the present arrangement during the course of each year or season. In effect, the lowermost tranche of the flow duration curve would remain in the Pullaugh Burn and the water required for Clatteringshaws reservoir would be collected from the middle and upper parts of the curve.

Since this arrangement would tend to increase fluctuations in storage (and thus water level) in Clatteringshaws Loch, an exercise to examine hydrological feasibility is required. It would also seem to be worth examining the possibility that additional water could be taken from the Pullaugh Burn whilst still providing an acceptable flow regime (baseflow with some superposed spate flow) there, and that the additional water thus secured for power generation could be "traded" for a compensation release at the Craigshinnie Burn intake (Water Body G07).

Table 30 Potential effects of all mitigation at Glenlee HMWBs (Craigshinnie Burn/Water of Ken).

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES			
Mitigation	Craigshinnie Burn	Water of Ken		Upstream waters
	G07	G08	G09	
*Import appropriate sediment to river channel below Craigshinnie offtake	BIF: favoured F: increased spawning density	None	None	
*Provide facilities for unimpeded passage of all appropriate fish species at Craigshinnie offtake	None	None	None	F: Given free access of fish to Craigshinnie Burn, all potential fish habitat available.
* Provide compensation flow from Craigshinnie Burn offtake, or remove offtake	BIF: favoured F: access eased; inc. spawning and feeding	None	None	F: Migratory fish access to upper reaches of Craigshinnie Burn eased
* Adjust timings of generation at Glenlee and Drumjohn power stations to give more equitable flow regime in Water of Ken	None	BIF: favoured F: access eased; increased spawning & feeding	BIF: favoured F: access eased; increased spawning & feeding	F: Salmonid access eased

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate that further survey is necessary to confirm any actual need before application of measures.

Table 31 Potential effects of all mitigation at Glenlee HMWBs (Black Water of Dee).

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES			
Mitigation	C. Loch	Black Water of Dee	Pullaugh	Upstream waters
Water Bodies	G01	G02/03	G06	
Reverse acidification	BIF: Replacement of acid-tolerant by acid-sensitive community. F: Increase in survival of juvenile salmonids			
*Provide facilities for unimpeded passage of fish at dam and Pullaugh Burn intake	Migratory fish admitted	None	None	Migratory fish admitted
*Import appropriate sediment to river channel below Clatteringshaws dam & Pullaugh Burn int.	None	BIF: favoured F: increased spawning density		None
*Provide compensation flow from dam and/or PB intake (without prejudice to generation capacity)	None	BIF: favoured F: access eased; increased spawning & feeding	BIF: favoured. F: access eased; increased spawning & feeding	F: access eased
*Provide more equitable hydrological regime in Clatteringshaws Loch (without prejudice to generation capacity)	MP: ? typical edge flora. BIF: inc. in littoral zone F: inc. spawning	None	None	None
* Draw water from Clatteringshaws dam at ambient temperature/from epilimnion	None	MP: decreased algal growth BIF: favoured F:growth/ spawning effects	None	None

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate further survey is necessary to confirm any actual need before application of measures.

Table 30 lists all mitigation measures appropriate to the identified non-physical pressures and to the physical quality risks flagged in Table 18 for the Craigshinnie Burn and Water of Ken HMWBs in this group. Table 31 applies to Clatteringshaws Loch (G01), the Black Water of Dee (G02-4) and the Pullaugh Burn (G06). For measures marked with asterisks, further investigation is necessary to confirm either a need for mitigation or its practicality (see above and early paragraphs of this Section).

Tongland HMWBs: Potential effects on biota of all mitigation

The only HMWBs in the Tongland group are the lower part of Loch Ken, Tongland Loch, and the part of the River Dee between Tongland dam and the tidal limit. Issues are principally, but not entirely, related to the fact that the fish pass at Tongland is the "gateway" to/from the entire river for migratory fish, so that its efficiency is of paramount importance for ecology. Table 30 lists all mitigation measures appropriate to the quality risks flagged in Table 19.

Figure 22 Tongland HMWBs (gold) and structures (red lines, cyan and mauve labels).

Table 32 Potential effects of all mitigation at Tongland HMWBs.

	POTENTIAL EFFECT ON BIOLOGICAL QUALITY ELEMENTS OF INDIVIDUAL WATER BODIES				
Mitigation	Loch Ken	Tongland Loch	River Dee		Upstream waters
Water body	T02	T04	T05	T06	
Reduce BOD and P levels in Loch Ken	MP: reduced algae; changes towards typical aquatic flora BIF: favoured	None	None	None	None
Prevent fish strandings below dam	F: Increase in adult salmonids		F: Adult mortality reduced	None	F: Increased salmonid spawning
*Provide for unimpeded passage of all fish species at Tongland dam	F: All potential fish habitat accessible				
*Import appropriate sediment to river channel below dam	None	None	BIF: favoured		None
*Provide more compensation and/or more equitable hydrological regime from dam/fish pass	F: Increase in adult salmonids		F: less stranding	BIF: favoured F: salmonid passage eased	F: Increased salmonid spawning in headwaters
* Draw water from Tongland Loch at ambient temperature/ from epilimnion	None	None	MP: reduced algal growth BIF: favoured		None

Key: MP: Macrophytes and Phytobenthos; BIF: benthic invertebrate fauna; F: fish. Asterisks indicate that further survey is necessary to confirm any actual need before application of measures.

8.3 Comparison with Comparable Water Body

Water bodies for which HMWB designation involves a change of reference category

In Section 6, all assessments of ecological status that were possible on the basis of available data were carried out by comparing (principally) hydromorphological and (where available) biological quality elements for each water body with those of an unimpacted analogue. Since there has been no change in category or type for most of the water bodies now designated HMWB, these assessments remain valid in defining ecological potential (MEP = to << GES). The exceptions are the six reservoirs created by impoundment of rivers, whose ecological condition should now be assessed according to the criteria set for lochs. The principal tool available is DHRAM (Section 5.3), which uses as its reference the set of natural Scottish lochs identified by Smith *et al*. (1987), although some biological data were also located (Section 6). An assessment, carried out in the same terms as those in Tables 14-19, is shown in Table 33.

This analysis indicates that, ignoring non-physical pressures and their apparent effects, the ecological condition of Carsfad and Kendoon Lochs and Loch Ken (River Dee) are equivalent to good ecological status in terms of their new (loch) category, whereas the ecological condition of the other three reservoirs is assessed as being equivalent only to moderate ecological status on grounds of disruption to their hydrological regimes. An indication of the level at which MEP might be set in relation to GES_{loch} is given in the bottom row of Table 33.

Comparisons based on biological data

It was noted in Section 6 that direct assessment of the ecological status/condition of the various water bodies in the Dee system was severely constrained by the lack of standards with which biological data could be compared. Until the Scottish reference typologies become available, a practical route to definition of missing standards will be based on biological data from individual natural water bodies selected (on the basis of typological attributes) to match the impacted water bodies under investigation. The analogues used in deriving DHRAM scores (Annex A) were not suitable in this respect; they were selected for hydrological criteria only from the sparse network of Scottish river gauging sites, most were distant from the Dee system and constituted inadequate matches on the basis of the relevant typological criteria (Section 4.3). In order to overcome this problem, a targeted programme of biological sampling, focusing on benthic invertebrate fauna, but including some other biological quality elements, was planned for the summer of 2001 (Annex C). The suite of sampling sites was selected to include a sub-set of the water bodies impacted by hydro-power operations together with non-impacted reference water bodies nearby. The selection of reference sites was map based, and to some degree subjective, but aimed to find a small number of reasonably accessible sites, each with similar altitude and geology to a group of the selected impacted sites. Where possible, the reference water bodies were also matched for size/catchment area, but in practice were often smaller than the impacted ones.

Table 33 Assessment of ecological condition of the 6 reservoirs whose reference category has altered in conjunction with HMWB designation. The standard applied is GES for natural Scottish lochs (GES_{loch}). Format follows that for Tables 14-19 (Section 6.3).

LOCH NAME	Carsfad	C'shaws	Earlstoun	Ken(Dee)	Kendoon	Tongland
ELEMENT Water Body	C01	G01	E01	T02	K01	T04
BIOLOGICAL						
Phytoplankton					×	
Macrophytes/phytobenthos				**M**		
Benthic invertebrate fauna						
Fish fauna						
HYDROMORPHOLOGICAL						
Hydrological regime		?	?			?
River continuity (connection to d/s waters)	??	??	??	??	??	??
Morphological conditions						
PHYSICOCHEMICAL						
General						
Synthetic pollutants						
Non-synthetic pollutants		∗		∗	∗	
Risk Score	**1**	**2**	**2**	**1**	**1**	**2**
ECOLOGICAL CONDITION	**G**	**M**	**M**	**G**	**G**	**M**
MEP relative to GES_{loch}	**= GES**	**= GES**	**= GES**	**= GES**	**= GES**	**= GES**

A second approach to establishing reference data for river/stream water bodies was also incorporated in the scheme. River Habitat Survey (RHS) was to be carried out at the selected sites. This is essentially a technique for standardised geomorphological survey; some of the results are reported in Table 8 (Section 5.3). These data were to be submitted to the Environment Agency (EA) for entry to the UK RHS database, enabling the sites to be matched through physical and chemical attributes to natural reference sites included in the UK invertebrate database (RIVPACS), and thus yield reference data on invertebrate species and abundance appropriate to the impacted sites in the Dee system.

Due to the access restrictions that applied to agricultural land during most of 2001, it was possible to undertake only part of the planned programme of fieldwork, mostly on the Black Water of Dee where access is through forestry plantations but also at other sites close to public roads. The work was undertaken by Scottish Environment Protection Agency (SEPA) biologists based in Dumfries. Eight standard invertebrate samples were collected and RHS survey was conducted at three locations in mid-July 2001 (Table 38). The invertebrate samples were subsequently counted by SEPA, and further invertebrate data from routine monitoring work since 1990 were made available. However, the timescale of this project proved to be incompatible with EA data processing schedules, and at the time of writing the updated RHS database is not to hand. Therefore, the search for standard sites in the RHS database cannot be undertaken and the only reference data originate from the Dee catchment itself.

Lochs

Invertebrate samples were taken from Loch Ken, Clatteringshaws Loch (2 sites) and Woodhall Loch (reference site, see Section 6.1). The results are shown in Table 34. The data have been analysed to “mixed taxon” level so that most species have been distinguished, and actual numbers of individuals are shown, so that they might form the basis of a quantitative comparison. However, for consistency with much of the other data available, the samples are compared only at the level of presence/absence of taxa at this stage. Table 34 indicates the method used to compare them by calculation of Ecological Quality Ratios (EQRs) as required by the Water Framework Directive (Annex V section 1.4.1). For each set of data, the number ***C*** of taxa in common with Woodhall Loch (shown in green type), the number ***E*** of taxa not recorded at Woodhall Loch (“exotic” taxa, shown in black type) and the number ***M*** of Woodhall Loch taxa that are missing (shown in red type) is calculated. The EQR is then calculated as:

EQR = ***C*** / (***M*** + ***C*** + ***E***).

All taxa recorded have been taken into account. These include all those required for standard RIVPACS (water quality) analysis plus additional taxa noted at the ends of the forms. Also, where juveniles are recorded separately from adults of the same group (e.g. Corixidae in Table 34), they are counted as separate taxa.

The EQR values are generally low. The invertebrate fauna of Loch Ken (15 common taxa) is more similar to that of Woodhall Loch than is that of Clatteringshaws Loch (8-9 common taxa), and there are fewest taxa in total at Clatteringshaws.

Tables 35 and 36 show similar comparisons of the macrophyte flora of Clatteringshaws, Kendoon and Struan Lochs with that of Woodhall Loch. Table 37 shows the results (only) of a similar calculation based on the macrophyte flora of Loch Ken as detailed in Tables 9 and 10. For edge flora, the EQR is calculated using the flora of Woodhall Loch as standard; for submerged and floating species separate EQRs are calculated using Woodhall Loch and the constancy data for UK classes 3 and 5 (Palmer *et al*. 1992).

Table 34 Calculation of Ecological Quality Ratios (EQRs) for Loch Ken and Clatteringshaws Loch, on the basis of invertebrate data (standard site Woodhall Loch).

Loch	Clatteringshaws		Ken		Woodhall
Sample date: mid-July 2001	west	south			[STANDARD]
National Grid Reference	NX 532776	NX547757	NX 649736		NX 674671
Sample ID					
Water Body	**G01**	**G01**	**T01**		**T07**
Corixidae (adult)	39	502	43		86
Copepoda	11	10	72		126
Cladocera	18	2	12		12
Caenis horaria	4	19	4		2
Asellus meridianus	3	157	202		96
Asellus aquaticus	10	36	19		9
Agraylea sp	3	0	218		69
Cyrnus flavidus	0	0	49		392
Crangonyx pseudogracilis	0	0	33		147
Chironomidae	0	0	1		1
Ceraclea nigronervosa	0	0	29		28
Centroptilum pennulatum	0	0	13		12
Ancylus fluviatilis	0	0	5		2
Acroloxus lacustris	0	0	20		1
Corixidae (larvae)	0	0	1		2
Lumbriculidae	3	4	0		6
Notonecta sp	5	0	0		35
Naididae	0	1	0		1
Holocentropus dubius	0	0	0		262
Gammarus pulex	0	0	0		83
Erpobdella sp	0	0	0		56
Ephemerella ignita	0	0	0		21
Gammarus lacustris	0	0	0		13
Glaenocorixa propingua	0	0	0		7

Helobdella stagnalis	0	0	0		6
Haliplidae	0	0	0		5
Halipus sp	0	0	0		4
Holocentropus picicornus	0	0	0		4
Hydroporus sp	0	0	0		3
Erpobdella octoculata	0	0	0		2
Helophorus sp	0	0	0		2
Hygrobia hermanni	0	0	0		2
Dytiscidae	0	0	0		1
Enchytraeidae	0	0	0		1
Hydraena sp	0	0	0		1
Hydroporinae	0	0	0		1
Limnephilus lunatus	0	0	0		1
Lymnaea peregra	0	0	0		2
Lymnaea sp	0	0	0		2
Lymnaea stagnalis	0	0	0		1
Mites	0	0	0		17
Moth larvae	0	0	0		14
Mystacides azurea	0	0	0		1
Nematode	0	0	0		105
Nemoura sp	0	0	0		1
Odonata	0	0	0		2
Triaenodes bicolor	1				
Tubificidae	1				
Tipulidae		4			
Planorbis crista		1			
Protonemura sp		1			
Planaria tarva			24		
Planorbis sp			13		
Oxyethira sp			8		
Oulimnius sp			7		
Sphaeridae			4		

Potamonectes griseostriatus			3		
Theronyzon tessulatum			3		
Ostracoda			2		
Phryganea sp			2		
Potamonectes depessus-elegas			2		
Rhantus sp			2		
Segmentina lacustris			2		
Phryganea bipunctata			1		
Planorbis albus			1		
Sialis lutaria			1		
Valvata macrostoma	41	39			
Zygoptera	1		2		
NUMBER OF TAXA	13	12	31		46
C: number of taxa in common with standard	9	8	15		
M: number of missing taxa	37	38	31		
E: number of exotic taxa	4	4	16		
Preliminary EQR: C/(M+C+E)	**0.18**	**0.16**	**0.24**		

Table 35 Calculation of Ecological Quality Ratios (EQRs) for Clatteringshaws Loch, Kendoon Loch and Stroan Loch on the basis of macrophyte data (emergent and edge species); standard site Woodhall Loch.

Scores based on DAFOR scale: Dominant; Abundant; Frequent; Occasional; Rare. (l) indicates local occurrence, e.g. O/F(l) = Occasional, locally Frequent. Source: SNH, 1996.

EMERGENT AND EDGE SPECIES	Clatteringshaw	Kendoon Loch	Stroan Loch	Woodhall Loch
Agrostis stolonifera	F	F(l)	F	F / A(l)
Alisma lanceolatum	×	×	×	O / F(l)
Alisma plantago-aquatica	×	×	×	F(l)
Caltha palustris	O	O	O	O
Carex aquatilis			O/A(l)	
Carex echinata			O/F(l)	
Carex lasiocarpa	×	×	O/D(l)	R / D(l)
Carex nigra	×	O(l)	O/F(l)	F / A(l)
Carex panicea	O/F(l)		F	
Carex rostrata	O/D(l)	O/F(l)	F/D(l)	O / D(l)
Carex vesicaria	×	F	R	O / F(l)
Carex viridula ssp. oedocarpa			O	
Eleocharis acicularis	×	×	×	R
Eleocharis multicaulis	×	×	O(l)	R / F(l)
Eleocharis palustris	O/F(l)	O/F(l)	O/F(l)	F / A(l)
Eleocharis quinqueflora			O(l)	
Equisetum fluviatile	F(l)	×	O/F(l)	F / A(l)
Eriophorum angustifolium	O(l)	R/F(l)	O/F(l)	
Galium palustre			O	
Glyceria fluitans	O/F(l)	R	O(l)	R / F(l)
Hydrocotyle vulgaris	O	×	F	F (l)
Iris pseudacorus		O/A(l)		
Juncus acutiflorus	O/F(l)	A	×	A
Juncus articulatus	O/F(l)	×	F/A(l)	F(l)
Juncus bulbosus	A	×	O	O(l)

Juncus conglomeratus	×	×	R	O
Juncus effusus	O/F(l)	O	O	F / A(l)
Littorella uniflora	×	×	×	O / A(l)
Lysimachia vulgaris			O(l)	
Lythrum salicaria	×	×	×	R
Mentha aquatica	×	F	×	F / A(l)
Menyanthes trifoliata	R	×	O	O / F(l)
Montia fontana	R	×	×	R
Myosotis laxa	×	R	×	F
Myosotis scorpioides	×	×	×	R
Oenanthe crocata	×	×	×	O
Persicaria hydropiper	F	O(l)	×	O
Phalaris arundinacea	O/D(l)	A/D(l)	R / F(l)	F / D(l)
Phragmites australis	×	×	F/A(l)	A / D(l)
Potentilla palustris	×	F/A(l)	O / F(l)	O / F(l)
Ranunculus flammula	F	F(l)	O (l)	F
Rorippa palustris	×	×	×	O
Schoenoplectus lacustris	×	×	A / D(l)	A / D(l)
Sparganium emersum	×	×	×	F(l)
Sparganium erectum	×	×	×	R / F(l)
Triglochin palustre			R	
Veronica scutellata	×	×	×	R
Viola palustris	F(l)		F	
Number of species	19	17	31	37
C: No.common species	16	15	21	
M: No. missing species	21	22	16	
E: No. exotic species	3	2	10	
Preliminary EQR: C/(M+C+E)	**0.40**	**0.38**	**0.45**	

Table 36 Calculation of Ecological Quality Ratios (EQRs) for Clatteringshaws Loch and Kendoon Loch, on the basis of submerged and floating macrophytes; standard site Woodhall Loch.

Scores based on DAFOR scale: Dominant; Abundant; Frequent; Occasional; Rare. (l) indicates local occurrence, e.g. O/F(l) = Occasional, locally Frequent. Source: SNH, 1996.

SUBMERGED AND FLOATING SPECIES	Clatteringshaws Loch	Kendoon Loch	Stroan Loch	Woodhall Loch
pH	7.6	6.6	5.7	6.6
Alkalinity (meq/l)	0.16	0.26	0.06	0.28
Conductivity (µS/cm)	55	63	44	95
Apium inundatum			R	O / F(l)
Callitriche hamulata	F(l)	F/A(l)	R	
Callitriche hermaphroditica				
Callitriche stagnalis	F(l)			R
Eleogiton fluitans				O / F(l)
Elodea canadensis				O / F(l)
Fontinalis antipyretica		F	O	F
Isoetes lacustris			O(l)	F
Juncus bulbosus			O / F(l)	R
Lemna minor				O
Lemna trisulca				A(l)
Littorella uniflora			F	F / A(l)
Lobelia dortmanna			F / A(l)	O
Myriophyllum alterniflorum	R/D(l)	R	O	R
Nuphar lutea			F / D(l)	F / D(l)
Nuphar pumila			O / D(l)	
Nuphar x spennerana				F
Nymphaea alba			F / D(l)	F / A(l)
Potamogeton alpinus				O / F(l)
Potamogeton berchtoldii		R		
Potamogeton gramineus				O(l)

Potamogeton natans			R / F(l)	F / D(l)
Potamogeton obtusifolius				F / A(l)
Potamogeton polygonifolius				O(l)
Sparganium angustifolium				R
Sparganium emersum				F
Sparganium natans				O(l)
Sparganium sp.	R			
Sphagnum sp.	O			
Utricularia stygia			O / F(l)	
Utricularia vulgaris/australis agg.			F	
No. species	5	4	14	24
C: No.common species	2	2	10	
M: No. missing species	22	22	14	
E: No. exotic species	3	2	4	
Preliminary EQR: C/(M+C+E)	**0.04**	**0.08**	**0.36**	

Table 37 EQRs for Loch Ken, based on macrophyte data (standard site Woodhall Loch); data from Tables 9 and 10 (Section 6.1).

Loch Ken: Water Body T01		Sample date:		
	EDGE FLORA	SUBMERGED AND FLOATING VEGETATION		
NUMBER OF SPECIES	37	24		
Standard		Woodhall Loch	Type 3	Type 5(5A)
C: No.common species	29	16	13	9
M: No. missing species	8	8	3	12
E: No. exotic species	8	8	11	15
EQR: C/(M+C+E)	**0.64**	**0.50**	**0.48**	**0.25**

Rivers

The biological data available were entirely invertebrate data, collected for various purposes, using standard kick sampling.

> **New** sites were sampled specifically for this project, sorted and counted at "mixed taxon" level; Table 34 shows an example of the type of data produced.
>
> Acid Water Baseline (**AWB**) sites are sampled annually, in spring, and analysed to mixed taxon level.
>
> Water Quality Classification (**WQC**) sites have been sampled seasonally, often in spring and autumn each year (some since 1990), and are analysed to family level for calculation of BMWP scores (RIVPACS 3) and SEPA water quality indices[11].
>
> At Discharge Monitoring (**DM**) sites, samples are taken upstream and downstream of the target outfall, some on a "one-off" basis and others annually. If any of these data are used here, only the upstream sample is employed.

A thorough preliminary analysis of the data was undertaken, with a view to deriving as many EQR values as possible by comparing data collected from sites in the candidate HMWB and other main stem water bodies with appropriate samples from unimpacted parts of the system. In calculating EQRs from WQC data, the total species complement recorded in the available run of samples was derived. In general, this complement was never present in a single seasonal sample, so that data from sites where one-off and annual sampling were conducted were avoided whenever possible. Some of the AWB data were used in different ways, e.g. Table 39. The results (only) of the various comparisons undertaken appear in the Tables that follow.

[11] The SEPA water quality classification scheme has classes A1, A2 (good); B, C becoming worse (http://www.sepa.org.uk/data/classification/classification_scheme_rivers_2000.htm)

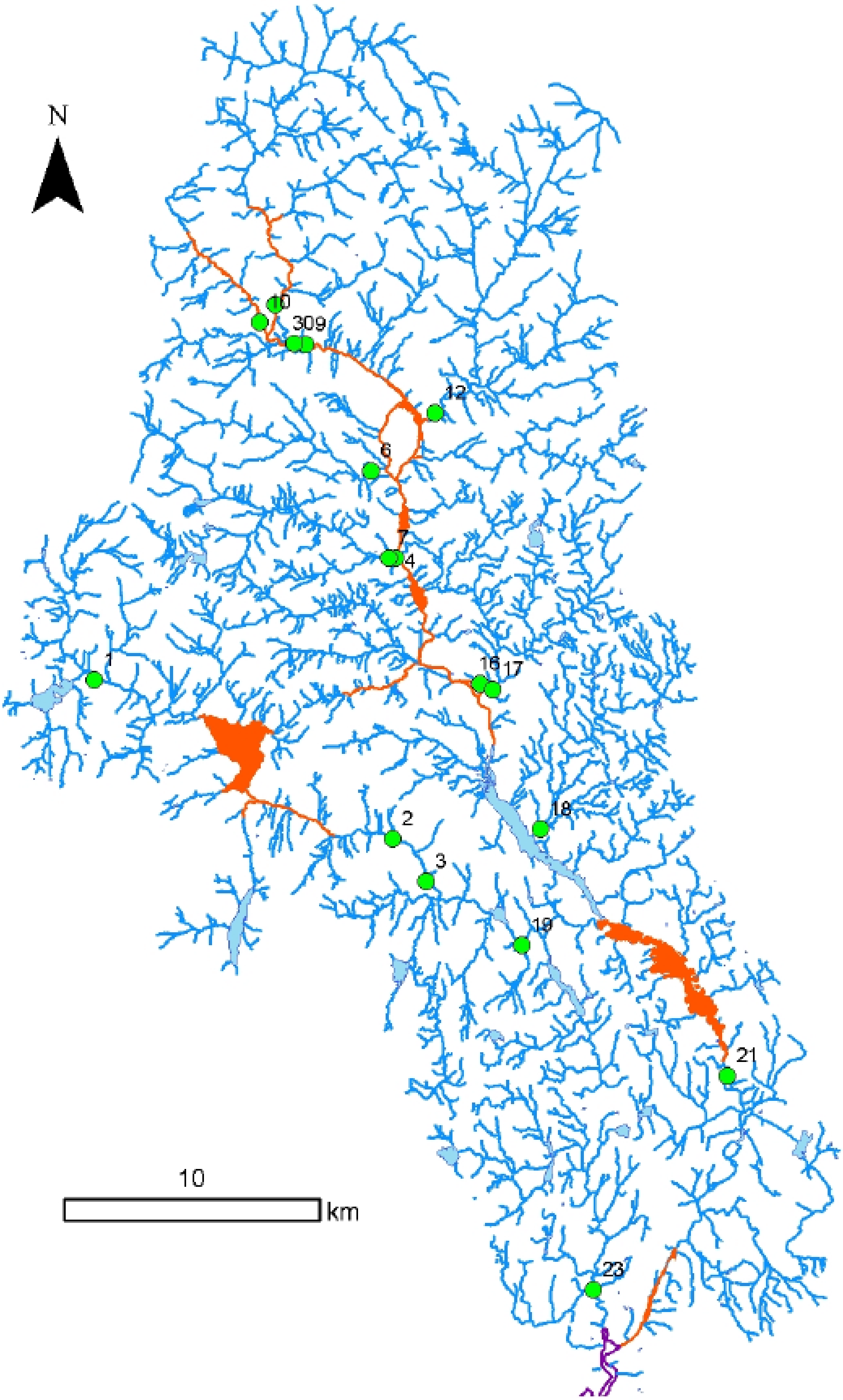


Figure 23 Locations of SEPA biological sampling sites (green points) used in calculation of river EQRs; see Table 38 for key. HMWBs are indicated in red.

Table 38 Details of SEPA sites and sampling regimes where data used in calculation of EQRs were collected.

					Water quality (no. of samples)					
ID	Data type	Water Body	Water course	National Grid Ref.	1990	1995	1998	1999	2000	2001
1	New	G10	Black W. of Dee	NX485794						(1)
2	New	G04	Black W. of Dee	NX602733						(1)
3	New	G04	Black W. of Dee	NX616715						(1)
4	New	C03	Water of Ken	NX604847						(1)
5	AWB	D04	Water of Deugh	NX557946	A1	A1	(1)	(1)	(1)	
6	AWB	C05	Polmaddy Burn	NX595879		A1	A1(1)	A1(1)	A1(1)	
7	AWB	E04	Polharrow Burn	NX602844	A2	A2	A2(1)	A1(1)	A1(1)	
9	WQC	D04	Water of Deugh	NX569929	A1(3)	A1(2)				
10	WQC	D01	Carsphairn Lane	NX550939			A2(1)	A2(2)		
10	WQC	D02	Water of Deugh	NX557946			A1(2)	A2(2)	A1	
11	WQC	K05	Water of Ken	NX619902	A1(3)	A1(2)	A1(2)	A2(2)	A1(2)	
16	WQC	G08/9	Water of Ken	NX638794	A2(2)	B(2)	B(1)	A2(2)	B(2)	
17	WQC	T07	Garple Burn	NX641793	A2(3)	A1(2)	A2(2)	A2(2)	(2)	
18	WQC	T07	Shirmers Burn	NX 660737	A2(3)	A2(2)	A2(2)	A2(2)	A2(2)	
19	WQC	G05	Black W. of Dee	NX653692	A2(3)	A1(2)	A1(2)	A2(2)	A2(2)	
29	WQC	D04	W. of Deugh('94)	NX564929		(1)				
21	DM	T03	River Dee	NX732641	B(2)	A2(2)	A2(1)	B(2)	B(2)	
23	DM		Tarff Water	NX682557	A2(2)	A2(2)	A2(2)	A2(2)	A2(2)	

Sample types: New sites sampled once, specifically for this project, in mid July 2001; AWB acid Water Baseline sites; WQC: Water Quality Classification; DM: Discharge Monitoring sites.

Drumjohn group

WQC (family level) data for three of the HMWBs in this group are used to derive EQRs in Table 38. In addition, an EQR was derived from each annual sample of the AWB monitoring run for Water Body D04 (Table 40). This analysis yielded lower EQR values than were obtained from the WQC data, and these varied over a range of 0.17 from year to year.

Table 39 EQRs for Water Bodies D01, D02 and D04 (Carsphairn Lane and Water of Deugh) derived from WQC (family level) invertebrate data.

[Standard site is on the Water of Ken above Kendoon Loch].

Water Body	D01	D02	D04	K05
Site ID	10	11	9	12
Number of samples	3	4	5	11
Number of taxa	29	32	33	35
C: No.common taxa	25	30	27	
M: No. missing taxa	10	5	8	
E: No. exotic taxa	4	2	6	
EQR: C/(M+C+E)	**0.64**	**0.81**	**0.66**	

Table 40 Annual EQRs for Water Body D04 (Water of Deugh) derived from AWB (mixed taxon) invertebrate data for single annual samples.

[Standard site is the AWB site on the Polmaddy Burn].

	1998		1999		2000	
Water Body	D04	C05	D04	C05	D04	C05
Site ID	5	6	5	6	5	6
Number of samples	1	1	1	1	1	1
Number of taxa	28	26	32	28	28	23
C: No.common taxa	16		15		17	
M: No. missing taxa	10		13		6	
E: No. exotic taxa	12		17		11	
EQR: C/(M+C+E)	**0.43**		**0.33**		**0.50**	

Carsfad group

An EQR is derived for the 2001 (summer) sample from the Water of Ken, using the total species complement indicated by AWB sampling (in spring) close by, on the Polharrow Burn (Table 41). Despite the proximity of the two sites, the EQR is extremely low. This might be attributable partly to the different seasons in which the two sites were sampled, but this is currently the best estimate possible of EQR for any of the water bodies in this part of the Dee system.

Table 41 EQR calculation for Water Body C03 (Water of Ken) derived from a single new (2001, mixed taxon) invertebrate sample.

[Standard site is the AWB site on the Polharrow Burn; total species complement in 3 annual samples].

Water Body	C03	E04
Site ID	4	7
Number of samples	1	3
Number of taxa	37	43
C: No.common taxa	13	
M: No. missing taxa	30	
E: No. exotic taxa	24	
EQR: C/(M+C+E)	**0.19**	

Glenlee group

WQM (family level) data were available for a site on the Water of Ken downstream of the Glenlee power station tailrace, close to the junction of Water Bodies G08 and G09. These were compared with data from the nearby Garple Burn (T07). There is another WQM site on the Black Water of Dee, between Stroan Loch and Woodhall Loch (T07), for which the closest reference site is on the Shirmers Burn (T07). In addition, new (2001) mixed taxon data were available for three sites on the Black Water of Dee, one upstream of Clatteringshaws Loch (reference site) and two in Water Body G04. All these comparisons are summarised in Table 42.

Table 42 Derivation of EQRs for three water bodies in the Glenlee group, based on either family level (WQM) or mixed taxon (new) data and a separate reference site for each.

Watercourse	Water of Ken		Black Water of Dee				
Reference site	Garple Burn		Shirmers Burn		Black W. of Dee		
Water Body	G08/9	T07	G05	T07	G04	G04	G10
Site ID	16	17	19	18	5	6	
Type of data	WQM	WQM	WQM	WQM	New	New	New
Number of samples	9	11	11	11	1	1	1
Number of taxa	40	43	37	50	16	18	25
C: No.common taxa	36		28		12	12	
M: No. missing taxa	7		22		13	13	
E: No. exotic taxa	4		9		4	6	
EQR: C/(M+C+E)	**0.77**		**0.47**		**0.41**	**0.39**	

Tongland group

An EQR was estimated from family level (WQM) data for one site in Water Body T03, just downstream of the Glenlochar barrage. Some reference data were available from tributaries in the vicinity, but were prejudiced by poor water quality. Therefore a reference site was chosen from those available on the Tarff Water, which joins the Dee downstream of Tongland Dam.

Table 43 Derivation of EQR for Water Body T03 (River Dee) derived from family level WQM invertebrate samples. [Standard site is on the Tarff Water].

Watercourse	River Dee	Tarff Water
Water Body	T03	
Site ID	21	23
Number of samples	9	10
Number of taxa	44	50
C: No.common taxa	40	
M: No. missing taxa	10	
E: No. exotic taxa	4	
EQR: C/(M+C+E)	**0.74**	

So far, the EQRs calculated for rivers take no account of HMWB designation; the fauna of water bodies where there are potential hydro-power impacts having been simply compared with fauna of nearby unimpacted tributaries. The Water Framework Directive (Annex V, 1.4.1) stipulates that the procedure for expressing monitoring results in terms of EQRs shall refer to ecological potential. In other words, the EQR should express the degree of success achieved not in approaching high ecological status (that of an unimpacted water body) but in approaching maximum ecological potential, which in the present context is limited by the modifications that are unavoidable in order to achieve hydro-power generation. The only such distortions identified in Section 8.2 are those that involve changes to the flow regime. Therefore, the appropriate standard water bodies for assessment of MEP would be river reaches with distorted flow regimes but without sediment starvation, pollution, river continuity and temperature/hypolimnion effects.

A search was made to find standard water bodies where impacts other than those to the flow regime were minimal. Only three such water bodies were identified; D04 (Water of Deugh), G05 (Black Water of Dee in the vicinity of Stroan Loch) and T03 (River Dee downstream of Glenlochar Barrage). D04 was matched with water bodies D01 and D02 which have similar degrees of hydrological distortion (as indicated by DHRAM score). G05 and T03 had similar DHRAM scores and small but different other impacts; an EQR was calculated to compare them with one another. The EQR calculations are shown in Tables 44 and 45.

Table 44 EQR calculation for Water Bodies D01 and D02 relative to Water Body D04, based on WQM invertebrate data.

Site	10	11		9
No. samples	3	4		5
Water Body	**D01**	**D02**		**D04**
DHRAM score (Table 4)	5	4		(estimate 4)
Water quality class (Table 37)	A2	A1-A2		A1
Other risk categories (Table 14)	Continuity; re-sectioned; temperature; acidifcation	Continuity; sediment effect; acidification		Continuity
Taxon				
Siphlonuridae	×	×		v
Heptageniidae	v	v		v
Leptophlebiidae	v	v		v
Ephemerellidae	v	×		v
Taeniopterygidae		v		

Leuctridae	v	v		v
Perlodidae	v	v		v
Perlidae	×	v		v
Chloroperlidae	v	v		v
Leptoceridae	v	v		v
Goeridae	×	×		v
Lepidostomatidae	v	v		v
Brachycentridae	×	×		v
Sericostomatidae	×	v		v
Cordulegasteridae	v	×		v
Psychomyiidae		v		
Caenidae	×	v		v
Nemouridae	v	v		v
Rhyacophilidae	v	v		v
Polycentropodidae	v	v		v
Limnephilidae	v	v		v
Ancylidae	v	v		v
Hydroptilidae	v	v		v
Gammaridae		v		
Dytiscidae	v	v		v
Gyrinidae	v	v		
Hydrophilidae	v	v		v
Elmidae	v	v		v
Hydropsychidae	v	v		v
Tipulidae	v	v		v
Simulidae	v	v		v
Planariidae	v	v		
Baetidae	v	v		v
Sialidae	×	×		v
Lymnaeidae		v		
Sphaeridae	v	×		v
Glossiphoniidae	v	×		v

Erpobdellidae	v	v		
Chironomidae	v	v		v
Oligochaeta	v	v		v
Number of taxa	28	32		33
C: number of taxa in common with standard	26	25		
M: number of missing taxa	7	8		
E: number of exotic taxa	2	7		
Preliminary EQR: C/(M+C+E)	**0.74**	**0.63**		

Table 45 EQR calculation to compare the ecological status of Water Bodies T03 and G05 on the basis of invertebrate data.

Site	21	19
No. samples	9	6
Water Body	**T03**	**G05**
DHRAM score (Table 5)	2	2
Water quality class (Table 37)	B-A2	A2-A1
Other risk categories (Tables 18-19)	Continuity; sediment effect	Continuity; acidification
Taxon		
Water quality class	B-A2	A2-A1
Siphonuridae	×	v
Heptageniidae	v	v
Leptophlebiidae	v	v
Ephemerellidae	v	
Taeniopterygidae	×	v
Leuctridae	v	v
Perlodidae	v	v
Chloroperlidae	v	v
Aphelocheiridae	v	
Phryganeidae	×	v

Leptoceridae	v	v
Lepidostomatidae	v	v
Brachycentridae	×	v
Sericostomatidae	v	
Cordulegasteridae	×	v
Psychomyiidae	v	v
Caenidae	v	
Nemouridae	v	v
Rhyacophilidae	×	v
Polycentropodidae	v	v
Limnephilidae	v	v
Ancylidae	v	
Hydroptilidae	v	v
Gammaridae	v	
Coenagriidae	×	v
Corixidae	v	
Haliplidae	v	
Dytiscidae	v	
Gyrinidae	v	v
Hydrophilidae	v	v
Elmidae	v	v
Hydropsychidae	v	v
Tipulidae	×	v
Simuliidae	×	v
Planariidae	v	
Dendrocoelidae	v	
Baetidae	v	v
Sialidae	v	v
Valvatidae	v	
Hydrobiidae	v	
Lymnaeidae	v	
Physidae	v	

Planorbidae	v	
Sphaeriidae	v	v
Glossiphoniidae	v	
Erpobdellidae	v	
Asellidae	v	
Chironomidae	v	v
Oligochaeta	v	v
Emipididae	×	v
Mites	v	v
Muscidae	×	v
Ceratopogonidae	v	v
Clinocera	v	v
Limnophora	×	v
Spongilla	v	
Number of taxa	44	36
C: number of common taxa	24	
M: number of missing taxa	12	
E: number of exotic taxa	20	
Preliminary EQR: C/(M+C+E)	**0.43**	

For Water Bodies D01 and D02, the EQRs obtained by this method were rather similar to those obtained using unimpacted reference site in Table 39. For T03 and G05, it is not entirely clear whether the low EQR value indicates the effect of acidification in the Black Water of Dee or that of sediment starvation downstream of Glenlochar Barrage. What is clear is that it will be impossible to test directly the biological impact of the latter until a non-acidified reference site can be found. For the time being, the initial set of biologically based EQRs, achieved by comparisons with unimpacted streams, seem as satisfactory as any. These are shown with the information upon which the ecological assessments derived in Section 6.3 were based in Tables 46-51. The EQR values obtained using biological data bear no clear relationship to other indications of degree of physical modification. Since the biological data were collected for other purposes, they related to only a small fraction of the water bodies, and the performance of biota is likely to be prejudiced by chemical as well as physical factors in most cases, this is simply a null result.

Thus, the problem of deriving EQR values in the short term remains to be solved. For this purpose, it would seem expedient to use physical information, which is more readily available than biological information. One possibility is to derive the quality ratio as the reciprocal of the Risk Score. EQR values indicating approach to good ecological status are shown in the second row from the bottom of each of Tables 46-51. The target EQR for MEP is obtained by re-calculating the Risk Score to incorporate only those risk factors that can be removed (through "all mitigation") without prejudice to the designated water use. The bottom row of each Table shows adjusted EQRs for MEP where appropriate (i.e. for HMWBs only).

Table 46 Drumjohn group; summary of ecological risks and EQRs.

ELEMENT Water Body	D01	D02	D03	D04	D05	D06
BIOLOGICAL EQRs						
Phytoplankton						
Macrophytes and phytobenthos						
Benthic invertebrate fauna	0.64	0.81		0.66		
Fish fauna						
HYDROMORPHOLOGICAL						
DHRAM score (impact points)	5(20)	4(17)	4(18)			
Hydrological regime	?	?	?	?		
River continuity (conn to d/s)	?	?	?	?	??	??
Morphological conditions	?	?	?			
PHYSICOCHEMICAL						
General	? ∗	∗	∗		∗	∗
Synthetic pollutants						
Non-synthetic pollutants						
Risk Score	**4**	**3**	**3**	**2**	**1**	**1**
OVERALL	**P**	**M**	**M**	**M**	**G**	**G**
Physical EQRs (rel. GES)	*0.25*	*0.33*	*0.33*	*0.5*	**1**	**1**
Physical EQRs (rel. MEP)	**0.33**	**0.5**	**0.5**	**1**		

Table 47 Kendoon group: summary of ecological risks and EQRs.

ELEMENT Water Body	K01	K02	K03	K04	K05	K06	K07
BIOLOGICAL EQRs							
Phytoplankton							
Macrophytes & phytobenthos	0.08/ 0.38						
Benthic invertebrate fauna							
Fish fauna							
HYDROMORPHOLOGICAL							
DHRAM score (impact points)	3		5(16)				
Hydrological regime	?	?	?	?			
River continuity (conn to d/s)	??	?	?	?	?	??	?
Morphological conditions	?	?	?	?			
PHYSICOCHEMICAL							
General							
Synthetic pollutants							
Non-synthetic pollutants	*						
Risk Score	**3**	**3**	**3**	**3**	**1**	**1**	**1**
OVERALL	**M**	**M**	**M**	**M**	**G**	**G**	**G**
Physical EQRs (rel. GES)	*0.33*	*0.33*	*0.33*	*0.33*	**1**	**1**	**1**
Physical EQRs (rel. MEP)	**0.5**	**0.5**	**0.5**	**0.5**			

Table 48 Carsfad group: summary of ecological risks and EQRs.

ELEMENT Water Body	C01	C02	C03	C04	C05
BIOLOGICAL EQRs					
Phytoplankton					
Macrophytes and phytobenthos					
Benthic invertebrate fauna			0.19		
Fish fauna					
HYDROMORPHOLOGICAL					
DHRAM score (impact points)	3		5(21)	4-5(12)	
Hydrological regime	?	?	?	?	
River continuity (conn. to d/s waters)	??	?	?	?	?
Morphological conditions	?	?	?	?	
PHYSICOCHEMICAL					
General		?	?		
Synthetic pollutants					
Non-synthetic pollutants					
Risk Score	**3**	**4**	**4**	**3**	**1**
OVERALL	**M**	**P**	**P**	**M**	**G**
Physical EQRs (rel. GES)	*0.33*	*0.25*	*0.25*	*0.33*	**1**
Physical EQRs (rel. MEP)	**0.5**	**0.33**	**0.33**	**0.5**	

Table 49 Earlstoun group: summary of ecological risks and EQRs.

ELEMENT Water Body	E01	E02	E03	E04
BIOLOGICAL EQRs				
Phytoplankton				
Macrophytes and phytobenthos				
Benthic invertebrate fauna				
Fish fauna				
HYDROMORPHOLOGICAL				
DHRAM score (impact points)	4		4-5(16)	
Hydrological regime	?	?	?	
River continuity (conn. to d/s waters)	??	?	?	?
Morphological conditions	?	?	?	
PHYSICOCHEMICAL				
General		?	?	
Synthetic pollutants				
Non-synthetic pollutants				
Risk Score	**3**	**4**	**4**	**1**
OVERALL	**M**	**P**	**P**	**G**
Physical EQRs (rel. GES)	*0.33*	*0.25*	*0.25*	**1**
Physical EQRs (rel. MEP)	**0.5**	**0.33**	**0.33**	

Table 50 Glenlee group: summary of ecological risks and EQRs.

Water Body **ELEMENT**	G01	G02	G03	G04	G05	G06	G07	G08	G09	G10	G11	G12
BIOLOGICAL EQRs												
Phytoplankton												
Macrophytes and phytobenthos	0.04 0.40				0.36 0.45							
Benthic invertebrate fauna	0.17			0.40	0.47			0.77				
Fish fauna												
HYDRO-MORPHOLOGICAL												
DHRAM score (impact points)	5	5 (25)		3 (6)	2 (3)			4-5 (12)	4-5 (12)			
Hydrological regime	?	?	?			?	?	?	?			
River continuity (conn. to d/s waters)	??	?	?	?	?	?	?	?	?	?	??	??
Morphological conditions	?	?	?	?		?	?					
PHYSICO-CHEMICAL												
General	∗	? ∗	? ∗	∗		∗				∗	∗	
Synthetic pollutants												
Non-synthetic pollutants												
Risk Score	**3**	**4**	**4**	**2**	**1**	**3**	**3**	**2**	**2**	**1**	**1**	**1**
OVERALL	**M**	**P**	**P**	**M**	**G**	**M**	**M**	**M**	**M**	**G**	**G**	**G**
Physical EQRs (rel. GES)	*0.33*	*0.25*	*0.25*	**0.5**	**1**	*0.33*	*0.33*	*0.5*	*0.5*	**1**	**1**	**1**
Physical EQRs (rel. MEP)	**0.5**	**0.33**	**0.33**			**0.5**	**0.5**	**1**	**1**			

Table 51 Tongland group: summary of ecological risks and EQRs.

ELEMENT Water Body	T01	T02	T03	T04	T05	T06	T07	T08
BIOLOGICAL EQRs								
Phytoplankton								
Macrophytes and phytobenthos	0.50-0.64							
Benthic invertebrate fauna	0.24		0.74					
Fish fauna								
HYDROMORPHOLOGICAL								
DHRAM score (impact points)	3		2 (3)	5		4-5 (13)		
Hydrological regime		?		?	?	?		
River continuity (to d/s)	?	??	?	??	?		?	?
Morphological conditions		?	?	?	?	?		
PHYSICOCHEMICAL								
General	*	*						
Synthetic pollutants								
Non-synthetic pollutants								
Risk Score	**1**	**3**	**2**	**3**	**3**	**2**	**1**	**1**
OVERALL	**G**	**M**	**M**	**M**	**M**	**M**	**G**	**G**
Physical EQRs (rel. GES)	**1**	*0.33*	**0.5**	*0.33*	*0.33*	*0.5*	**1**	**1**
Physical EQRs (rel. MEP)		**0.5**		**0.5**	**0.5**	**1**		

8.4 Discussion and Conclusions

This chapter sought to assess maximum ecological potential (MEP) for the water body groups of the Galloway Dee. Water body groups were established on the basis of individual power stations as well as for the Ken Cascade (Kendoon, Carsfad and Earlstoun power stations). Whereas MEP is the reference condition for ecological well-being, good ecological potential (GEP) is recognised as the minimum acceptable target in practice. The pursuit of GEP may require various mitigation measures to be introduced, however these measures should not compromise the designated hydro power use of water.

The analysis produced a range of measures which would likely result in improvements to aquatic ecosystems, building on many elements of good practice already established by the hydro power operator. Most remain subject to considerable uncertainty; further research is required to unequivocally establish quantitative response, and thus the proposals should be regarded as provisional. For example, measures to address hypolimnion water quality effects may not be necessary where the discharge from a power station is quickly mixed with additional flows not subject to such effects.

Acidification is an important consideration in assessing ecological potential in some tributaries of the Galloway Scheme, notably the Black Water of Dee, where impacts on the ecology are widely recognised. Under the Water Framework Directive, acidification is an issue that should be remedied, and the maximum ecological potential reference condition must therefore assume that acidification will ultimately be reduced to acceptable levels. However, because the acidification phenomenon is not attributable to the hydro-activities, the pursuit of good ecological potential described in the following chapter makes no direct reference to the resolution of this issue.

As discussed in Chapter 6, defining the ecological response to hydro-morphological alteration remains a still poorly understood issue. Major uncertainties persist because of the paucity of available data, or because of representativeness questions associated with the single-period biological samples obtained for this study. Relatively few ecological quality ratio (EQR) values were generated, but again methodological issues complicate straightforward interpretation. In the Water of Deugh case-study (D04), EQRs were calculated using different data and reference sites (i.e. family level invertebrate data compared to mixed taxon data). The resultant values varied from 0.33 to 0.66 highlighting the need for more consistent guidelines. In the light of such variability, relatively little confidence can be placed in generalising the results obtained for the study area as a whole.

Comparisons with reference sites outside the Dee system were also excluded for similar data availability and compatibility issues. The biologically-derived EQRs were found to have no systematic relationship to the other indications of the degree of physical modification, though this may partially be accounted for by the added complexity of the acidification issue.

More research is required, underpinned by appropriate field data collection, and thus the assessments of MEP must be regarded as provisional. Ultimately, it was felt that a good working knowledge of existing hydro operations within the Dee system provided the best foundation for identifying and establishing appropriate reference conditions, particularly through the use of the physically-based EQR scheme, wherein the quality ratio was defined as the reciprocal of the risk score used to determine ecological status. The target EQR in this case only incorporates those risk factors that can be mitigated without prejudicing the designated water use. The application of this approach generated significantly higher EQRs, though most values remained below the arbitrary threshold of 0.75 (explained in Chapter 9). Clearly, the nature of establishing MEP will be an important element for consideration when the European synthesis and intercalibration exercises (Annex V, part 1.4) are undertaken.

9 Definition of Good Ecological Potential

9.1 Determination of Good Ecological Potential

Good ecological potential (GEP) is the target ecological condition set by the Water Framework Directive. At this condition, the values of the relevant biological quality elements deviate slightly from those found at maximum ecological potential. The requirement here, then, is for definition of a level of deviation of biological quality from MEP that can be regarded as "slight", using either statistical and/or ecological approaches. However, the definition adopted should be based on some understanding of the relationships between biological quality estimates and hydromorphological/ physicochemical conditions, in order to facilitate the design of programmes of measures to meet the GEP objective (HMW paper 12 ver 3).

The uncertainties encountered in arriving at biological interpretations of MEP and in estimating EQRs preclude rigorous definition of GEP levels in terms of the biological quality elements. One approach that might be explored is based on economic analysis. This would define reasonable/practical mitigation measures in terms of a cost threshold, which would then be related to a minimum level of biological quality for GEP status. Another possible approach would be to set a GEP threshold value for the EQR. Initially, the scale from 0 to 1 might be divided into 4 equal intervals corresponding to the levels of ecological potential:

Ecological potential	EQR range
Maximum	1.00
Good	0.75-0.99
Moderate	0.50-0.74
Poor	0.25-0.49
Bad	0.00-0.24

Results of the intercalibration exercise (Annex V, part 1.4) may be helpful in this regard once available, but in the meantime the nominal values above will be used for this study.

9.2 Identification of Measures for Protecting and Enhancing the Ecological Quality

Article 11 of the Water Framework Directive requires the establishment of a programme of measures designed to achieve the objectives of the Directive. **Basic measures** are those that are required to implement EU legislation for the protection of water, including the various Directives listed in part A of Annex VI, and measures required (for HMWBs) for the achievement of good ecological potential. In particular, basic measures must include abstraction and impoundment controls (unless no significant impact on water status is expected), and measures required to ensure that hydromorphological conditions are consistent with the achievement of GEP (Article 11). **Supplementary measures** such as those listed in part B of Annex VI may also be employed where appropriate in order to protect and enhance ecological potential. These supplementary measures may be important in increasing the probability of achieving environmental objectives in situations where basic measures do not guarantee such outcomes, e.g. via the development and application of codes of good practice.Most of the measures proposed in the following sections are accompanied by qualifiers addressing such issues as technical viability and economic impact on the designated water uses. Another general point is that, while the following paragraphs suggest individual measures which should be investigated in relation to the various types of structure and sites around the study area, not all may be compatible with each other. Alterations to generating or compensation patterns may, for example, constrain the opportunities for change in the upstream reservoir. The adoption of measures should be guided by the relative ecological merits of the various possibilities available, and the practicability of implementing them.

9.2.1 Basic Measures

Following the proposed division of EQR scores, it follows that EQR values must exceed 0.75 to attain GEP in the water bodies of the study area. As previously mentioned, relatively few biologically-based EQR values were obtained, and those reported in Tables 34-45 did not correlate well with the assessments of ecological status reported in Chapter 6.

In order to propose measures for GEP, it is necessary to bear in mind the following:

- Measures proposed for MEP do not significantly compromise the designated use of water bodies
- Values of ecological quality elements at GEP deviate only slightly from those at MEP
- Basic measures should include provisions for exercising control over freshwater abstractions and impoundments, except when these exert no significant impact on status.
- No basic measures need be proposed in relation to water bodies in which ecological status is presently identified as being 'good' (since GEP = GES).

The following measures are proposed for the achievement of GEP on the basis of the assumption that any measure currently responsible for downgrading of ecological status should be the subject of reasonable measures for improvement so long as these do not significantly impact adversely on hydro power generation. Links between GEP and measures are therefore based on present understanding of physical factors which are known or thought to exercise controls on ecological status. For the sake of simplicity, measures are presented for each type of hydro structure in the Dee system, and apply to each example of the various types unless indicated otherwise. The measures have been obtained by examining lists of all water bodies in similar locations, relative to hydro installations.

Catchwater intakes

Sediment - starvation downstream of intake structures should be reversed if warranted, by periodic provision of sediment (in late summer, to minimise impacts on spawning success and filter feeding), in quantities and with grain size characteristics appropriate to the downstream flow regime. This is most likely to be achieved by the development of practicable codes of good practice. Sediment starvation issues are expected to be more important at catchwater intakes than in most other parts of hydro schemes.

Compensation flows cannot normally be required (because of the importance of catchwater flows to the overall efficiency of the hydro scheme), except in the case of locally important watercourses presently without compensation flow. It is proposed that compensation provision should be made at all abstraction points where the natural catchment area exceeds 20 km^2 and where normal flows are wholly diverted by hydro structures. This threshold area is arbitrary, but generally is effective in distinguishing 'main valley' rivers from 'tributary' streams. A threshold size greater than the minimum water body catchment area has been selected, in recognition of the fact that catchwater intakes are numerous (though quantitative data on this are scarce), and capital costs of construction and operating costs would be high (perhaps 10-20%) in relation to overall scheme revenue if uniformly required. In catchments exceeding the threshold area, compensation provisions should be variable in time, and be designed to deliver maximum ecological benefit from the water used. This might best be achieved by seeking savings in compensation losses at certain times of the year, or through alterations in daily requirements where compensation is presently provided.

Provisions for fish passage should be made if a hydro structure prevents natural migration and if any measures exist which are technically feasible for the site in question (e.g. if there is flow through sufficient days in the year to allow migrants to reach the intake structure). If the introduction of fish passage would result in access being provided, but other local constraints such as acidification, precludes the existence of a healthy population of the migratory species, then the immediate requirement to provide passage can be relaxed. In practice, this assessment is expected to result in the requirement for very few if any fish passes being provided at catchwater intakes.

Impounding dams

Existing fish passes – efficiency of these passes should be improved if problems are known, if proposed solutions are technically viable for the site(s) in question and if there are grounds to believe that improvements will lead to significant improvements in the ecological status of migrant species. It should be recognised that improvements may relate to both upstream and downstream migration, e.g. it is necessary to retain regular review of screening arrangements as well as to consider fish pass efficiencies *per se*. This consideration has stimulated considerable activity at the Tongland fish pass, where the operators have collaborated extensively to improve the hydraulic regime of the system.

Dams presently without fish passes – passes should be provided at sites where their installation would allow improvements in ecological status as a result of achieving more natural conditions, and where solutions are technically viable.

Compensation flows and freshet releases – hydrological regime changes account for some of the greatest and most widespread physical changes in the study area. Compensation flow and freshet releases must be altered (a) if evidence suggests that there are problems due to present practices, (b) changed regimes would enhance ecological status, and (c) changes are technically feasible while avoiding the use any greater amounts of water than under present arrangements. Measures should also be taken to remedy stratification effects (e.g. discharge of unseasonably warm or cold water, low dissolved oxygen levels) and their associated chemical effects where scientific research indicates that such effects are responsible for a lowering of ecological status as measured on the 5-point scale of Annex V, and where practicable.

Sediment - starvation downstream of dams should be reversed if warranted, by periodic provision of sediment (in late summer, to minimise impacts on spawning success and filter feeding), in quantities and with grain size characteristics appropriate to the downstream flow regime (see comments under 'catchwater intakes' above regarding codes of good practice).

<u>Power stations</u>

Thermal effects (discharge of unseasonably warm or cold water) and associated water quality effects, such as the discharge of water with low dissolved oxygen levels, should be remedied where scientific research indicates that such effects are responsible for a lowering of ecological status as measured on the 5-point scale of Annex V, and where practicable.

Generation discharges - must be altered (a) if evidence suggests that there are problems due to present practices, (b) changed regimes would enhance ecological status, and (c) changes are technically feasible while avoiding the compromise of the designated use of the water bodies for hydro power generation.

<u>Control weirs</u>

Sediment – impacts of control weirs, such as the Glenlochar barrage, are considered to be relatively minor. However, if evidence of downstream sediment starvation exists, the effects should be reversed by periodic provision of sediment following an appropriate code of good practice.

Flow releases - must be altered (a) if evidence suggests that there are problems due to present practices, (b) changed regimes would enhance ecological status, and (c) changes are technically feasible while avoiding the compromise of the designated use of the water bodies for hydro power generation.

9.2.2 Supplementary Measures

The following measures are proposed to deliver environmental improvements in addition to those listed under the basic measures above. At any one site, these may or may not result in changes in ecological status as assessed under the 5-point scale of Annex V, but nevertheless should contribute to ecological improvements through the implementation of best practice. In some cases, they will increase the chances of environmental objectives being met.

Impounding dams

Water levels – notwithstanding the comments regarding hydrological regimes in 9.2.1 above, ecological benefit may be achieved if water levels are controlled to achieve ecological targets in terms of the timing and magnitudes of extreme high and low water levels. Such targets would need to be secondary to any operational activities necessary for reservoir safety purposes, would need to be considered alongside other proposed measures (e.g. changes to generation or compensation regimes) and must not cause any significant loss of power generation.

Compensation flow and freshet releases should be reviewed if evidence suggests that existing quantities of water released for environmental benefit could be used to deliver greater ecological benefit in future. This may necessitate some recourse to revision of legislative requirements (perhaps by transfer of responsibilities to a regulatory body) or may already be possible through negotiations with the District Salmon Fishery Board, and in either case would be warranted by the requirements of the Directive.

Power stations

Phasing of generation – where evidence indicates that the abrupt start and end to power generation is causing ecological problems (e.g. fish stranding caused by a sudden drop in river levels), the start and/or end of generation should be phased over a period of time long enough to substantially reduce such problems. This might be achieved by starting/stopping generating sets separately rather than simultaneously. In the case of the Dee system, this issue is most obviously relevant in relation to the Glenlee power station discharges, which when operating simultaneously with the Earlstoun power station can lead to especially high local variations in the discharge of the River Ken. The economic impacts of any change in practice would need to be investigated as part of the development of any proposals.

9.3 Discussion and Conclusions

The clearest issue to emerge from this part of the study was the inadequacy of the existing biological monitoring programme in Scotland to provide the necessary data to define ecological status, maximum ecological potential and to define credible and robust EQRs, and the definition of a threshold value for defining GEP. The threshold value of 0.75 proposed in this report is a nominal value and is likely to require adjustment in the light of more detailed assessments of the effects of various measures on the ecology. Noting that measures will only be warranted if their effects on the ecology are significant, the sections above specify measures in a provisional manner, subject to scientific validation.

It is notable that the few EQRs generated did not strongly correlate to the abiotic approach. Formulation of mitigation measures to achieve GEP may be focused specifically on the study area or ecoregion in question, but should also draw from the wider literature for techniques which can provide best practice (best available technology). In the vacuum of available biological data and suitable typologies for establishing high ecological status and GEP, it is likely that abiotic approaches will form the basis of initial implementation of the Water Framework Directive in Scotland. Because of the uncertainties remaining within the abiotic approach, such as the need for extensive calibration of the potentially invaluable DHRAM method, it will be necessary to establish a stakeholder forum, e.g. for the Dee sub-district of the eventual River Basin Planning District created, to arbitrate on management priorities and implementation timetables. Such an arrangement would be in keeping with issues of stakeholder involvement, as set out in Article 14 of the Directive. Such a forum could consider other designation issues within the same sub-district, or a similar expert panel function could be exercised say for all hydro schemes in a coordinated manner nationally. In either case, benefits in efficiency and consistency of decision-making would be achieved.

Delivery of the objectives of the Directive will rest to a large extent on the specification and implementation of appropriate measures, and so the focus on measures in this chapter is clearly warranted. It is necessary for the specified measures to avoid significant compromise of the designated water use – hydro power generation. In effect this limits mitigation which requires excessive water loss, save for the provision of compensation flow at catchwater structures at sites draining catchments >20 km^2 and presently without compensation provisions. This is a result of a subjective judgement, and represents a proposed mechanism for balancing the need to achieve ecological improvements with the protection afforded by the Directive to designated socially desirable water uses. It was proposed that compensation flows should be provided to the Water of Deugh and Bow Burn in the Drumjohn power station group, and that this would have only a modest impact on the overall power generation scheme. The significance of this impact varies according to perspective: to the scheme operator, it undoubtedly represents some financial loss, while in the wider context of investing in new infrastructure for renewable energy generation, the loss seems very small in comparison. The loss will also be small in comparison with the effects of natural climatic variability.

Additional financial costs would be involved in respect of restoring sediment equilibria (mostly annual operating costs) and, if found to be necessary, for improving fish passage arrangements and reducing water quality effects (mostly capital costs; some may be unachievable on economic grounds and may warrant the specification of less stringent environmental objectives – Article 4.5). Emphasis on fish passage arrangements is certainly appropriate given the emphasis on ensuring the best approximation to ecological continuum within Annex V. The supplementary measures proposed were intended to have negligible financial impacts. Thus, the expected outcome of the measures is that the ecology of the water bodies affected is improved and the ability of the hydro scheme to generate electricity is only minimally impacted.

Guidance from Europe on these subjects will be of critical importance in implementing the Directive. Different solutions may be proposed among Member States in seeking to balance impacts on water body ecology against impacts on designated uses (which in the case of hydro power may then be linked to other environmental impacts, namely the emissions generated by other methods of electricity production). European guidance should recognise that tensions between these competing demands exist, and clarify the requirements of the Directive and the scope for Member States to make their own choices in this context.

PART III

10 Conclusions, Options and Recommendations (5 pages)

10.1 Conclusions

This study has undertaken a comprehensive review of the hydromorphological alterations and ecological impacts resulting from hydro-power generation in the Galloway Dee. The catchment system was divided into component water bodies, which were subsequently grouped on the basis of power stations.

Scale is a fundamental issue in the assessment and designation process. In the Galloway Dee study a total of 42 constituent water bodies were identified, equating to a mean size of 21 km^2. However, this average figure belies considerable variation with the smallest units featuring channel reaches of c. 200 m. Whilst this channel length is considerably lower than 1 km (1 km^2) threshold suggested in HMW paper 5, local features such as barrages and weirs can have profound influences on the upstream area. The nested-scale concept of small constituent water bodies within a „water body group" thus gave maximum transparency in problem identification and enables mitigation measures to be prioritised to the most problematic water bodies.

The main sources of biological data identified for the Dee catchment were the West Galloway Fisheries Trust, the SEPA water quality monitoring programme, and the SNH lochs survey. Although much valuable information was collected and reviewed, it proved difficult to use for systematic evaluation of ecological status due to the non-availability of reference standards. Furthermore, the lack of replicate sampling and questions of spatial representativeness encouraged a strong focus on abiotic assessment methods. The two key tools identified for this analysis were the River Habitat Survey, principally the Habitat Modification Score and Environmental Quality Index, developed by the Environment Agency of England and Wales (c.f. Raven *et al*. 1997), and the hydrological regime alteration analysis tool DHRAM, *Dundee Hydrological Regmine Alteration Method*, developed at Dundee University (Black *et al*. 2000).

In the Galloway case-study it was not possible to undertake extensive RHS mapping because of the UK Foot and Mouth epidemic in 2001 which effectively prohibited any fieldwork throughout Stage 1 of the project. However, the particular nature of the channel network, which evidences widespread bedrock channels and relatively minor physical modifications, meant that morphological change was not a key issue. In contrast, hydrological regime variations were thought to be fundamental, thus elevating the utility of the DHRAM methodology. The DHRAM approach has a sound academic pedigree, derivative of widely cited research (c.f. Poff *et al*., 1997; Richter *et al*. 1996; 1998). Nevertheless, important calibration and validation experiments remain to be completed on the DHRAM outputs. Provision of funding to enable this basic science to be completed could be seen as a priority for both SEPA as the likely competent authority required to implement WFD, and stakeholders such as hydro power operators, who may wish to model the effects of changing management practices.

The eventual approach adopted for ecological assessment was essentially semi-quantitative, but highly pragmatic. A checklist was developed embracing biological, hydromorphological and physicochemical attributes e.g. the hydromorphology category featured the 3 elements of regime, continuity and morphology. Where two or more elements were compromised this was assumed to produce ‘less than good ecological status’. This scheme, supported by discussion with local experts and supplemented with the archive of available biological data thus focused attention on problem areas, and thus a catchment management plan can begin to be prioritised. It therefore seems inevitable that during the initial implementation phase of the Directive a premium will be placed on the acquistion of basic data (i.e. fluvial audits) that map structures, monitor the efficacy of fish passes and use morphological and hydrological regime alteration scores to provide the basis for ecological assessment and subsequent HMW designation tests.

Of the four power station groups identified, Drumjohn, the Ken cascade and Glenlee (i.e. all except Tongland) were designated as Heavily Modified because (a) no better environmental option was available and, supposing that this argument were disputed, (b) because of disproportionate cost. Given the assessment that no better environmental option is available to provide the power presently generated by the Galloway scheme, there are grounds for believing that the same result (designation) would follow for other major hydro schemes in Scotland. This has proven to be the case in the companion study to this report undertaken on the Tummel (Black *et al*. 2002). It should also be noted that while all but the Tongland water body groups were designated as HMWBs, a series of technically feasible and environmentally beneficial improvement options were identified for all water bodies where partial (conservative) estimates of environmental benefits exceeded costs of implementing the changes. These options all relate to relatively minor investments in fish ladders and passes (Drumjohn (ii), Ken (ii), Glenlee (ii)), and could all form part of a River Basin Management Plan, although who would pay for them is a moot point. It should be recognised that that, in arriving at these options, much well-directed effort in the design of the schemes has been evident in measures already taken to address ecological (albeit mostly fisheries) interests.A major limitation in the methodology used for comparing benefits with costs was that it was not possible to obtain appropriate quantitative estimates of the wider ecological benefits of measures designed to deliver GES. In the present study the ecological benefits were evaluated primarily in relation to salmon fisheries. Wider issues of greater species diversity, or abudance measures were largely unquantified. Currently, there is a lack of existing suitable studies to place adequate monetary values on these kinds of ecological improvements, although work currently underway for DEFRA may rectify this situation at least partially. This work estimates the values of improving water quality from "fair" to "good" status on three criteria: river ecology, river appearance, and bankside vegetation. These values, shortly to be published by DEFRA, exist for two rivers, the Clyde (Scotland) and the Wear (England), and can be converted to a set of per-km measures. However, the transferability of these values to other rivers has not been tested. Thus the development of suitable methods should be a research priority to allow benefit assessment at sites across the UK, and may impact on the designation results reached in some areas.

The approach adopted for definition of ecological status was developed further in chapter 8, where ecological potential of HMWB groups was assessed in relation to the physical constraints, discounting alterations integral to hydro power operations. The mitigation measures required to achieve GEP were outlined in generic terms and this will provide the foundation for establishing priorities in the River Basin Managemnt Plans.

10.2 Options and Recommendations

The following recommendations are made in relation to implementation of the Directive:

- Further guidance on the identification of 'disproportionate costs' would be valuable in allowing consistent application of the Directive. It is not easy to relate costs (which are generally economic in nature) with benefits to the ecology. In the UK, some studies are now under way looking at valuation techniques for application to two selected catchments, but this issue is a pan-European one, and guidance on the suitability of such methods, or recommendations concerning other methods or values would promote consistency.
- The development and recognition of appropriate methodologies for quantifying the wider benefits of enhancing water body ecology should be a priority. Use of the SERCON methodology, which quantifies and allows comparisons of conservation value, should be considered.
- In cases where multiple impacts affect ecological status (in this case hydropower and acidification), objective setting must be done on a pragmatic basis. It should be made clear that objectives for hydro operators should not address acidification problems.
- Energy policies in Member States should link to the objectives of the Directive, and it seems desirable that some of the ecological gains not presently proposed because of the (hydro) protection offered by designation could be achieved through future reductions in electricity consumption. This should fit well with policies such as those developed by the UK, seeking to increase both energy efficiency and the use of renewable sources; it would be logical to explicitly recognise that energy and water policies are linked.
- Given the restriction of HMWB designation to water bodies physically modified by human activity, guidance should make clear that less stringent environmental objectives will be required for those water bodies upstream of hydro schemes where migration of species has been compromised by structures built as part of these schemes.
- The guidance of HMW paper 12 should be clarified in relation to the requirement that maximum ecological potential should not cause 'significant' adverse effect on the designated use(s) of water. 'Significant' is likely to be interpreted in different ways among Member States. This is to be expected

given the diverse physical conditions, patterns of water use and socio-economic conditions among Member States, but it would be helpful for guidance to address this point in order that interpretations are not contradictory. For example, it would be helpful to have guidance on the circumstances in which it may be possible to consider that no adverse impact on designated uses should be permitted.

- Particular attention in forthcoming guidance must be paid to the definition of good ecological potential, since this is the target which will be required in all water bodies designated as HMWB. Costs will be borne by hydro operators, and it is important that required measures are proportionate to their objectives.
- Recommendations should be made in relation to research in order that Member States devote sufficient effort to be able to make ecological assessments and specifications of measures with appropriate levels of confidence.
- Scientific justification and/or expert judgements must be used to justify the specification of measures in an accountable manner.

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BGS [Solid & Drift Geology @ 1:625,000]

Ordnance Survey Meridian data

Institute of Hydrology Rivers data

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13 List of Annexes

ANNEX A: **Dee DHRAM scores**

	Site Name	Grid ref	Points	DHRAM Score
1	Ness Glen	NS 477 020	-	-
2	D/s of Drumjohn PS	NX 525 967	19	5
3	Bridge at Brochloch	NX 533 962	-	-
4	Water of Deugh	NX 560 930	-	-
5	D/s Kendoon Loch	NX 611 885	16	5
6	D/s Kendoon PS	NX 605 875	11	5
7	D/s Carsfad Loch	NX 605 850	21	5
8	D/s Polharrow Burn Trib	NX 606 843	12	5
9	D/s Earlstoun Loch	NX 614 817	16	5
10	South of Holm of Dalry	NX 617 802	12	5
11	D/s of Ken Bridge	NX 641 780	12	5
12	River Dee d/s of Clatteringshaws Loch	NX 547 752	25	5
13	Dee (East of Orchars)	NX 585 735	6	3
14	U/s of Stroan Loch	NX 636 708	3	2
15	D/s of Loch Ken Dam	NX 733 644	3	2
16	D/s Tongland PS	NX 695 535	13	5
17	Deuch intake weir 1		17	4
18	Deuch intake weir 2		18	4

Key features of DHRAM results

Site 2 - Down stream of Drumjohn Power Station: DHRAM score 5; points 20. The DHRAM scores show that the impacts of the upstream power station discharges have resulted in the following changes to the flow regime. Mean monthly flows have risen dramatically for all months except June, July and August where flows have reduced slightly, there is mixed variation in mean monthly flow conditions between years. The magnitude of the maximum annual extreme has increased dramatically for all durations while the magnitude of the minimum annual extremes has changed little for all durations. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate decrease in the number of high pulses but with a dramatic increase in their duration, low pulses have moderately increased but with a slight reduction in their duration. The frequency and duration of high pulses has become more variable between years due to the inconsistent discharge patterns from the power station. The magnitude of the rise and fall of discharge has increased moderately; these rates of change have become more constant for all years. The number of rises has increased slightly.

Site 5 - Down stream of Kendoon Loch: DHRAM score 5; points 16. The DHRAM scores show that the impacts of the upstream impoundment have resulted in the following changes to the flow regime. Mean monthly flows have fallen dramatically for all months with slight variation in mean monthly flow conditions between years. The magnitudes of the maximum annual extreme have decreased slightly from the norm while no flows can occur for periods greater than 90 days. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate decrease in the frequency and duration of high pulses. The magnitude of the rise and fall of discharge has increased dramatically while the number of rises has decreased slightly.

Site 6 - Down stream of Kendoon Power Station: DHRAM score 5; points 11. The DHRAM scores show that the impacts of the upstream power station discharge and the impoundment have resulted in the following changes to the flow regime. Mean monthly flows have risen moderately for all months except, July and August where flows have declined slightly, there is more consistent mean monthly flow conditions between years. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Low pulses have moderately increased but with a slight reduction in their durations. The frequency and duration of high and low pulses has become less variable between years. The magnitude of the rise and fall of discharge has increased slightly becoming more constant for all years. The number of rises has increased moderately.

Site 7 - Down stream of Carsfad Loch: DHRAM score 5; points 21. The DHRAM scores show that the impacts of the upstream impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have fallen dramatically for all months with mean summer flows becoming more consistent between years and only slight variation in the mean winter month flows between years. The magnitudes of the maximum annual extreme have decreased slightly from the norm while the compensation flow provides a base level for the annual minimum extreme flow that remains consistent for all years. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate decrease in the frequency and duration of high pulses. The magnitude of the rise and fall of discharge has increased dramatically while the number of rises has decreased slightly.

Site 8 - Down stream of Carsfad Power Station (Polharrow Burn Trib): DHRAM score 5; points 12. The DHRAM scores show that the impacts of the upstream power station discharges, the impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have risen dramatically for all months except August where flows have reduced slightly, there is prevalence for consistent mean monthly flow conditions between years. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate increase in the number of low pulses but with a slight decrease in duration. The frequency and duration of high pulses has become less variable between years. The magnitude of the rise and fall of discharge has increased slightly becoming more constant for all years. The number of rises has increased moderately.

Site 9 - Down stream of Earlstoun Power Station and Loch: DHRAM score 5; points 16. The DHRAM scores show that the impacts of the upstream power station discharges, the impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have risen slightly for all months except July and August where flows have reduced slightly, there is prevalence for more consistent mean monthly flow conditions between years. The magnitude of the minimum annual flow is considerably reduced from the expected, therefore the compensation flow can be considered to be below the expected baseflow. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate increase in the frequency of low and high pulses but with a slight decrease in duration. The frequency and duration of high pulses has become less variable between years. The magnitude of the rise and fall of discharge has increased slightly becoming more constant for all years. The number of rises has increased moderately.

Site 10 – South of Holm of Dalry: DHRAM score 5; points 12. The DHRAM scores show that the impacts of the upstream power station discharges, the impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have risen dramatically for all months, there is prevalence for more consistent mean monthly flow conditions between years. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Dramatic increase in the frequency of low pulses but with a slight decrease in duration. The frequency and duration of high pulses has become less variable between years. The magnitude of the rise and fall of discharge has increased slightly becoming more constant for all years. The number of rises has increased moderately with much less variation between years.

Site 11 – Down stream of Ken Bridge: DHRAM score 5; points 12. The DHRAM scores show that the impacts of the upstream power station discharges, the impoundment and the compensation flows have resulted in the following changes to the flow regime. Mean monthly flows have risen dramatically for all months, there is prevalence for more consistent mean monthly flow conditions between years. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Dramatic increase in the frequency of low pulses but with a slight decrease in duration. The frequency and duration of high pulses has become less variable between years. The magnitude of the fall of discharge has increased slightly becoming more constant for all years. The number of rises has increased moderately with much less variation between years.

Site 12 - Down stream of Clatteringshaws Loch: DHRAM score 5; points 25. The DHRAM scores show that the impacts of the upstream impoundment and compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have fallen dramatically for all months with annual flow patterns not changing. No flow conditions can last for greater than 90 days and the magnitude of the maximum annual extreme have decreased by almost 100% from the norm for all durations. There are really no extremes, there is either no flow for half the year or stable compensation flow for the rest. No high or low pulses occur.

Site 13 – Dee, East of Orchars: DHRAM score 3; points 6. The DHRAM scores show that the impacts of the upstream impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have declined dramatically for all months resulting in a slight fall in the magnitudes of annual extremes. The magnitude of the fall and rise of discharge has decreased slightly, presumably because the more flashy flows from the uplands are no longer passing down the river.

Site 14 – Upstream of Stroan Loch: DHRAM score 2; points 3. The DHRAM scores show that the impacts of the upstream impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have declined moderately for all months resulting in a slight fall in the magnitudes of annual extremes. The magnitude of the fall and rise of discharge has decreased slightly, presumably because the more flashy flows from the uplands are no longer passing down the river, instead being intercepted by the reservoir.

Site 15 – Downstream of Loch Ken barrage: DHRAM score 2; points 3. The DHRAM scores show that the impacts of the upstream impoundment have resulted in the following changes to the flow regime. Mean monthly flows have declined moderately for all months resulting in a slight fall in the magnitudes of annual extremes. The magnitude of the fall and rise of discharge has decreased slightly.

Site 16 - Down stream of Tongland Power Station: DHRAM score 5; points 13. The DHRAM scores show that the impacts of the upstream power station discharges, the impoundment and the compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have risen slightly with only a couple of exceptions, there is prevalence for more consistent mean monthly flow conditions between years. The magnitude of the minimum annual flow is considerably reduced from the expected. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate increase in the frequency of low pulses but with a slight decrease in duration. The frequency and duration of high and low pulses has become less variable between years. Slight decline in the rate of rise in flow conditions and a more consistent rate and frequency of change in conditions between years.

Site 17 – Bow Burn intake weir: DHRAM score 4; points 17. The DHRAM scores show that the impacts of the upstream intake and compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have declined, there is prevalence for more variability in mean monthly flow conditions between years. Little change in the magnitude and frequency of annual extremes, however, because of the compensation flows, the annual variabilities have reduced significantly. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate decline in the frequency and magnitude of high pulses. The frequency and duration of high and low pulses has become less variable between years. Dramatic increase in the rate of rise and fall in flow conditions but with a decrease in the total number of rises.

Site 18 – Deuch intake weir: DHRAM score 4; points 18. The DHRAM scores show that the impacts of the upstream intake and compensation flow have resulted in the following changes to the flow regime. Mean monthly flows have declined, there is prevalence for more variability in mean monthly flow conditions between years. Little change in the magnitude and frequency of annual extremes, however, because of the compensation flows, the annual variabilities have reduced significantly. Again, the timing of the one-day minimum date has changed to a winter date from a summer date, and the annual timings have become more consistent. Moderate decline in the frequency and magnitude of high pulses. The frequency and duration of high and low pulses has become less variable between years. Dramatic increase in the rate of rise and fall in flow conditions but with a decrease in the total number of rises.

DHRAM derivations

1. Ness Glen DHRAM was not done (outside Dee catchment area).
2. Drumjohn DHRAM was calculated using synthetically generated natural flow and synthetic impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 80003 (Marsh and Lees, 1998). Impacted, synthetic flow was calculated from adding the synthetic natural flow with the power station discharge and the needle valve spillage. The last two values were obtained from daily flow sheet recordings supplied to us from Scottish Power covering a period of two years.
3. Bridge at Brochloch DHRAM was not calculated.
4. Carsphairn Tributary DHRAM was not calculated.
5. Down stream of Kendoon Loch DHRAM was calculated using synthetically generated natural flow and measured impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees, 1998). Impacted, measured flow consisted of only spill from the reservoir.
6. Down stream of Kendoon Power Station DHRAM was calculated using synthetically generated natural flow and measured impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees,

1998). Impacted, measured flow consisted of spill from the reservoir and the power station discharge.

7. Down stream of Carsfad Loch DHRAM was calculated using synthetically generated natural flow and measured impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees, 1998). Impacted, measured flow consisted of spill from the reservoir plus compensation flow provided by the fish pass.
8. Down stream of Polharrow Burn Tributary DHRAM was calculated using synthetically generated natural flow and measured impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees, 1998). Impacted, measured flow consisted of spill from the reservoir, compensation flow and the power station discharge.
9. Down stream of Earlstoun Loch DHRAM was calculated using synthetically generated natural flow and measured impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees, 1998). Impacted, measured flow consisted of spill from the reservoir, compensation flow and the power station discharge.
10. South of Holm of Dalry DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated taking the natural flow of 9 from the natural flow of 10 then adding the impacted flow of 9 and the discharge from Glenlee power station.
11. Down stream of Ken Bridge DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 018010 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated taking the natural flow of 10 from the natural flow of 11 then add the impacted flow of 10.
12. River Dee down stream of Clatteringshaws Loch DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 021034 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated by using a figure of 12 million gallons a day (supposed to be a measure of the compensation flow that Scottish Power release from Clatteringshaws between the 1st of May and 31st of October) this was then converted to cumecs and was the only flow at this site.

13. River Dee (east of Orchars) DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 021034 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated by taking the natural 12 away from natural 13 and adding the impacted 12.

14. River Dee upstream of Stroan Loch DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 021034 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated by taking the natural 13 away from natural 14 and adding the impacted 13.

15. Down stream of Loch Ken dam DHRAM was calculated using synthetically generated natural flow and gauged impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 021007 (Marsh and Lees, 1998). Impacted, gauged flow was obtained from gauging station 080002 (Marsh and Lees, 1998).

16. Down stream of Tongland power station DHRAM was calculated using synthetically generated natural flow and measured impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 021007 (Marsh and Lees, 1998). Impacted, measured flow consisted of spill from the reservoir, compensation flow and the power station discharge.

17. Deugh intake weir 1 DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 021034 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated from the assumption that the intake weirs spill, on average, 20 times a year (~5% of the time). Therefore, the synthetic natural flow was sorted into a decreasing order and the 95^{th} percentile calculated. This value was then assumed to represent the maximum capacity of the intake tunnels and for all values above this spill would occur. Therefore the impacted flow was the synthetic natural flow minus the value of the 95^{th} percentile plus the addition of compensation flow.

18. Deugh intake weir 2 DHRAM was calculated using synthetically generated natural flow and synthetically generated impacted flow. Natural, synthetically generated flow was derived in the usual DHRAM method (Black *et al*., 2000) using the gauged analogue 079004 (Marsh and Lees, 1998). Impacted, synthetically generated flow was calculated from the assumption that the intake weirs spill, on average, 20 times a year (~5% of the time). Therefore, the synthetic natural flow was sorted into a decreasing order and the 95^{th} percentile calculated. This value was then assumed to

represent the maximum capacity of the intake tunnels and for all values above this spill would occur. Therefore the impacted flow was the synthetic natural flow minus the value of the 95^{th} percentile plus the addition of compensation flow.

ANNEX B: DHRAM tables

Site 2 Carsphairn Lane downstream of Drumjohn Power Station

unimpctd/iha80801.txt (Un-i	Un-impacted record...		Impacted record.........		Increase in		Absolute change	
impacted/iha80a01.txt(Impa	Mean	CV(%)	Mean	CV(%)	Mean(%)	CV(%)	Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	0.471	34.105	4.75	28.421	907.6	-16.7	907.6	16.7
Feb-Mean	0.44	51.526	5.5	21.818	1150	-57.7	1150	57.7
Mar-Mean	0.452	38.36	5.4	22.222	1093.7	-42.1	1093.7	42.1
Apr-Mean	0.295	50.646	2	65	577.4	28.3	577.4	28.3
May-Mean	0.186	67.06	1	80	438.5	19.3	438.5	19.3
Jun-Mean	0.205	47.483	0.2	0	-2.4	-9000	2.4	9000
Jul-Mean	0.235	59.078	0.15	33.333	-36.2	-43.6	36.2	43.6
Aug-Mean	0.32	74.346	0.3	0	-6.2	-9000	6.2	9000
Sep-Mean	0.43	68.239	0.55	45.455	27.9	-33.4	27.9	33.4
Oct-Mean	0.54	46.995	2.9	48.276	437	2.7	437	2.7
Nov-Mean	0.42	40.963	4	57.5	852.4	40.4	852.4	40.4
Dec-Mean	0.585	40.189	6.1	1.639	942.7	-95.9	942.7	95.9
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	0.036	37.424	0.036	9.859	-2	-73.7	2	73.7
1-Day-Max	6.018	13.023	11.382	10.631	89.1	-18.4	89.1	18.4
3-Day-Min	0.038	35.56	0.037	13.514	-2.4	-62	2.4	62
3-Day-Max	3.626	29.765	7.803	4.063	115.2	-86.4	115.2	86.4
7-Day-Min	0.042	35.995	0.04	20	-4.2	-44.4	4.2	44.4
7-Day-Max	2.179	34.176	7.146	1.329	228	-96.1	228	96.1
30-Day-Min	0.087	58.533	0.128	30.469	47	-47.9	47	47.9
30-Day-Max	0.958	25.21	6.717	0.596	600.8	-97.6	600.8	97.6
90-Day-Min	0.174	50.9	0.201	9.677	16	-81	16	81
90-Day-Max	0.671	18.803	5.253	9.241	683.1	-50.9	683.1	50.9
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	337.556	62.345	1.188	14.903	7.8	-76.1	7.8	76.1
1-Day-Min-Date	191.206	37.232	362.299	35.692	46.9	-4.1	46.9	4.1
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	40.526	10.87	18	44.444	-55.6	308.9	55.6	308.9
Low-Pulses	13.737	19.454	23.5	10.638	71.1	-45.3	71.1	45.3
Mean-Hi-Pulse-Durn	2.221	10.592	5.65	23.894	154.4	125.6	154.4	125.6
Mean-Lo-Pulse-Durn	6.916	26.709	3.75	9.333	-45.8	-65.1	45.8	65.1
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	0.447	21.806	0.94	4.255	110.3	-80.5	110.3	80.5
Mean-decrease	0.232	21.109	0.61	8.197	162.4	-61.2	162.4	61.2
No-rises	76.15	7.86	88	3.409	15.6	-56.6	15.6	56.6
Valid-years	22		2					
Start year	1980		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores

unimpctd/iha80801.txt (Un-impacted)

impacted/iha80a01.txt(Impacted)

	Mean changes		Impact points	
Group	Means	CVs	Means	CVs
1	539.3	1531.7	**3**	**3**
2	122.7	67.5	**2**	**0**
3	27.4	40.1	**2**	**1**
4	81.7	136.2	**2**	**3**
5	96.1	66.1	**2**	**1**
	TOTAL POINTS			**19**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 5 Water of Ken downstream of Kendoon Loch

unimpctd/iha80804.txt (Un-i impacted/iha80a04.txt(Impa	Un-impacted record... Mean	CV(%)	Impacted record......... Mean	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	8.988	54.225	1.05	100	-88.3	84.4	88.3	84.4
Feb-Mean	7.787	61.323	0.3	66.667	-96.1	8.7	96.1	8.7
Mar-Mean	6.673	43.072	1.3	69.231	-80.5	60.7	80.5	60.7
Apr-Mean	3.247	46.37	0.35	100	-89.2	115.7	89.2	115.7
May-Mean	1.82	70.968	0	-9990	-100	-100	100	100
Jun-Mean	1.58	34.45	0	-9990	-100	-100	100	100
Jul-Mean	1.664	61.301	0	-9990	-100	-100	100	100
Aug-Mean	1.979	60.414	0.1	100	-94.9	65.5	94.9	65.5
Sep-Mean	2.971	57.218	1.65	15.152	-44.5	-73.5	44.5	73.5
Oct-Mean	6.386	56.806	1.8	100	-71.8	76	71.8	76
Nov-Mean	6.029	56.403	3.05	96.721	-49.4	71.5	49.4	71.5
Dec-Mean	7.857	59.398	6.25	2.4	-20.5	-96	20.5	96
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	0.495	66.721	0	-9990	-100	-100	100	100
1-Day-Max	63.361	22.595	84.551	14.419	33.4	-36.2	33.4	36.2
3-Day-Min	0.519	68.568	0	-9990	-100	-100	100	100
3-Day-Max	47.517	35.182	35.845	17.908	-24.6	-49.1	24.6	49.1
7-Day-Min	0.579	81.723	0	-9990	-100	-100	100	100
7-Day-Max	31.691	38.574	19.01	0.095	-40	-99.8	40	99.8
30-Day-Min	0.956	113.163	0	-9990	-100	-100	100	100
30-Day-Max	16.727	29.326	7.925	15.117	-52.6	-48.5	52.6	48.5
90-Day-Min	1.639	76.938	0	-9990	-100	-100	100	100
90-Day-Max	10.043	20.191	4.121	0.109	-59	-99.5	59	99.5
(Zero-flow days)*	0	-9990	0	0				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	358.297	20.04	-4.6	-57.5	4.6	57.5
1-Day-Min-Date	204.47	31.522	0.125	0.331	44	-99	44	99
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.857	16.795	16	12.5	-19.4	-25.6	19.4	25.6
Low-Pulses	9.5	29.169	0	-9990	-100	-100	100	100
Mean-Hi-Pulse-Durn	4.636	16.258	1.55	9.677	-66.6	-40.5	66.6	40.5
Mean-Lo-Pulse-Durn	9.9	26.246	0	-9990	-100	-100	100	100
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	3.319	24.39	23.33	32.105	602.9	31.6	602.9	31.6
Mean-decrease	1.686	25.057	19.3	33.109	1044.7	32.1	1044.7	32.1
No-rises	56.6	14.989	16.5	15.152	-70.8	1.1	70.8	1.1
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores
unimpctd/iha80804.txt (Un-impacted)
impacted/iha80a04.txt(Impacted)

	Mean changes		Impact points	
Group	Means	CVs	Means	CVs
1	77.9	79.3	**3**	**1**
2	72.3	81.5	**1**	**0**
3	24.3	78.3	**2**	**3**
4	71.5	66.5	**2**	**1**
5	572.8	21.6	**3**	**0**
	TOTAL POINTS			**16**
	Interim Classification			**4**
	Flow cessation**			1
	Significant sub-daily oscillation**			
	Final classification			**5**

Site 6 Water of Ken downstream of Kendoon Power Station

unimpctd/iha80805.txt (Un-i impacted/iha80a05.txt(Impa	Un-impacted record... Mean	CV(%)	Impacted record......... Mean	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	24.731	52.265	37.5	20.267	51.6	-61.2	51.6	61.2
Feb-Mean	21.407	60.721	29.05	10.499	35.7	-82.7	35.7	82.7
Mar-Mean	18.46	42.371	22.85	20.35	23.8	-52	23.8	52
Apr-Mean	9.027	46.315	11.25	7.556	24.6	-83.7	24.6	83.7
May-Mean	5.053	71.954	8.7	36.782	72.2	-48.9	72.2	48.9
Jun-Mean	4.347	34.421	9.25	50.27	112.8	46	112.8	46
Jul-Mean	4.636	61.904	4.5	53.333	-2.9	-13.8	2.9	13.8
Aug-Mean	5.521	60.667	5.3	58.491	-4	-3.6	4	3.6
Sep-Mean	8.279	57.265	17.2	22.674	107.8	-60.4	107.8	60.4
Oct-Mean	17.557	55.171	21.45	61.305	22.2	11.1	22.2	11.1
Nov-Mean	16.629	55.023	25.05	3.393	50.6	-93.8	50.6	93.8
Dec-Mean	21.636	57.665	45.05	5.66	108.2	-90.2	108.2	90.2
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.348	67.829	0.229	4.139	-83	-93.9	83	93.9
1-Day-Max	166.332	22.146	150.408	11.021	-9.6	-50.2	9.6	50.2
3-Day-Min	1.413	69.777	0.241	0.621	-82.9	-99.1	82.9	99.1
3-Day-Max	125.699	34.216	101.966	13.792	-18.9	-59.7	18.9	59.7
7-Day-Min	1.581	83.373	0.651	24.635	-58.8	-70.5	58.8	70.5
7-Day-Max	84.734	37.284	76.348	1.696	-9.9	-95.5	9.9	95.5
30-Day-Min	2.635	115.658	1.838	13.275	-30.2	-88.5	30.2	88.5
30-Day-Max	45.319	28.208	51.202	7.316	13	-74.1	13	74.1
90-Day-Min	4.541	77.964	4.915	21.322	8.2	-72.7	8.2	72.7
90-Day-Max	27.503	19.671	34.151	12.493	24.2	-36.5	24.2	36.5
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	358.297	20.04	-4.6	-57.5	4.6	57.5
1-Day-Min-Date	204.47	31.522	359.425	40.684	42.5	29.1	42.5	29.1
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.857	16.795	22.5	2.222	13.3	-86.8	13.3	86.8
Low-Pulses	9.5	29.169	22	13.636	131.6	-53.2	131.6	53.2
Mean-Hi-Pulse-Durn	4.636	16.258	4.05	6.173	-12.6	-62	12.6	62
Mean-Lo-Pulse-Durn	9.9	26.246	4.15	13.253	-58.1	-49.5	58.1	49.5
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	8.965	23.372	10.07	5.462	12.3	-76.6	12.3	76.6
Mean-decrease	4.554	24.061	7.75	1.548	70.2	-93.6	70.2	93.6
No-rises	56.6	14.989	97.5	2.564	72.3	-82.9	72.3	82.9
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores

unimpctd/iha80805.txt (Un-impacted)
impacted/iha80a05.txt(Impacted)

	Mean changes		Impact points	
Group	Means	CVs	Means	CVs
1	51.4	54.0	**2**	**1**
2	34.9	78.2	**0**	**0**
3	23.6	43.3	**2**	**1**
4	53.9	62.9	**1**	**1**
5	51.6	84.4	**1**	**2**
	TOTAL POINTS			**11**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 7 Water of Ken downstream of Carsfad Loch

unimpctd/iha80806.txt (Un-i impacted/iha80a06.txt(Impa	Un-impacted record... Mean	 CV(%)	Impacted record......... Mean	 CV(%)	Increase in Mean(%)	 CV(%)	Absolute change Mean(%)	 CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	25.175	52.203	1.7	70.588	-93.2	35.2	93.2	35.2
Feb-Mean	21.773	60.763	0.8	37.5	-96.3	-38.3	96.3	38.3
Mar-Mean	18.78	42.332	1.95	64.103	-89.6	51.4	89.6	51.4
Apr-Mean	9.207	46.136	0.9	44.444	-90.2	-3.7	90.2	3.7
May-Mean	5.14	72.732	0.5	0	-90.3	-9000	90.3	9000
Jun-Mean	4.44	33.976	0.5	0	-88.7	-9000	88.7	9000
Jul-Mean	4.729	61.736	0.5	0	-89.4	-9000	89.4	9000
Aug-Mean	5.621	60.54	0.5	0	-91.1	-9000	91.1	9000
Sep-Mean	8.421	57.204	1.2	58.333	-85.8	2	85.8	2
Oct-Mean	17.871	55.06	2.25	77.778	-87.4	41.3	87.4	41.3
Nov-Mean	16.921	54.977	2.3	78.261	-86.4	42.4	86.4	42.4
Dec-Mean	22.021	57.556	6.3	15.873	-71.4	-72.4	71.4	72.4
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.375	67.759	0.47	0	-65.8	-9000	65.8	9000
1-Day-Max	169.089	22.137	104.196	25.649	-38.4	15.9	38.4	15.9
3-Day-Min	1.441	69.701	0.47	0	-67.4	-9000	67.4	9000
3-Day-Max	127.8	34.197	43.06	39.301	-66.3	14.9	66.3	14.9
7-Day-Min	1.612	83.317	0.47	0	-70.8	-9000	70.8	9000
7-Day-Max	86.169	37.258	20.218	35.167	-76.5	-5.6	76.5	5.6
30-Day-Min	2.686	115.548	0.47	0	-82.5	-9000	82.5	9000
30-Day-Max	46.103	28.182	8.261	9.496	-82.1	-66.3	82.1	66.3
90-Day-Min	4.627	77.899	0.47	0	-89.8	-9000	89.8	9000
90-Day-Max	27.988	19.654	3.999	0	-85.7	-9000	85.7	9000
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	360.974	15.642	-3.9	-66.9	3.9	66.9
1-Day-Min-Date	204.47	31.522	0.125	0.331	44	-99	44	99
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.857	16.795	13	15.385	-34.5	-8.4	34.5	8.4
Low-Pulses	9.5	29.169	0	-9990	-100	-100	100	100
Mean-Hi-Pulse-Durn	4.636	16.258	1.55	16.129	-66.6	-0.8	66.6	0.8
Mean-Lo-Pulse-Durn	9.9	26.246	0	-9990	-100	-100	100	100
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	9.119	23.343	26.36	26.593	189.1	13.9	189.1	13.9
Mean-decrease	4.631	24.037	19.69	33.164	325.1	38	325.1	38
No-rises	56.6	14.989	14	21.429	-75.3	43	75.3	43
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

IHA scores

unimpctd/iha80806.txt (Un-impacted)
impacted/iha80a06.txt(Impacted)

	Mean changes		Impact points	
Group	Means	CVs	Means	CVs
1	88.3	3023.9	**3**	**3**
2	71.1	5011.4	**1**	**3**
3	24.0	83.0	**2**	**3**
4	75.3	52.3	**2**	**1**
5	196.5	31.6	**3**	**0**
	TOTAL POINTS			**21**
	Interim Classification			**5**
	Flow cessation**			
	Significant sub-daily oscillation**			
	Final classification			**5**

Site 8 Water of Ken downstream of Polharrow Burn Tributary

unimpctd/iha80807.txt (Un-i	Un-impacted record...		Impacted record.........		Increase in		Absolute change	
impacted/iha80a07.txt(Impa	Mean	CV(%)	Mean	CV(%)	Mean(%)	CV(%)	Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	25.462	57.08	47.8	22.594	87.7	-60.4	87.7	60.4
Feb-Mean	22.573	57.072	35.4	13.559	56.8	-76.2	56.8	76.2
Mar-Mean	19.687	41.051	27.85	20.287	41.5	-50.6	41.5	50.6
Apr-Mean	10.413	43.724	14.2	13.38	36.4	-69.4	36.4	69.4
May-Mean	5.687	62.966	10.75	34.884	89	-44.6	89	44.6
Jun-Mean	5.133	31.999	11	46.364	114.3	44.9	114.3	44.9
Jul-Mean	5.493	60.28	5.7	49.123	3.8	-18.5	3.8	18.5
Aug-Mean	6.357	56.603	6.05	58.678	-4.8	3.7	4.8	3.7
Sep-Mean	9.129	54.332	21.8	24.771	138.8	-54.4	138.8	54.4
Oct-Mean	18.943	54.774	26.4	61.364	39.4	12	39.4	12
Nov-Mean	18.2	54.17	29.55	13.367	62.4	-75.3	62.4	75.3
Dec-Mean	22.079	62.318	56.55	5.217	156.1	-91.6	156.1	91.6
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.599	69.039	0.615	2.602	-61.5	-96.2	61.5	96.2
1-Day-Max	193.205	23.669	182.87	17.644	-5.3	-25.5	5.3	25.5
3-Day-Min	1.678	70.749	0.632	0.949	-62.3	-98.7	62.3	98.7
3-Day-Max	143.268	37.055	131.699	15.229	-8.1	-58.9	8.1	58.9
7-Day-Min	1.885	83.692	0.841	1.784	-55.4	-97.9	55.4	97.9
7-Day-Max	92.269	43.248	99.383	1.292	7.7	-97	7.7	97
30-Day-Min	2.952	96.922	2.403	14.547	-18.6	-85	18.6	85
30-Day-Max	48.281	32.1	64.418	4.319	33.4	-86.5	33.4	86.5
90-Day-Min	5.185	66.183	5.903	20.542	13.8	-69	13.8	69
90-Day-Max	28.833	20.868	42.195	11.51	46.3	-44.8	46.3	44.8
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	360.974	15.642	-3.9	-66.9	3.9	66.9
1-Day-Min-Date	204.47	31.522	359.381	40.589	42.4	28.8	42.4	28.8
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	26.357	16.944	25.5	9.804	-3.3	-42.1	3.3	42.1
Low-Pulses	10.357	29.333	22.5	6.667	117.2	-77.3	117.2	77.3
Mean-Hi-Pulse-Durn	3.5	22.131	3.55	7.042	1.4	-68.2	1.4	68.2
Mean-Lo-Pulse-Durn	9.036	24.774	4.05	6.173	-55.2	-75.1	55.2	75.1
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	10.684	24.776	12.545	2.91	17.4	-88.3	17.4	88.3
Mean-decrease	5.477	26.431	9.97	4.514	82	-82.9	82	82.9
No-rises	62.467	15.331	96	4.167	53.7	-72.8	53.7	72.8
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores

unimpctd/iha80807.txt (Un-impacted)

impacted/iha80a07.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	69.3	50.1	**3**	**1**
2	29.6	79.4	**0**	**0**
3	23.2	47.9	**2**	**1**
4	44.3	65.7	**1**	**1**
5	51.0	81.3	**1**	**2**
	TOTAL POINTS			**12**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 9 Water of Ken downstream of Earlstoun Loch

unimpctd/iha80808.txt (Un-ii impacted/iha80a08.txt(Impa	Un-impacted record... Mean	CV(%)	Impacted record......... Mean	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	29.925	51.571	40.5	20.247	35.3	-60.7	35.3	60.7
Feb-Mean	25.893	60.213	31.4	16.242	21.3	-73	21.3	73
Mar-Mean	22.413	41.812	24.25	25.773	8.2	-38.4	8.2	38.4
Apr-Mean	11.073	45.48	12.4	12.903	12	-71.6	12	71.6
May-Mean	6.22	71.337	10	33	60.8	-53.7	60.8	53.7
Jun-Mean	5.38	34.066	9.65	47.15	79.4	38.4	79.4	38.4
Jul-Mean	5.714	61.017	5.05	52.475	-11.6	-14	11.6	14
Aug-Mean	6.8	59.805	5.65	59.292	-16.9	-0.9	16.9	0.9
Sep-Mean	10.114	56.743	19.1	19.372	88.8	-65.9	88.8	65.9
Oct-Mean	21.3	54.503	24.3	61.728	14.1	13.3	14.1	13.3
Nov-Mean	20.171	54.373	26.25	20.381	30.1	-62.5	30.1	62.5
Dec-Mean	26.193	56.918	50.05	2.897	91.1	-94.9	91.1	94.9
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.687	66.896	0.47	0	-72.1	-9000	72.1	9000
1-Day-Max	198.427	22.048	159.645	4.184	-19.5	-81	19.5	81
3-Day-Min	1.766	68.848	0.47	0	-73.4	-9000	73.4	9000
3-Day-Max	150.183	34.014	112.529	4.364	-25.1	-87.2	25.1	87.2
7-Day-Min	1.973	82.152	0.47	0	-76.2	-9000	76.2	9000
7-Day-Max	101.491	36.993	84.151	9.952	-17.1	-73.1	17.1	73.1
30-Day-Min	3.265	113.528	2.017	13.408	-38.2	-88.2	38.2	88.2
30-Day-Max	54.515	27.904	56.275	0.656	3.2	-97.7	3.2	97.7
90-Day-Min	5.598	76.704	5.228	19.893	-6.6	-74.1	6.6	74.1
90-Day-Max	33.228	19.459	36.538	14.78	10	-24	10	24
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	360.974	15.642	-3.9	-66.9	3.9	66.9
1-Day-Min-Date	204.47	31.522	7.644	31.623	46.1	0.3	46.1	0.3
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.857	16.795	26	11.538	30.9	-31.3	30.9	31.3
Low-Pulses	9.5	29.169	24	12.5	152.6	-57.1	152.6	57.1
Mean-Hi-Pulse-Durn	4.636	16.258	3.5	0	-24.5	-9000	24.5	9000
Mean-Lo-Pulse-Durn	9.9	26.246	3.6	13.889	-63.6	-47.1	63.6	47.1
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	10.745	23.146	12.335	2.148	14.8	-90.7	14.8	90.7
Mean-decrease	5.458	23.88	11.815	4.359	116.5	-81.7	116.5	81.7
No-rises	56.6	14.989	94	1.064	66.1	-92.9	66.1	92.9
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores
unimpctd/iha80808.txt (Un-impacted)
impacted/iha80a08.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	39.1	48.9	**1**	**1**
2	36.8	3055.7	**0**	**3**
3	25.0	33.6	**2**	**1**
4	67.9	2283.9	**2**	**3**
5	65.8	88.4	**1**	**2**
	TOTAL POINTS			**16**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 10 Water of Ken south of Holm of Dalry

unimpctd/iha80809.txt (Un-i impacted/iha80a09.txt(Impa	Un-impacted record... Mean	CV(%)	Impacted record......... Mean	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	32.712	51.334	52.8	17.235	61.4	-66.4	61.4	66.4
Feb-Mean	28.327	60.078	42.8	18.925	51.1	-68.5	51.1	68.5
Mar-Mean	24.533	41.637	34.4	29.942	40.2	-28.1	40.2	28.1
Apr-Mean	12.133	45.217	17.35	25.648	43	-43.3	43	43.3
May-Mean	6.82	71.509	14.05	28.826	106	-59.7	106	59.7
Jun-Mean	5.9	34.146	14.25	27.018	141.5	-20.9	141.5	20.9
Jul-Mean	6.279	60.814	11.5	46.957	83.2	-22.8	83.2	22.8
Aug-Mean	7.457	59.771	8.75	9.714	17.3	-83.7	17.3	83.7
Sep-Mean	11.093	56.621	23.1	22.944	108.2	-59.5	108.2	59.5
Oct-Mean	23.314	54.217	36.9	56.64	58.3	4.5	58.3	4.5
Nov-Mean	22.064	54.222	38.2	19.895	73.1	-63.3	73.1	63.3
Dec-Mean	28.636	56.781	71.15	9.346	148.5	-83.5	148.5	83.5
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.853	66.778	0.588	0.68	-68.3	-99	68.3	99
1-Day-Max	215.841	22.006	172.659	8.476	-20	-61.5	20	61.5
3-Day-Min	1.94	68.759	0.595	0.084	-69.4	-99.9	69.4	99.9
3-Day-Max	163.478	33.925	128.857	12.522	-21.2	-63.1	21.2	63.1
7-Day-Min	2.166	82.017	2.027	16.626	-6.4	-79.7	6.4	79.7
7-Day-Max	110.587	36.873	104.216	0.011	-5.8	-100	5.8	100
30-Day-Min	3.582	113.355	5.334	4.874	48.9	-95.7	48.9	95.7
30-Day-Max	59.487	27.794	79.409	2.843	33.5	-89.8	33.5	89.8
90-Day-Min	6.139	76.573	9.799	21.59	59.6	-71.8	59.6	71.8
90-Day-Max	36.304	19.399	50.5	16.817	39.1	-13.3	39.1	13.3
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	360.974	15.642	-3.9	-66.9	3.9	66.9
1-Day-Min-Date	204.47	31.522	359.425	40.684	42.5	29.1	42.5	29.1
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.857	16.795	21	14.286	5.8	-14.9	5.8	14.9
Low-Pulses	9.5	29.169	26	15.385	173.7	-47.3	173.7	47.3
Mean-Hi-Pulse-Durn	4.636	16.258	4.35	1.149	-6.2	-92.9	6.2	92.9
Mean-Lo-Pulse-Durn	9.9	26.246	3.6	27.778	-63.6	5.8	63.6	5.8
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	11.718	23.054	11.61	1.981	-0.9	-91.4	0.9	91.4
Mean-decrease	5.951	23.761	10.075	2.035	69.3	-91.4	69.3	91.4
No-rises	56.6	14.989	102	0.98	80.2	-93.5	80.2	93.5
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores
unimpctd/iha80809.txt (Un-impacted)
impacted/iha80a09.txt(Impacted)

	Mean changes		Impact points	
Group	Means	CVs	Means	CVs
1	77.7	50.4	**3**	**1**
2	37.0	84.5	**0**	**0**
3	23.2	48.0	**2**	**1**
4	62.3	40.2	**1**	**1**
5	50.1	92.1	**1**	**2**
	TOTAL POINTS			**12**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 11 Water of Ken downstream of Ken Bridge

unimpctd/iha80810.txt (Un-i	Un-impacted record...		Impacted record.........		Increase in		Absolute change	
impacted/iha80a10.txt(Impa	Mean	CV(%)	Mean	CV(%)	Mean(%)	CV(%)	Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	35.162	51.133	55.35	17.615	57.4	-65.6	57.4	65.6
Feb-Mean	30.44	59.97	45	19.556	47.8	-67.4	47.8	67.4
Mar-Mean	26.387	41.539	35.85	28.591	35.9	-31.2	35.9	31.2
Apr-Mean	13.067	45.291	18.1	25.967	38.5	-42.7	38.5	42.7
May-Mean	7.36	71.164	14.6	29.452	98.4	-58.6	98.4	58.6
Jun-Mean	6.367	33.905	14.75	26.78	131.7	-21	131.7	21
Jul-Mean	6.75	60.712	11.9	47.059	76.3	-22.5	76.3	22.5
Aug-Mean	8.043	59.504	9.15	11.475	13.8	-80.7	13.8	80.7
Sep-Mean	11.943	56.659	24.65	22.921	106.4	-59.5	106.4	59.5
Oct-Mean	25.05	54.032	38.45	56.047	53.5	3.7	53.5	3.7
Nov-Mean	23.729	53.968	40.25	16.77	69.6	-68.9	69.6	68.9
Dec-Mean	30.779	56.475	74.8	10.963	143	-80.6	143	80.6
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	2.004	66.537	0.696	1.149	-65.3	-98.3	65.3	98.3
1-Day-Max	230.926	21.971	179.952	9.736	-22.1	-55.7	22.1	55.7
3-Day-Min	2.097	68.503	0.709	0.071	-66.2	-99.9	66.2	99.9
3-Day-Max	175.002	33.852	137.389	15.579	-21.5	-54	21.5	54
7-Day-Min	2.341	81.745	2.181	16.296	-6.8	-80.1	6.8	80.1
7-Day-Max	118.483	36.773	110.382	2.808	-6.8	-92.4	6.8	92.4
30-Day-Min	3.867	113.007	5.627	3.475	45.5	-96.9	45.5	96.9
30-Day-Max	63.814	27.7	85.219	3.716	33.5	-86.6	33.5	86.6
90-Day-Min	6.619	76.375	10.23	21.627	54.6	-71.7	54.6	71.7
90-Day-Max	38.99	19.346	53.855	16.406	38.1	-15.2	38.1	15.2
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	10.184	47.195	360.974	15.642	-3.9	-66.9	3.9	66.9
1-Day-Min-Date	204.47	31.522	359.425	40.684	42.5	29.1	42.5	29.1
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.857	16.795	21.5	20.93	8.3	24.6	8.3	24.6
Low-Pulses	9.5	29.169	24.5	10.204	157.9	-65	157.9	65
Mean-Hi-Pulse-Durn	4.636	16.258	4.3	4.651	-7.2	-71.4	7.2	71.4
Mean-Lo-Pulse-Durn	9.9	26.246	3.75	22.667	-62.1	-13.6	62.1	13.6
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	12.561	22.981	12.215	1.269	-2.8	-94.5	2.8	94.5
Mean-decrease	6.379	23.704	10.32	4.07	61.8	-82.8	61.8	82.8
No-rises	56.6	14.989	101.5	1.478	79.3	-90.1	79.3	90.1
Valid-years	16		2					
Start year	1986		1999					
Finish year	2001		2000					

* not included in impact points calculation.

IHA scores

unimpctd/iha80810.txt (Un-impacted)

impacted/iha80a10.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	72.7	50.2	**3**	**1**
2	35.8	81.7	**0**	**0**
3	23.2	48.0	**2**	**1**
4	58.9	43.7	**1**	**1**
5	48.0	89.1	**1**	**2**
	TOTAL POINTS			**12**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 12 River Dee downstream of Clatteringshaws Loch

unimpctd/iha80811.txt (Un-i	Un-impacted record...		Impacted record.........		Increase in		Absolute change	
impacted/iha80a11.txt(Impa	Mean	CV(%)	Mean	CV(%)	Mean(%)	CV(%)	Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	9.474	55.27	0	-9990	-100	-100	100	100
Feb-Mean	8.094	71.292	0	-9990	-100	-100	100	100
Mar-Mean	7.219	58.145	0	-9990	-100	-100	100	100
Apr-Mean	4.694	50.959	0	-9990	-100	-100	100	100
May-Mean	3.5	70.589	0.6	0	-82.9	-100	82.9	100
Jun-Mean	2.394	46.788	0.6	0	-74.9	-100	74.9	100
Jul-Mean	2.1	46.39	0.6	0	-71.4	-100	71.4	100
Aug-Mean	2.906	73.57	0.6	0	-79.4	-100	79.4	100
Sep-Mean	4.174	73.774	0	-9990	-100	-100	100	100
Oct-Mean	5.868	59.423	0	-9990	-100	-100	100	100
Nov-Mean	7.894	56.655	0	-9990	-100	-100	100	100
Dec-Mean	8.758	56.577	0	-9990	-100	-100	100	100
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	0.788	31.41	0	-9990	-100	-100	100	100
1-Day-Max	66.233	24.95	0.632	0	-99	-9000	99	9000
3-Day-Min	0.826	32.836	0	-9990	-100	-100	100	100
3-Day-Max	48.783	35.662	0.632	0	-98.7	-9000	98.7	9000
7-Day-Min	0.898	37.035	0	-9990	-100	-100	100	100
7-Day-Max	32.675	39.577	0.632	0	-98.1	-9000	98.1	9000
30-Day-Min	1.194	42.671	0	-9990	-100	-100	100	100
30-Day-Max	17.526	32.759	0.632	0	-96.4	-9000	96.4	9000
90-Day-Min	1.853	41.473	0	-9990	-100	-100	100	100
90-Day-Max	11.578	27.445	0.632	0	-94.5	-9000	94.5	9000
(Zero-flow days)*	0	-9990	0	0				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	2.814	55.039	120.996	NaN	32.4	-9000	32.4	9000
1-Day-Min-Date	221.755	62.717	1	0.045	39.5	-99.9	39.5	99.9
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	13.129	24.907	0	-9990	-100	-100	100	100
Low-Pulses	11.484	45.483	0	-9990	-100	-100	100	100
Mean-Hi-Pulse-Durn	7.184	32.194	0	-9990	-100	-100	100	100
Mean-Lo-Pulse-Durn	10.023	61.203	0	-9990	-100	-100	100	100
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	3.148	41.526	0.63	0	-80	-100	80	100
Mean-decrease	1.653	38.013	0.63	0	-61.9	-100	61.9	100
No-rises	53.774	11.383	1	0	-98.1	-9000	98.1	9000
Valid-years	31		31					
Start year	1969		1969					
Finish year	1999		1999					

* not included in impact points calculation.

IHA scores

unimpctd/iha80811.txt (Un-impacted)

impacted/iha80a11.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	92.4	100.0	**3**	**2**
2	99.1	4055.6	**2**	**3**
3	36.0	4550.0	**3**	**3**
4	100.0	100.0	**3**	**2**
5	80.0	3066.7	**1**	**3**
	TOTAL POINTS			**25**
	Interim Classification			**5**
	Flow cessation**			1
	Significant sub-daily oscillation**			
	Final classification			**5**

Site 13 River Dee east of Orchars

unimpctd/iha80812.txt (Un-ii impacted/iha80a12.txt(Impa	Un-impacted record... Mean	CV(%)	Impacted record......... Mean	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	12.955	54.582	3.474	52.908	-73.2	-3.1	73.2	3.1
Feb-Mean	11.048	70.609	2.958	68.1	-73.2	-3.6	73.2	3.6
Mar-Mean	9.89	57.503	2.671	56.149	-73	-2.4	73	2.4
Apr-Mean	6.468	50.445	1.761	49.406	-72.8	-2.1	72.8	2.1
May-Mean	4.816	69.961	1.374	62.707	-71.5	-10.4	71.5	10.4
Jun-Mean	3.306	47.023	0.987	37.355	-70.1	-20.6	70.1	20.6
Jul-Mean	2.887	46.618	0.913	33.358	-68.4	-28.4	68.4	28.4
Aug-Mean	4.019	73.217	1.216	59.409	-69.7	-18.9	69.7	18.9
Sep-Mean	5.723	72.62	1.558	70.53	-72.8	-2.9	72.8	2.9
Oct-Mean	8.045	58.745	2.171	57.665	-73	-1.8	73	1.8
Nov-Mean	10.794	56.159	2.897	54.86	-73.2	-2.3	73.2	2.3
Dec-Mean	11.965	56.007	3.206	54.71	-73.2	-2.3	73.2	2.3
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.091	31.306	0.358	28.289	-67.2	-9.6	67.2	9.6
1-Day-Max	88.908	24.752	22.675	24.175	-74.5	-2.3	74.5	2.3
3-Day-Min	1.144	32.716	0.377	28.543	-67	-12.8	67	12.8
3-Day-Max	65.653	35.326	16.87	34.354	-74.3	-2.8	74.3	2.8
7-Day-Min	1.243	36.926	0.421	32.233	-66.1	-12.7	66.1	12.7
7-Day-Max	44.137	39.143	11.461	37.906	-74	-3.2	74	3.2
30-Day-Min	1.651	42.571	0.588	24.953	-64.4	-41.4	64.4	41.4
30-Day-Max	23.811	32.366	6.285	31.279	-73.6	-3.4	73.6	3.4
90-Day-Min	2.559	41.369	0.814	29.785	-68.2	-28	68.2	28
90-Day-Max	15.79	27.131	4.212	26.281	-73.3	-3.1	73.3	3.1
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	2.814	55.039	2.814	55.039	0	0	0	0
1-Day-Min-Date	221.755	62.717	273.24	74.499	14.1	18.8	14.1	18.8
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	13.129	24.907	13.129	24.907	0	0	0	0
Low-Pulses	11.484	45.483	11.484	45.483	0	0	0	0
Mean-Hi-Pulse-Durn	7.184	32.194	7.184	32.194	0	0	0	0
Mean-Lo-Pulse-Durn	10.023	61.203	10.023	61.203	0	0	0	0
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	4.256	41.07	1.235	42.021	-71	2.3	71	2.3
Mean-decrease	2.233	37.611	0.65	37.885	-70.9	0.7	70.9	0.7
No-rises	53.774	11.383	48.903	13.607	-9.1	19.5	9.1	19.5
Valid-years	31		31					
Start year	1969		1969					
Finish year	1999		1999					

* not included in impact points calculation.

IHA scores
unimpctd/iha80812.txt (Un-impacted)
impacted/iha80a12.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	72.0	8.2	**3**	**0**
2	69.9	12.9	**1**	**0**
3	7.1	9.4	**1**	**0**
4	0.0	0.0	**0**	**0**
5	50.3	7.5	**1**	**0**
	TOTAL POINTS			**6**
	Interim Classification			**3**
	Flow cessation**			
	Significant sub-daily oscillation**			
	Final classification			**3**

Site 14 River Dee upstream of Stroan Loch

unimpctd/iha80813.txt (Un-ii impacted/iha80a13.txt(Impa	Un-impacted record... Mean	 CV(%)	Impacted record......... Mean	 CV(%)	Increase in Mean(%)	 CV(%)	Absolute change Mean(%)	 CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	16.594	54.856	7.113	54.391	-57.1	-0.8	57.1	0.8
Feb-Mean	14.126	71.105	6.032	70.812	-57.3	-0.4	57.3	0.4
Mar-Mean	12.645	58.281	5.413	58.766	-57.2	0.8	57.2	0.8
Apr-Mean	8.206	51.629	3.513	52.159	-57.2	1	57.2	1
May-Mean	6.065	71.947	2.571	73.41	-57.6	2	57.6	2
Jun-Mean	4.11	48.17	1.745	47.405	-57.5	-1.6	57.5	1.6
Jul-Mean	3.594	48.001	1.526	47.113	-57.5	-1.9	57.5	1.9
Aug-Mean	5.045	75.375	2.177	75	-56.8	-0.5	56.8	0.5
Sep-Mean	7.255	74.133	3.084	74.621	-57.5	0.7	57.5	0.7
Oct-Mean	10.232	59.623	4.361	59.612	-57.4	0	57.4	0
Nov-Mean	13.787	56.87	5.9	56.853	-57.2	0	57.2	0
Dec-Mean	15.313	56.51	6.552	56.479	-57.2	-0.1	57.2	0.1
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	1.317	32.061	0.594	23.756	-54.9	-25.9	54.9	25.9
1-Day-Max	113.673	24.589	47.44	24.084	-58.3	-2.1	58.3	2.1
3-Day-Min	1.382	33.459	0.62	24.627	-55.1	-26.4	55.1	26.4
3-Day-Max	84.108	35.076	35.326	34.268	-58	-2.3	58	2.3
7-Day-Min	1.504	37.77	0.669	29.046	-55.6	-23.1	55.6	23.1
7-Day-Max	56.66	38.903	23.985	37.987	-57.7	-2.4	57.7	2.4
30-Day-Min	2.017	43.62	0.879	36.446	-56.4	-16.4	56.4	16.4
30-Day-Max	30.591	32.326	13.065	31.753	-57.3	-1.8	57.3	1.8
90-Day-Min	3.171	42.571	1.349	41.485	-57.5	-2.5	57.5	2.5
90-Day-Max	20.254	27.244	8.676	26.988	-57.2	-0.9	57.2	0.9
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	2.814	55.039	2.814	55.039	0	0	0	0
1-Day-Min-Date	221.755	62.717	229.125	75.725	2	20.7	2	20.7
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	13.129	24.907	13.129	24.907	0	0	0	0
Low-Pulses	11.484	45.483	11.484	45.483	0	0	0	0
Mean-Hi-Pulse-Durn	7.184	32.194	7.184	32.194	0	0	0	0
Mean-Lo-Pulse-Durn	10.023	61.203	10.023	61.203	0	0	0	0
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	5.477	40.835	2.448	42.896	-55.3	5	55.3	5
Mean-decrease	2.873	37.386	1.276	37.539	-55.6	0.4	55.6	0.4
No-rises	53.774	11.383	51.903	14.051	-3.5	23.4	3.5	23.4
Valid-years	31		31					
Start year	1969		1969					
Finish year	1999		1999					

* not included in impact points calculation.

IHA scores
unimpctd/iha80813.txt (Un-impacted)
impacted/iha80a13.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	57.3	0.8	**2**	**0**
2	56.8	11.4	**1**	**0**
3	1.0	10.4	**0**	**0**
4	0.0	0.0	**0**	**0**
5	38.1	9.6	**0**	**0**
	TOTAL POINTS			**3**
	Interim Classification			**2**
	Flow cessation**			
	Significant sub-daily oscillation**			
	Final classification			**2**

Site 15 River Dee downstream of Loch Ken Dam

iha80814.txt (Un-impacted) iha21007.txt(Impacted)	Un-impacted record... Mean(m3/s	CV(%)	Impacted record......... Mean(m3/s	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions								
Jan-Mean	49.8	51.399	22.325	44.105	-55.2	-14.2	55.2	14.2
Feb-Mean	65.15	69.153	26.525	62.722	-59.3	-9.3	59.3	9.3
Mar-Mean	32.475	36.6	14.25	29.463	-56.1	-19.5	56.1	19.5
Apr-Mean	26.725	48.67	12.8	52.329	-52.1	7.5	52.1	7.5
May-Mean	24.625	20.248	11.2	16.158	-54.5	-20.2	54.5	20.2
Jun-Mean	21.4	36.888	10.075	39.599	-52.9	7.3	52.9	7.3
Jul-Mean	14.95	53.123	6.925	56.043	-53.7	5.5	53.7	5.5
Aug-Mean	14.15	81.042	6.6	85.723	-53.4	5.8	53.4	5.8
Sep-Mean	18.2	46.11	8.675	47.096	-52.3	2.1	52.3	2.1
Oct-Mean	37.95	60.136	15.7	54.742	-58.6	-9	58.6	9
Nov-Mean	51.05	23.787	23.85	20.279	-53.3	-14.7	53.3	14.7
Dec-Mean	64.125	38.907	28.325	28.223	-55.8	-27.5	55.8	27.5
Group 2: Magnitude and duration of annual extremes								
1-Day-Min	4.098	26.405	1.827	24.19	-55.4	-8.4	55.4	8.4
1-Day-Max	411.902	9.236	157.718	36.63	-61.7	296.6	61.7	296.6
3-Day-Min	4.246	26.907	1.883	24.808	-55.6	-7.8	55.6	7.8
3-Day-Max	275.078	28.474	103.002	28.517	-62.6	0.2	62.6	0.2
7-Day-Min	4.662	28.452	2.049	26.508	-56.1	-6.8	56.1	6.8
7-Day-Max	209.485	30.391	77.245	27.885	-63.1	-8.2	63.1	8.2
30-Day-Min	8.026	49.727	3.518	49.753	-56.2	0.1	56.2	0.1
30-Day-Max	114.895	27.476	45.876	22.586	-60.1	-17.8	60.1	17.8
90-Day-Min	13.676	60.272	6.34	63.643	-53.6	5.6	53.6	5.6
90-Day-Max	62.718	16.333	26.624	11.401	-57.6	-30.2	57.6	30.2
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes								
1-Day-Max-Date	0.644	49.051	1.129	49.673	0.1	1.3	0.1	1.3
1-Day-Min-Date	238.052	52.121	238.052	52.121	0	0	0	0
Group 4: Frequency and duration of high and low pulses								
High-Pulses	24	44.585	24	44.585	0	0	0	0
Low-Pulses	8.5	25.641	8.5	25.641	0	0	0	0
Mean-Hi-Pulse-Durn	4.075	17.557	4.1	18.17	0.6	3.5	0.6	3.5
Mean-Lo-Pulse-Durn	10.35	35.385	10.35	35.385	0	0	0	0
Group 5: Rate and frequency of change in conditions								
Mean-increase	24.257	25.459	9.068	21.551	-62.6	-15.4	62.6	15.4
Mean-decrease	12.435	24.274	4.653	21.484	-62.6	-11.5	62.6	11.5
No-rises	66.25	7.942	66.25	7.942	0	0	0	0
Valid-years	4		4					
Start year	1996		1996					
Finish year	1999		1999					

* not included in impact points calculation.

IHA scores
iha80814.txt (Un-impacted)
iha21007.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	54.8	11.9	**2**	**0**
2	58.3	39.1	**1**	**0**
3	0.1	0.7	**0**	**0**
4	0.2	0.9	**0**	**0**
5	41.7	9.0	**0**	**0**
	TOTAL POINTS			**3**
	Interim Classification			**2**
	Flow cessation**			
	Significant sub-daily oscillation**			
	Final classification			**2**

Site 16 River Dee downstream of Tongland Power Station

unimpctd/iha80815.txt (Un-i	Un-impacted record...		Impacted record.........		Increase in		Absolute change	
impacted/iha80a15.txt(Impa	Mean	CV(%)	Mean	CV(%)	Mean(%)	CV(%)	Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	59.251	50.398	68.8	20.93	16.1	-58.5	16.1	58.5
Feb-Mean	50.133	68.223	57.8	29.412	15.3	-56.9	15.3	56.9
Mar-Mean	44.662	55.929	46.9	27.505	5	-50.8	5	50.8
Apr-Mean	27.762	41.383	11.75	42.979	-57.7	3.9	57.7	3.9
May-Mean	22.633	65.062	19.25	15.844	-14.9	-75.6	14.9	75.6
Jun-Mean	14.938	51.418	15.7	19.745	5.1	-61.6	5.1	61.6
Jul-Mean	13.815	71.212	14.25	50.877	3.1	-28.6	3.1	28.6
Aug-Mean	19.836	81.378	10.8	21.296	-45.6	-73.8	45.6	73.8
Sep-Mean	29.105	66.548	37.65	27.224	29.4	-59.1	29.4	59.1
Oct-Mean	41.597	53.145	54.35	62.833	30.7	18.2	30.7	18.2
Nov-Mean	52.082	54.159	52.55	20.266	0.9	-62.6	0.9	62.6
Dec-Mean	60.372	46.946	105.4	4.08	74.6	-91.3	74.6	91.3
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	3.972	26.452	0.63	0	-84.1	-9000	84.1	9000
1-Day-Max	434.138	15.378	214.681	0.031	-50.6	-99.8	50.6	99.8
3-Day-Min	4.127	27.093	2.577	75.553	-37.6	178.9	37.6	178.9
3-Day-Max	299.246	26.884	194.418	1.957	-35	-92.7	35	92.7
7-Day-Min	4.52	29.647	2.776	77.301	-38.6	160.7	38.6	160.7
7-Day-Max	199.684	30.621	157.992	10.246	-20.9	-66.5	20.9	66.5
30-Day-Min	6.402	39.979	3.717	83.051	-41.9	107.7	41.9	107.7
30-Day-Max	106.078	27.347	115.048	1.896	8.5	-93.1	8.5	93.1
90-Day-Min	11.036	43.947	11.866	19.375	7.5	-55.9	7.5	55.9
90-Day-Max	71.285	21.905	73.667	21.267	3.3	-2.9	3.3	2.9
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	0.136	53.904	363.409	10.141	-0.5	-81.2	0.5	81.2
1-Day-Min-Date	205.946	38.868	2.925	21.288	44.4	-45.2	44.4	45.2
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	19.026	27.774	16.5	15.152	-13.3	-45.4	13.3	45.4
Low-Pulses	9.59	34.924	19	10.526	98.1	-69.9	98.1	69.9
Mean-Hi-Pulse-Durn	4.974	27.631	5.5	1.818	10.6	-93.4	10.6	93.4
Mean-Lo-Pulse-Durn	10.392	44.764	4.05	3.704	-61	-91.7	61	91.7
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	26.147	28.637	15.025	4.027	-42.5	-85.9	42.5	85.9
Mean-decrease	12.524	29.484	13.235	1.322	5.7	-95.5	5.7	95.5
No-rises	64.154	8.267	75	1.333	16.9	-83.9	16.9	83.9
Valid-years	39		2					
Start year	1962		1999					
Finish year	2000		2000					

* not included in impact points calculation.

IHA scores

unimpctd/iha80815.txt (Un-impacted)

impacted/iha80a15.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	24.9	53.4	**1**	**1**
2	36.1	1095.0	**0**	**3**
3	22.5	63.2	**2**	**2**
4	45.8	75.1	**1**	**1**
5	21.7	88.4	**0**	**2**
	TOTAL POINTS			**13**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			1
	Final classification			**5**

Site 17 Deuch Intake Weir 1

unimpctd/iha80816.txt (Un-ii impacted/iha80a16.txt(Impa	Un-impacted record... Mean	CV(%)	Impacted record......... Mean	CV(%)	Increase in Mean(%)	CV(%)	Absolute change Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	6.353	60.641	3.425	111.545	-46.1	83.9	46.1	83.9
Feb-Mean	5.519	79.419	2.984	131.016	-45.9	65	45.9	65
Mar-Mean	4.619	65.649	1.966	109.348	-57.4	66.6	57.4	66.6
Apr-Mean	2.791	60.769	0.691	124.788	-75.3	105.3	75.3	105.3
May-Mean	1.944	90.197	0.659	173.948	-66.1	92.9	66.1	92.9
Jun-Mean	1.2	58.999	0.309	16.872	-74.2	-71.4	74.2	71.4
Jul-Mean	1.028	60.166	0.309	16.872	-69.9	-72	69.9	72
Aug-Mean	1.597	91.293	0.45	114.8	-71.8	25.7	71.8	25.7
Sep-Mean	2.525	87.044	0.962	179.329	-61.9	106	61.9	106
Oct-Mean	3.741	67.207	1.603	117.193	-57.1	74.4	57.1	74.4
Nov-Mean	5.231	62.401	2.666	97.311	-49	55.9	49	55.9
Dec-Mean	6.175	67.514	3.588	112.069	-41.9	66	41.9	66
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	0.292	37.018	0.283	0	-3.2	-9000	3.2	9000
1-Day-Max	49.856	26.02	49.856	26.02	0	0	0	0
3-Day-Min	0.31	38.743	0.283	0	-8.7	-9000	8.7	9000
3-Day-Max	36.589	36.63	35.788	40.553	-2.2	10.7	2.2	10.7
7-Day-Min	0.344	43.996	0.283	0	-17.7	-9000	17.7	9000
7-Day-Max	24.371	41.946	22.098	52.963	-9.3	26.3	9.3	26.3
30-Day-Min	0.501	51.623	0.283	0	-43.5	-9000	43.5	9000
30-Day-Max	12.571	35.244	9.325	53.015	-25.8	50.4	25.8	50.4
90-Day-Min	0.878	52.412	0.283	0	-67.8	-9000	67.8	9000
90-Day-Max	7.972	29.967	4.752	50.401	-40.4	68.2	40.4	68.2
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	355.981	54.21	355.981	54.21	0	0	0	0
1-Day-Min-Date	219.606	60.374	1.219	0.781	40.2	-98.7	40.2	98.7
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	13.219	24.274	7.656	43.271	-42.1	78.3	42.1	78.3
Low-Pulses	11.5	44.072	0	-9990	-100	-100	100	100
Mean-Hi-Pulse-Durn	7.106	32.205	2.519	29.132	-64.6	-9.5	64.6	9.5
Mean-Lo-Pulse-Durn	9.884	60.522	0	-9990	-100	-100	100	100
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	2.392	43.767	19.44	28.196	712.8	-35.6	712.8	35.6
Mean-decrease	1.263	41.967	16.537	23.682	1209.2	-43.6	1209.2	43.6
No-rises	53.906	10.939	8.719	47.743	-83.8	336.4	83.8	336.4
Valid-years	32		32					
Start year	1969		1969					
Finish year	2000		2000					

* not included in impact points calculation.

IHA scores
unimpctd/iha80816.txt (Un-impacted)
impacted/iha80a16.txt(Impacted)

	Mean changes		Impact points	
Group	Means	CVs	Means	CVs
1	59.7	73.8	**2**	**1**
2	19.8	5009.7	**0**	**3**
3	20.1	49.4	**1**	**1**
4	76.7	72.0	**2**	**1**
5	668.6	138.5	**3**	**3**
	TOTAL POINTS			**17**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			
	Final classification			**4**

Site 18 Deuch Intake Weir 2

unimpctd/iha80817.txt (Un-ii impacted/iha80a17.txt(Impa	Un-impacted record... Mean	 CV(%)	Impacted record......... Mean	 CV(%)	Increase in Mean(%)	 CV(%)	Absolute change Mean(%)	 CV(%)
Group 1: Magnitude of monthly water conditions (flows in cumecs)								
Jan-Mean	10.866	44.735	5.1	82.364	-53.1	84.1	53.1	84.1
Feb-Mean	8.987	58.522	4.034	104.488	-55.1	78.5	55.1	78.5
Mar-Mean	7.371	44.413	2.316	92.421	-68.6	108.1	68.6	108.1
Apr-Mean	4.565	57.071	1.057	142.981	-76.9	150.5	76.9	150.5
May-Mean	3.476	64.319	0.589	123.074	-83	91.4	83	91.4
Jun-Mean	2.424	57.584	0.332	40.813	-86.3	-29.1	86.3	29.1
Jul-Mean	2.132	61.589	0.438	113.062	-79.5	83.6	79.5	83.6
Aug-Mean	3.541	87.155	1.005	160.227	-71.6	83.8	71.6	83.8
Sep-Mean	6.059	66.296	2.384	114.173	-60.7	72.2	60.7	72.2
Oct-Mean	9.051	52.653	4.246	85.445	-53.1	62.3	53.1	62.3
Nov-Mean	9.603	44.828	3.995	81.869	-58.4	82.6	58.4	82.6
Dec-Mean	11.695	47.03	6.122	83.008	-47.7	76.5	47.7	76.5
Group 2: Magnitude and duration of annual extremes (flows in cumecs)								
1-Day-Min	0.608	34.552	0.283	0	-53.5	-9000	53.5	9000
1-Day-Max	94.471	12.03	94.471	12.03	0	0	0	0
3-Day-Min	0.631	36.455	0.283	0	-55.1	-9000	55.1	9000
3-Day-Max	58.823	25.288	56.026	29.112	-4.8	15.1	4.8	15.1
7-Day-Min	0.677	38.055	0.283	0	-58.2	-9000	58.2	9000
7-Day-Max	36.824	26.307	31.353	35.773	-14.9	36	14.9	36
30-Day-Min	0.995	59.066	0.283	0	-71.6	-9000	71.6	9000
30-Day-Max	19.614	23.338	13.129	36.357	-33.1	55.8	33.1	55.8
90-Day-Min	1.891	60.324	0.361	113.522	-80.9	88.2	80.9	88.2
90-Day-Max	13.576	21.793	7.504	35.011	-44.7	60.7	44.7	60.7
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes (Julian dates)								
1-Day-Max-Date	349.986	60.183	349.986	60.183	0	0	0	0
1-Day-Min-Date	199.363	36.046	1.216	0.622	45.7	-98.3	45.7	98.3
Group 4: Frequency and duration of high and low pulses (durations in days)								
High-Pulses	23.27	21.859	13.297	31.222	-42.9	42.8	42.9	42.8
Low-Pulses	9.676	35.726	0	-9990	-100	-100	100	100
Mean-Hi-Pulse-Durn	4.046	25.818	1.478	17.237	-63.5	-33.2	63.5	33.2
Mean-Lo-Pulse-Durn	10.884	54.763	0	-9990	-100	-100	100	100
Group 5: Rate and frequency of change in conditions (increases/decreases in cumecs)								
Mean-increase	6.587	26.8	40.279	19.031	511.5	-29	511.5	29
Mean-decrease	2.954	26.394	38.295	14.784	1196.4	-44	1196.4	44
No-rises	67.135	8.47	13.757	32.919	-79.5	288.7	79.5	288.7
Valid-years	38		38					
Start year	1964		1964					
Finish year	2001		2001					

* not included in impact points calculation.

IHA scores
unimpctd/iha80817.txt (Un-impacted)
impacted/iha80a17.txt(Impacted)

	Mean changes		**Impact points**	
Group	Means	CVs	Means	CVs
1	66.2	83.6	**2**	**1**
2	41.3	4021.7	**0**	**3**
3	22.9	49.2	**2**	**1**
4	76.6	69.0	**2**	**1**
5	595.8	120.6	**3**	**3**
	TOTAL POINTS			**18**
	Interim Classification			**4**
	Flow cessation**			
	Significant sub-daily oscillation**			
	Final classification			**4**

ANNEX C: **DEE: biological samples for Dundee/SNIFFER HMWB project**

No.	***ID***	***EAG***	***Site name***	***Grid reference***	***Sample type***	***Reach description, notes***
			DEE			
1		1A	Tarff Water or another river? Eg. NX 819635 Urr Water at Ford Knowe		M I Rhs	Analogue site for group 1; need a river of similar size and geology with no water quality issues, unregulated; altitude preferably <50m OD
2	16	1	River Dee d/s of Tongland Power Station discharge point	NX 695 535	M I Rhs F?	Tongland Loch to Tongland Bridge. One of issues is effectiveness of fish pass at Tongland.
3			*Tongland Loch*	*NX 702551*	*M I L*	
4			Loch Whinyeon (alternative Loch Dungeon BUT that is dammed)	NX 623608	M I L	Analogue for Clatteringshaws Loch? Best geological analogue is L. Whinyeon, preferred if accessible. L. Dungeon closer to the granite and deep but also dammed. We have NCC loch macrophytes survey for Loch Dungeon.
5	15	1	River Dee d/s of Loch Ken Dam	NX 733 644	M I Rhs F?	Loch Ken dam to Black Bridge Burn confluence.
6			Woodhall Loch		M I L	Analogue for Loch Ken (and Tongland). We have an NCC macrophytes survey from 1996.
7	14	4	Black Water of Dee u/s of Stroan Loch	NX 636 708	M I Rhs	Airie Burn confluence to Stroan Loch
8		4A	Grobdale Lane/Airie Burn south of Birch Island	NX 615703	M I Rhs	
9	13	4	Black Water of Dee, east of Orchars	NX 585 735	M I Rhs	White Burn confluence to Lowring Burn confluence
10	**12**	**6**	**Black Water of Dee d/s Clatteringshaws Loch**	**NX 547 752**	**M I Rhs F**	**Clatteringshaws dam to Pullaugh Burn confluence**
11			**Clatteringshaws Loch**	**NX 544770**	**M I L**	**"Measures"; but we have 1996 SNH macrophyte survey**
12		**6A**	**Black Water of Dee at bridge d/s Loch Dee**	**NX 495794**	**M I Rhs F?**	**Analogue for section d/s of Clatteringshaws. One of issues is (lack of) fish pass at dam.**
			WATER OF KEN			
13			**Loch Ken**		**M I L**	**RSPB "measures" to be costed. We have SNH 1996 survey and *The future of Loch Ken***
14	11	2	Water of Ken south of Ken Bridge	NX 641775	M I Rhs	Garple Burn confluence to Loch Ken
15	10	2	Water of Ken south of Holm of Dalry (d/s of Glenlee power	NX 617 802	M I Rhs	Coom Burn confluence to Garple Burn confluence

			station discharge point)			
16		2A	Coom Burn north of Glenlee Mains (at bridge, d/s of tributary)	NX 603810	M I Rhs	Analogue site for group 2; rather small
17	9	3	Water of Ken below Earlstoun Loch	NX 614 817	M I Rhs	Earlstoun Loch to Coom Burn confluence
18			Lochinvar		M I L	Analogue for Carsfad, Kendoon, some resemblance of type factors also to Earlstoun and Clatteringshaws.
19	8	3	Water of Ken d/s of Polharrow Burn confluence	NX 606843	M I Rhs	Polharrow Burn confluence to Earlstoun Loch
20		3B	Polharrow Burn near Knocknalling	NX598845	M I Rhs	Little forested analogue for group 3
21	7	3	Water of Ken d/s of Carsfad Loch	NX 605 850	M I Rhs	Carsfad Loch to Polharrow Burn confluence
22			Carsfad Loch (alternatives are Kendoon and Earlstoun Lochs in that order)	NX 612831	M I L	One reservoir on Ordovician geology; Kendoon has a fish farm thus possible water quality issue; Earlstoun straddles geological boundary.
23	6	3	Water of Ken d/s of Kendoon Power Station	NX 605 875	M I Rhs	Water of Deugh confluence to Carsfad Loch
24		5A	Water of Ken near Smittons	NX 633917	M I Rhs	Analogue site for group 5
25	5	3	Water of Ken in Glenhoul Glen	NX 611 886	M I Rhs	Kendoon Loch to Black Water confluence
			DEUGH			
26		3A	Polmaddy Burn near Polmaddy	NX 588878	M I Rhs	Forested analogue for group 3
27	18	3	Water of Deugh near Carminnows	NX 602904	M I Rhs	Kendoon Loch to confluence with Water of Ken
28	4	5	Water of Deugh at Carsphairn	NX 560929	M I Rhs	Garryhorn Burn confluence to Marbrack Burn confluence
29	**17**	**7**	**Water of Deugh d/s sluice, near Knockengorroch**	**NX 552983**	**M I Rhs**	**Sluice to Bow Burn confluence. One of issues is provision of compensation flow here.**
30	**17a**	**7A**	**Water of Deugh u/s sluice, south of Waterhead**	**NX 545987**	**M I Rhs**	**Brownhill Burn confluence to sluice; analogue for group 7**
31	**2**	**7**	**Carsphairn Lane u/s Lamloch Bridge**	**NX 525967**	**M I Rhs F**	**Drumjohn power station outfall to Lamloch Burn confluence**

EAG: eco-analogue group (A/B denote undisturbed analogue sites)

M: macrophytes; I: invertebrates; F: fish; Rhs: river habitat survey; L: Loch survey

Total 31 sites; *Italics* indicate lowest priority (1 site), **Bold** indicates highest priority; related to “measures” (6 sites).

Total normal and bold *(italics)*: 30 *(2)* sites; Impacted lakes: 3 *(1);* Analogue lakes: 3; Impacted river: 16; Analogue river: 8.