METHODS OF ASSESSING ANTHROPOGENIC IMPACTS ON THE HYDROLOGY OF RIVERS AND LOCHS

A USER MANUAL INTRODUCING THE DUNDEE HYDROLOGICAL REGIME ASSESSMENT METHOD

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University Of Dundee GEOGRAPHY

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ANTHROPOGENIC IMPACTS ON THE HYDROLOGY OF RIVERS AND LOCHS

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1 Introduction

1.1 Aims and scope

This manual presents a set of methods for the assessment of anthropogenic impacts on the hydrology of Scotland's rivers and lochs. Although the methods have been tested with Scottish data only at this stage, the principles are also applicable to Northern Ireland. Anthropogenic impacts are, for the purposes of this document, considered to be any direct interventions in the drainage network which cause a material change to the hydrological regime of a river or loch.

This definition is adopted in order to include all those activities where the flows of water through the drainage network are directly controlled by human activity in the drainage network itself, but excludes indirect controls. The following lists illustrate the definition:

Included:

- Abstractions for public water supply, irrigation or catchment transfer
- Discharges of trade, sewage or minewater effluents
- Storages in reservoirs or impounded lochs
- Abstractions from groundwater are included in all cases where it is expected that such abstractions might impact on the hydrology of a water body being classified.

Excluded:

- Land use effects such as those due to afforestation, urbanisation or agricultural drainage

The object of the methods is to allow, for any site, the classification of anthropogenic impact of ecological significance according to the following scale:

Class	Description
1	Un-impacted condition
2	Low risk of impact
3	Moderate risk of impact
4	High risk of impact
5	Severely impacted condition

The manual adopts a practical approach, and is intended to offer all necessary guidance to allow application to any stream, river or loch with a drainage area of at least 10 km^2. The methods are intended for application by staff with experience in physical hydrology, since some of the steps require hydrological judgement to be exercised. The methods are the result of a SNIFFER R&D project, and the underlying research is presented in a *Research Report* which accompanies this manual (Black *et al.*, 2000). It will be noticed that the methods for running waters are considerably more elaborate than those for standing waters. Those for running waters involve steps which require daily flow values to be obtained or generated for un-impacted and impacted conditions at the site of interest, using specially created synthetic data where necessary. The impact assessment then consists of a comparison of the un-impacted and impacted data series. This approach is considered realistic, and optimal in terms of making a direct assessment of the impact. For standing waters, however, this approach has been judged unrealistic because of the difficulties of obtaining time series data describing un-impacted loch level regimes. The methods developed for standing waters are therefore rather more simple, but do require daily observations of water level for impacted water bodies.

The manual represents a new initiative in the assessment of anthropogenic impact on Scotland's watercourses. The ultimate object is to present measures of impact which are *relevant to ecology*, and references are made to the justification of the methods shown. Application of the methods is sure to generate considerable interest, and it is to be hoped that this will lead, in turn, to improvements in the understanding of the complex interactions between human activity, hydrology and ecology.

1.2 Structure of the manual

The manual is presented in five main sections.
Section 1 - Introduction presents an overview of the methods, and includes information on the scale at which the method should be applied.
Section 2 - Data sources provides some guidance on a range of data types necessary for the work, and specifies precisely some of the sources to be used.
Section 3 - Running waters is the largest section of the manual and comprises methods which should be applied, according to the availability of data, for an impact assessment on a running watercourse.
Section 4 - Standing waters covers lochs and reservoirs, and presents a simple, rule-based method for impact assessment.
Section 5 - Reporting and using measures of hydrological alteration provides some final points of guidance about how to interpret the results of applying the methods of the manual, and notes some limitations.

1.3 Scale of application

The methods presented in Sections 3 and 4 of this manual are suitable for application to any site on a stream or river, or to a standing water body (loch or reservoir) as a whole. However, a number of guidelines are necessary in order to make application of the methods practical:

1. Application should be made only to running or standing waters draining an area of at least 10 km^2;
2. Application for standing waters should be undertaken for water bodies as whole entities (it is assumed that water level data are representative of standing waters as whole entities);

3. Application to running waters should be undertaken only when deemed necessary by the presence of an upstream anthropogenic activity, and at points which are either:
   a) immediately downstream of the impact,
   b) the location of an appropriate source of flow data (i.e. primary gauging station standard; ideally at least 20 years record), or
   c) immediately downstream of major confluences lying between (a) and (b) above (see Figure 1.1).

The starting point for any assessment of anthropogenic impact on hydrological regime should be a mapping of all the impacts of the following types for the entire catchment of interest:

- abstractions (e.g. direct to water supply, for agricultural abstraction, or at a catchwater intake)
- discharges (e.g. sewage or trade effluents, mine pumping or by catchment transfer)
- storages (e.g. for hydro generation or water supply, and possibly also involving discharges (transfers) from other catchments and abstractions to supply).

For running waters, the assessment of impact in the catchment should then be undertaken for the whole catchment, working downstream from each of the impact sites identified on the map, and according to the guidelines immediately above. The impact of a human activity on hydrological regime will be greatest immediately downstream of its point of impact, and will lessen with distance downstream as new tributaries join the watercourse being followed. In those cases where two impacted watercourses join, the impact assessment will need to assess the disturbance to flow regime attributable to all upstream sources. No presumption is made regarding the class of impact on running waters downstream of an impacted loch or reservoir; these should be classified separately.

All methods in this manual use the 5-class scale of anthropogenic impact severity shown on page 1.

Section 3 explains that Class 1 conditions may apply either to sites with no upstream impact or to those for which the upstream impacts are found to be insignificant. Iterative application of the method is necessary only for the purposes of identifying those points on the map at which class boundaries occur. These changes will always occur immediately downstream of confluences. The user can identify the correct boundary position by finding adjacent confluences with differing impact classes.

Figure 1.1 shows a typical situation in the headwaters of a large river basin:

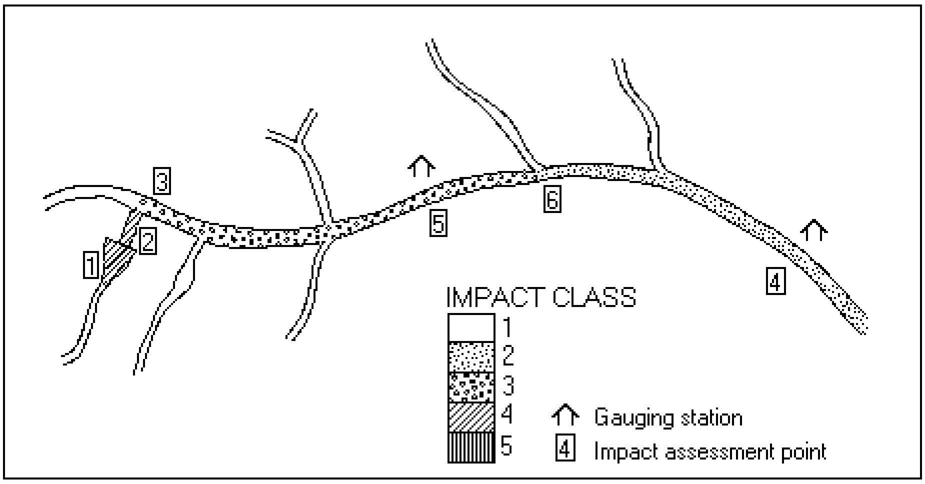

Figure 1.1 Assessment of hydrologic alteration in standing waters, at river gauging stations and at intermediate points

Impact assessment point numbers indicate a suggested sequence for application of the methods to points required to identify class boundaries. Un-impacted water bodies belong, by default, to Class 1.

2 Data sources

The purpose of this section is to indicate the sources of data that should be used for undertaking impact assessments using the methods in this manual.

2.1 Abstraction data

The time intervals between measurements of abstraction rates and the availability of such data will vary between different types of abstraction. With the introduction of abstraction licensing being widely anticipated for Scotland in the early years of the 21st century, the availability of such data might reasonably be expected to increase, with commensurate benefits for the application of the methods of this manual.

Direct abstractions for water supply - the appropriate Water Authority will usually maintain records of rates of abstraction

Catchwater[1] intake abstraction rates - not usually recorded, but design capacities should be available from the Water Authority or hydro power operator responsible for the facility. Intake works may be designed to maintain a compensation flow before any abstraction is achieved; rates of abstraction should be assumed to be:

- the *natural flow* in the watercourse immediately upstream of the abstraction
- *up to* the design capacity of the aqueduct or tunnel (an average capacity should be used if backing-up affects the effective capacity)
- *less* any compensation requirement
- *less* any capacity in the receiving aqueduct or tunnel already occupied by flow from another intake.

Fish farm abstraction - usually metered near either the abstraction or the return discharge (the two should be assumed equivalent), and may be variable according to the flow in the watercourse and the terms of the consent to discharge effluent.

Agricultural irrigation abstraction - this is probably the most difficult abstraction type to quantify, on account of data limitations. For the catchment upstream of any point, the number of abstraction points, and the operating regime, abstraction rate and source of each should be ascertained - as far as may be realistic. So long as abstraction licensing is not provided for by law, farmers are under no obligation to provide information on abstraction rates, and their rights must be respected. Where farmers have agreed to co-operate with regulatory bodies by providing information, this will ease the estimation of abstraction rates; failing this, it will be necessary to make estimates of the abstraction demand on a catchment. The common type of hose reel should be assumed to require approximately 10,000 gallons/hour (=12.6 l/s), and to be operated continuously over the summer half-year April-September (though patterns may vary locally).

[1] A catchwater is a catchment from which flow is diverted to supplement the yield of another. Hydro power and water supply schemes provide the most common examples.

2.2 Base Flow Index values

The Base Flow Index (BFI) is the fraction of the annual runoff which occurs as baseflow (as distinct from peakflow), and is expressed on a 0.0-1.0 scale (Institute of Hydrology, 1980). Values of the BFI may be required for natural catchment conditions for a site of impact assessment. In particular, values should be obtained before selecting an analogue catchment[2] for use in the generation of synthetic flow records (the analogue catchment should have a BFI similar to the catchment of interest). The Institute of Hydrology Report No 101 *Low Flow Estimation in Scotland* (Gustard *et al*., 1987) includes a map of BFI for Scotland, and should be used for this purpose, except where observed natural flow data on the watercourse of interest are available.

2.3 Discharge data

The legal requirement for discharges to be controlled by consent ensures that at least some data will be available for the quantification of discharges. For the controlled discharge of effluents, licences will normally specify maximum rates of discharge, and effluent plant operators (industrial plant operators, Water Authorities) will often maintain records of their actual discharges.

In the case of mine water discharges, controlled releases should be regarded as anthropogenic activities and data should be sought as above. Where they are uncontrolled, the discharge should be regarded as part of the natural catchment response, and should not be regarded as an "impact".

2.4 Hydro power generation data

Where a channel reach or loch/reservoir is affected by a variable rate of hydro power releases upstream due to power generation in certain parts of the day, the downstream regime is affected by this pattern, as well as by changes in the regime as represented in the pattern of daily mean flows. The methods developed in this manual are focused principally at a daily time-step, and therefore require special adjustment in order to address this additional type of impact. For the time being at least, all that is required to be found from hydro operators is the location of their power station discharges and the median discharge rate (to be calculated excluding zero generation periods). Section 3.5.1 of the manual then uses a flow ratio calculation in order to define those reach lengths over which an impact is to be identified.

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[2] An analogue catchment is one with hydrological characteristics similar to the catchment of interest; see Section 3.3.

2.5 Micro Low Flows (MLF) data

The Institute of Hydrology PC package Micro Low Flows is central to the use of the methods for those sites where estimated un-impacted river flow data are required. The methods in Section 3 of this manual are based around the use of Micro Low Flows v2, as available in SEPA offices in 1999/2000. Future enhancements of the package may be made, with likely benefits for its use in anthropogenic impact assessment, since uncertainties in flow estimation may be reduced. While any such development should be welcomed, the methods presented in this manual should use Micro Low Flows v2 only, and data from any future release of MLF should not be used without revisions of the methods in the manual.

2.6 Reservoir or loch level data

Daily reservoir or loch level data are required for the methods for standing waters. For reservoirs, these should be obtained from the reservoir operator, and will normally be available in operating log sheets or in their digital equivalents. Care should be taken to properly identify “missing” data; such data may sometimes not be coded, with the last available data from a malfunctioning instrument repeatedly and misleadingly being entered instead. A “missing data” flag should be attached to such data, and they should be excluded from any analysis.

For lochs which may be affected by upstream anthropogenic activity, daily observations of loch level should be used wherever possible. However, few lochs are subject to routine water level measurement and, if these data are not available, then some possible alternative sources are:

- use of a downstream river gauging station or daily-read post gauge records, from which loch level data may be obtained by correlation with a temporary loch level gauge;
- information held by fisheries interests.

2.7 River flow (streamflow) data

Daily mean flow values are required for the running waters methods, and should be used as per the methods of Section 3. The SEPA national network of gauging stations is the primary source of data, but care should be taken to identify and make use of data for sites outwith the current SEPA network, e.g.

- stations operated by Water Authorities or hydro power generators (unconfirmed flow-stage ratings may be available, or practical opportunities may exist to develop new ratings for sites currently operated on a stage-only basis);
- stations previously operated by SEPA or its predecessor bodies;
- research sites operated by universities and research institutes.

Staff unfamiliar with local sources of hydrometric data should consult colleagues, or access the Directory of Gauging Stations maintained by the NERC Centre for Ecology and Hydrology (Wallingford) (the former Institute of Hydrology) in its National River Flow Archive.

3 Methods for running waters

This is the first of two sections devoted to explaining the DHRAM methods, which have been developed for assessing the severity of impact caused by anthropogenic activity. This section is for application to any stream or river draining an area of at least 10 km^2; Section 4 deals with standing waters.

If no significant anthropogenic impacts can be recognised in the catchment upstream of a stretch of running water, i.e. no reservoirs, abstractions, discharges or other point impacts are known, then the stretch is referred to as "un-impacted". This classification is the natural extreme of the classification scheme which forms the focus of this manual. By contrast, the bulk of the manual is concerned with sites at which the hydrology is affected by one or more anthropogenic activities.

Where impacts are known or suspected (i.e. one or more upstream anthropogenic activities affects the hydrology), the severity of impact must be assessed - this is the object of the methodology in this manual. In this section dealing with running waters, such assessments are achieved by comparing representations of **impacted** and **un-impacted** flow conditions. The following paragraphs outline the background to this approach, and Section 3.1 provides an overview of how an assessment procedure can be designed for any site.

Impacted conditions are those in which one or more upstream point processes impact on the hydrology of the channel reach of interest. Section 3.2 below describes the use of observed flow data for assessing anthropogenic impacts.

Un-impacted conditions are those in which no upstream point processes impact on the hydrology.

If a long flow record exists, it may include records from both before and after a change in the severity of anthropogenic impact on a watercourse. However, it is common to find that there are insufficient flow records from an impacted site to describe both situations, either because:

(a) there are no flow gauging sites on or near the channel reach of interest, *or*
(b) the available records are not long enough to cover both impacted and un-impacted conditions.

Where data are insufficient to allow the comparison of impacted and un-impacted conditions for a site, synthetic (estimated) data must be produced. The following pages provide procedures for achieving this, for two key situations:

- estimation of **natural (un-impacted) daily mean flow values** using Micro Low Flows and a gauged (representative) analogue[3] catchment (Section 3.3);
- estimation of **flow alteration data** using information directly relating to anthropogenic activities (e.g. abstraction or discharge rates), which can be used to generate impacted flow data (Section 3.4).

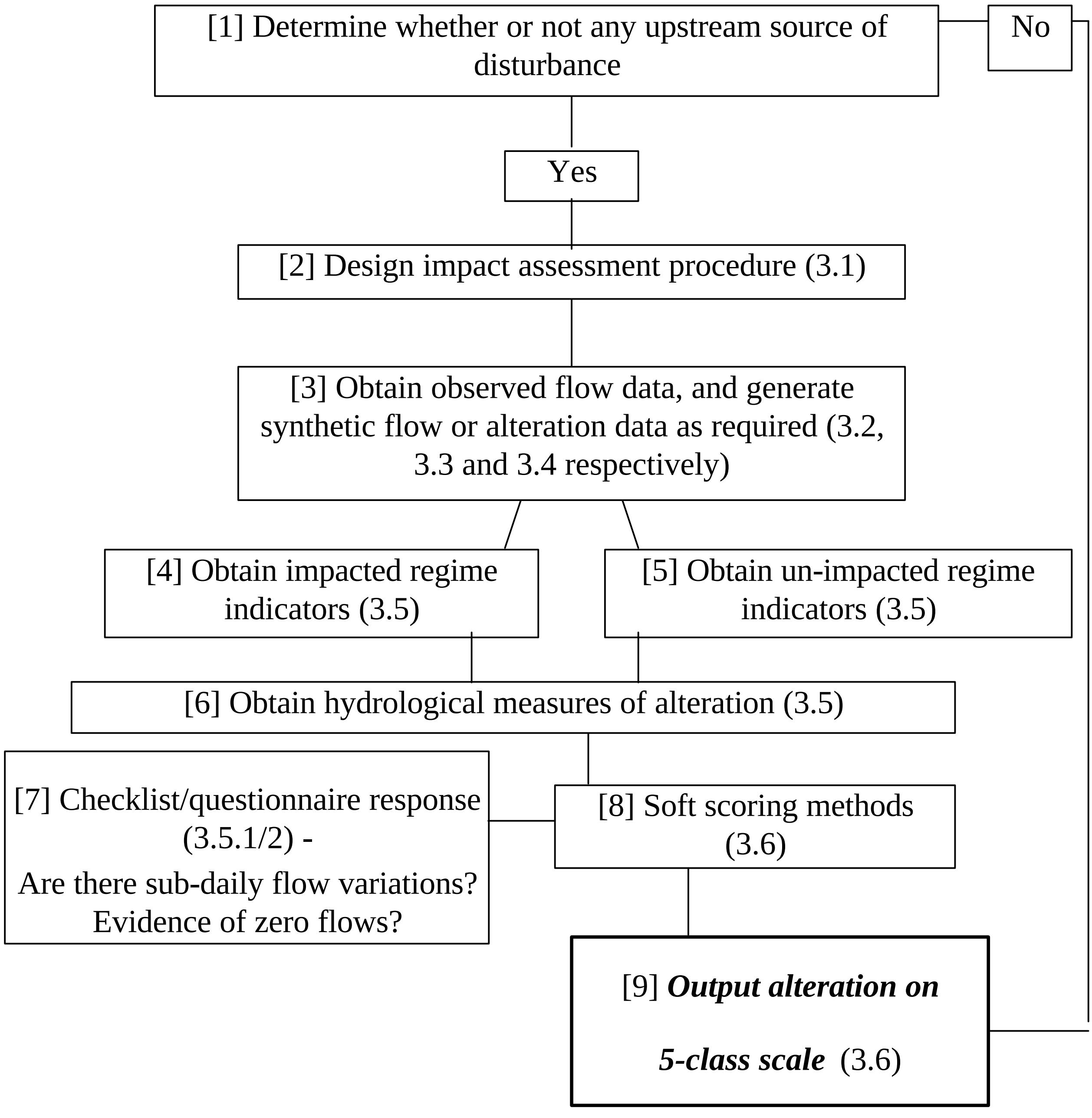
[3] An analogue catchment is one with hydrological characteristics similar to the catchment of interest; see Section 3.3.

However, when either of these types of procedure are attempted, care should be taken (insofar as is possible) to ensure that the synthetic data series generated do not differ from existing series in relation to the time periods they span. If they do, the risk is introduced that comparisons of impacted and un-impacted flow series may, in part, reflect the effects of climatic variations, land use change, or both. This theme is developed repeatedly over the course of Sections 3 and 4 of this manual.

When hydrological data have been gathered and/or generated to represent both impacted and un-impacted conditions, the comparison of them is undertaken using the Indicators of Hydrologic Alteration approach, as developed during the 1990s by Brian Richter and colleagues in the (United States) Nature Conservancy (e.g. Richter *et al*., 1996; see *Research Report*). This approach provides a detailed description of the differences between the impacted and un-impacted flow data, designed to be informative in itself but also serving as an input to a final procedure, which classifies hydrologic alteration using the 5-fold system introduced on page 1. Sections 3.5 and 3.6 provide details.

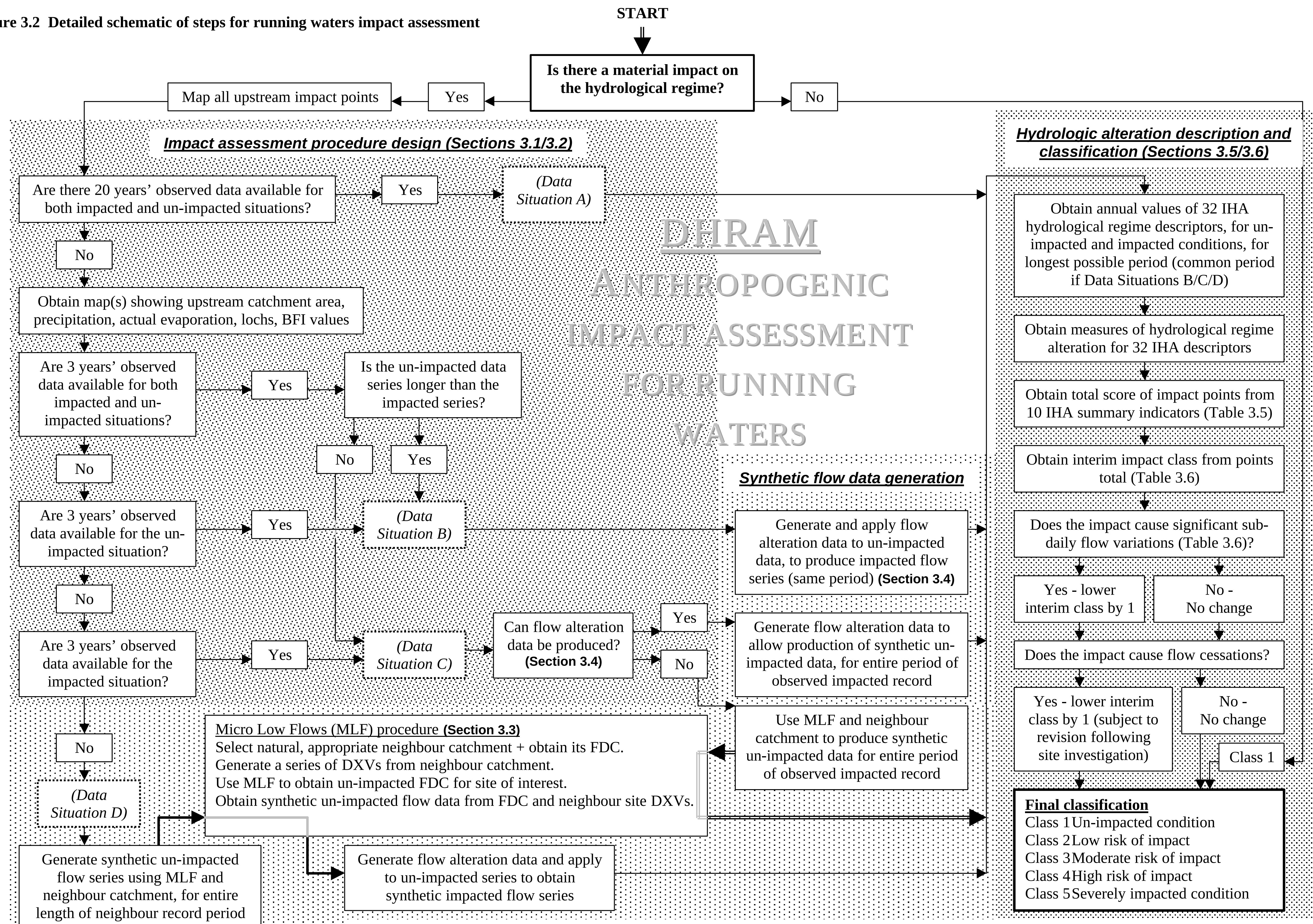
The general approach to assessing the severity of anthropogenic impacts for running waters is shown in Figure 3.1. To make a full impact assessment for any given reach of watercourse, a complete route should be taken from the start point [Step 1] to the end point [Step 9], including all the intermediate stages shown. Figure 3.2 provides a more detailed view of the method, including the choices to be made according to the data availability situation.

Figure 3.1 Overview of method for assessing severity of hydrological alteration in running waters



Sequential numbers are shown thus [1]
Report section references are shown thus (3.5)

Figure 3.2 Detailed schematic of steps for running waters impact assessment



BFI: Base Flow Index; DXV: daily exceedance value; FDC: flow duration curve; IHA: Indicators of Hydrologic Alteration; MLF: Micro Low Flows

3.1 Designing an impact assessment procedure

At a practical level, the work necessary to achieve an anthropogenic impact assessment is heavily dependent on the data available. Four data situations A-D can be recognised, identified in Table 3.1 below. The table shows the sources of data which need to be used in each data situation, in order to arrive at an acceptable impact assessment.

Table 3.1 Methods of designing an impact assessment depending on data available

Data situation	**A**	**B**	**C**	**D**
Un-impacted data available	Y	Y	N	N
Impacted data available	Y	N	Y	N
Un-impacted regime characterisation	Observed data (min 20 yrs)	Observed data	Process representation applied to observed impacted data or to MLF-derived data	MLF-derived data
Impacted regime characterisation	Observed data (min 20 yrs)	Process representation applied to observed natural data or to MLF-derived data	Observed data	Process representation applied to MLF-derived data
Impact assessment	IHA	IHA	IHA	IHA

MLF: Micro Low Flows; IHA: Richter Indicators of Hydrologic Alteration approach

Note: data for the impacted and un-impacted data situations may relate to either:

- data collected in different time periods for the same location (before and after the arrival of an impact), *or*
- data collected close upstream and downstream of the site of an impact over the same time period.

A **Type A** data situation represents an ideal case - the severity of hydrological alteration can be determined by comparing observed flow data representing the impacted condition with other observed flow data representing the un-impacted condition. As indicated above, this may be achieved by using data from two time periods, before and after the arrival of the impact, or from sites upstream and downstream of the impact over the same time period. However, to minimise the distortion of results by climatic or land use changes, at least 20 years' data are required for each of the two situations. Otherwise, a **Type B** or **Type C** data situation should be adopted, using whichever of the observed data series is the longer, and a synthetic data series for the same period to provide the second time series required.

Type B data situations are those for which observed flow data are available for un-impacted conditions, but not for impacted conditions, and occur relatively rarely. However, this data situation may arise in planning scenarios - an assessment may be required for the impact due to a proposed development.

The generation of impacted flow data for a Type B situation can be achieved only by use of some representation of the anthropogenic process(es), and this should be done using as much data about the process(es) as are available, e.g.

- subtraction of flow to a simple hydro intake, at a constant rate (according to the available flow)
- subtraction of flow according to a pattern of abstraction rates obtained from, or approximating to, the activities of a direct supply abstraction
- addition of flow at a steady or regular cyclic rate, according to measurements (or estimates) of an effluent discharge.

These anthropogenic alterations must then be superimposed onto a representation of the natural flow pattern. This can be achieved in one of two ways:

1. use of at least 3 years of measured un-impacted flow data from nearby on the watercourse of interest, or
2. if 3 years' data are not available, use of synthetic flow data generated using Micro Low Flows and data from a gauged analogue catchment, for as long a period as allowed by the length of the analogue catchment gauged record. This is a Type D data situation – see below.

Addition of discharges and/or subtraction of abstractions, at the daily time-step, will produce an impacted data series, allowing comparison with the un-impacted data.

Type C represents a more common data situation since, on many rivers, flow gauging has begun only after the establishment of major sources of anthropogenic impact, e.g. dams, canals. At least 3 years of observed data must be available, otherwise a Type D data situation must be adopted. In this case, impacted flow data are available, but not un-impacted data. Two methods of obtaining the un-impacted data are available:

1. if the anthropogenic impacts can be represented simply by a series of flow alteration values (e.g. constant abstraction or discharge rates, variable but measured abstraction data, near-constant steady seasonal abstraction rates) then these should be applied to the observed data in order to estimate the un-impacted flows;
2. otherwise, Micro Low Flows and a gauged analogue catchment must be used to obtain a natural synthetic flow series for as much of the impacted record period as is possible using the analogue catchment data.

In some cases, the complexity of flow alteration operations effectively precludes the first of these options, e.g. reservoirs in which spill rates vary rapidly and are not accurately measured.

Finally, in the **Type D** data situation, Micro Low Flows and a gauged analogue catchment must be used to obtain synthetic flow data for the un-impacted data situation, and these must then be used as the basis for obtaining the impacted series as well, by application of a series of flow alteration values. In this situation, the representation of the anthropogenic impact in a flow alteration series is the only means of producing the impacted flow data series, and so is dependent on the best available representation of the anthropogenic process(es), whether represented with confidence (e.g. using measured abstraction data) or not.

In the following sections (3.2-3.4), methods and guidelines are provided to show how the required data should be obtained and prepared. Sections 3.5-3.7 then show the steps required to obtain impact assessments. Refer to Figure 3.2 to see how individual steps relate to the procedure as a whole.

3.2 Use of observed flow data

3.2.1 Use of flow data measured on a reach of interest

Where flow data have been obtained for a channel reach of interest, this enhances the confidence with which assessments of anthropogenic impact can be made. Because of this, care should always be exercised in locating sources of observed flow data, whether relatively obvious (e.g. a SEPA gauging station) or less obvious, e.g. a gauge operated for a water undertaking or hydro-power body prior to the design and construction of a reservoir some decades ago. Section 2.7 provides further advice on sources of gauging station data.

Daily mean flow data are required, normally measured in m^3s^{-1}. Ideally, the data series collected should be:

- the result of consistent measurement practices in the field;
- as long as possible, covering a period of more than 20 years;
- of a good standard of accuracy (at least sufficient to persuade the user that observed data are of greater worth than the model estimates which could be provided as alternatives);
- totally complete, with estimated values being used to in-fill any gaps in the original record.

Where one or more of the above are not met, appropriate steps should be taken to ensure that the record to be used is of the maximum possible length and quality.

3.2.2 Use of flow data measured on an upstream or downstream reach

Experience of hydrology in practice often leads to observed hydrological data being used in preference to model estimates, where the site of interest is close upstream or downstream of a site of observed data. In the case where the difference in catchment area is less than 1%, it would be difficult to argue for the use of model data. However, textbooks tend not to give guidelines on the extent to which hydrological data gathered at one site can be readily transferred to another.

As a guide, the transfer of observed hydrological data from a gauging station site to an ungauged site may be attempted where the catchment area to the site of interest is ±20% of the area to the gauging station. In such cases, an acceptable representation of the flow behaviour will be achieved by scaling the observed flow data by the ratio of the catchment areas. This approach is recommended only for sites directly upstream or downstream of a source of observed flow data, and is not recommended for transfer to adjacent catchments.
For sites at which the difference in catchment areas exceeds 20%, the simple scaling described immediately above may become problematic, for example due to an increasing importance of the absolute magnitude of evaporative losses. Corrections may be made by reference to catchment actual evaporation and precipitation values, and this approach is encouraged across the range 50%-200% of the gauged catchment area, *subject to approval by an experienced hydrologist*. Otherwise, flow data should be generated using the Micro Low Flows package and data from a gauged analogue catchment (Section 3.3).

3.3 Generating synthetic natural flow data

A vital resource for the application of the methods outlined in this manual is Micro Low Flows (MLF), first developed by the Institute of Hydrology in the early 1990s and subsequently installed in SEPA offices. Its most valuable capability for the purposes of this project is the generation of a natural flow duration curve for an ungauged site. It does this by use of gridded data sets representing the hydrological characteristics of soils, precipitation, actual evapotranspiration, and a digital channel network.

Its application in this manual is always for the generation of synthetic natural flow data. The procedure is as follows:

1. Identify site
2. Obtain a flow duration curve (FDC) from Micro Low Flows for the site of interest. Assume no upstream reservoirs (the data required are always to represent the natural situation), and obtain the natural flow duration curve for the following exceedance values: 3%, 5%, each 5% up to 90%, 92%, 94%, 95%, 96%, 98%, 99%[4].
3. Select a natural, gauged analogue site which can be used as a source of daily exceedance values. This site should have catchment characteristics as similar as possible to the site of interest, assuming no anthropogenic effects. Factors to be considered are:

[4] These values span the range of exceedance values available with Micro Low Flows, and represent a compromise between the interests of the accurate description of the curve and speed of extraction. Future releases of Micro Low Flows may generate flow values outside the 3%-99% exceedance range, and may allow the curve ordinates to be written to file; both options would be useful and should be taken advantage of, but the latter only if the underlying science which generates the curve is unchanged from MLF v2.

- Area
- mean annual precipitation
- catchment aspect
- land use.
- Base Flow Index
- catchment slope
- catchment shape

The analogue site is expected to show a similar runoff response pattern to the site of interest. (The selection of an appropriate analogue site is vital to the success of the synthetic flow data generation process. Inappropriate selections threaten the production of reliable impact assessment results.)

4. Obtain a FDC for the gauged analogue site, using all the data in its measured flow series.
5. Convert the analogue site daily mean flow values into a series of daily exceedance values (DXVs), using the FDC obtained in 4.
6. Use the series of DXVs and the FDC for the site of interest to obtain a series of daily synthetic flows (DSFs)[5].

This method is represented in Figure 3.3, and will allow the production of a synthetic un-impacted flow series for the same period of time as covered by the record for the analogue catchment. Steps 4, 5 and 6 are data-intensive. While it should be possible to execute each using spreadsheet software only, custom-written programs have been written and are available to implement each of these steps as follows:

Step	Program	Function
4	fdc-calc	uses 1001 points to describe the flow duration curve based on the entire length of the observed flow series
5	q2x	uses the analogue site FDC and observed series to generate daily exceedance values
6	x2q	uses the MLF FDC and the analogue site DXVs to generate synthetic daily flow series for the ungauged (target) site

Figure 3.4 shows a comparison of observed and MLF-generated daily mean flows for the Megget catchment in the Borders, representing the outcome of using an accurately-generated flow duration curve with an analogue catchment which shows the same runoff response to catchment inputs as the target catchment.

Finally, it should be noted that some error is inevitable in the derivation of flow duration curves where it is not possible to use any locally observed data. Experienced users may find that Micro Low Flows regularly underestimates curve ordinates in one situation, or overestimates in another. In such circumstances, it would be entirely proper for MLF users to revise the ordinates of the curve on the basis of local experience, but only if the benefit of so doing is considered to outweigh the risk of producing a curve which does in fact deviate more from the real situation than does the MLF curve.

[5] The Micro Low Flows package does not generate the full length of the FDC. A study of 35 diverse natural Scottish catchments allowed the following relationships to be obtained for the two ends of the curve, allowing linear interpolation between the MLF output for $Q_{3.0}$, Q_{99} and the respective adjacent ends points:

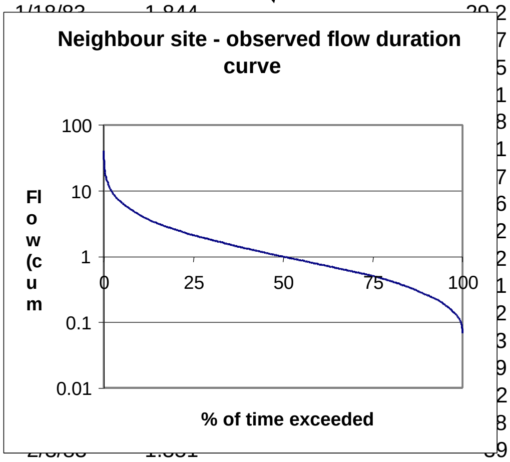
$Q_{0.0} = Q_3 + 10^{(0.6828 + 0.9006(\log Q3))}$

$Q_{100} = Q99 - 10^{(-0.4610 + 0.8869 (\log Q99))}$

Figure 3.3 Overview of flow simulation procedure

Flow simulation for Megget Water using upper Ettrick as 'neighbour'

Date	Daily mean flow (cumec)	Daily exceedance (%)	Simulated flow (cumec)
1/1/83	5.13	7.7	5.611
1/2/83	11.78	1.4	13.91
1/3/83	5.699	6.5	6.047
1/4/83	6.564	5.1	6.555
1/5/83	13.54	1	15.376
1/6/83	4.361	9.8	4.849
1/7/83	2.376	22	2.849
1/8/83	4.654	8.9	5.175
1/9/83	3.175	15.1	3.729
1/10/83	2.854	17.3	3.421
1/11/83	7.012	4.5	6.954
1/12/83	6.096	5.8	6.301
1/13/83	3.058	15.9	3.617
1/14/83	5.363	7.1	5.829
1/15/83	3.207	14.9	3.764
1/16/83	2.288	22.7	2.782
1/17/83	2.832	17.6	3.379
2/4/83	3.725	12.2	4.321
2/5/83	2.257	23.1	2.743
2/6/83	1.65	32.7	2.033
2/7/83	1.286	40.9	1.62
2/8/83	1.108	46	1.417
2/9/83	0.974	50.9	1.248
2/10/83	0.813	57.8	1.05
2/11/83	0.815	57.7	1.053
2/12/83	0.734	61.8	0.948



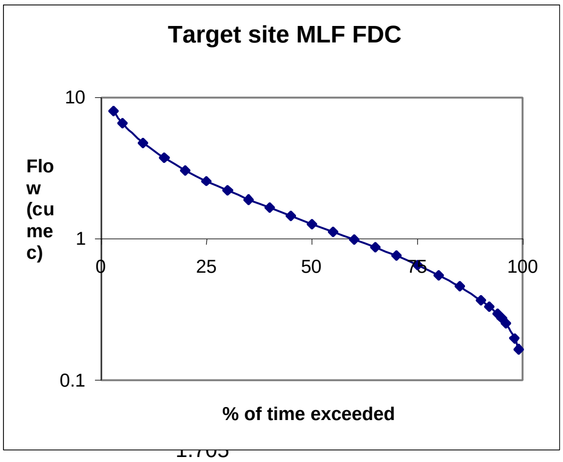
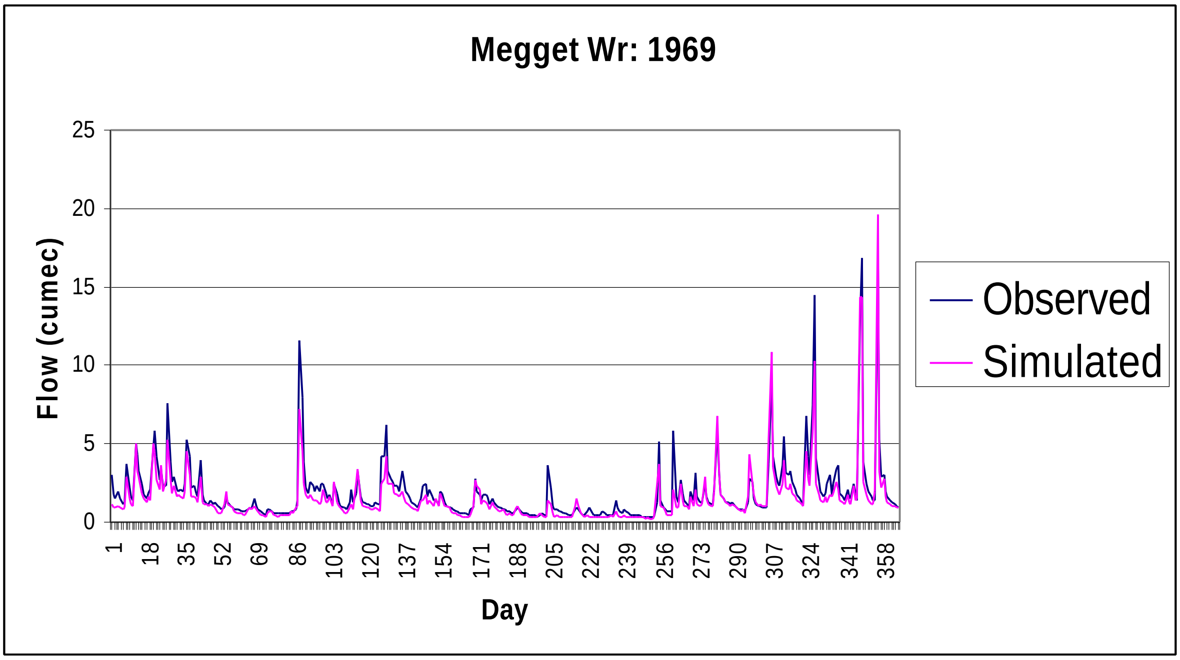


Figure 3.4 Comparison of observed and synthetic flow data, Megget Water, 1969



3.4 Generating flow alteration data

In the many cases where an assessment is to be undertaken without observed impacted and un-impacted flow data both being available, it will often be necessary to represent anthropogenic processes using whatever hydrological data are available to describe them directly. It should be remembered that the methods work at a daily time interval, so the representation of anthropogenic impacts should be undertaken at this interval.

Points of guidance are given here on how this should be achieved. Any impacts may be described by one of the following types listed, in order of increasing complexity:

1. effectively constant (there may be few examples)
2. consistently flow-dependent (e.g. catchwater intake, possibly with compensation allowance)
3. seasonal and consistently flow-dependent (e.g. agricultural irrigation abstraction)
4. variable (e.g. an impoundment - the impact is dependent on the reservoir level, rate of abstraction, compensation and amenity releases).

Wherever possible, observed data describing the scale of the impact should be used. This may be relatively straightforward in some instances, e.g. where a fish farm makes a direct abstraction, where no addition or loss of water occurs, and the rate of effluent return is metered - the rate of abstraction from the affected reach may be constant though most of the year. In other cases, especially reservoir situations, the impact on the downstream watercourse is highly complex. Operating logs may be available for scrutiny, but collection and processing of the available data may present unacceptable logistical problems.

Examples are offered in Table 3.2 below to illustrate how flow alteration values might be obtained for typical impact situations:

Table 3.2 Approaches to representing impact on channel flow

Impact type	Approach to representing impact
Sewage effluent discharge	Apply annual mean rate of discharge, monthly means or actual daily values, according to data availability
Direct abstraction for supply	Apply annual mean abstraction rate, monthly means or actual daily values, according to data availability
Catchwater intake (with compensation provision)	Abstraction is given by (un-impacted daily mean flow minus compensation requirement), up to limit determined by capacity of receiving structure
Impounding reservoir	Represent flow in the affected watercourse (rather than the magnitude of the alteration) as the compensation requirement (if any) + spillage rates + any additional amenity releases, on those days on which they can be assumed to occur. Spillage is likely to be the most difficult term to estimate. If observed data are not available, then a very simple approach would be to assume an annual sine wave representing available reservoir storage; daily spill amount could then be obtained from comparison of simulated inflow and available storage. More complex and realistic models may be available.
Agricultural irrigation abstraction	Local knowledge will allow the length of irrigation season to be estimated. For a given catchment area, numbers of irrigation units may be known (especially after the introduction of a licensing system), or may be estimated using information supplied by farmers or by field survey. If abstraction rates are not known, a rate of 10,000 gallons/hr (12.6 l/s) should be assumed for a typical reel unit.

Where multiple impacts affect the flow at a site, these should be added or subtracted as appropriate, to give a composite time series representing the full distortion of the un-impacted flow pattern.

3.5 Describing the hydrological alteration

This element of the methodology draws heavily on the work of Richter and the US Nature Conservancy. Once the impacted and un-impacted data series have been prepared as per Sections 3.2-3.4, this element can be achieved in a highly automated manner.

To recap, the two time series of flow data should represent impacted and un-impacted flow conditions for the reach of interest, and should have been produced according to the data type identified in Table 3.1. The flow data now assembled for comparison should:

- be calculated or measured for the same reach of river, so on the basis of the same catchment area, *and*
- each span 20 years if observed data are being compared with observed (Type A), *or*
- relate to as long a common period of years as possible, in all other cases.

A computer program `iha-describe` has been provided to SEPA[6] to produce the 32 adopted Richter descriptors of hydrological regime on an annual basis, for the two data series to be used. The Richter approach uses five groups of hydrological descriptors; the 32 component descriptors are set out in Table 3.3 below.

Application of Richter's *Indicators of Hydrologic Alteration* approach then assesses change in the means and coefficients of variation of the annual values of 31 of these indicators, between the un-impacted and impacted situations ('zero-flow days' is excluded at this stage). The program `iha-difference` performs the comparisons, and produces output in spreadsheet-ready form for visual inspection and further processing. Figure 3.5 shows an example of the output for a river subject to upstream reservoir impoundment.

The output from both computer programs allows the user to see the detail of the differences between un-impacted and impacted conditions. The output from the second program, `iha-difference`, can be summarised using a spreadsheet template in order to provide the correct form of input for the ultimate classification of the impact (Section 3.6). All of the indicators of alteration shown are used, and are grouped into summary indicators of change for the five groups mentioned above, referring to changes either in means or in coefficients of variation. Table 3.4 shows how the summary indicators are defined.

[6] the programs have been provided in the form of FORTRAN code with accompanying notes, and can be compiled to operate on PC or Unix systems. They are provided on an 'as-is' basis, and are not included as project deliverables of the SNIFFER R&D contract.

Table 3.3 Richter IHA descriptors in five groups

Group 1 - Magnitude of monthly water conditions
Mean January flow
Mean February flow
Mean March flow
Mean April flow
Mean May flow
Mean June flow
Mean July flow
Mean August flow
Mean September flow
Mean October flow
Mean November flow
Mean December flow
Group 2 - Magnitude and duration of annual extremes
1-day-minimum flow
1-day-maximum flow
3-day-minimum flow
3-day-maximum flow
7-day-minimum flow
7-day-maximum flow
30-day-minimum flow
30-day-maximum flow
90-day-minimum flow
90-day-maximum flow
Zero-flow days
Group 3 - Timing of annual extremes
Date of 1-day maximum flow
Date of 1-day-minimum flow
Group 4 - Frequency and duration of high and low pulses
Mean annual number of high pulses
Mean annual number of low pulses
Mean duration of high pulses (days)
Mean duration of low pulses (days)
Group 5 - Rate and frequency of change in conditions
Mean flow increase
Mean flow decrease
Number of flow reversals

Notes

1. Group 3 dates are given as Julian days
2. High and low pulses are defined as flows above Q_{25} and below Q_{75} respectively

Figure 3.5 Example output from program iha-difference

iha18502.txt (Un-impacted)	Un-impacted record......		Impacted record...........		Increase in		Absolute change	
iha18002.txt(Impacted)	Mean(m3/s)	CV(%)	Mean(m3/s)	CV(%)	Mean(%)	CV(%)	Mean(%)	CV(%)
Group 1: Magnitude of monthly water conditions								
Jan-Mean	8.175	39.49	7.511	48.822	-8.1	23.6	8.1	23.6
Feb-Mean	6.536	46.354	5.653	53.911	-13.5	16.3	13.5	16.3
Mar-Mean	6.819	47.919	5.717	51.691	-16.2	7.9	16.2	7.9
Apr-Mean	4.206	35.45	3.778	35.118	-10.2	-0.9	10.2	0.9
May-Mean	3.219	51.342	2.794	59.993	-13.2	16.9	13.2	16.9
Jun-Mean	2.364	51.774	2.075	54.232	-12.2	4.7	12.2	4.7
Jul-Mean	2.194	54.957	1.769	44.001	-19.4	-19.9	19.4	19.9
Aug-Mean	2.723	65.02	2.526	66.926	-7.2	2.9	7.2	2.9
Sep-Mean	3.983	55.219	3.791	72.836	-4.8	31.9	4.8	31.9
Oct-Mean	5.629	38.763	4.714	47.108	-16.2	21.5	16.2	21.5
Nov-Mean	6.909	38.382	6.426	54.218	-7	41.3	7	41.3
Dec-Mean	7.611	34.237	6.76	41.16	-11.2	20.2	11.2	20.2
Group 2: Magnitude and duration of annual extremes								
1-Day-Min	0.769	23.511	0.961	22.943	25	-2.4	25	2.4
1-Day-Max	33.178	9.794	39.215	44.094	18.2	350.2	18.2	350.2
3-Day-Min	0.79	23.979	0.994	22.883	25.8	-4.6	25.8	4.6
3-Day-Max	25.379	17.192	28.119	43.901	10.8	155.4	10.8	155.4
7-Day-Min	0.837	26.71	1.031	22.775	23.2	-14.7	23.2	14.7
7-Day-Max	19.464	21.822	20.484	38.309	5.2	75.6	5.2	75.6
30-Day-Min	1.097	33.508	1.213	24.327	10.6	-27.4	10.6	27.4
30-Day-Max	12.05	21.842	11.75	31.33	-2.5	43.4	2.5	43.4
90-Day-Min	1.84	39.353	1.659	34.524	-9.8	-12.3	9.8	12.3
90-Day-Max	9.013	17.29	8.32	21.012	-7.7	21.5	7.7	21.5
(Zero-flow days)*	0	-9990	0	-9990				
Group 3: Timing of annual extremes								
1-Day-Max-Date	3.631	67.462	360.091	60.486	-2.3	-10.3	2.3	10.3
1-Day-Min-Date	218.048	33.98	206.134	49.006	-5.5	44.2	5.5	44.2
Group 4: Frequency and duration of high and low pulses								
High-Pulses	23.457	20.769	13.8	28.975	-41.2	39.5	41.2	39.5
Low-Pulses	10	37.34	8.057	40.457	-19.4	8.3	19.4	8.3
Mean-Hi-Pulse-Durn	4.011	30.963	7.131	43.961	77.8	42	77.8	42
Mean-Lo-Pulse-Durn	10.434	54.305	12.666	58.878	21.4	8.4	21.4	8.4
Group 5: Rate and frequency of change in conditions								
Mean-increase	2.939	17.223	1.829	29.727	-37.8	72.6	37.8	72.6
Mean-decrease	1.43	16.432	0.95	26.597	-33.5	61.9	33.5	61.9
No-rises	65.972	12.218	64.167	12.481	-2.7	2.2	2.7	2.2
Valid-years	36		36					
Start year	1959		1959					
Finish year	1994		1994					

* not included in impact points calculation.

Table 3.4 Definition of ten summary indicators of hydrological alteration

	Mean of absolute percentage changes in	
IHA Group	**Means**	**Coefficients of variation**
Group 1	1a	1b
Group 2	2a	2b
Group 3	3a	3b
Group 4	4a	4b
Group 5	5a	5b

3.5.1 Sub-daily fluctuations

In addition to the main part of the method which uses changes in daily mean flows, reference has already been made to the possible impacts of hydro power generation or other activities leading to short-term impacts which would not be detectable using an analysis of daily mean flow data only. As an interim measure pending field calibration, such activity is deemed to cause discernible impact on the downstream ecology when the typical (median) instantaneous change in discharge amounts to 25% or more of the natural flow when the observed river flow corresponds to the 95 percentile exceedance value. This measure of change is recommended since impact will be greatest under low flow conditions.

3.5.2 Flow cessations due to anthropogenic activity

Also in addition to the main part of the method, it may be found that the operation of the anthropogenic process(es) causes flow to dry up, e.g. by spray irrigation abstraction. This should be noted, and feeds through to the allocation of impact scores in Table 3.6. Where any flow cessation occurs as a result of anthropogenic impacts (i.e. the un-impacted record has no flow cessation), the impact classification must be lowered by one class, pending a site investigation. Attempts should be made to refer to the biological quality of un-impacted conditions which would be expected (or may have been known) at the site. Local enquiries may be of assistance in assessing whether any lowering of status is required.

3.6 Classifying the hydrological alteration

This final stage of the method allows the results of applying the Richter IHA approach to be translated into a classification of severity of anthropogenic impact. For any reach, the result of applying the methods is the identification of one of five classes of alteration:

Class	**Description**
1	Un-impacted condition
2	Low risk of impact
3	Moderate risk of impact
4	High risk of impact
5	Severely impacted condition

To obtain this final classification, points are awarded on the basis of each of the ten IHA summary indicators shown in Table 3.4. Threshold values have been defined on the basis of the range of values found arising from real impacts, and on the distribution of values found arising from model error in simulating natural conditions, for each of the ten summary indicators. Points are awarded as follows (Table 3.5):

Table 3.5 Hydrological change thresholds used for allocation of impact points

	Percent change in IHA Group score		
IHA Summary Indicator	Lower Threshold (1 impact point)	Intermediate Threshold (2 impact points)	Upper threshold (3 impact points)
1a	19.9	43.7	67.5
1b	29.4	97.6	165.7
2a	42.9	88.2	133.4
2b	84.5	122.7	160.8
3a	7.0	21.2	35.5
3b	33.4	50.3	67.3
4a	36.4	65.1	93.8
4b	30.5	76.1	121.6
5a	46.0	82.7	119.4
5b	49.1	79.9	110.6

Points from the ten IHA summary indicators are then summed in order to arrive at a total impact score. Table 3.6 shows how these total scores are then used, with questionnaire responses, to determine the class of impact severity. It should be noted that the lower threshold values show a wide range, from 7.0% to 84.5%. This is because of the range of model performance scores across the ten summary indicators, which are positively correlated with the range of observed changes due to anthropogenic impacts. The theoretical maximum score from the method is 30. Table 3.7 shows some illustrative results from a selection of impacted catchments.

Table 3.6 Definition of final classes

Points classification

Class	Points range	Description
1	0	Un-impacted condition
2	1-4	Low risk of impact
3	5-10	Moderate risk of impact
4	11-20	High risk of impact
5	21-30	Severely impacted condition

Questionnaire responses

- *The classification is dropped (down the table) by one if sub-daily flow fluctuations are significant, as per Section 3.5.1, and/or*
- *Provisionally dropped by one class if flow cessation occurs as a result of the anthropogenic process(es), as per Section 3.5.2.*
- *Class 5 is the lowest classification which can be allocated.*

Table 3.7 Some illustrative results from impacted test catchments

River	1a	1b	2a	2b	3a	3b	4a	4b	5a	5b	TOTAL	Class	Impact type
Leven	0	0	0	3	0	1	0	0	0	0	4	2	Lomond barrage
N Calder	0	1	3	3	1	0	0	3	3	1	15	4	Supply reservoir
Clyde	0	0	0	0	0	0	0	0	0	0	0	1	Distant PWS reservoirs
S Calder	3	3	1	0	0	0	0	1	0	0	8	3	Industrial effluents and abstractions
Megget	0	0	1	0	0	1	3	0	1	2	8	3	Supply reservoir
Eas Gobhain	1	0	1	3	1	1	2	3	1	3	16	4	Compensation reservoir
U Tay	2	0	0	1	0	0	0	0	1	0	4	2	Net import via HEP stations
Farrar	1	1	1	1	0	1	1	1	2	1	10	4*	HEP generation
Elliot	0	0	0	0	0	0	0	0	0	0	0	2+	Spray irrigation
Garry	3	1	3	2	3	3	1	1	1	3	21	5	HEP intake
N Esk	0	0	0	0	0	0	0	0	0	0	0	1	Fish farm abstraction

** Class lowered by 1 due to sub-daily HEP generation impacts*
+ *Class lowered by 1 due to summer drying up*

3.7 Worked examples (refer to Figure 3.2)

Example 1 - assessment of impact assessment for river reach immediately downstream of a compensation reservoir

Step	Question/instruction	Response
1	Is there an upstream impact(s)?	Yes – compensation reservoir
2	Map all upstream impact points	Two reservoirs upstream of reach of interest (schematic map)
3	Are 20 years' observed data available?	No
4	Obtain physical information for the upstream catchment area	Area, mean annual precipitation, actual evaporation, natural BFI data obtained
5	Are 3 years' observed data available for un-impacted and impacted situations?	No
6	Are 3 years' observed data available for the un-impacted situation?	No
7	Are 3 years' observed data available for the impacted situation?	Yes – data since 1986; Data Situation C
8	Can flow alteration data be produced?	Not meaningfully – complex system upstream
9	Use MLF and an analogue catchment to produce un-impacted data for entire period of observed impacted record	• Natural, appropriate analogue catchment selected, + FDC obtained • Series of DXVs generated • Site of interest FDC from MLF • Synthetic un-impacted flows produced
10	Obtain annual IHA descriptors	For common period, for un-impacted (MLF) and impacted (observed) series (program iha-describe)
11	Obtain measures of hydrologic alteration	(program iha-difference)
12	Obtain total score of impact points	16 points
13	Obtain interim classification	Class 4 (Table 3.6)
14	Significant sub-daily flow variations?	No, so no change in class
15	Flow cessations?	No, so no change in class
16	Obtain final classification	Class 4

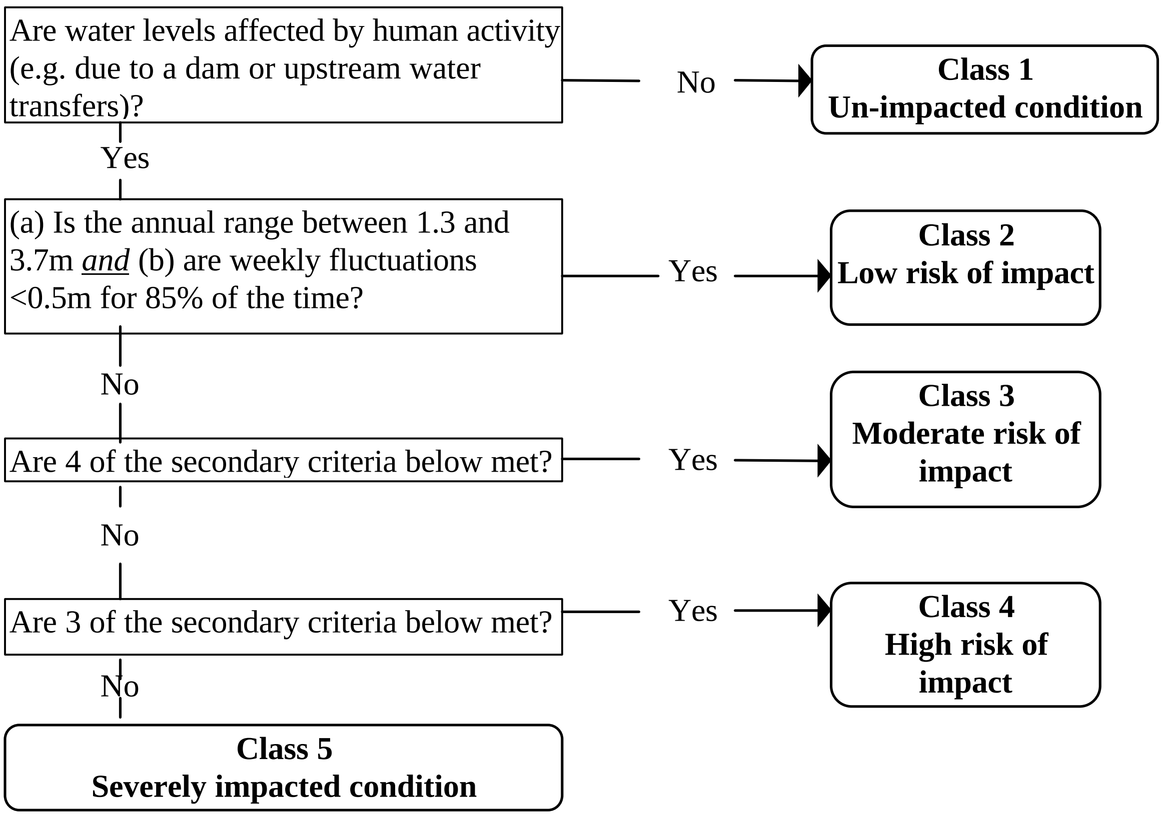
Example 2 - agricultural abstraction from a burn for spray irrigation

Step	Question/instruction	Response
1	Is there an upstream impact(s)?	Yes – several seasonal abstractions for spray irrigation
2	Map all upstream impact points	This done using information supplied by farmers
3	Are 20 years' observed data available?	No (the catchment is completely ungauged)
4	Obtain physical information for the upstream catchment area	Area, mean annual precipitation, actual evaporation, natural BFI data obtained
5	Are 3 years' observed data available for un-impacted and impacted situations?	No
6	Are 3 years' observed data available for the un-impacted situation?	No
7	Are 3 years' observed data available for the impacted situation?	No – Data Situation D
8	Generate synthetic un-impacted flow series using MLF and an analogue catchment, for entire length of analogue record period	• Natural, appropriate analogue catchment selected, + FDC obtained • Series of DXVs generated • Site of interest FDC from MLF • Synthetic un-impacted flows produced
9	Generate flow alteration data and apply to un-impacted series to obtain synthetic flow series	Flow alteration data generated for April-September half-year, using a steady abstraction rate of 40 l/s (information supplied by farmers)
10	Obtain annual IHA descriptors	For common period, for un-impacted (MLF) and impacted (observed) series (program iha-describe)
11	Obtain measures of hydrologic alteration	(program iha-difference)
12	Obtain total score of impact points	0 points
13	Obtain interim classification	Class 1 (Table 3.6)
14	Significant sub-daily flow variations?	No, so no change in class
15	Flow cessations?	Yes, so lower class by 1 pending site investigation
16	Obtain final classification	Class 2 pending site investigation

4 Methods for standing waters

There are few natural lochs for which there are any time series of water level available in Scotland. Furthermore, the perception of water level regime impact on loch ecology is relatively simple, focusing principally on the littoral zone. Both these factors are reflected in the development of methods for standing waters, which are less complex than those outlined for rivers in Section 3. The principal source of information used in devising this system is Smith *et al*. (1987) – see *Research Report* (Black *et al*., 2000) for more details.

A flow diagram allows the appropriate classification to be obtained, assuming that daily water level data for the impacted water body are available. Regular readings of water level taken at the same time each day should be used if possible, e.g. 0900 hrs daily. The classification shown produces the same 5 classes as for running waters.



Secondary criteria

1. Mean annual number of level reversals (detected using daily level data) is at least 50
2. 80% of dates of annual maximum level fall between October 1st and March 31st
3. 80% of dates of annual minimum level fall between March 1st and October 31st
4. Mean of annual maximum daily rises is between 0.60 and 1.0 m *and* mean of annual maximum daily falls is between 0.20 and 0.55 m
5. Mean annual range lies between 1.3 and 3.7 m.

Notes
Characteristics of water level data should be obtained from as long a run of complete years of data as possible. Reservoir operating logs are the key source expected to be of use for most reservoirs.

However, in the case of un-dammed lochs with altered level regimes (i.e. due to upstream activities), alternative sources of data may be considered:

- use of a downstream river gauging station or daily-read post gauge records, from which loch level data may be obtained by correlation with a temporary loch level gauge
- information held by fisheries interests

In the absence of any useful loch level information, reference to the nature of the anthropogenic processes and estimated relationships between inflow disturbance and loch levels may allow an estimated assessment of impact to be made. A SNIFFER project (W99(42)), underway at the time of writing, on the physical characteristics of standing waters in Scotland and Northern Ireland may provide more data in the future.

4.1 Worked examples

Example 1: a hydro-power reservoir

(Box 1) Are water levels affected by human activity?
Yes (impoundment) – go to Box 2

Obtain water level data for a long a period as practically available
7 years of daily water levels obtained, containing occasional gaps in some years

(a) Calculate mean annual range for the calendar years of data available
(b) Calculate weekly absolute[7] water level fluctuations for all possible 7-day periods. Rank the values and find the 15 percentile value, i.e. the value exceeded for 15% of the time.
(Box 2) If result (a) is outwith the range 1.3-3.7m <u>or</u> if result (b) >0.5m, then go to Box 3.
On both grounds above, user must proceed to Box 3.

(Boxes 3/4) Assess all the secondary criteria. Note that:
Level reversals are all those days on which a falling limb (of any length) is followed by a rise (of any length), or vice versa. Days of no change are not counted as reversals, but instead are regarded as parts of an existing rise or fall.
Date ranges are inclusive.
Annual maximum daily rises and falls are calculated on a calendar year basis. Care is required to avoid values arising from use of missing data.

Only one of the secondary criteria is met: Class 5 applies.

---

[7] i.e. all negative change values are made positive

Example 2: a loch affected by upstream flow diversions and regulation

(Box 1) Are water levels affected by human activity?
Yes (upstream) – go to Box 2

Obtain water level data for a long a period as practically available
Fifteen years of loch level data available from a post gauge located at the loch outflow, post-dating the upstream hydrological changes.

Calculate mean annual range for the calendar years of data available.
Calculate weekly absolute[8] water level fluctuations for all possible 7-day periods.
Rank the values and find the 15 percentile value, i.e. the value exceeded for 15% of the time.
(Box 2) If result (a) is outwith the range 1.3-3.7m or if result (b) >0.5m, then go to Box 3.
Result (a) is 1.33m and result (b) is 0.305m. Therefore, loch is classified as Class 2.

4.2 Illustrative results

To illustrate the range of results which can be obtained in applying this method to Scottish lochs and reservoirs, results for five selected standing waters are presented in Table 4.1 below.

Table 4.1 Examples of loch impact assessment results

Name	Impact	Mean annual range (m)	15%ile weekly range (m)	Mean annual No. Revers-als	% of annual maxima 1 Oct-31 Mar	% of annual minima 1 Mar - 31 Oct	Mean annual max daily rise (m)	Mean annual max daily fall (m)	Class assigned
Loch Quoich	Large HEP storage	11.60	0.93	64	100%	33%	1.94	0.71	Class 5
Loch Garry (Inver-ness)	Medium HEP storage	2.70	0.82	184	100%	86%	1.54	0.79	Class 3
Loch Tay	HEP u/s	1.33	0.31						Class 2
Talla Res'r	PWS	4.50	0.46	57	75%	83%	0.65	0.17	Class 5
Loch Insh	HEP storage u/s	1.87	0.38						Class 2

[8] i.e. all negative change values are made positive

5 Reporting and using measures of hydrological alteration

The user is reminded of the guidelines in Section 1.3 - the methods are applied to the drainage network at only as many sites as are required to locate the changes in impact class. In addition to this practical guidance, some specific points must be emphasised regarding the interpretation of results from the methods presented.

Firstly, it should be noted that the procedures have been developed, as far as possible, to reflect impacts in an ecologically significant manner. However, they do not purport to present results which are calibrated to the specific ecology of any specific site. Rather, they are based on assessing changes in a large number of ecologically significant regime descriptors, and averaging across five summary change indicators, each of which is justifiably attached an equal weighting. The specific calibration of the methods to the ecology of individual sites is a matter which may require the development and application of further rules appropriate to the needs of SEPA.

Following from this, it is suggested that when results are presented, e.g. in SEPA reports or maps, some emphasis is placed on the results being approximate rather than reflecting absolute changes. The method outlined in this manual goes far to include the effects of a wide range of hydrological changes, and to produce impact assessments in a balanced manner. This is done in a way which deliberately takes account of typical model error, and avoids the attachment of significance to such effects.

Nevertheless, the three middle impact classes report impact with reference to risk, partly as a means of accommodating the possible effects of hydrological modelling error, and partly to reflect possible ecological impact error. The ecological response to hydrological change at any site will be a function of many factors, and not just hydrological regime change; e.g. the response to a change in hydrological regime may often be greater at a site already under water quality stress than at another which is not.

Future research in this area may supersede the precise methods outlined in this manual, at which time new guidance may be required.

6 References

Black, A R, Bragg, O M, Rowan, J S, Duck, R W, Jones, A M and Werritty, A (2000) Anthropogenic Impacts on the Hydrology of Rivers and Lochs: Research Report. SNIFFER R&D report W98(50) F2.

Gustard, A, Marshall, D C W and Sutcliffe, M F (1987) Low Flow Estimation in Scotland. Report No 101, Institute of Hydrology, Wallingford.

Institute of Hydrology (1980) Low Flow Study. Institute of Hydrology, Wallingford.

Richter, B D, Baumgartner, J V, Powell, J and Braun, D P (1996) A method for assessing hydrological alteration within a river network. *Conservation Biology*, **10**(4), 1163-1174.

Smith, B D, Maitland, P S and Pennock, S M (1987) A comparative study of water level regimes and littoral benthic communities in Scottish Lochs. *Biological Conservation*, **39**, 291-316.