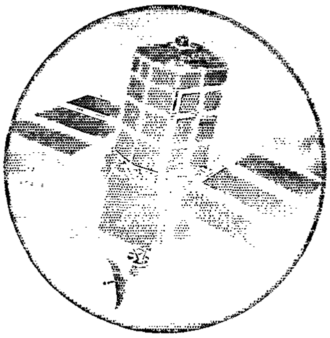
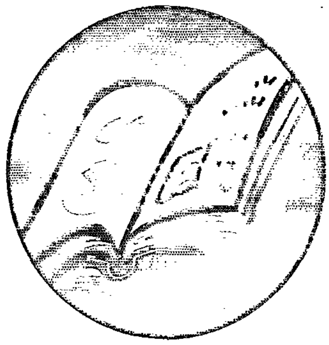
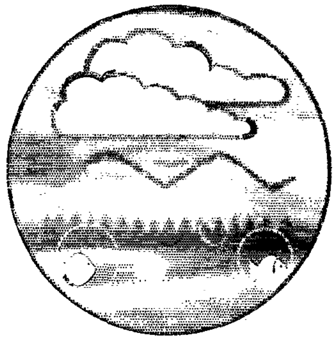
Evaluating the Benefits of Hydrometric Networks

Research and Development

Technical Report
W146

SNIFFER
SCOTLAND & NORTHERN IRELAND FORUM FOR ENVIRONMENTAL RESEARCH

ENVIRONMENT AGENCY

Evaluating the Benefits of Hydrometric Networks

R&D Technical Report W146

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Research Contractor:
University of Dundee
In collaboration with University of Stirling *and* Scotia Water Services

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Dissemination status
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Statement of use
This report will be of interest to anyone interested in attempting to assess in an objective manner the benefits of the environmental data that they collect. It is hoped to produce a manual which should enable the evaluation of gauging station networks in a reasonable straightforward manner.

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EXECUTIVE SUMMARY

This report provides a self-standing, detailed account of the work of an Environment Agency/SNIFFER R&D project, commissioned to make progress in the field of quantifying the benefits of hydrometric data-gathering networks. The work arises from an increasing need for UK hydrometric authorities to be able to quantify the benefits of their monitoring activities, and to relate these to their costs of operation.

The report is directed towards assessing benefits at the catchment scale, for networks of up to ten gauging stations. The results of such assessments will be appropriate to the comparison of benefits and costs of monitoring at a local scale, and are designed to support investigations of the effects of changing local gauging networks.

The research is based on an extensive review of the relevant literature, and a major survey of data users both within the UK agencies and also with external data users. It identifies a number of economic concepts which allow clearly identifiable user benefits to be translated into monetary benefits of hydrometric data use. A system of Approximate Cost Benefit Analysis is developed, as a framework for identifying and combining the quantified benefits of data usage for given catchment areas. For each benefit type, base values, representing typical user benefits, are produced on the basis of applying methods derived from the literature. These are then scaled according to local conditions in order to reflect actual benefit: scalings are applied for data accuracy, data representativeness and period of record as appropriate, and are adjusted to represent annual rates of benefit receipt.

The research identifies the need to represent those benefits of data use which are not amenable to quantification, and presents a checklist designed to allow a broad overview of the water resources and data use characteristics of a catchment. For completeness, a brief consideration of national monitoring needs is also presented. The checklist is designed to provide a context for subsequent economic assessment of benefits; quantitative and qualitative methods are therefore designed to be complementary.

The report presents an evaluation of the methods developed, noting the strengths of objective methods which can be used to assess the effects of possible future network changes, and also weaknesses, particularly in relation to the sometimes arbitrary nature of scaling factors. This evaluation forms the basis of recommendations for future research, and for development of the methodology into practise. Finally, comments are offered on the scope and format of a future R&D Note, in the form of a manual, which would allow hydrometric staff to use the methods for the review of current networks.

ACKNOWLEDGEMENTS

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GLOSSARY

While the great majority of terms in this report will be familiar to its target audience, some derive either from an economics background, or have meanings specific to this project and, accordingly, are defined here in the interests of clarity.

Base benefit value: value obtained from application of a standard benefit assessment method, indicating typical value before account taken of local factors (see *scaling*)

Benefit: advantage(s) accruing solely from the collection of hydrometric data, whether directly monetary in nature or not, whether benefiting individuals, organisations or entire communities, and excluding any benefits which would accrue without the collection of such data

Benefit type: benefit accruing from one type of hydrometric data usage, e.g. alleviation of low flows

Component benefit value: the scaled benefit accruing from one benefit type

Marginal benefit: additional benefit gained by incremental unit of monitoring, typically an addition year's operation of a gauging station

Potential benefit value: see *base benefit value*

Scaling: process or factor by which the magnitude of a base benefit value is adjusted to reflect local conditions, e.g. with respect to hydrometric data accuracy; scaling by appropriate number of factors results in production of *component benefit value*

Total quantitative benefit: sum of all *component benefit values*

CONTENTS

1. INTRODUCTION

1.1 Background

Hydrometric monitoring has for many years been an established part of the activities of all the UK environmental agencies. Rainfall measurement has been common on a widespread basis since the 19th century and, in more recent times, increasing attention has been directed towards the measurement of river levels and flows, groundwater levels, evaporation and other meteorological variables. The range of uses to which data are put is wide, encompassing water resources, pollution control, and flood hazard applications amongst many others. Such monitoring activities underlie the core functions of many water industry personnel.

Because of the particularly high manpower demands of field maintenance, current meter gauging and data processing, river flow measurement occupies a dominant position within the field of hydrometry in practice. The growth of flow measurement activity in the UK has necessitated great increases in the deployment of resources to hydrometry. Some £11 million p.a. is now expended on supporting approximately 1600 primary flow gauging stations across the UK (providing high-quality data suitable for a range of applications), plus many other secondary stations providing lower-quality data for more specific purposes. Two recent internal National Rivers Authority studies reported on the organisational arrangements and value-for-money delivered by its hydrometry function (Fawthrop and Streeter 1996a, b), as a means of assessing the effectiveness of its substantial resource allocations in this sphere. The key findings were that it was in the Authority's best interests to maintain most hydrological functions in-house, and that newly-introduced Service Level Agreements were providing a useful mechanism for delivering good value for money to data customers.

The 1995 Environment Act requires the Environment Agency (successor to the National Rivers Authority in England & Wales) and the Scottish Environment Protection Agency (successor to the seven River Purification Boards and other bodies) to take account of the costs and benefits arising from their activities, and this can be seen as encouraging the more formal assessment of value-for-money in terms of cost-benefit ratio assessments where appropriate. Such assessments will be helpful in considering resource allocations to and within hydrometry functions.

The progress made in the NRA reports mentioned above, the requirements of the 1995 Environment Act and the general desirability of being able to justify resource allocations have together created a clear need for research which will help with the definition of the benefits arising from hydrometric monitoring. While methods are available to assess the costs of generating hydrometric data, the research record shows that benefits cannot so easily be defined, yet the need for undertaking such assessments is now more pressing than ever before.

1.2 Objectives of the Research

The object of the research described in this report is to allow progress to be made in this area, and it is the principal output of a National R&D Project commissioned jointly by the Environment Agency and SNIFFER (the Scotland and Northern Ireland Forum for Environmental Research) in 1996. Specifically, the research project was to ***provide methods for assessing the benefits of hydrometric monitoring networks***.

The benefits forming the focus of the study were to be studied on a broad and inclusive basis, and have been defined as: ***the sum of all advantages accruing solely from the collection of hydrometric data, whether directly monetary in nature or not, whether benefiting individuals, organisations or entire communities, and excluding any benefits which would accrue without the collection of such data.***

In turn, the provision of these methods will allow hydrometric authorities to:

a) compare absolute costs of hydrometric monitoring with the absolute benefits thus accrued, and
b) establish the effects of hydrometric network changes on cost-benefit ratios, particularly by comparing marginal costs with marginal benefits.

The terms of reference of the study are provided as Appendix I to this report. In particular, it should be noted that the scope of the study is to extend only to the development of methods for assessing benefits, with cost definitions remaining to be addressed by users of the research (taking advantage of work already done by the Environment Agency). It should also be noted that, although the research is to be based on river flow measurement hydrometry, the methods developed should be generic in nature, such that later application to other aspects of environmental monitoring could also be made.

In initiating the study, the project sponsors were aware of many of the difficulties and obstacles to progress which would be inherent in the topic. The most important points are summarised here:

- It is difficult to translate the benefits of data into economic terms.
- There may be a wide range of potential benefits from additional data, ranging from very specific requirements ... to much less well-defined benefits
- The true value of data may not always become apparent for years. Data [have in the past] been used for purposes that could not have been foreseen when a stations was built.
- Some users need real time data while others need historic data [and the benefits derived will depend on a user's type of need].
- Estimates can always be made, based on theoretical models or existing data at another site. [Benefits of data use must be just that - they must give no credit for the use of estimates which could otherwise be generated.]
- The levels of accuracy may be different for different parameters [and] ... benefits will therefore probably need to be assessed for each potential data use.
- The selection of the site for [a gauge] is controlled by many practical constraints other than just the need for data. [Data produced by the gauge may not be as appropriate to the perceived need as intended.]

- Costs of feasibility studies for major sites such as gauging stations are already high, and additional costs caused by unnecessarily complex benefit assessments would not be welcome. Any proposed methods should be as simple as possible to apply, and flexible and robust enough to accommodate the many and varied aspects of site selection.

Often, the object of the research was to devise viable methods for overcoming some of these problems.

It should be noted at the outset that benefits accrue at a range of scales. Often, they are local, involving the use of data in a local water management application. Sometimes, however, the data may be used in a much more general sense, for example in the detection of a national or regional trend in river flow, or in the development of new methods of hydrological analysis through research. The latter type of benefit is of considerable importance to the development of hydrological science and its contribution to environmental and resource management, and adds to the challenge of fully defining the benefits of hydrometric networks. The methods developed in this report are much more concerned with assessing benefits at the local rather than any wider scale, however their importance in the latter sense is discussed throughout the following chapters.

1.3 Objectives of this Report

This report aims to provide a comprehensive account of the research undertaken under this project. It should be accessible to any personnel within the UK environmental agencies responsible for the running of hydrometric (or other) monitoring networks and, while the concepts and background of the project will be explained clearly, some matters involving excessive detail have been omitted from the main report in the interests of balance. The Project Record for this research contains further relevant information, and appendices are used in this report where appropriate.

The specific objectives of the report are to:

1) Review the background to the project
    - by setting out the context in which it was initiated (Chapter 1)
    - by detailing the objectives and scope of the project (Chapter 1)
    - and by providing a detailed review of all relevant literature (Chapter 2).
2) Explain the evolution of ideas leading to the chosen methods of benefit assessment, including
    - the results of a data use survey (Chapter 3)
    - the need for a dual method of assessing benefits (Chapter 4)
    - the development of non-quantitative benefit assessment methods (Chapter 5)
    - the development of quantitative benefit assessment methods, including the conceptual bases involved (Chapter 6)
    - and with a range of scalings to be applied to benefit values (Chapter 7)
3) Support the application of the methods in practice, through
    - giving guidance on information sources (Chapter 8)
    - presentation of worked examples (from project testing phase) with notes of guidance (Chapter 9)
4) Review the achievements of the project

- summarising its findings
- evaluating the research
- and making recommendations for development of the work and further research

Readers should note that it is the stated intention of the Project Board for this research that an R&D note, in the form of a manual, should be produced after this report. That manual will have the purpose of guiding users through the application of the benefit assessment methods described in this report.

2. LITERATURE REVIEW

The literature relevant to this topic is extensive, reflecting a long history of interest in the benefits arising from hydrometric monitoring. The object here is to provide a condensed review of the key areas of relevance, in order to provide the reader with an understanding of the concepts on which subsequent chapters build. This review begins with a consideration of principles of benefit assessment (generally based in economic theory) which have been used in previous studies. A summary of the most important applications of hydrometric benefit assessment is then presented, before concluding with a review of those studies considering benefits on a whole-network basis. This entire review is based on two detailed surveys of the relevant literature in the fields of hydrology and economics, which are included in Appendices II and III to this report respectively.

2.1 Economic Benefit Assessments

Economic benefit assessment owes much to the development of cost-benefit analysis in the 1950s, when it began to gain recognition as a useful tool for appraising resource allocation decisions in water projects. Since then, benefit assessments in hydrometry have become increasingly common. The methods and results of these assessments have been reported in both the hydrological and the economics literature. Many studies have concentrated on single uses of data, or the uses of data from specific gauges or groups of gauges, with a small minority addressing whole networks in a general manner. At the same time, there has been a history of methods which do not attempt to fully quantify benefits in economic terms, but which set out criteria to guide the review of an existing network.

The fundamental advantage of economic methods of benefit assessment is that they allow monetary values to be attached to benefits, and then also to be used in comparisons, e.g. with benefits arising under different circumstances or with costs. In all cases, benefits are based on the concept of economic value, measured as either maximum willingness to pay or minimum compensation demanded for an increase or decrease in a quantity, quality or price. The prime example of a cost-benefit assessment is one where the benefits and costs of a planned project are compared, in order to determine whether it should proceed. Four basic economic approaches underlie the range of quantitative assessments of the benefits of hydrometric data use.

1. Benefits of applying real-time data to reduce damages - e.g. by the issue of flood warnings based on hydrometric data.
2. Benefits of applying real-time data in resource management - costs can be avoided, e.g. in a drought situation, if real-time information allows actions to be taken to avoid likely costs, such as pumping to maintain river flows or to provide supply from distant sources.
3. Benefits relating to investment planning - costs are associated with under-design and over-design and so, where data can be used to reduce uncertainty in the design process, a benefit arises. Examples include bridge and dam design, and major commercial or residential developments.
4. Benefits assessed within the context of a production function - hydrometric data can be treated as an input in the production of a desired level of water quality, e.g. more information as an input can allow for less expenditure in abatement costs.

Each of these approaches has been applied in the selected economic case studies which are summarised below, covering six main areas of benefit (the list is not exhaustive).

2.1.1 Storage reservoir design

The design of a reservoir is based on the delivery of a required yield and, in order for the reservoir to deliver this in practice, a knowledge of the behaviour of the inflow streams is desirable. Synthetic data are regarded as a less valuable alternative. Adeloye (1995, 1996) indicates that the coefficient of variation of annual inflows is the most important streamflow parameter for design purposes, and that capacity estimates are highly sensitive to record length. He also illustrates (1990) that a six-year record implies a 30% error in required capacity estimate, while even 20 years still result in a 15% error. Longer records are of particular importance because of their increased likelihood of including critical periods (e.g. droughts) which cannot be synthetically generated from shorter records (Barlishen *et al.*, 1989). In New South Wales, Cordery and Cloke (1990) were able to assess the sensitivity of reservoir capital costs to record lengths, identifying savings in over-design and under-design as data benefits. They developed this work to show that if data from the 500 gauging stations in New South Wales were applied only to this type of work, data collection benefits would remain in excess of costs until record lengths reached approximately 80 years. Such an analysis excludes other benefits from consideration, not least the benefits of reservoir operating strategies which employ comprehensive hydrological data (Tejadaguibert *et al.*, 1995).

2.1.2 Design of bridges

Cordery and Cloke (1990) also present benefit-cost ratios for data used in New South Wales for the design of small stream crossings. Design guidelines have been issued in Australia in 1958, 1977 and 1987, based on successively larger amounts of streamflow data (Institution of Engineers, Australia, 1987). Each revision of the guidelines is associated with changes in the costs and benefits accruing from the design of new crossings, namely:

a) capital loss/saving due to overdesign/underdesign,
b) cost/saving of damage to structure due to underdesign/overdesign, and
c) cost/saving of delays, extra travel distance, etc.

(Cordery and Cloke, 1990, p222).

A benefit-cost ratio based on data collection costs and benefits relating to this data use only, between the years of 1958 and 1987, produces a ratio of 92:1. Even when all data collection costs in the state are considered over the period, a substantial ratio of 22:1 is found. Benefits accruing from the application of data to other design work were additional to the reported analyses.

2.1.3 Flood protection

Uncertainty reduction is important within the design of flood defences. Mawdsley *et al.* (1990) report a study in north-east England, relating the benefits of data in this context to the costs of collection. Benefits were given as approximately 4-5% of construction costs, giving benefit-cost ratios of 1.0, 0.37 and 0.05 in the three examples studied. By contrast, however, Cordery and Cloke (1994) produce benefit-cost ratios of up to 80:1, and suggest that there should be a general expectation that data benefits will outweigh collection costs whenever flood protection works are contemplated. On this basis, they recommend that whenever data are scarce and a future need of this sort is likely, instrumentation programmes should be commenced immediately.

2.1.4 Flood warning systems

Hydrometric data are needed for both the design and operation of flood warning systems. Benefits of flood warning are assessed by reference to damages avoided - flood-threatened residents and businesses can move possessions or stock and equipment to avoid the effects of inundation. The most significant UK effort in assessing flood damages and the possible avoidance of costs by structural and flood warning measures has been undertaken by the Middlesex University Flood Hazard Research Centre. Recent research for the National Rivers Authority (Heijne *et al.*, 1996), following these methods, has indicated that tangible benefits from fluvial flood warning in England and Wales could amount to some £15 million annually. Recent research for the Environment Agency (1997) indicates that in some circumstances, tangible losses may be reduced by as much as 50% as a result of warnings. However, little work has been done on relating the possible benefits of schemes to the costs of providing data.

2.1.5 Pollution control

Some progress towards valuing water quality maintenance and improvements has been made in the UK by Adeloye and Mawdsley (1990). However, they report low data values, and consider it important to stress intangible benefits. The difficulties here relate to the problem of water quality not being a marketed good. However, data benefits can be arrived at by the application of a production function (see above). Benefits may also accrue from being able to avoid costly actions in order to maintain quality standards. Sections below will discuss how this approach may be used in this study.

Recreational benefits are often associated with water quality management. Green *et al.* (1989) suggest that improvements in water quality due, for example, to the avoidance of low flow episodes, will lead to benefits in terms both of increased quality and quantity of fishing, and may allow other benefits such as swimming or other clean-water sports. Willis and Garrod (1995) present the results of a willingness-to-pay study based on the River Darent, an English low flow river, which allow the development of methods for assessing low flow alleviation benefits. Progress in quantifying these benefits is difficult: benefits are not as clearly identifiable as with flood defence projects, for example. Nonetheless, economic principles can be invoked to quantify some benefits, and a recent F. W. R. (1996) manual gives monetary benefits of up to £25.66 per angler-visit resulting from water quality improvements.

Methods used to assess benefit include assessment of demand and the willingness of anglers to pay for recreational benefits, e.g. by reference to travel costs over different journey lengths. However, it is not the concern of these methods to identify that fraction of recreational benefit which is directly attributable to data collection.

2.1.6 Hydropower scheme design

As with some of the other types of benefit assessment presented, it is recognised that hydrometric data can lead to the avoidance of costs caused by overdesign or underdesign, in relation to HEP schemes. On this topic, there is little of assistance in the literature (the only papers found relate to operational uses on rivers of much greater scale than are found in the UK - Appendix III, Section 3.3), but empirically-based methods are presented in Chapter 6.

Many more studies are known than those reported here, but the selection serves to illustrate the range of circumstances in which data benefit assessment has been attempted. In some examples, differences in benefit assessment are reported for similar applications of data. Part of the explanation for this must lie in the circumstances of a specific project, e.g. the costs of a proposed investment project, or the local costs of data collection. However, it must also be possible that different approaches could be taken to appraising the benefits arising in one given project. Reference to the means by which data collection costs are assigned to individual benefits gives one illustration of this.

2.2 Non-Economic Benefit Assessments

Non-economic benefit assessment methods have been developed where comparative data-generating values have been required as part of the review of a gauging network. Although numerical scores are used, these do not purport to represent the economic value of the data being generated. One example comes from Canada where Davar and Brimley (1990) report the application of a general approach by Wahl and Crippen (1984). In it, scores were accumulated under each of four headings:
a) site characteristics,
b) identified client needs - regional hydrology,
c) identified client needs - operational hydrology, and
d) regional importance of water resources.
This allows an objective basis for discriminating amongst stations, but offers no direct potential for assessing the absolute benefits of data, and is therefore discounted from application in this study.

2.3 Network Reviews

Perhaps as an indication of the increasing emphasis being placed on accounting for public expenditure, the literature search for this study indicated a substantial growth in data benefit cost papers since the mid-1980s. One particularly important study for the UK is the broad-based cost-benefit assessment undertaken for the whole UK flow gauging network by C. N. S.

Scientific & Engineering Services (1991). At *c.* 1987 prices, total UK annual costs for flow gauging were estimated at £9 million, with benefits being quantified in five main areas:

a) the risk of climatic change or other factors causing a significant change of river flow (assuming that the gauging network had been abandoned);
b) water authority operations, including the supply of potable water;
c) irrigation;
d) flood alleviation;
e) flood warning.

(C. N. S., 1991; p.1)

Perhaps surprisingly, the study reported only "small benefits" being quantifiable from flood warning, and none from consents to discharge effluent, although the latter was seen to be important nonetheless. The final benefit values ranged from £11 million to £60 million, representing benefit-cost ratios of 1.2:1 to 7:1, with a best estimate of 2.3:1. This indicated that UK expenditure on gauging was producing cost-effective returns, but the report did not provide a methodology for the assessment of local networks. It is noticeable that the range of ratios is large, reflecting the importance of the methods used for assessing benefit. It is recognised that costs can be quantified with much greater confidence than is often possible for benefits.

Through the Nordic Coordinating Committee for Hydrology, the Nordic countries have been undertaking a review of their hydrometric monitoring programmes (Puupponen, 1996). Their assessment of benefits has so far been limited to the classification of the networks with respect to the utilisation of data, using three broad categories:

- hydrological analysis and process studies,
- water resources management, and
- environmental monitoring.

The importance of each site for each function was assessed by local hydrometric staff, rather than by data users.

The review considered the economic properties of hydrological data and hydrological network operation, concluding that "the economic characteristics of hydrologic data and acquisition and hydrologic data as a commodity show that the conditions for a comparative market are not met, so economically efficient conditions for the production and exchange of hydrologic data will not be established" (Puupponen, 1996). However, this view does not preclude the application of economic theory to the evaluation of benefits accruing from networks presently in place or proposed for the future.

2.4 Summary

This overview of the literature relevant to hydrometric data benefit assessment has illustrated the breadth of interest in the topic, and also the international distribution of research work. Studies have been undertaken ever since the establishment of cost-benefit analysis as an effective decision-making tool, and have used a number of economic approaches to arriving at benefit values. The most well established applications of these techniques have been in relation to the avoided costs of the over/under-design of capital projects, such as dams, bridges or flood defences. However, other benefit types such as uses of real-time data in avoiding the costs of flood damages or pumping operations, and the value of maintaining acceptable flows are equally part of the modern picture of hydrometric data benefit assessment. Attention has also been directed to studies which have identified benefits on a non-economic basis (where economic approaches have been found to be inappropriate), and to one in which a full UK cost-benefit analysis was presented. In the following chapters, elements of both the quantitative and non-quantitative approaches will be developed further, in order to guide the reader towards undertaking a full assessment of a chosen hydrometric network. In particular, the four basic economic approaches to benefit assessment outlined in Section 2.1 (relating to different basic categories of benefit) are more fully developed in Chapter 6.

3. SURVEY OF DATA USES AND BENEFITS

One method of moving towards a comprehensive assessment of data benefits, which was identified by the research team, was a survey of data users. It was felt important to undertake such a process in order that the following development of methods could be done on a well-informed basis. A survey was undertaken in two parts:

- a questionnaire survey, and
- interviews with data users.

Interviews were undertaken both with agency staff (at an early stage, to guide this phase of the work) and with external data users.

The questionnaire survey formed the main part of this phase of the project. Separate questionnaires were drawn up for nine distinct functions of the environmental agencies in England & Wales, Scotland and Northern Ireland, these being:

- Freshwater chemistry
- Freshwater biology
- Estuary/marine survey
- Water resource management
- Abstraction licensing
- Pollution control
- Flood warning
- Flood defence
- Fisheries & conservation

Questionnaires were directed either to regional or area offices, and recipients were provided with circulation lists and asked to send on copies to any relevant colleagues who may not have been directly mailed.

Questions were formulated with a view to serving a number of interests: at a basic level, the research team wished to ensure that the extent of hydrometric data usage was clearly understood and some questions reflected this. However, the questionnaires were also used to help ascertain the value of data to users in different functions, so questions were asked either on a direct basis, e.g. "what is the estimated annual benefit of issuing flood warnings in your area", or on an indirect basis, e.g. "how would the hypothetical lack of flow data for rivers in your area affect the setting of consents to discharge"? A complete set of blank questionnaires is included as Appendix IV to this report.

3.1 Results of Questionnaire Survey

A total of 138 responses were received in time for analysis, 58% of the number of requested responses, but including multiple responses from within some regions/areas. Often, self-completion questionnaires yield response rates of 10% or less, so this high level was very pleasing.

Table 3.1 provides a summary of all data uses identified by the questionnaire, arranged according to the nine agency functions identified for questionnaire survey. It should be noted that some responses were received from more than one function, in which case such responses have been listed only under the one function in which a response was most frequent. It should be noted also that because an open questionnaire approach was employed, this list is not exhaustive: other data uses may not have been specified.

Many of the main data uses (those most frequently cited) are well known to all agency staff across the functions, e.g. flow data requirements for discharge consent determinations, abstraction licensing, flood warning system operation, calculation of marine loadings. However, others must be less well known, or can easily be overlooked. Fisheries, Recreation, Conservation & Navigation Officers are reported to value flow data in the design of environmental enhancements for conservation and recreational purposes (e.g. canoeing) - a far cry from the oft-quoted dams, bridges and culverts for which flow data are more often required for design purposes. Flow data are required not only for the operation of flood warning systems, but also for their design and for ongoing validation: if some change in the hydrological behaviour of a catchment occurs, or one in its channel hydraulics, then information is required in order that a warning system can be modified and perhaps also for the purposes of adjusting risk assessments. Field scientists in freshwater biology, freshwater chemistry and marine science functions all referred to the value of real-time telemetry data in being able to plan effective fieldwork.

On the assessment of data benefits by agency users, only a small number of responses yielded directly useful information. Where the potential was thought to exist, users were asked to refer us to quantitative estimates of benefit. So when Flood Defence Managers were asked if the results of cost-benefit analyses for flood defence schemes were available, responses were generally positive, yet when Flood Warning Managers were asked to indicate the value of savings accruing from operation of their area systems, only two (out of 16) were able to indicate values: £150k for NW Area of EA-NW Region, and £1m for EA-Midlands Region. A minority of other responses indicated potential sources of data and, if pursued, these further sources (often at a Regional level) could yield rather greater value than the information which was provided.

In some further questions, users were asked to indicate the effect of reductions in data availability on their functions, allowing some indirect assessment of data benefit to be made. For example, Pollution Control Managers were asked to assess the likely difference between consents based on estimated flow data and those based on measured streamflows. Most were unable to give a response, several commenting that this was an "impossible task". Four of the 17 respondents did offer estimates, varying between 10% and 25% of the consent. While groups of responses of this sort can be of help in confirming some existing suppositions (direction of effects), they offer limited further value in relation to the quantification of benefits. Further economic perspectives are included in the full analysis of the responses, which is presented as Appendix V to this report.

Table 3.1 Summary of hydrometric data uses, listed by function

[key:	SUBJECT
n	main data uses in order of frequency
-	other cited data uses]
	POLLUTION
1.	consent determination/review
2.	calculation and modelling of mass balance/pollutant loads
3.	assessing and managing pollution events
-	design of surface-water treatment
-	sewerage modelling
-	timing of engineering work
-	risk assessment for pollution prevention
	ABSTRACTION
1.	abstraction licences; determining new levels and altering existing ones
2.	investigating derogation complaints
3.	enforcing residual and compensation flow licences
-	catchment model construction and evaluation
-	estimation of dry weather flows in ungauged catchments
-	setting 'hands off' flows
-	compensation
	CHEMICAL
1.	calculating chemical loads to North Sea for PARCOM/Red List/Harmonised Monitoring Scheme/Global Environmental Monitoring
2.	modelling catchment water quality and quantity (including SIMCAT modelling)
-	information about time of sampling for result interpretation
-	studying effects of low flows on water quality
-	compliance with Drought Orders
-	planning fieldwork
	BIOLOGICAL
1.	input into RIVPACS
2.	determining whether conditions are suitable and safe for sampling
3.	calculating dilution available for effluent for sampling/cost recovery
4.	loading models (solute loadings and loch retention) and water quality models (loch eutrophication/phosphorus concentration)
5.	interpreting survey results
-	to 'trigger' surveys on low flow effects/drying/recovery
-	Base Flow Index input to SERCON conservation assessment scheme

Continued/...

Table 3.1 *(continued)*

	FISHERIES/CONSERVATION/RECREATION/NAVIGATION
1.	relating flow/discharge with run-times and the suitability/utilisation of various habitats
2.	targeting vulnerable areas for monitoring/improving/restoring habitat
3.	operational use; survey information, critical levels, enforcement, fish rescue
-	access; canoeing only at high flows
-	low flow research projects
-	design of channels (environmental enhancement) and fish passes
-	maintenance of navigation and power generation purposes
	FLOOD WARNING
1.	flood warning system development
2.	flood warning system calibration
3.	flood warning system operation
-	level to level correlation
-	extended use of radar
-	flood forecasting modelling
	FLOOD DEFENCE
1.	assessing return periods (flood frequencies)
2.	assessing particular flooding events (post flood analysis)
3.	design of new works; flood alleviation schemes
4.	calibration of design models for schemes/investigations
5.	management of infrastructure (maintenance work)
-	checking design tolerances
-	improving Flood Studies estimates
-	development of control purposes e.g. building above sea level
	MARINE/ESTUARINE
1.	river loads and freshwater inputs for water quality modelling
-	estuarine salinity and current studies
-	calibrating models/predictive simulation
-	marine survey evaluation
-	design purposes
	WATER RESOURCES MANAGEMENT
Data uses encompass a number of uses cited above, from most subjects;	
-	water resources planning and monitoring
-	low flows and abstraction issues
-	flood risk and warning
-	insurance/legal purposes
-	research projects

One final specific aspect of the responses to note is the importance of real-time data. With the widespread advent of telemetry, new uses have developed and become established in several areas of agency operations, e.g. model-based flood warning systems, pollution dispersion models, RiverLine telephone services for anglers and information for field staff when planning daily work schedules. Here a technological development has greatly increased the data utility of existing networks and, in some instances, has underpinned the justification of new stations for flood warning or low flow monitoring.

3.2 External Data Users

After interviews with EA/SEPA staff, it became clear that many of the largest benefits accruing from data use would be associated with external rather than internal data users. From a theoretical point of view, the value of data to external users should be the maximum amount which they would be willing to pay to obtain it. In reality, however, only nominal amounts are ever charged (if at all), so values were expected to be hard to uncover.

Given the perceived dominance of external users, we approached three Regions to try and establish a breakdown of the data use, both between external and internal users, and between different classifications of external data users. The results from this are included in Appendix VI, which also includes details of interviews held with some of the external data users.

From the responses received, it would appear that the majority of *information requests* are received from external data users. However, it must also be anticipated that there are many internal users who do not formally request the data, or who are able to extract it directly from the computer systems themselves. It was also noticeable that there is a significant difference in the split between SEPA and the Environment Agency, with the Environment Agency recording many more requests from external users. This may be due to the Environment Agency's predecessor organisation having a much higher profile, along with the fact that the data are available free of charge from the Environment Agency whereas a charge is made by SEPA.

As the extent of external data use was so large, it was decided to try and classify it for the two Environment Agency offices visited (Midlands Region and Ridings Area of North East Region). Three main user types emerged:

1. water companies (the second largest single user in the Ridings Area, possibly due to the well publicised drought problems recently experienced by Yorkshire Water, and the third largest in Midlands Region),
2. external consultancies (second largest in Midlands and third largest in Ridings), and
3. students/schools/colleges, primarily for project work, who were the largest single user type for both the Midlands Region and Ridings Area.

Whilst it could be argued that the data supplied to students has important benefits in both the short and long terms, we felt that it would be impossible to quantify these, and that further time should not be allocated to this benefit. Instead, efforts were concentrated on the water companies and external consultants - a visit was made to Yorkshire Water Services and a number of Scottish consultancies.

The findings from these visits are also included in Appendix VI. It would appear that the water companies rely heavily on a few stations for their day to day activities of resource management, but also use data from the wider network when the system is under heavy operational stress (e.g. a severe drought situation). However, both the departments that were interviewed were unable to assign a benefit value to the data that they use, other than stating that in the case of abstraction sites they felt the Environment Agency would be prevented from closing the relevant gauging station by the legislation. External consultants often have difficulty in expressing the value of hydrometric data to projects, but some indicative figures in flood defence design work have been obtained. The research team has also been directed to a recent study by the Institute of Hydrology and Edinburgh Hydro Systems Ltd. (Young *et al.*, 1996) assessing errors in the low flow estimates used in small-scale hydro project design, which points to the importance of representative observed data in underpinning estimation procedures.

This raises the issue of the importance of data use in research. Of pivotal importance here is the work of the NERC Institute of Hydrology, responsible in the 1970s and early 1980s for developing methods reported in the *Flood Studies Report* (NERC, 1975) and the *Low Flow Study* (IH, 1980), and continuing to the present with work on these and related topics. Major national studies such as these always require a large database of discharge information, and benefit from the accumulation of additional data as record lengths increase. It is important for such studies to draw on data from a wide range of catchment types, in order that the research outputs are as robust as possible in relation to the range of catchment conditions or types found across the UK, and the value of some gauging station records for such research can sometimes greatly exceed their value for local operational or planning purposes.

The benefits of such research is partly a function of the databases used, and it is difficult to relate these benefits to individual sites or local networks, or to assign benefits in monetary terms. Similar considerations apply to the value of data in identifying national or regional trends in runoff behaviour, such as in relation to assessing the effects of climatic changes. However, such benefits must be borne in mind, and will be referred to in further chapters.

Finally, it is worth noting one difference found between users of the data from SEPA and the Environment Agency. When interviewing Flood Defence staff within the Environment Agency, the general feeling was that, whilst hydrometric data were useful if not essential in some cases, the engineers felt that they could rely on theoretical methods if they had to. In Scotland, flood defence works have traditionally been carried out by external consultants, and it was interesting to note that they assigned a much greater importance (and associated benefit) to the availability of hydrometric data, stating that project costs would significantly rise and confidence decrease if the data were not available. There are some grounds, therefore, for suspecting that external data users place a higher value on data than internal data users undertaking the same work, possibly because they have to actively seek the data rather than being able to extract it from the computer archives available.

3.3 Summary

The data uses listed in Table 3.1 clearly illustrate a great breadth of uses to which hydrometric data are put. With some unexpected uses being identified, this activity was clearly a useful one. However, the exercise was limited in the progress made in gathering leads for the quantitative assessment of benefit arising from these many uses. Some quantitative data were usefully gathered in relation to flood warning and water transfer benefits. Uncertainty in other areas, regarding the contribution of hydrometric data to decision-making in such areas as abstraction licensing/control and pollution control was disappointing. In some cases, the responses appeared to result from a lack of information, and they are not seen as precluding the successful application of quantitative methods in some areas.

One important point to emerge from this exercise is that a distinction must be recognised between the value of a function (e.g. pollution control) and the value of the data underpinning it. Particularly where functions can be executed in the absence of data, the benefit of hydrometric data is the additional value derived from an activity as a result of data being available. Even when a function cannot be carried out with data (e.g. flood warning), the point must be made that the value of the data may not be the same as the value of the function, if other activities such as data interpretation or dissemination contribute to the value of the function delivered. This point is discussed further in Chapter 6.

4. A FRAMEWORK FOR UNDERTAKING BENEFIT ASSESSMENTS

Chapter 2 has illustrated the development of a large number of economic methods of benefit assessment for use with hydrometric data benefit assessments. In Chapter 3, it has been shown that a very wide range of uses is made of hydrometric data in the UK. Not all of these uses can be translated into a quantitative benefit assessment, but part of the ethos of this R&D project has been to devise methods of assessing benefits which are as comprehensive as possible. Some examples of data use benefits which present quantification difficulties, because of either a lack of appropriate theoretical framework, or the unavailability of data, include:

1. assessment of river chemical loads discharged to sea
2. assessing suitability/safety for biological/chemical field sampling
3. identification of target areas for monitoring/improving/restoring habitat

- each a function in which agencies wish to attain high standards of achievement.

In these cases, benefit is identified as deriving from: (1) being able to satisfy the requirements of an intergovernmental agreement; (2) planning effective deployment of staff/ensuring high-quality field results and (3) having information which can be used to maintain and improve aquatic habitats, respectively. However, none of these benefits can be confidently quantified.

Yet while findings such as these are found for rivers across the UK, the advantages of being able to quantify the benefits of hydrometric data use are undiminished. Only with quantitative data is it possible to make comparisons with the costs of monitoring; equally it is only with quantitative data that the effects of changing network configurations or station performance can be related to changes in cost-benefit ratios. This type of approach must therefore be undertaken wherever possible in order to maximise information gain.

In relation to those benefits which cannot be quantified in an economic sense, the rationale which emerges from the study is that procedures must be developed so that these are also recognised, despite the impossibility of quantification. In such cases, the potential of a data use survey is limited since quantitative methods (e.g. cost-benefit ratio computations) cannot be applied. It therefore falls to the project team to develop methods which will allow the recognition of unquantifiable benefits to be used to the maximum possible advantage. The benefit methodology to be developed must therefore be able to combine the results of assessing benefits using both quantitative and non-quantitative methods.

4.1 Combining Quantitative and Non-Quantitative Benefits

It is a simple observation that while all uses of hydrometric data benefit can be identified, only some can be successfully quantified using economic methods, i.e. the latter are a subset of the former. The following paragraphs and Chapters 5 and 6 will develop methods which will allow benefits identified by either means to be brought together. Therefore a framework is advanced for combining these results. It is represented in Figure 4.1, and consists of three parts:

1. Identification of all benefits irrespective of type, and qualitative assessment of importance
2. Assessment of all benefits capable of quantitative treatment
3. Synthesis of all results of preceding parts

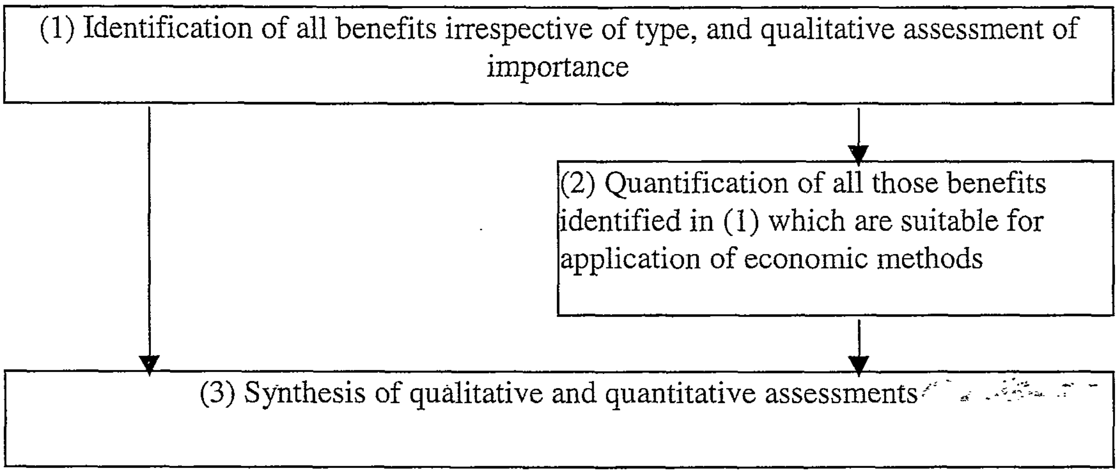

Figure 4.1 Framework for assessing benefits by quantitative and non-quantitative methods and combining results

The following two chapters will explain in detail the methods to be adopted to carry out each of these stages, however it is important to establish at this stage the general relationship between these various activities. The nature of the process is such that the results of the separate quantitative and non-quantitative benefit assessment methodologies will be reported in different terms.

It should be borne in mind at this stage that these will not readily combine in any one final unit of benefit measurement. Rather, they will need to be considered together by decision-makers using the results, such as those responsible for hydrometric network review. The onus for effective use of the results therefore rests with the user. In applying the methods, maximum use of quantitative approaches will be encouraged, subject to the limitations of each benefit identified. The number of benefits subject to quantitative benefit assessments in any one study will depend on local conditions, and so it must be anticipated that while in some areas there will be many quantitative benefit assessment opportunities (e.g. a built-up area with large numbers of water uses), elsewhere these may be relatively few. These points will be returned to in Chapter 9.

4.2 Catchment Context of Benefit Assessments

A final consideration at this stage is the geographical scale at which benefit assessments are to be undertaken. Two key aspects have been agreed between the client and contractor:

- River basins are to be used as the coherent units in which assessments are undertaken - this is because of the river flow through the drainage system which provides a logical basis for local information transfer, between gauging stations (data gathering points) and points of data use.

- In the interests of avoiding over-complexity (though not because of any conceptual limitation), networks being reviewed should normally consist of no more than 10 gauging stations, and should cover readily identifiable geographical units.

An added benefit of the latter point is that benefit assessments should therefore be reasonably-sized pieces of work for staff to undertake: depending on the complexity of use data patterns and the assessment methods to be used, a network benefit assessment should take between one and five working days.

However, it should be noted that an inevitable corollary of the catchment context is that national benefits are difficult to represent in the same framework. In Chapter 5, therefore, measures are introduced to cater for national interests, and this point is again represented in later discussion.

5. APPROACHES TO NON-QUANTITATIVE BENEFIT ASSESSMENT

In order to ensure that any benefit assessment is fully comprehensive, a mechanism is required which will ensure that all benefits arising from hydrometric monitoring in a particular area are identified and recorded. The research team and the Project Board agreed during this study that a checklist provides the most effective means of achieving this.

A specimen checklist (constructed in a general form, for widespread application) is included with this report at Appendix VII. The checklist is to be completed as the first substantive part of a hydrometric data benefit assessment. It should be completed by the staff member responsible for undertaking the assessment, and he/she should consult widely with appropriate colleagues in all areas of the checklist where he/she may not have to hand all the information desirable for making complete and representative entries. By completing the checklist before moving on to other parts of the benefit assessment exercise, a well-informed view of the range of different benefit types is assured. The checklist also provides an initial indication of the relative importance of different benefits, but this is to be regarded as a preliminary step in advance of the application of quantitative methods.

5.1 Data Benefit Checklist

The checklist is presented in four parts (Appendix VII):

A. The resource
B. Current uses of data
C. Potential future uses of data
D. National network/baseline monitoring utility

Some background to the intended use of each, and notes to assist completion, are given here.

A The resource

The purpose of this section is to necessitate the collection of background information on the basic catchment characteristics of the catchment under review, from a water resources point of view (Part A1), and then also on the uses of water in that area (Part A2). Information on water use should give a crude guide to the main benefits of hydrometric monitoring.

A1 Catchment characteristics

Size of area: defines the extent of the area to be assessed. Allows gauged catchments within this area to be considered as draining an identifiable fraction of the total area under review.

Mean annual rainfall: identifies the average wetness of the area. In addition to a value for the area as a whole, values are required for the wettest and driest gauged catchments, so that areas of relative abundance and deficiency can be identified; the spatial variability of water availability can thus be assessed. The latest Met Office standard period should be used for the definition of these values if possible, e.g. 1961-90 standard period, or any other generally accepted long-term average.

Mean annual actual evaporation: gives an indication of the total losses of water to the atmosphere, thus allowing an areal estimate of mean annual runoff to be made. This will differ from the runoff gauged at the outflow of a catchment if transfers/ abstractions are significant. Estimates should be obtained either from MORECS data, or from assessing losses in a locally representative natural catchment (data quality permitting).

Fractional area below 20m AOD contour: to be used to indicate the extent of low-lying land, e.g. coastal plain, as a percentage of total catchment area. Indicates areas of generally flat land, often with characteristic drainage patterns. Data may be available from a digital elevation model (via hypsometric curve), or can be extracted from OS sheets.

Altitude of 3 highest hills/mountains: the question seeks to direct awareness to the extent of relief in the area: how high are the highest peaks, and where are they?

Geology of the area: the first part, on permeability, addresses the relative importance of deep and shallow/surface runoff pathways in the catchment area. The second, on acidity, is important in relation to water quality in the area, e.g. for supply purposes, or the buffering of acidic inputs, and affects the aquatic biota of the catchment.

A2 Uses of water

Primary use of water: likely answers are public supplies, irrigation, hydropower, industrial abstraction, and should be available from abstraction licensing or other regulatory records.

Abstractions for public water supply schemes: information on surface and groundwater abstractions should be available again through the regulatory framework. The rate, timing and location of PWS abstractions are generally important in relation to the other uses of water made in a catchment, and are often linked to monitoring requirements.

Are surface reservoirs used for storage purposes?	) Each of these is expected to
Are surface reservoirs used for HEP?	) impact (at least locally) on flow
Are there run-of-river HEP schemes; if so where?	) behaviour, and may necessitate monitoring, e.g. for compensation flows.

Over approximately what % of the area are there agricultural abstractions? - in periods of low runoff, these can produce critically low flows in rivers and streams. The avoidance of such situations is generally an objective of environmental regulators, and is best approached with the availability of relevant hydrometric data. An awareness of the extent of agricultural abstractions therefore helps in the understanding of the need for flow data, and may relate to other issues e.g. Nitrate Vulnerable Zones.

How many sewage treatment works discharging to watercourses are there in the area? - this indicates the pattern of STW discharges, and therefore the distribution of points where flow data may be advantageous in the determination/review of consents to discharge and other water quality modelling studies. Population equivalent data may be added for the various works if readily available.

Level of urban development: water quality and runoff responsiveness of urban surfaces are two major implications of urbanisation; flood risk may also be important. An awareness of the extent of urbanisation provides a useful part of approaching the assessment of data benefits.

What and where are the main industrial users of water? - as with some of the above points, abstractions of this sort may lead to the risk of unacceptably low flows and are often associated with a need for hydrometric data.

Is there any flow regulation scheme(s) in the area; if so, where? - these may be provided for the purposes of maintaining minimum acceptable flows, or for supporting downstream abstractions, and almost invariably necessitate accurate flow monitoring.

B Current uses of data

This part of the checklist serves two purposes:
a) to identify those uses where the application of hydrometric data is known, and
b) to assess the data/station standards required in order to fully serve these uses.

The checklist should be completed only for the whole catchment under review, rather than for each station in it.

The preferred source of information for this task is data request log sheets. It is strongly suggested that this is the most reliable means of assessing data use, because large numbers of request sheets can be scrutinised, representing all external data requests (if sheets have been consistently used as part of an internal procedure) and many internal data requests. To include the effects of cycles in the demand for data for different purposes, log sheets for complete years should be used if possible.

With respect to those internal 'requests' which have been fulfilled directly through use of an in-house IT system, efforts must be made to identify all those with access to the hydrometric data for the catchment being assessed. This should then be followed up by direct interview or questionnaire, in order to ascertain the data uses and needs of these users. While these users may be relatively few in number, it is anticipated that internal users will account for a high fraction of the total volume of data use, so these users are of considerable importance.
If data request log sheets are not in use, a survey of all data users over (say) a one-year period may be ideal in theory, but difficult to achieve in practice. A more realistic compromise would be for hydrometric staff to use whatever documentary records are available, along with their working knowledge, to attempt completion of the Part B checklist. However, in such cases, the establishment of a logging system for future use - if only to help assess the needs of

data users as a management information tool - is strongly recommended. Some explanatory comments on the classes of data use, and the associated data requirements, are provided in Tables 5.1 and 5.2 below.

Table 5.1 Notes on listed data use types

Data use	Notes
Flood warning	Uses include design, calibration, checking and operation of systems
Flood design	Data application to flood estimation problems (e.g. design of bridges, culverts, etc.); comment may be made on the advantage of ongoing monitoring *vs.* use of existing data
Storage design	i.e. flow data for reservoir design
Low flows	Monitoring may be required upstream or downstream of an abstraction or of a flow return to a river channel
HEP operational	Monitoring data required in real-time for operational management
HEP design	Data required for design of new schemes
Water resources - operational	As 'HEP operational' above, e.g. for control of timing of a freshet release, or in relation to PWS abstractions
Consent determination/ review	Use of observed flows in preference to estimates to assess terms of consent
Mass balance/ pollutant loads	Less point-specific uses than immediately above, e.g. pollutant loadings to sea
Assessing/ managing pollution events	Use includes point protection studies for PWS abstractions (time of travel studies)
License determination/ review	Use relates specifically to license determination/review, rather than monitoring of existing licenses, or general low-flow problems
Enforcement of licenses, derogation investigations	Use of flow data where actual abstraction rates require investigation
Real-time data use with variable licenses	Use where licensed abstraction rate is a function of river flow
Scientific support	Other uses of flow data in support of regulator functions
Fieldwork planning	For effective deployment of agency staff
Recreational	Real-time and historic data uses to be considered equally
Navigation	Uses include application to lockage monitoring requirements
Education	University/college/school projects

Table 5.2 Notes on listed requirements of data uses

Requirements of data use	Notes
Telemetry	Indicate level of need, i.e. need for real-time data
Low-flow accuracy required	Determined both by whether the use requires any low-flow data and (if so) the level of accuracy necessary
Limit of high flow required	Five choices given as broad indicators of max. flow required with accurate measurement. Leave blank if not needed.
Comments	Any additional information relating to the demands of the data use should be entered, e.g. any apparent over/under-provision of stations, reliability, site sensitivity

Note that the checklist also requires numbers of logged requests to be recorded against each use - this allows quantification of the level of usage for each, thus indicating relative importance in volume terms. Such data do not form part of the quantitative assessment methodology, however, because links have not been established between numbers of requests and benefit. Rather, the methods in Chapter 6 are more soundly based on benefits which can be estimated on the basis of identified data uses.

C Future uses of data

It is recognised that anticipating future changes in data use cannot be undertaken with great certainty. However, network managers' understanding of current and anticipated patterns of environmental monitoring and data needs should be incorporated into any assessment of the suitability of a network for future needs. Some comments are provided here for each question of Part C of the checklist.

Any uses not expected to require long-term data collection: these may be uses where only short-term monitoring for definition of some flow parameter is needed, and where monitoring is not required to detect any future changes due to land use or climatic effects. Alternatively, short-term needs may arise where model calibration is required, and where subsequently no further flow data requirement will be justified. Responses should relate to a type of data need, rather than to a need at a specific location.

Any uses where data from a greater number of stations may be required in future: such uses are expected to be those where an increasing data usage is anticipated, or those where increasing levels of accuracy may be required.

New types of data use expected to arise: an opportunity to suggest uses which may arise from changes in legislative requirements, increasing/new environmental problems, etc.

Completion of the checklist provides a well-informed basis on which to proceed to quantitative methods of benefit assessment (Chapter 6). For this reason, it is strongly recommended that the checklist is completed before continuing to the next stage of the benefit assessment.

D National network/baseline monitoring utility

As a final section to the checklist component of a review, this section draws attention to the value of specific stations in relation to maintaining a comprehensive national hydrometric monitoring network, and in relation to baseline monitoring. The need for the latter is an important consideration in the former. Two aspects of current Government policy make these considerations very important. Firstly, Government is developing means of promoting sustainable development and, as part of this, it is important to be able to quantify natural resources - such as water. Proposals for a European Water Framework Directive, and other proposals to revise the means of granting abstraction licenses in England & Wales, will both place substantial demands on the provision of high-quality hydrometric data. Secondly, the importance of assessing the effects of any climatic changes on UK water resources is recognised, so ongoing monitoring is needed in order to detect any change.

Specific attributes can be used to determine the value of any station to the needs of national or baseline monitoring. Section D of the checklist therefore requires the following to be assessed for each station in the network under review:

Baseline Monitoring Criteria (BMCs)
1. Naturalness of catchment - is the actual Q_{95} of the river within 10% of the natural?
2. Naturalness of catchment - is the flow regime essentially free of anthropogenic influences?
3. Is the hydrometric accuracy of the station high throughout the flow range (in comparison with other stations in the region)?
4. Is the length of archived flow record greater than 30 years?
5. Is the archived record of a high standard of completeness (in comparison with other stations in the region)?
6. Is the record representative of the flow regime in its region?

- assistance of the Institute of Hydrology gratefully acknowledged

(At 4. above, 30 years is arbitrarily used to define a record of high value on account of its length - see also Section 7.3.1/Table 7.5)

If answers to the above are all "yes" for a station, then it is of clear value to the national network and to baseline monitoring for the detection of any change.

Two more specific criteria are:
7. Is the station listed in the Institute of Hydrology's core national network?
8. Is the station considered to be of value in detecting climatically-induced changes or in assessing sustainable resource use?

Forthcoming research from the Institute of Hydrology will provide guidance on the identification of stations with these latter criteria. If the answer to either 7. or 8. is "yes", or if the Baseline Monitoring Criteria above are all "yes", then a presumption to retaining such stations should be considered. In cases where most but not all of the BMCs are answered "yes", local environment agency personnel may wish to argue for the protection of a station against closure or downgrading proposals, on the basis of specific local factors. Examples may include cases where a station provides the best available combination of record length and data quality in an extended area, or where one might in the future provide a rare opportunity to assess the effect of some unusual land use change.

It should be noted that the CNS (1991) review of the UK hydrometric network as a whole found that one of its most important capabilities was the detection of climatically-induced changes. While the economic evaluation of such benefits is difficult to achieve, it must be assumed that the association of individual stations with utility in this field could amount to very large benefits, at least comparable with some of those which can be defined using economic methods.

6. APPROACHES TO QUANTITATIVE BENEFIT ASSESSMENT

As stated in previous chapters, an important objective of this research project has been to make progress in providing methods which can yield quantitative assessments of the benefits of hydrometric data. These can then be compared with data gathering costs, and allow the cost-benefit implications of gauging changes to be assessed.

In Chapter 2, four approaches to the economic assessment of benefits were outlined, and are repeated here:

1 Benefits of applying real-time data to reduce damages - e.g. by the issue of flood warnings based on hydrometric data.
2 Benefits of applying real-time data in resource management - costs can be avoided, e.g. in a drought situation, if real-time information allows actions to be taken to avoid likely costs, such as pumping to maintain river flows or to provide supply from distant sources.
3 Benefits relating to investment planning - costs are associated with under-design and over-design and so, where data can be used to reduce uncertainty in the design process, a benefit arises. Examples include bridge and dam design, and major commercial or residential developments.
4 Benefits assessed within the context of a production function - hydrometric data can be treated as an input in the production of a desired level of water quality, e.g. more information as an input can allow for less expenditure in abatement costs.

6.1 Method for Combining Benefit Assessment Estimates

A method of approximate cost-benefit analysis (ACBA) was conceived, whereby these general categories could be applied to a number of different data benefit types in a given catchment, summed to give an overall approximate benefit assessment, and then related to costs for data collection. The basis of such comparisons would be using annual benefits and annual costs converted into present values, over some discrete time period, in order to compute a cost-benefit ratio. Use of these data would then allow hydrometric network managers to assess networks and changes to them, taking into account the results of a checklist survey to assess the importance of benefits which could not be represented using quantitative methods. A paper outlining the development of the ACBA concept is appended at Appendix VIII.

At one stage in the study, consideration was given to incorporating in the methodology a parallel hydrologically-based component, which would separately assess the value of gauging stations with respect to hydrometric station performance criteria, such as accuracy, and also the representativeness of gauging stations in relation to the wider areas in which they are located. Some sort of synthesis would then be required to integrate both sets of results, and some difficulty was anticipated in performing this in an objective way.

Further consideration has revealed another approach to accommodating gauging station performance and representativeness. Part of this preferred solution has been to accommodate hydrometric aspects of data requirements in the checklist approach (Chapter 5 - checklist Part B (Appendix VII)). More importantly, the ability of hydrometric data to serve identified needs is identified explicitly in the procedures developed to handle quantitative benefit assessments. In this chapter of the report, attention is focused on economic assessments of benefit based on reported empirical data or numerical relationships from published literature, assuming base values of potential benefit for default situations, e.g. assessing the benefit of data in the design of a bridge as a function of its total cost. Such base values are then adjusted according to pertinent local factors, such as data accuracy, representativeness and length of record - and the procedures for this are presented in Chapter 7. The benefit values described in this chapter are therefore **base benefit values** (sometimes referred to in Progress Reports for this project as 'potential values') and, after scaling by appropriate factors as described above, will produce **component benefit values** for each data use. Summation of these latter values then yields a **total quantitative benefit value** for the network being assessed (Figure 6.1).

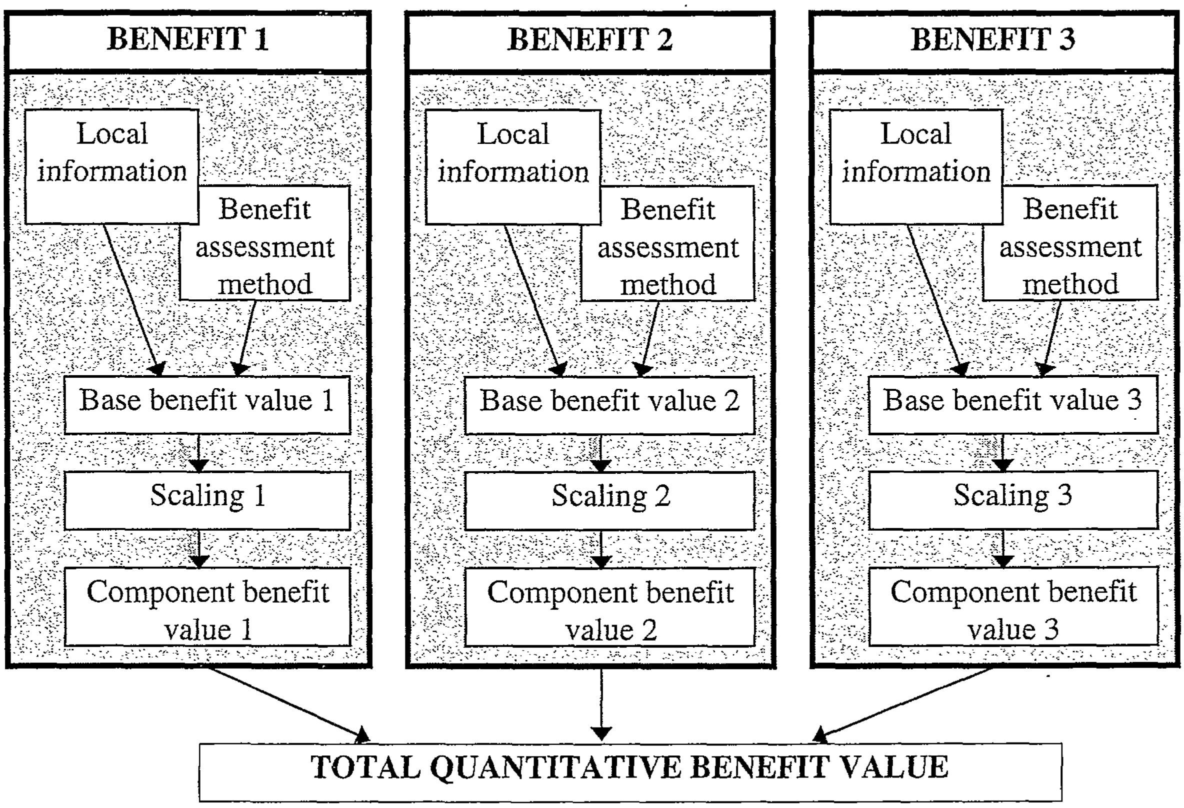

Figure 6.1 Relationship between base benefit, component benefit and total quantitative benefit values

6.2 Methods of Assessing Benefit for Data Benefit Types

In this section, guidance is given regarding the recommended methods by which base benefit values should be assessed for a number of distinct benefit types. In Chapter 7, scalings will be introduced in detail and in Chapter 8, worked examples (drawing mostly on two test catchments) will be presented. The list of benefit types covered is:

1. Improved design of bridges and culverts: major new investment
2. Improved design of bridges and culverts: major repairs
3. Improved design of flood protection works
4. Avoidance of costs of unsound hydro-power investment
5. Avoidance of excess pollution control costs
6. Improved determination of abstraction licenses/avoidance of low flow problems
7. Reduction of flood damages achieved through telemetry-based flood warnings
8. Avoided pumping costs achieved by use of telemetry hydrometric data

Benefit	**Improved design of bridges and culverts: major new investment**
Basis of assessment	The use of hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty
Approach	(3) - Benefit relating to investment planning
Source of information	Acres (1977): 10% of construction costs are sensitive to hydrometric data, and the benefit of the data is 10% of the data-sensitive element, i.e. benefit = 1% of construction cost. (This source was identified as the most suitable of a number of alternatives.)
Applicability	All major investment projects where hydrometric data have been applied in the design process
Output	Total benefit

Benefit	**Improved design of bridges and culverts: major repairs**
Basis of assessment	The use of hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, in this case in the application of data to significant periodic maintenance activities requiring flow data.
Approach	(3) - Benefit relating to investment planning
Source of information	Acres (1977): 10% of construction costs are sensitive to hydrometric data, and the benefit of the data is 10% of the data-sensitive element, i.e. benefit = 1% of construction cost. Interpreting maintenance to lie within this type of costs, benefit = 1% of annual budget for major repair of structures.
Applicability	Annual budgets for major bridge repairs - local/highway authorities, Railtrack plc.
Output	Annual benefit

Benefit	**Improved design of flood protection works**
Basis of assessment	Specialist literature indicates that the value of streamflow data may be estimated as 4-5% of flood protection scheme cost.
Approach	(3) - Benefit relating to investment planning
Source of information	Benefit may be estimated as 4.5% of scheme cost. Source: Mawdsley *et al.* (1990)
Applicability	Any flood protection works designed using hydrometric data.
Output	Total benefit

Benefit	**Avoidance of costs of unsound hydro-power investment**
Basis of assessment	Use of hydrometric records has allowed an assessment of the viability of a hydro-power scheme to be made, and has indicated that the scheme could be of no/low profitability or non-viable. On this basis it has been decided that the investment should not be made. The value of the data is thus equivalent to the avoided losses.
Approach	(3) - Benefit relating to investment planning
Source of information	Consultancy sources: Scheme capital cost (£) = 1000 * installed capacity (kW) Annual income to break even = £12,000 + (£225/kW installed capacity) [A] Annual revenue based on 50% efficiency (£) = kW capacity * unit charge (£) * 24 * 365 * 50% [B] Annual avoided loss (£) = [A] - [B] *(1997 prices)*
Applicability	Small-scale HEP scheme which has been the subject of a viability study and deemed unprofitable (i.e. where A>B; see above)
Output	Annual benefit

Note that, unusually, this benefit type involves assessment of avoided of losses in a situation where no commitment of investment funds or running costs occurs. Any application of the method must be based on the avoidance of losses which must have been assumed to have occurred in the absence of hydrometric data.

Benefit	**Avoidance of excess pollution control costs**
Basis of assessment	Hydrometric data are necessary for the accurate setting of consent standards for discharges. In the absence of such data, questionnaire survey indicates that consent setting would be more cautious. Consents are reviewed on a regular basis as a means of responding to changing catchment and regulatory conditions. It therefore follows that the collection of hydrometric data results in a benefit through the avoidance of those excess pollution control costs which would otherwise be borne if standards were higher (as a result of a lack of data). Benefits are to be assessed as 20% of the variable costs of treatment, on the basis that questionnaire responses indicate that consent standards would be 20% higher without hydrometric data. Benefit can therefore be estimated as 20% of variable effluent treatment costs.
Approach	(4) Benefits assessed within the context of a production function
Source of information	Variable treatment costs can be estimated as a function of actual population equivalent for major works, or may be obtained direct from STW operators. Variable treatment costs C_{vt} (£ p.a.) can be estimated from the equation: $C_{vt}=47000+0.613PE^{1.065}$ where PE is actual population equivalent for the plant. Benefit to be assessed as 20% of the above, i.e. $0.2*C_{vt}$. Sources: An English Water Company Questionnaire/interview responses *(1997 prices)*
Applicability	Sewage treatment costs serving population equivalents of at least 5,000.
Output	Annual benefit

Note: if it is possible to obtain variable treatment costs from trade effluent dischargers, a similar approach with benefit assessed at 20% of C_{vt} may be employed, and the resultant benefit handled with others from different benefit types. However, it should be noted that this information is often of a commercially-sensitive nature, and costs are not suitable for generalisation from one plant to another.

Benefit	**Improved determination of abstraction licenses/avoidance of low flow problems**
Basis of assessment	General surveys of willingness to pay (WTP) indicate the value of maintaining acceptable low flow rates to both 'general river users' and 'non-river users'. These values relate to low flow rivers where alleviation measures are needed to avoid the occurrence of unacceptable flows. Benefits accruing can be related to both the provision of hydrometric data and other agency functions such as controlling licenses, pumping, etc.; the total benefit of data provision is arbitrarily set at 20% of the total willingness to pay.
Approach	(4) Benefits assessed within the context of a production function
Source of information	General river users' WTP is assessed at £0.05/km river /household/annum. Non-river users' WTP is assessed at £0.03/km river /household/annum. ERM (1997) shows that roughly 45% of population can be assumed to be 'users' and 55% as 'non-users': these values are recommended unless more locally specific data are available. It is recommended that component WTP values are found for each of the above, using the total number of households in the catchment area being assessed, and that these are then added. The total WTP should then be multiplied by 20% to give total benefit. Source: ERM report to Environment Agency (SW Region) 1997
Applicability	Low flow rivers - i.e. those where alleviation measures are required to avoid unacceptably low flows
Output	Annual benefit

Benefit	**Reduction of flood damages achieved through telemetry-based flood warnings**
Basis of assessment	Telemetry-linked hydrometric monitoring can provide benefits when used as the input to a telemetry-based flood warning scheme (FWS). The benefits are not wholly attributable to the monitoring because of the value of other functions (data interpretation, issue of warnings, etc.) so a nominal 10% scaling is applied to translate total benefit to the benefit arising from hydrometric monitoring. 10% is used rather than the 20% applied to the 'low flow problems' or 'avoided pumping costs' categories, to reflect the finding of the Environment Agency (1997) that the probability of an effective warning system lies in the range 0.378-0.504.
Approach	(1) Benefits of applying real-time data to reduce damages
Source of information	Annualised total benefits are routinely produced as part of the justification process for new FWSs, and may be available for existing schemes. Data are based on the expected annual average reduction in damages to be achieved by the issue of warnings.
Applicability	All catchments where FWSs are in operation, effected through the use of telemetry hydrometric data, and where annual benefit assessment have been made. Scale the estimated annual benefit by 10% to represent the benefit accruing from hydrometric monitoring.
Output	Annual benefit

Note: owing to the choice of test catchments, this benefit assessment method has not been tested by the research team.

Benefit	**Avoided pumping costs achieved by use of telemetry hydrometric data**
Basis of assessment	In conditions where pumping is necessary for water resources or other reasons, unnecessary pumping costs can be avoided by the collection and interpretation of telemetry-linked monitoring data. The benefits are not wholly attributable to the monitoring because of the value of other functions (data interpretation, decision-making and implementation functions, etc.) so a nominal 20% scaling is applied to translate total benefit to the benefit arising from hydrometric monitoring.
Approach	(2) Benefits of applying real-time data in resource management
Source of information	Water resources planning/operations staff. Benefit attributable to hydrometric data provision to be calculated on the basis of the difference in pumping costs between a scenario in which no hydrometric data are available, and one in which data provision allows pumping costs to be reduced/avoided. The resultant figure should represent the average annual benefit due to the use of hydrometric data, and should be scaled by 20% to represent the value of data in the overall benefit-producing process. *Beware of possible major difficulty arising from the 'no data' scenario being judged unrealistically hypothetical.*
Applicability	All catchments where hydrometric data are used in determining pumping operations.
Output	Annual benefit

Note: owing to the choice of test catchments and the unavailability of data elsewhere, this benefit assessment method has not been tested by the research team.

Note that under 'output', benefits are shown either as being annual benefits or total benefits. Annual benefits are indicated where the value obtained represents an ongoing benefit rate, whereas total benefits relate to some one-off investment. The means of representing the latter as an annual rate are discussed in Section 7.4.

Further benefit types may be developed - but those presented are thought to represent the main possibilities arising from the availability of appropriate methodological frameworks and data.

7. SCALING OF BENEFITS

In Chapter 6 (Figure 6.1), it was explained that the benefit values being produced directly from the economic methods should be regarded initially as base values representative of average benefits arising from average benefit situations. To translate these benefits into specific values, reflecting benefits in a specific situation, requires the inclusion of factors which take account of the relevant aspects of any instance of a benefit being accrued. It is vital that the methods to be put into practice, as a result of this research, do reflect actual conditions - in order that benefits can be compared with costs, and that the effects of network changes can be assessed. The purpose of this chapter is to outline the means by which the inclusion of locally specific factors is to be achieved.

The research has identified four types of scaling or benefit adjustment which are needed in order to fully reflect actual benefits. It should be noted at this early stage that the factors to be used for these purposes are often arbitrary in relation to their absolute magnitudes. Objective values suitable to this purpose would be used if available, but none are known. Nonetheless, the factors are presented as logically-sound ones based on physically-sensible principles, worthy of application in practice. A discussion of their utility is offered at the conclusion of this chapter. Each of the four types of scaling is now outlined in turn (Sections 7.1-7.4). Each of the scalings represents a means of translating base benefit values into component quantitative benefit values, by multiplication. Scalings may be used singly or in combinations; methods of combining scalings are explained in Section 7.5.

7.1 Scaling for Hydrometric Data Accuracy

In virtually all instances where hydrometric data are used to assist with decision making it can be argued that higher quality data will lead to higher quality decisions. In particular, high quality data will enable uncertainties to be reduced, whereas poor data may, in some cases, be worse than no data at all (e.g. the possible effects of artificially high 'measurements' of Q_{95} on licensing). It can thus be seen that the actual benefits derived from using hydrometric data will, in turn, be related to the quality of the data (more specifically the accuracy of the data), and in order to reflect this the potential benefit values identified in the literature need to be scaled accordingly. By applying this scaling to a benefit assessment, it may be found that some stations yield surprisingly small benefits. In such cases, consideration should be given to upgrading stations in order to help realise their potential, or to discontinuing operation where further expenditure does not seem to be warranted.

In attempting to scale the potential benefit values it is essential that the quality/accuracy of the data is first quantified in an objective manner. The Environment Agency already use a standard methodology for this, developed as a result of the hydrometric efficiency review undertaken by the NRA in 1995 (NRA, 1995). It is proposed that, where it is already implemented, this methodology is used as the basis for assessment of data accuracy.

As neither SEPA nor the Northern Ireland authorities have a similar methodology at present, it is also necessary to develop an alternative methodology which does not rely on the existing

NRA/Environment Agency approach. Whilst it may be desirable to have a single method that is used across the whole of the UK it will, at present, be necessary for the Scotland and Northern Ireland organisations to choose one approach or the other. As with other scaling factors it is important to ensure that once a method has been selected it is then used in a consistent manner when comparing different network configurations.

7.1.1 Scaling for data accuracy using the existing Environment Agency gauging station classification methodology

The Environment Agency system for classifying gauging stations is described in full in the NRA report 'Gauging Station Classification', produced in 1995 by the National Hydrometric Group (NRA, 1995). The classification is objective, and used statistical parameters to determine gradings of quality output, independent of how the data are derived. The system classifies a particular gauging station with respect to three flow indicators, namely the mean annual flood (MAF), average daily flow (ADF) and 95% exceedance flow (Q_{95}), and identifies these as high (H), medium (M) and low (L) flow indicators respectively. Four quality classes (1-4, on a 'good' - 'poor' scale) are then derived for each of these indicators in turn. The classification is completed by the inclusion of the period of record to which the classification applies, a site descriptor and a measure of the gauge reliability.

The system is based on two different methods, the 'empirical' applied to open channel sites which are rated by current meter, and the 'theoretical' which is based on the theoretical error associated with the conversion of levels to flow at sites where a British Standard gauging structure is used. The empirical method is based on the value of 2 times the standard error of the mean relationship (SMR) at the relevant point on the station rating curve. The error associated with 2xSMR gives a figure within 95% confidence limits. The theoretical method is based on the initial assumption that if a gauging station is built to BS3680, it will perform to the relevant theoretical equation. If this is the case then there is a high probability that the theoretical flow estimates will be within the percentage error bands given by the summation of the known and theoretical uncertainties for that structure. The theoretical classification is thus based on the theoretical error as described in the appendices of the relevant section of BS3680.

There are contrasting views on the validity and fairness of the classification system within the Environment Agency, and efforts have been made to take account of these in deriving the scaling factors. The following points have all been considered:

- It is recognised that hydrometric practices (and resources) vary within the Agency. Care has been taken to ensure that any proposed methodology does not favour one particular Region/Area or approach, whilst at the same time rewarding sound hydrometric practice and improvements in data quality.
- Different benefit types will, in turn, have different requirements for data quality. Some benefit types (some flood warning systems for example) may only need to use levels, yet these will rarely have been classified at stations where flows have been derived even though the methodology allows for this.
- It is considered that the classification system can, in some circumstances, favour 'BS structures', i.e. standard weirs or flumes. In particular, concern has been expressed that a

theoretical rating that has yet to be confirmed or validated carries the same classification as one which has been ratified by current meter calibration.

- It is accepted that in the majority of cases, for low and possibly mid range flows, it is reasonable to assume that such structures will perform as well as their theoretically derived classification would suggest. Consequently it is proposed that the scaling of benefit for data used from within this range is the same whether or not the classification has been confirmed.
- In contrast to this it is considered that for higher flows, particularly non-modular flows, there has to be greater uncertainty in the derived flows for a site where the theoretical rating has yet to be confirmed. This increase in uncertainty reduces the potential benefits arising from the data, and requires a different scaling to be applied.
- For the theoretically based classification to be used, whether confirmed or not, it is considered essential that the classification is only undertaken after the '*as built*' dimensions have been derived. Whilst these are known for many Environment Agency structures, particularly following recent Asset Surveys, many structures are presently classified on '*design*' dimensions. If this is the case it is proposed that the classification at such stations should be based on the empirical approach which forms the basis of the current-meter derived rating classification. Once stations have been surveyed they can then revert to the theoretical classification.

Whilst the above list of points is far from exhaustive they do serve to demonstrate just how complex the issue of scaling for data quality is, even when there is an existing method of gauging station classification. Although it makes sense to base the scaling factors on the existing classification, this is one particular area which would benefit from further research. Issues that might be studied are the distribution of different classification gauging stations, both within individual regions and across the whole of England and Wales, the proportion of gauging stations from within each classification, and a comparison of the different classification methods to confirm whether or not one approach produces more favourable results than another. Given this, care has been taken to ensure that the scaling factors do not reduce the potential benefits to unreasonably low levels. Instead, the factors that are proposed have been derived with the intention of enabling stations producing data of different quality to be differentiated whilst significantly reducing the benefit values in only the very worst cases. The proposed scaling factors are listed in Table 7.1.

Table 7.1 Proposed scaling factors for data accuracy, based on the gauging station classification system used by the Environment Agency (Standard accuracy terms defined in NRA, 1995).

Accuracy	Type of calibration			
	Level Only	**Empirical (2SMR)**	**Unconfirmed Theoretical**	**Confirmed Theoretical**
Low Flow, LF1, S1, T1, C1	110%	110%	110%	110%
Low Flow, LF2, S2, T2, C2	100%	100%	100%	100%
Low Flow, LF3, S3, T3, C3	90%	90%	90%	90%
Low Flow, LF4, S4, T4, C4	75%	75%	75%	75%
Low Flow, worse than 4	50%	50%	50%	50%
Mid Flow, MF1, S1, T1, C1	110%	110%	110%	110%
Mid Flow, MF2, S2, T2, C2	100%	100%	100%	100%
Mid Flow, MF3, S3, T3, C3	90%	90%	90%	90%
Mid Flow, MF4, S4, T4, C4	75%	75%	75%	75%
Mid flow, worse than 4	50%	50%	50%	50%
High Flow, HF1, S1, T1, C1	120%	120%	90%	120%
High Flow, HF2, S2, T2, C2	100%	100%	80%	100%
High Flow, HF3, S3, T3, C3	90%	90%	75%	90%
High Flow, HF4, S4, T4, C4	75%	75%	60%	75%
High flow, worse than 4	50%	50%	40%	50%

H/M/L=high/medium/low flow or stage range
F=flow descriptor, confirmed by gaugings
S=stage-only descriptor (insufficient gaugings for F descriptor)
T=unconfirmed BS3680 flow structure descriptor
C=confirmed BS3680 flow structure descriptor, confirmed by gaugings
Station quality: 1=good ... 4=poor;
2SMR=rating confirmed within 2 x standard error of mean relationship

7.1.2 Scaling for data accuracy using an alternative approach

An alternative method for scaling potential benefits according to the quality of the data has been developed for Scottish and Northern Irish hydrometric authorities. This approach has been developed knowing that, on the whole, these authorities derive flows using a rating equation derived from current meter gaugings and that it is only a very small minority of stations that are rated theoretically using BS 3680 equations for standard structures. As with the Environment Agency approach, the method produces scaling factors for low, medium and high flows, but takes account of differing hydrological conditions and the greater geographical spread of stations by using different criteria to separate these flow ranges. The details of this are explained in turn for each range of flows.

Scaling for low flows

Q_{95} is assumed to be the parameter of interest in the majority of low flow analyses. Scalings are proposed on the basis of annual frequency of gauging at or below the Q_{90} flow and assume that, where higher frequencies are involved, some gaugings will be at or below the Q_{95} flow. Scaling factors are given in Table 7.2 for gauging stations of both velocity-area and structural control types.

Table 7.2 Low flow accuracy scalings based on gauging frequency

Number of gaugings per year at flows of Q_{90} or less	Velocity-Area station	Structural Control
<0.5	25%	40%
0.5-0.9	75%	80%
1.0-1.9	100%	100%
2.0-3.9	110%	110%
>4.0	120%	120%

Scaling for flood flows

Here the ratio of highest ever gauging at the site to the highest recorded flow is taken as a measure of accuracy. Ratios are likely to vary considerably on a regional basis, but this is considered to reflect the difficulty of flood flow measurement. Proposed scaling factors are as follows (Table 7.3):

Table 7.3 High flow accuracy scalings based on gauging frequency

Highest gauging equal to or greater than	Flood accuracy scaling factor
90% of maximum recorded flow	130%
Average of MAF and max. recorded	120%
MAF	110%
0.75 x MAF	100%
0.5 x MAF	90%
ADF	80%
<ADF	50%

It is assumed that hydrologists applying this method will take into account material factors which would affect results, such as a change in the flood control of a site mid-way through a period of record. In such a situation, it may be assumed that only gaugings undertaken after the change would contribute to the accuracy of the station.

Scaling for mid-range flows

The approach proposed for assessing mid-range accuracy is similar to that for low flow accuracy in that it is based on the frequency of gauging with differentiation according to control type. However, to ensure that gaugings are taken in both the higher and lower parts of the mid-flow range, the proposed procedure involves summing scaling factors for the upper and lower parts of the mid-flow range (Table 7.4).

Table 7.4 Mid-flow accuracy scalings based on gauging frequency

Number of gaugings per year at flows between Q_{10} and Q_{50}	Velocity-area station	Structural control
<0.5	12.5%	20%
0.5-0.9	37.5%	40%
1.0-1.9	50%	50%
2.0-3.9	55%	55%
>4.0	60%	60%

Number of gaugings per year at flows between Q_{50} and Q_{90}	Velocity-area station	Structural control
<0.5	12.5%	20%
0.5-0.9	37.5%	40%
1.0-1.9	50%	50%
2.0-3.9	55%	55%
>4.0	60%	60%

SCALING FACTORS ARE OBTAINED BY ADDING TOGETHER ONE VALUE FROM EACH OF THE TWO MID-RANGE FLOW CATEGORIES

These procedures offer a consistent methodology so that hydrometric authorities can adjust base values to reflect actual levels of benefit likely to result from the different levels of data accuracy.

7.2 Scaling for Hydrometric Data Representativeness

This scaling is undertaken on the basis of the ratio of catchment areas between a point of data application/benefit and a gauging station used to deliver benefit for that point. In the case where a gauging station is upstream of a point of data application ("target point") the ratio *gauged catchment area: target point catchment area* is to be used. As the gauging station measures flow for successively smaller areas, so the scaling drops.

Conversely, where the gauge to be used is downstream of the target point, the scaling must be close to unity where drained areas are the same, and is required to reduce as the target point catchment becomes a successively smaller fraction of the gauged area, i.e. use the ratio *target point catchment area : gauged catchment area*. While other bases for scaling could be derived, this approach is commended on its physical basis.

While the use of catchment areas is recommended for standard application, it is recognised that certain project types warrant an *alternative approach*.

For projects involving the construction of *communications links* (routes of railway or road rather than single structures such as bridges), these often extend beyond the limits of any one gauged catchment. Where this occurs, the representativeness scaling should be given as the fraction of the scheme length occurring in the catchment being studied. Where all of the project lies within the catchment, however, the benefits can be seen to derive fully from data in the catchment of interest, and a 100% scaling is therefore justified.

Methods for other situations may be added to the list (see Section 10.2 - Recommendations for Research and Implementation).

7.3 Scaling for Period of Hydrometric Data Record

When considering the benefits arising from hydrometric data use, the extent to which a data user realises any potential benefit will often depend on the length of record. Consequently, it is necessary to scale the potential benefit to reflect specific circumstances and obtain figures which reflect the actual benefit derived from the use of the data.

In deriving a set of scaling factors for the period of record two issues need to be considered:
1. The general relationship between the length of record and the extent to which the potential benefit will be obtained.
2. The validity of this relationship, and subsequent scaling, will vary depending on the benefit type that is being assessed.

Each of these issues will be dealt with in turn.

7.3.1 The general relationship between potential benefit and length of record

It is reasonable to assume that, as the length of record of a hydrological dataset increases, the record becomes more representative, i.e. there is an increasing probability of conditions at either end of the flow regime being present within the data record. Therefore, as record length increases, the benefit which may be derived from it may be expected to increase. Previous research confirms this link, but shows that the record length-benefit relationship is not linear (Thomas, 1994), instead taking the form of the general relationship shown below in Figure 7.1. This shows three distinct phases in the relationship between benefit and data record:

1. Immediately after a gauging station has been constructed there will be a rapid increase in the actual benefits arising from the data record. This is because the data will quickly enable an indication of the hydrological response and characteristics of a catchment to be obtained. The reliability of this indication will rise rapidly as the record length increases. (Whilst this will, to a certain extent, depend on the proximity of other gauging stations within the same and neighbouring catchments, it is considered that to try and allow for this additional factor within the scaling will be too complex and inaccurate; a more pragmatic approach will be to consider this when assessing the validity and applicability of the total benefit assessment.) Nonetheless, where short periods of record place a limitation on the benefits which actually accrue from applying data in some situations, a scaling of less than 100% must be applied.

2. After a number of years the rate of increase of actual benefit with period of data record will decline and, in some cases, may level off. This occurs at the point when the actual benefit approaches the potential benefit. This phase represents the 'typical' conditions of a record being of sufficient length to quantify the hydrology of the catchment sufficiently well to enable the potential benefits to be derived. In turn, this reflects the 'average' conditions which previous authors have used to derive the potential benefit values which this study has proposed to be used within the assessments. Consequently, no scaling adjustment is applied to stations whose length of record falls within this phase.

3. Finally, and at present in the minority of cases, there is a third phase which indicates a rise in actual benefit *above* the potential benefit value. This represents data records which are significantly longer than 'typical' records, and which consequently offer greater benefits than 'typical' gauging stations. Such datasets offer a number of enhanced benefits which, whilst depending on the benefit type as outlined below, may result in the benefit value being scaled *above* those indicated in the literature.

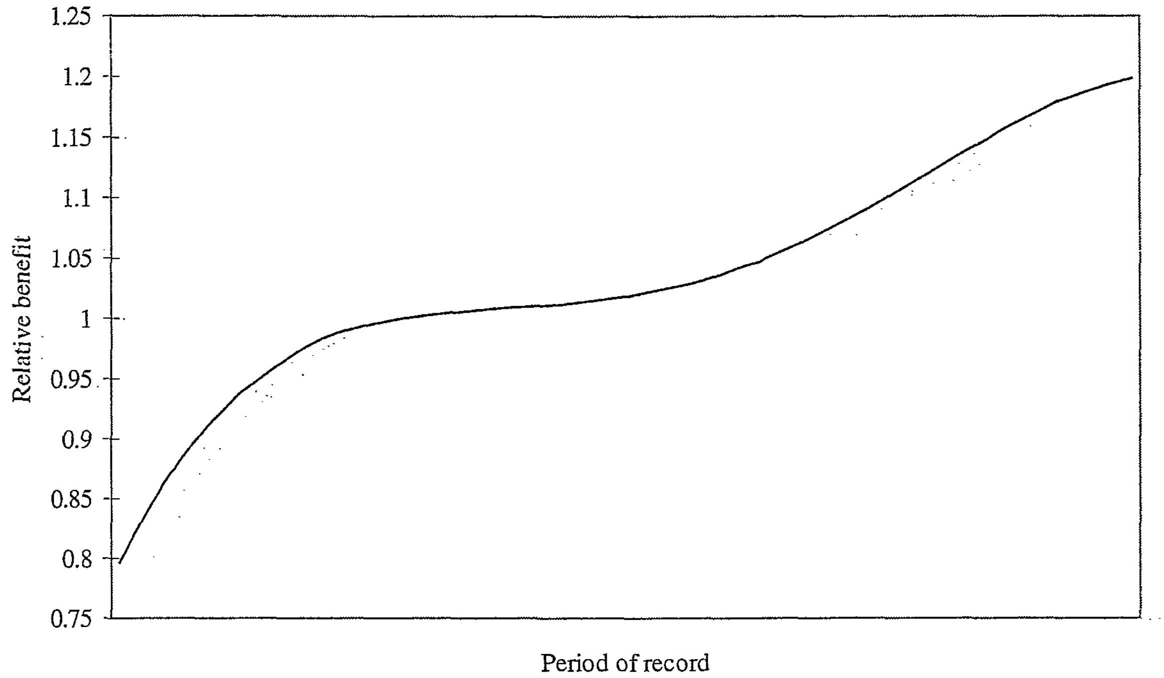

Figure 7.1 The general relationship between period of record and the relative benefit that might be derived from the use of the data. The nature and strength of the relationship will vary for different benefit types and gauging stations.

It is acknowledged that the above explanation has only considered the general relationship which has been found to exist. Whilst this provides a useful starting point in determining a suitable approach to scale the potential benefits according to the length of record, it must also be remembered that the duration of each of the different phases will vary according to a number of factors, including:

- Proximity of other gauging stations, particularly with reference to the third phase;
- The catchment physiology and topography;
- The hydrological response of the catchment, and whether or not the catchment type is reflected by another station within the network;
- Whether or not the period of record contains known drought or high flow events, enabling a short record to be placed in a wider context;
- The applicability of known, statistical methods to the catchment - for example, many of the 'standard' low flow estimation techniques are known to provide estimates that can, at best, be described as uncertain.

Given these factors and the paucity of published material relating to this issue it is considered that, at present, the length of each of the three periods can only be defined by means of a 'best estimate'. It is considered that, where necessary, these estimates may be adjusted by practitioners working in different geographic areas who have a greater feel for the 'typical' conditions within their networks and are able to place this within the wider framework. Further research and analysis, possibly starting with the length of records contained within the

National Water Archive, may in time allow the limits to be based on a more objective analysis.

Accepting these points, it is proposed that the scaling factors shown below in Table 7.5 are used to scale the potential benefits according to period of record from a gauging station:

Table 7.5 Proposed scaling factors to adjust potential benefit values for period of data record.

Length of record	1-5 years	6-10 years	11-30 years	>31 years
Scaling factor	80%	90%	100%	110%

Notwithstanding the qualifications made in the preceding paragraphs, the method presented here provides a means of formalising the increasing benefit which data users will experience as a function of increasingly long hydrometric records. It therefore allows assessments of total benefit being received from any network to be sensitive to the lengths of record contributing to those benefits. As a static network ages, the quantified benefits will increase, in line with the increasing value of the data to users. In the process of conducting a network review, it may be of interest to consider the effect of future period of record scalings for some point x years into the future, based on all other factors remaining constant. However, as mentioned above, not all benefits are expected to be sensitive to period of record, and so this point is now considered.

7.3.2 The validity of scaling the potential benefit for period of record

It has already been indicated that the need for, or validity of, scaling potential benefits for period of record will vary depending on the benefit type that is being considered. For example, whilst topics relating to the extremes of the flow regime, such as low flow alleviation or flood defence programmes, may benefit from longer periods of record, other users of hydrological data may consider that a shorter period of record may be sufficient for their purposes. Such projects might include:

- detailed studies to calibrate water quality models,
- determination of the relationship between river levels and/or flows, or
- yield assessment studies for hydro-electric/water supply **storage** systems
  (note that this is only true for systems utilising storage - those based on run of river supplies will benefit from longer periods of record).

It can thus be seen that when deriving benefit values for the different uses of hydrometric data, it will be necessary to consider whether or not this (and other) scaling types apply to the particular use being considered. Whilst it is possible to draw up a list of yes/no examples (see guidance in Section 7.5.2), there will always be exceptions to this, and it is felt that the person undertaking the assessment will need to be able to decide whether or not the scaling should apply.

By way of further reference to deviation from the methods outlined above, it is recognised that situations may arise where the most appropriate scaling may differ from that shown in the tables above. For example, data from a gauging station may have been used as part of a low flow study. Whilst the period of record from this station may be less than five years (and thus merit reducing by a factor of 80% according to Table 7.5), the presence of other gauging station(s) within the same catchment with longer datasets, and the occurrence of drought flows within the past five years, may allow the scaling factor to be ignored in this particular instance. The decision of whether or not this is applied must be taken by the person undertaking the review. If it is decided to 'override' the recommended approach they must ensure that a consistent approach is adopted when comparing different catchments or network configurations.

7.4 Annualisation of Benefit

This aspect concerns the difference between some benefits which can be seen to be accruing continuously, and others which apply over more limited periods of time. Some examples help illustrate this point:

1. In the case of the benefits of avoiding low flow alleviation problems, benefits are assessed through the willingness of a population to pay for the necessary measures. These are expressed on a per household per annum basis, and can be assumed to continue at the given level so long as no material change occurs, e.g. cessation of the need for low flow alleviation. The method of assessing this benefit gives an annual value, and is therefore in a form which will allow comparison with annual monitoring costs.
2. In relation to the construction of a major project, it cannot be expected that the benefits of hydrometric data application should continue at a constant level with time. In this case, recognition needs to be made of the unique nature of the benefit although, in attempting to recognise the long-term relation between benefits and costs, allowance should be made for other comparable projects which might yield comparable benefits. Methods of handling the benefits arising from major projects are discussed in the following paragraphs.

In order to make helpful comparisons of benefit and cost, all benefits should ideally be expressed in an annual form. The distinction drawn above illustrates, however, that this will not always be straightforward. While some benefits can be considered to accrue annually (type 1. above), a form of translation is required for major projects (type 2. above). Three essential problems exist here and are not readily reconciled:

1. the need to express capital sums in annual terms (solved by use of the annuity formula, but creating further problems, viz.:);
2. the periodicity/unevenness of these types of benefits; and
3. the problem of predicting future investments.

It is difficult to provide any method which could take account of all of these factors in a satisfactory way - in fact, any possible method which would fully cater for all such requirements would require so much information as to render it impracticable. A solution is proposed, however, which strikes an effective balance between academic rigour and practical considerations.

7.4.1 Methods for representing benefits accruing from investment projects

A - Recommended approach

Benefits from recent investments are to be estimated and used as representative of a long-term annual benefit from such. It is suggested that, in general terms, the value of such benefits varies regionally according to such factors as patterns of development. While an imperfect basis, it is further suggested that past investment decisions are used as a guide to the future level of benefit to be expected from investment decisions. The method proceeds thus:

1. A five-year period is to be used for simple averaging.
2. Over the five-year period, all major investment projects yielding benefits of hydrometric data use should be identified, and subject to the application of methods described in Chapter 6 for the estimation of benefit base values.
3. Each benefit value should then be subject to scaling for all other appropriate factors covered in sections 7.1-7.3 of this Chapter.
4. Once all benefits have been scaled in this way, they should be combined by simple addition, and the total divided by 5 to represent an annual benefit.

This approach does not address the time value of money at all. However, by taking a period which is long enough to allow for some smoothing of the year-to-year variability of major projects, while remaining short enough to allow identification of all qualifying major projects over the averaging period, a reasonable estimate should be achieved. Future benefit is in this way estimated using the recent past as a guide.

B - Alternative approach

In some cases it may be suspected (on the basis of local knowledge) that the result of applying this method is unrepresentative of the long-term norm - probably as a result of the dominant effect of one investment project yielding benefits much larger than historically may have been experienced. Dominance may be taken as >90% of total arising from one source. In these cases, an alternative approach is recommended, using a discounting approach.

For a major benefit to be assessed by this means, the scaled benefit value (after application of scalings detailed in Sections 7.1-7.3) should be annualised by multiplication by an annual equivalent factor (AEF):

$$AEF = i/(1-((1+i)^{-N}))$$

where i = discount rate (as a fraction of 1)
N = design life of project

(Source: Lumby, 1991)

The annualised benefit value may then be added to other benefits already in an annual form and scaled by appropriate factors, to provide a total annual benefit.

It should be noted, however, that the results of applying the AEF method will always be underestimates of total benefit wherever benefits from further investment projects may be expected to accrue in future - unless future investments can be predicted for some period, based on historical evidence; benefits could then be annualised using the differed annuity formula (as above).

It is recommended that, on completion of an approach (B) assessment, a comparison with the results of applying approach (A) is made. The user should satisfy him/herself that the more appropriate benefit assessment has been adopted before proceeding.

7.5 Addition of Benefit Values

7.5.1 Combination of benefit values from inherently annual and annualised sources

For those benefits arising from investment decisions, whether annual values have been obtained by (7.4.1 A) the recommended approach or (7.4.1 B) the alternative approach, the finally adopted value should be added to all those inherently annual benefit values (after appropriate scaling have been applied to them) to yield a Total Quantitative Benefit Value (Figure 7.2).

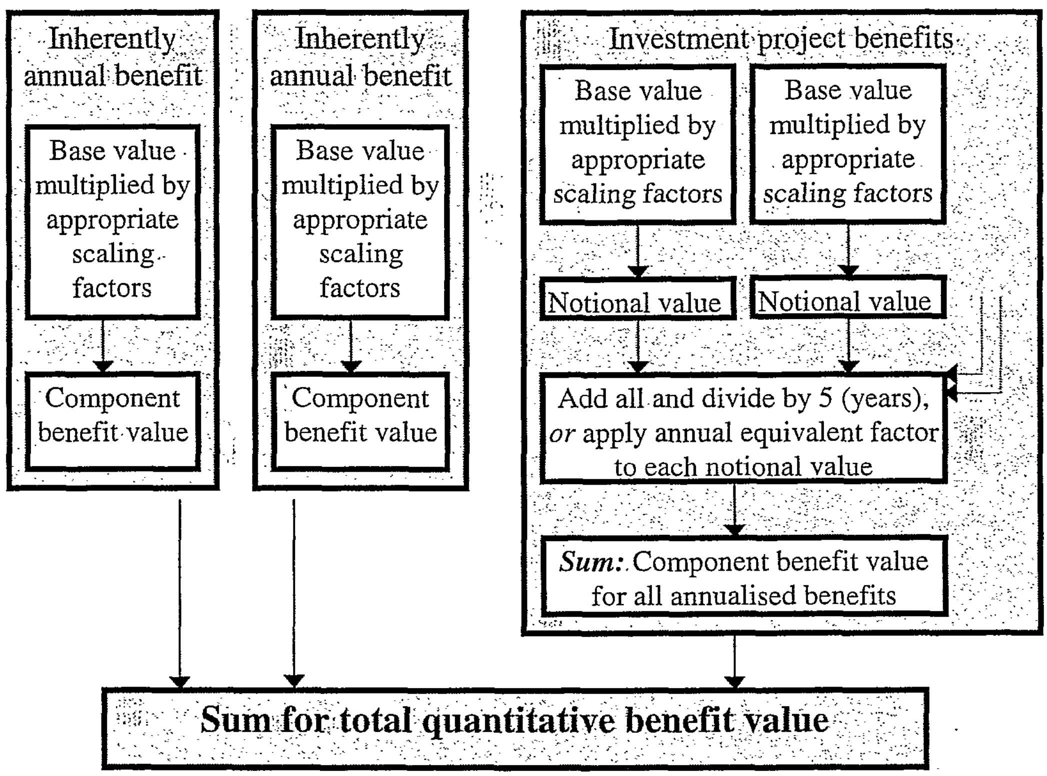

Figure 7.2 Combining benefits from inherently annual and annualised data sources

7.5.2 Summary of scaling combinations

At this point, having given the detail of how to implement or combine scaling procedures, it is worth summarising the scaling combinations which may be appropriate to any given assessment of a single benefit type: some scalings will always be necessary while others may not be, but the reality of a given situation will depend on the type of benefit being assessed. Table 7.6 indicates which scalings will be essential, situation-dependent and inappropriate, with benefit types based on the descriptions of Section 6.2.

Table 7.6 Guide to scalings required by benefit type

√ = required; ? = situation-dependent; blank = inappropriate

Benefit type	Accuracy	Representativeness	Record length	Annualisation
Flood warning	√	√		?
Improved design of flood protection works/other structures	√	√	√	√
Non-routine repair /maintenance of structures	√	√	√	?
Avoidance of excess pollution control costs	√	√	√	
Improved license setting/low flow alleviation	√	?	?	
Avoidance of costs of unsound HEP costs	√	√	√	
Avoided costs of pumping	√	√	?	

In each case, scalings are given as percentages, and to combine all relevant scaling factors with a base value, only a simple process of multiplication is needed.

e.g. Base value £1,200 * accuracy scaling 75% * representativeness scaling 80% * period of record scaling 110% = £792.

However, although this guidance is presented to assist the user in the consistent application of the methodology, it is anticipated that grounds could occur where some scaling was, unusually, either required or inappropriate in a way contrary to normal situations. In such a situation, a clear justification would be needed for departing from normal practice, and an awareness of the need for consistency would be important. Similar comments apply to the use of non-standard period of record scalings, as discussed in Section 7.3.2. With this in mind, the reader will appreciate the importance of the user having an understanding of the theoretical basis on which these methods have been derived.

In summary, the scaling methods presented here are comprehensive in the scope of factors they address, and should go a long way to helping ensure that component benefit values are representative of local conditions. This is vital for the comparison of benefits and costs to be meaningful, and it is important to note that benefits and costs of hydrometric data are equally liable to vary on both local and regional scales. As with all methods however, it is recognised that anomalous or difficult situations may occur, and research needs have been identified to help address some of these in detail, and in relation to improving the definition of scaling factors for accuracy, representativeness and period of record. Example benefit assessments using these scaling factors are provided in Chapter 9.

8. SOURCES OF INFORMATION

This chapter is presented to assist users in obtaining data prior to being able to implement the methods described in this report. It is divided into two sections, for the non-quantitative methods (Chapter 5) and quantitative methods (Chapter 6) respectively. The information is intended to provide a helpful guide to the user, but does not exclude the possibility of alternative data gathering strategies where these can be justified.

8.1 Sources of Data for Non-Quantitative Benefit Assessments

The structure of this section follows closely that of the Checklist of Data Benefits (Appendix VII), in order that guidance may be provided for each of its sections. Because of the broad scope of some of the checklist items, the guidance cannot be exhaustive, but points to a range of sources of information which should allow successful completion. It is anticipated that all information required for the checklist should be forthcoming from the various sections of a typical environmental agency area office: ultimately, the questions are all relevant to the interests and functions of water regulation

Part A The resource

A1 Catchment characteristics

Information	Source
Size of area, catchment rainfall data, mean actual evaporation	All information should be available from hydrometry staff. Note requirement for mean *actual* evaporation: this can be found from rainfall-runoff losses for wholly natural catchments; otherwise recourse to MORECS data will be necessary.
% of area which lies below 20m AOD contour	Digital elevation model (DEM) (if available). Otherwise approximation based on Ordnance Survey 1:50,000 maps will suffice.
Highest peaks	DEM/OS sheets
Geological information	Locally-available catchment descriptions may provide this information (e.g. in catchment planning documents). Otherwise BGS 1:625,000 or larger-scale maps (depending on catchment size) will be suitable.

A2 Uses of water

It is intended that this section can be completed entirely by the person responsible for the network assessment if he/she is well acquainted with the usage of water in the target catchment. Where the person is less familiar, all the necessary information should be readily available from personnel in the following functions:

- abstraction licensing;
- pollution control;
- water resources.

In Scotland and Northern Ireland where there is presently no licensing system for abstractions, organisational frameworks reflect local conditions but nonetheless information on major abstractors, their location and timing of usage should still be available from knowledgeable staff. Quantitative data may be necessary to answer such questions as "what is the primary use of water?".

Part B Current uses of data

Sections I and III

The first object of this important part of the checklist is to register the usage of hydrometric data being made for different purposes. This can be undertaken in one of two ways:

1. *Analysis of data request log sheets*[1] (preferred option). This will allow not only an objective response to whether data have been used for a given purpose over the past x months/years, but will also allow quantification of the level of usage for different purposes. Establishment of logging systems provides for the needs of any future scrutiny exercises and, if log sheets are accumulated over a number of years, allows the identification of trends in users needs (and thus may support future responsiveness in terms of network changes). Efforts should be made, in using this method, to quantify the level of usage made by staff members who have direct (and unrecorded) access to the hydrometric database.
2. *Consult users* (if log sheets are not available). This will only provide a qualitative response, but one which will nonetheless be valuable. The identification of data users internally will need to be guided by organisational arrangements reflecting local conditions and, for external users, may require consultation of many colleagues and perhaps follow-up telephone calls to external data users.

[1] Log sheets from at least one whole year should be consulted in order to give a representative view of data usage. It should be noted that some types of data request follow a seasonal pattern, and so part-year analysis may yield misleading results.

Section II

In addition to this first objective, it is intended that some supplementary information is collected - using the central columns of the checklist form (headed Telemetry ... Comments). Against each data use identified by the user, the opportunity is presented to collect information showing the requirements of the use in terms of telemetry provision, data accuracy at both low and high flow rates, and in other respects (using the Comments column). It is suggested that informal discussion or correspondence with (primarily internal) data users is the only effective means of expeditiously obtaining the desired information for this part of the checklist. Discussion provides the advantage of the opportunity for dialogue.

The collection of this information will then allow a comparison of user-perceived needs with actual performance. Where benefits fall within the scope of quantitative benefit assessment, the scaling mechanism for accuracy should reflect the difference between potential benefit and actual. Whether or not quantitative benefit assessment is undertaken, the collection of this information at this stage will allow its inclusion in any scenario-testing or decision-making which follows the initial network assessment. Where it is undertaken, the opportunity is provided for some assessment of the value of the quantitative methods provided.

Value may be added to this procedure if comparison can be made with either the number of uses, or the number of requests made for data in the chosen network, in relation to those pertaining to other networks which might already have been subject to the same exercise. The results of such a comparison should be recorded in paper form and included with the result of the network assessment.

Part C Potential future uses of data

This part of the checklist must be recognised as by far the most challenging. No simple or easy approach can be recommended for identifying changes in the future requirements for hydrometric data. Nonetheless, the results of some considered thought, reported alongside those of applying more direct methodologies, must be recognised as offering potentially useful guidance to the decision-maker.

It is suggested that:

- consideration be given to recent trends in data usage (both type and quantity),
- the opinions of some senior/experienced hydrometric staff be sought, and
- no hard rules be established regarding what can and cannot be included in this section - only that any comments are well justified.

Part D National network/baseline monitoring utility

All information required for assessing station status in relation to the Baseline Monitoring Criteria should be obtained from the hydrometric records of the hydrometric authority. Internally used station descriptions, and/or entries in the latest Institute of Hydrology *Hydrometric Register & Statistics* may be used.

Assessment of the status of a station in relation to the IH's core national network, or in terms of its value for detecting climatic change or indicating sustainable resource use, should be done by reference to listings and criteria expected from the Institute in late 1998 or 1999.

8.2 Sources of data for quantitative benefit assessments

This section is provides guidance on information sources for each of the methods of benefit assessment described in Chapter 6.

Benefit type: Improved design of bridges and culverts

Information	**Source**
Construction cost of project	Consult client (e.g. Highways Authority, County Council, Unitary Authority, Railtrack, company/private individual). Ensure that the figure obtained is a construction cost and not an overall scheme cost (which might also include such elements as legal, compulsory purchase, etc. costs).
Annual cost of bridge/ culvert maintenance	For any ongoing programmes (e.g. local authorities), ensure figure is for typical annual budget to cover *occasional* maintenance works which are expected to require the use of hydrometric data.

Benefit type: Avoidance of costs of inappropriate hydro-power investment

Information	**Source**
Scheme installed capacity	Use formula capacity (kW) = W Qi H η *where*: W = constant (specific weight of water) 9.81 kN m^{-3} Q_i = installed flow (m^3s^{-1}) H = head (m) η = overall efficiency Recommended method for estimating Q_i (if not known) is $Q_i = (Q_{mean} - Q_{95})$ as recommended by ETSU (1989), where Q_{mean} = long-term average flow (m^3s^{-1}), and Q_{95} = 95-percentile flow (m^3s^{-1}) H is entirely site-specific η is the expected fraction of a year in which the scheme is expected to operate. It should be obtained from the potential developer wherever possible; normal values lie in the range 40-60% for run-of-river schemes and 90-100% for storage schemes
Sale price of electricity (per unit) to grid	4.2p at time of writing Updates available through Department of Energy (England/Wales/Northern Ireland) or Scottish Office (Scotland only) (Non-Fossil Fuels Obligation/Scottish Renewables Obligation)
All other information	See Chapter 6 (p32)

Benefit type: Avoidance of excess pollution control costs

Information	Source
Actual population equivalent (PE) being serviced by sewage treatment works	Enquire of sewerage treatment utility company
Variable treatment cost (for plant with PE>=5000)	See formula (Chapter 6)
Variable treatment cost (for plant with PE<5000)	Enquire of sewerage treatment utility company (for such small works, costs are very difficult to generalise)

Benefit type: Improved determination of abstraction licenses/avoidance of low flow problems

Information	Source
Catchment population data (number of households)	Information may be held in regional/area environmental agency offices for river basins. Otherwise, reference should be made to census data.
River length	Use main river length, defined by environmental agencies for their own and external use, for the catchment under review. Measure in km.

Benefit type: Improved design of flood protection works

Information	Source
Construction cost	Consult client. Ensure that the figure obtained is a construction cost and not an overall scheme cost (which might also include such elements as legal, compulsory purchase, etc. costs).

9. APPLICATION OF QUANTITATIVE METHODS (WITH WORKED EXAMPLES)

9.1 Introduction

To assist with the development of the proposed methods during the course of the project, three case study catchments were used. Two of these were recommended by the Project Board and the third was selected as it was known that a recent project had relied heavily on the use of hydrometric data. The three catchments were:

1. The Bollin, in the South Area of the North West Region of the Environment Agency.
2. The Foyle, in the north west of Northern Ireland.
3. The Tay, in the East Region of SEPA

These provided a realistic insight into the practicalities of applying the methods to real data, as well as providing a feedback mechanism to the research. By gaining experience of this sort, a practical perspective is obtained which will assist the development of a manual (in the form of a R&D Note) for future release as a guide to those responsible for undertaking network evaluations and reviews in the future (see Section 10.3). In particular, the following general points were discovered during the course of the case study evaluations:

1. On the basis of the experiences encountered during the project it is considered that the proposed benefit assessment methods should only be undertaken by personnel working within the hydrometric authorities, preferably within the hydrometric function, and who are familiar with the working structure of their Region/Area. Even though the catchments had been proposed by the Project Board as part of a national R&D project numerous problems were encountered with obtaining relatively straightforward data from the administrative structures operated by the Environment Agency.
2. This observation is further supported by the fact that a working knowledge of the catchment and the processes taking place in it are highly desirable in order to fill in the checklist efficiently.
3. The data will need to be collected from a variety of agency functions.
4. Whilst efforts have been made to ensure that wherever possible a review can be undertaken using mainly hydrometric and hydrological data, data are also required from external sources. Depending on the circumstances, these might include population totals for a catchment and current prices for hydro-power outputs etc. In particular, there is likely to be a need to obtain data from the relevant water supply companies (see Chap. 8).

The following pages contain a number of worked examples that were used during the case study stage of the project. Examples are not provided for all benefit types, but a range of examples are provided, together with different examples of the same benefit type within one catchment. It can be seen from these that, even though the requests for some of the data were made more than six months before the writing of this report, not all of the assessments are complete, because of missing data.

Each worked example consists of two parts; the left hand page contains a narrative on the issues to be considered under each heading of the assessment proforma, whilst the right hand page details the actual data and calculations. *All italic text is the narrative.* In order to keep worked examples on a single page wherever possible, the first two categories (i.e. 'Test catchment' and 'Benefit type') have been omitted in some cases.

9.2 Bollin Catchment Case Study Worked Examples

9.2.1 Manchester airport extension

Test catchment
Indicate catchment/network to be reviewed

Benefit
Identify benefit type

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature. The literature confirms that typical benefit values can be derived from construction costs (excluding legal/planning fees)

Data required
Project costs
Gauging station(s) used for the assessment, & details of catchment areas etc.;
Gauging station classification
Length of period scanned for projects of this type

Calculation of potential benefit
The large scale of this project and the consequently sensitive nature of its costings make detailed data difficult to obtain for this project. However, a total construction cost of £172 million (1993 Q3 prices) has been provided, and it is known that because a major river crossing for the runway is involved in the project, then real benefits should be expected to accrue from the use of hydrometric data. Typical benefit values are 1% of the total construction cost.

Scaling for data accuracy
Reference to Chapter 7 provides details of data accuracy scaling based on the Environment Agency classification system. As the high flows are the main source of data for the design specification, the scaling for this category is the most appropriate.

Scaling for data representativeness
The site is a short distance downstream of the Bollin/Dean confluence, and a short distance downstream of the 2 gauging stations on those watercourses respectively. Taking the two gauges as a combined catchment area, the ratio of this area to that draining to the site gives a ratio of 89%.

Scaling for period of record
Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit
For the same reasons as for other major capital projects, it is proposed to distribute this benefit over 5 years (the period scanned to identify such projects). A scaling of 20% is therefore proposed to account for period of benefit.

Component benefit assessment
Base value benefit scaled for data accuracy, data representativeness, period of record and period of benefit.

Test catchment
Bollin

Benefit
Improved design of bridges and culverts - (1) Manchester Airport Runway 2.

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature

Data required
Project costs - £172 million (1993 Q3 prices)

Wilmslow GS - LF(2) MF(4) HF(2)
Stanneylands GS - LF(3) MF(3) HF(3)
89% of development area is covered by the above two gauging stations

5 year period scanned for project

Calculation of potential benefit
Potential benefit can be assessed as 1% of scheme construction costs, i.e. £1.72 million.

Scaling for data accuracy
Wilmslow - scaling factor of 1.0 applies
Stanneylands - scaling factor of 0.9 applies

Combined scaling factor is thus 0.95

Scaling for data representativeness
Ratio of combined gauging station catchment area to development site is 0.89.

Scaling factor is thus 0.89

Scaling for period of record
Wilmslow = 25 years, scaling factor 1.0
Stanneylands = 31 years, scaling factor 1.1

Combined scaling factor thus 1.05

Scaling for period of benefit
This benefit arose within a five year timescale. A scaling of 0.2 is therefore used.

Component benefit assessment

Assessed as £1,720,000 * 0.95 * 0.89 * 1.05 * 0.20 = £305,394 pa

9.2.2 A34 by-pass

Basis of benefit assessment

Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature. The literature confirms that typical benefit values can be derived from construction costs (excluding legal/planning fees)

Data required

Project costs
Gauging station(s) used for the assessment, & details of catchment areas etc.;
Gauging station classification
Length of period scanned for projects of this type

Calculation of potential benefit

The large scale of this project and the consequently sensitive nature of its costings make detailed data difficult to obtain for this project. However, a total construction cost of £60 million (excluding indirect costs such as planning, land purchase etc.) has been provided, and it is known that because major river crossings are involved in the project, then real benefits should be expected to accrue from the use of hydrometric data. Typical benefit values are 1% of the total construction cost.

Scaling for data accuracy

Reference to Chapter 7 provides details of data accuracy scaling based on the Environment Agency classification system. As the high flows are the main source of data for the design specification, the scaling for this category is the most appropriate.

Scaling for data representativeness

Benefits arise from application of hydrometric data to the construction of both major and minor river crossings. A simple measure which can be obtained by the hydrologist is the fraction of a capital project which is located within a catchment of interest. In this case, some 70% of the route length of the project lies within the catchment of the Bollin and its tributaries. The remainder lies within the Mersey catchment to the north. (Incidentally, the two major river crossings of the A34 by-pass are almost immediately adjacent to gauging stations on the River Bollin and its main tributary the River Dean. However, no information is available locally for the smaller watercourses of the area.)

Scaling for period of record

Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit

For the same reasons as for other major capital projects, it is proposed to distribute this benefit over 5 years (the period scanned to identify such projects). A scaling of 20% is therefore proposed to account for period of benefit.

Component benefit assessment

Base value benefit scaled for data accuracy, data representativeness, period of record and period of benefit.

Test catchment
Bollin

Benefit
Improved design of bridges and culverts - (2) A34 by-pass project

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature. Typically, benefit values are of the order of 1% of construction costs.

Data required
Project costs - £60 million

Wilmslow GS - LF(2) MF(4) HF(2)
Stanneylands GS - LF(3) MF(3) HF(3)
70% of development is covered by the above two gauging stations

5 year period scanned for project

Calculation of potential benefit
Potential benefit can be assessed as 1% of scheme construction costs, i.e. £600k.

Scaling for data accuracy
Wilmslow - scaling factor of 1.0 applies
Stanneylands - scaling factor of 0.9 applies

Combined scaling factor is thus 0.95

Scaling for data representativeness
Proportion of development falling within gauged catchments is 70%. Thus, a scaling of 0.7 should be applied.

Scaling for period of record
Wilmslow = 25 years, scaling factor 1.0
Stanneylands = 31 years, scaling factor 1.1

Combined scaling factor thus 1.05

Scaling for period of benefit
This benefit arose within a five year timescale. A scaling of 0.2 is therefore used.

Component benefit assessment
Assessed as £600,000 * 0.95 * 0.7 * 1.05 * 0.2 = £83,790 pa.

9.2.3 Cheshire County Council maintenance of structures

Test catchment
Indicate catchment/network to be reviewed

Benefit
Identify benefit type

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature. The literature confirms that typical benefit values can be derived from construction costs (excluding legal/planning fees)

Data required
Project costs and details
Gauging station(s) used for the assessment, & details of catchment areas etc.;
Gauging station classification
Length of period scanned for projects of this type (only if benefits <u>*not*</u> *calculated as annual)*

Calculation of potential benefit
CCC annual budget (1997 prices) is of the order of £600k for the maintenance of structures; 1% of the pro-rata budget is thus the total potential annual benefit.

Scaling for data accuracy
Reference to Chapter 7 provides details of data accuracy scaling based on the Environment Agency classification system. As the high flows are the main source of data for the design specification, the scaling for this category is the most appropriate.

Scaling for data representativeness
Benefits arise from application of hydrometric data to the construction of both major and minor river crossings. A simple measure which can be obtained by the hydrologist is the fraction of a capital project which is located within a catchment of interest. In this case, dealing with an annual maintenance programme, it is appropriate to scale the total area covered by the budget to that covered by the gauged catchments.

Scaling for period of record
Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit
As the data are based on an annual budget figure, no scaling is required for period of benefit.

Component benefit assessment
Base value benefit scaled for data accuracy, period of record and data representativeness.

Test catchment
Bollin

Benefit
Improved design of bridges and culverts - (3) Cheshire County Council maintenance of structures

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature

Data required
Project costs - £600k per annum

Wilmslow GS - LF(2) MF(4) HF(2)
Stanneylands GS - LF(3) MF(3) HF(3)
Dunham Massey GS - LF(1) MF(1) HF(1)

15% of area to which budget applies is covered by the gauging stations

Calculation of potential benefit
1% of total scheme costs, i.e. £6k

Scaling for data accuracy
Wilmslow - scaling factor of 1.0 applies
Stanneylands - scaling factor of 0.9 applies
Dunham Massey - scaling factor of 1.2 applies

Combined scaling factor is thus 1.03

Scaling for data representativeness
Data uses and therefore benefits are distributed widely throughout the catchment and must vary from year to year. As 15% of the area to which the budget is applied is covered by the hydrometric network, a scaling of 0.15 is applied.

Scaling for period of record
Dunham Massey = 22 years, scaling factor 1.0
Wilmslow = 25 years, scaling factor 1.0
Stanneylands = 31 years, scaling factor 1.1

Combined scaling factor thus 1.03

Scaling for period of benefit
Annual benefit data used.

Component benefit assessment
Assessed as £6,000 * 1.03 * 0.15 * 1.03 = £955 pa

9.2.4 Quarry Bank Mill Hydro Scheme

Benefit
Identify benefit type

Basis of benefit assessment
This is a rather unusual and complicated case study which demonstrates the flexibility of the approach that has been developed. The potential benefit in this instance relates to the avoided losses arising from the use of hydrometric data to assess the viability of a proposed hydro-electric scheme.

Data required
Project costs and details of the government subsidy/contract relating to schemes of this type
Gauging station(s) used for the assessment, & details of catchment areas etc.;
Gauging station classification

Calculation of potential benefit
Wherever possible costs have been linked to scheme capacity to enable the method to be applied to similar examples.
In order to identify the potential benefit it is necessary to determine the typical annual income that the scheme will yield, and relate this to the typical annual costs that the scheme will need to meet to be viable. Run of river schemes typically operate for 45% of time at full power equivalent based on flow duration curve (derived from 25% at full power, and the remainder at lower power). To ensure that a conservative estimate is derived, it is suggested that a value of 50% of the year is used for the period of time that the scheme will be operational. This value may differ for alternative schemes.

Scaling for data accuracy
Reference to Chapter 7 provides details of data accuracy scaling based on the Environment Agency classification system. As most run-of-river schemes are designed to operate within the Q_{80} - Q_{10} range scaling for the middle flow category is the most appropriate.

Scaling for data representativeness
Gauging station data for the project was derived from two gauging sites (on the main stem and its main tributary to Bollin), measuring flow for more than 90% of the area draining to the site of interest. This represents a high degree of representativeness. It is of fundamental importance that the benefit arises from use of observed data, these being inherently superior to use of theoretically derived flow duration curves.

Scaling for period of record
Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit
As the data are based on an annual budget figures, no scaling is required.

Component benefit assessment
Base value benefit scaled for data accuracy, period of record and data representativeness.

Basis of benefit assessment
The value of the data is equivalent to the avoided losses.

Data required
Suggested installed capacity for Bollin site is 240 kW
Scheme capital cost = £1,000 * power (kW) = £240,000 (*general figure*)
Wilmslow GS - LF(2) MF(4) HF(2)
Stanneylands GS - LF(3) MF(3) HF(3)
90% of scheme catchment area is represented by the two gauging stations

Calculation of potential benefit
Maximum annual revenue @ 4.2p per unit determined by:
kW capacity x unit charge x 24 hours x 365 days x % of time generation possible
= 240 x 0.042 x 24 x 365 x 50%
= £44,150

Annual costs for scheme to be viable (various sources)	
10% payback of capital expenditure	£24,000
10% return on capital investment	£24,000
Rent to landowners/water charges at £10,000 per MW	£ 2,400
Rates at £10,000 per MW	£ 2,400
Insurance at £5,500 per MW	£ 1,320
Wages/operational costs at £5-6,000 minimum per site	£ 5,500
Admin. and scheme management costs at £6,000 per site	£ 6,000
TOTAL annual income to break even	£65,620

Annual avoided loss thus equivalent to £65,620 - £44,150 = £21,470 = potential benefit

Scaling for data accuracy
Wilmslow - scaling factor of 0.75 applies
Stanneylands - scaling factor of 0.9 applies

Combined scaling factor is thus 0.825

Scaling for data representativeness
90% of scheme catchment is covered by the gauging stations, scaling factor is thus 0.9.

Scaling for period of record
Wilmslow = 25 years, scaling factor 1.0
Stanneylands = 31 years, scaling factor 1.1

Combined scaling factor thus 1.05

Scaling for period of benefit
Annual data - no scaling required.

Component benefit assessment
Assessed as £21,470 * 0.825 * 0.9 * 1.05 = £16,739 pa

9.2.5 Abstraction licence determination & low flow alleviation

Test catchment
Indicate catchment to be reviewed

Benefit
Identify benefit type

Basis of benefit assessment
Willingness to pay (WTP) for the maintenance and improvement of flow regime has been studied for the rivers of south-west England. WTP values have been found for both 'general river users' and 'non-river users'. Values are:

General river users:	*£0.05/km river/household/year)*	*to be based on population*
Non-river users:	*£0.03/km river/household/year)*	*of catchment area*

(Typical split of population is 55% river users/45% non-river users, so weighted average of £0.041/km river/household/annum can be used as typical WTP.)

Information from the Environment Agency (North West Region) indicates that because of summer agricultural abstractions, there is a low flow risk and the abstractions have to be managed carefully to avoid this situation. On this basis, results of the Darent study are considered to be transferable to the Bollin. However, for direct applicability to be justified, it would need to be assumed that the environmental characteristics of the Bollin were the same as those of the south-west, and similarly that the population characteristics of those willing to pay (e.g. income, age distribution, interests) were the same in both cases. This is unlikely to be true, but nonetheless, it is hoped that these data will be of good indicative value.

This basis would not be applicable to a catchment where no serious risk of low flows was likely.

Data required
Access to case studies such as that indicated above
Number of households in catchment
Gauging station(s) used for assessment, details of catchment areas, length of main river, etc. gauging station classification

Calculation of potential benefit
A lower bound to the total WTP value may be obtained by multiplying the product of the catchment number of households and the length of main river by the Willingness To Pay (WTP) value.

However, this assumes that all of the benefit derives only from application of the hydrometric data, counting nothing for the abstraction determination/licensing and enforcement functions of the Environment Agency. A hydrometric data benefit of 10% of the total assessed from WTP is considered to be a conservative value, and is proposed as an approach to be applied consistently in assessment of this type.

(Continued on page 70)

Test catchment
Bollin

Benefit
Improved determination of abstraction licenses/avoidance of low flow problems

Basis of benefit assessment
Previous research has indicated that people are willing to pay to prevent rivers from suffering extreme drought conditions. Where such conditions can be prevented there is a potential benefit equivalent to the WTP value. The basis of this assessment is that a proportion of this benefit is attributable to the use of hydrometric data.

Data required
WTP value of £0.041/km river/household/year
Catchment population is 55,000 households
Main river length in catchment: 55 km
Wilmslow GS - LF(2) MF(4) HF(2)
Stanneylands GS - LF(3) MF(3) HF(3)
Dunham Massey GS - LF(1) MF(1) HF(1)

Calculation of potential benefit
A lower bound to the willingness to pay may be obtained from the resident population of the catchment, (55,000 households), and the main river length (55 km).
With a WTP of £0.041/km river/household/year, this gives a potential benefit of £124,025 pa.

A hydrometric data benefit of 10% of the total assessed from WTP is considered to be a conservative value, and is proposed as an approach to be applied consistently in assessment of this type. Potential benefit therefore becomes £12,403.

(Continued on page 71)

Scaling for data accuracy

Low flow data, at around the Q_{95} *flow, are central to the derivation of this benefit. Abstractions are located throughout the catchment, and so data from all three gauging stations in the catchment are necessary to derive the scaling factor.*

As with some other test applications, this example reveals a possible shortfall in the proposed approach. Whilst it is meaningful to assess the accuracy of the low flow data provided by the three gauging stations within the catchment, the approach may initially result in lower benefits if a new gauging station were to be built. This is because it will take a number of years/low flow events to develop/confirm the rating and, during this period, the accuracy is likely to result in a lower accuracy scaling factor than that of the three existing stations. Consequently, the overall accuracy scaling factor will be lower. However, the change in the final benefit assessment will depend not only on accuracy scaling but also on representativeness scaling, for which there should be an increase.

Scaling for data representativeness

Abstractions occur in all parts of the catchment, and it could be considered that the current disposition of 3 gauging stations is broadly appropriate to abstraction licensing needs in the catchment. However, it could equally be argued that the establishment of more stations would improve data representativeness, and that the converse would apply with fewer stations. A means is required to cope with the distributed nature of the abstractions around the catchment. It is proposed that a method be developed which would use the largest n abstractions in the catchment, and for each assess the representativeness of available hydrometric data. This has not yet been possible within the process of testing in this catchment and, for the sake of illustration only, it is assumed that a scaling of 50% should be applied to reflect a wide distribution of abstractions in relation to gauging sites.

(Note - further research into gauged catchment area: population or licence ratios may enable this suggestion to be quantified in a more objective manner)

Scaling for period of record

Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit

The data provided are annual rates - no further scaling is required for this factor.

Component benefit assessment

Base value benefit scaled for data accuracy, period of record and data representativeness.

Scaling for data accuracy
Dunham Massey - 1.1
Wilmslow - 1.0
Stanneylands - 0.9

Average scaling factor is thus 1.0.

Scaling for data representativeness
Following discussion contained in narrative, a scaling factor of 0.5 is suggested.

Scaling for period of record
Dunham Massey = 22 years, scaling factor 1.0
Wilmslow = 25 years, scaling factor 1.0
Stanneylands = 31 years, scaling factor 1.1

Combined scaling factor thus 1.03

Scaling for period of benefit
The data provided are annual rates - no further scaling is required for this factor.

Component benefit assessment
Product of the above = £12,403 * 1.0 * 0.5 * 1.03 = £6,388

9.2.6 Pollution control costs

Test catchment
Indicate catchment to be reviewed

Benefit
Identify benefit type

Basis of benefit assessment
Hydrometric data are necessary for the accurate setting of consent standards for discharges. In the absence of such data, questionnaire survey indicates that consent setting would be more cautious, typically by 20%. Consents are reviewed on a regular basis as a means of responding to changing catchment and regulatory conditions. It therefore follows that the collection of hydrometric data results in a benefit through the avoidance of those excess pollution control costs which would otherwise be borne if standards were higher (as a result of a lack of data). For reasons of simplicity this case study only relates to benefits arising through the setting of consents for STWs. Where it is known that significant industrial discharges occur these may merit separate assessment in areas where they are licensed directly by the hydrometric authority.

Data required
Gauging station details and classification - for gauge(s) relating to each discharge
Details of catchment areas draining to STW/Industry, or proportion of this gauged by gauging station, together with details of major STWs/discharges

Calculation of potential benefit
Population equivalent values for the major STWs can be combined with typical treatment costs (data will need to be provided by water companies). These values can then be scaled by 0.2 to represent the avoided costs of over-cautious treatment. The derived values for each STW can then be summed to give the total potential annual benefit. It is recognised that a single factor of 0.2 oversimplifies the reality of what is often a complex industry. Effluent treatment costs are heavily linked to capital expenditure, which will not provide a linear relationship with target standards.

Scaling for data accuracy
As for alleviation of low flows, this benefit type is based on low flow measurement, and the requirement for accuracy must reflect this. Scaling factors from Chapter 7 need to be obtained for the low flow range.

Scaling for data representativeness
It is suggested that to scale potential benefits according to the location of gauging stations relative to data benefit points (e.g. STW), a ratio of catchment areas should be used as indicated in Chapter 7.

(Continued on page 74)

Test catchment
Bollin

Benefit
Avoidance of excess pollution control costs

Basis of benefit assessment
Research has shown that if no observed flow data are available for a receiving watercourse, consent conditions will be tightened to ensure that potential pollution events are minimised as far as possible. Typically, consents would be 'tightened' by 20%. On the basis of questionnaire/interview responses, the potential benefit provided by the use of hydrometric data is related to 20% of the existing variable treatment costs of the effluent.

Data required
Dunham Massey GS - LF(1) MF(1) HF(1) - most appropriate gauge to all works, because of their position in the lower catchment.
Other data are detailed in individual categories below.

Calculation of potential benefit
Population equivalent values for the major sewage works in the Bollin catchment were obtained, and related to estimated treatment costs (obtained from a curve based on data supplied by an English Water Company). Results for the five works are given in the table:

Works	**Population equivalent**	**Est annual cost (£)**	**Est benefit (@20%) (£)**
Hale	15,200	64,425	12,885
Alderley Edge	14,100	60,835	12,617
Knutsford	12,800	61,510	12,302
Bowdon	4,700	51,990	10,398
Mobberley	3,600	50,760	10,152

Summing the right-hand column, the total potential benefit arising from data application at these works is £58,354.

Scaling for data accuracy
Dunham Massey - 1.1

Scaling for data representativeness
Individual catchment area ratios for each of the STWs were obtained:

Hale	Bollin u/s of confluence with major tributary	70%
Alderley Edge	on Mobberley Brook (ungauged)	5%
Knutsford	on Birkin Brook (ungauged)	12%
Bowdon	Bollin u/s of confluence with major tributary	70%
Mobberley	on Mobberley Brook (ungauged)	10%

(Continued on page 75)

Scaling for period of record

Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit

These are annual data, and no scaling in this respect is therefore required.

Component benefit assessment

Base value potential benefit value scaled for data accuracy, period of record and data representativeness

Notes

This example illustrates a conceptual difficulty with the present 'scaling for data representativeness' methodology that is proposed. Much of the UK hydrometric network is based on obtaining data from representative areas, and applying this to catchments which are not gauged but have similar catchment characteristics. Whilst neither the Mobberley or Birkin Brook catchments contain a gauging station, their outflows are part of the flow gauged at Dunham Massey. However, the fraction of runoff they contribute to Dunham Massey is small, and the representativeness scaling values are therefore very small (5-12%), i.e. a major benefit reduction is proposed. Whether the scaling by area ratio is the most desirable/applicable method must be a matter for conjecture, but has been adopted at present to ensure that a consistent approach is used. Further work will undoubtedly improve the situation. The adopted approach must be robust, and must be sensitive to the addition of a new gauging station within an ungauged catchment.

Substantial scope may exist for siting a new gauge within the Mobberley Brook catchment - benefits accruing from accurate consent setting for just one STW (e.g. Alderley Edge, Mobberley) with a ~100% accuracy scaling and a high representativeness scaling could more than justify the annual running costs of a new station.

Finally, this worked example also highlights the problems associated with the use of the Environment Agency gauging station classification system. Stations in the Bollin catchment generally appear to have been gauged frequently at low flows, although EA information for Dunham Massey GS at the catchment outfall describes "severe weedgrowth and [site] has no stable control; flow measurement is therefore poor ...". Consequently, whilst the theoretical low flow classification may be of the highest category, it can be seen that those who are actually responsible for operating the station believe that this does not reflect the true situation. In this instance, the total benefit value is likely to be an overestimate as a direct result of this.

Scaling for period of record
Dunham Massey = 22 years, scaling factor 1.0

Scaling for period of benefit
These are annual data, no scaling is required.

Component benefit assessment

Works	Potential benefit (@20%) (£)	Scaling and result
Hale	12,885	1.1 accuracy scaling 0.7 representativeness scaling 1.0 record length scaling Benefit = £9,921
Alderley Edge	12,617	1.1 accuracy scaling 0.05 representativeness scaling 1.0 record length scaling Benefit = £694
Knutsford	12,302	1.1 accuracy scaling 0.12 representativeness scaling 1.0 record length scaling Benefit = £1,624
Bowdon	10,398	1.1 accuracy scaling 0.7 representativeness scaling 1.0 record length scaling Benefit = £8,007
Mobberley	10,152	1.1 accuracy scaling 0.1 representativeness scaling 1.0 record length scaling Benefit = £1,117

TOTAL BENEFIT = £21,362 pa (attributable to Dunham Massey alone)

9.3 Tay Catchment Case Study Worked Example

9.3.1 Perth flood defences

Test catchment
Indicate catchment/network to be reviewed

Benefit
Identify benefit type

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature. The literature confirms that typical benefit values can be derived from construction costs.

Data required
Project costs
Gauging station(s) used for the assessment, & details of catchment areas etc.;
Gauging station classification/gauging details
Length of period scanned for projects of this type

Calculation of potential benefit
The large scale of this project and the consequently sensitive nature of its costings make detailed data difficult to obtain for this project. Typical benefit values are 4-5% of the total construction cost.

Scaling for data accuracy
As this case study relates to a SEPA catchment reference to Chapter 7 provides details of data accuracy scaling based on details of high flow gaugings. As the high flows are the main source of data for the design specification, the scaling for this category is the most appropriate.

Scaling for data representativeness
The site is a short distance downstream of the confluence of the Tay with the Almond, a major tributary, and upstream of Ballathie gauging station. Catchment ratios will thus need to be based on this information.

Scaling for period of record
Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit
For the same reasons as for other major capital projects, it is proposed to distribute this benefit over 5 years (the period scanned to identify such projects). A scaling of 20% is therefore proposed to account for period of benefit.

Component benefit assessment
Base value benefit scaled for data accuracy, data representativeness, period of record and period of benefit.

Test catchment
Tay at Perth

Benefit
Improved design of flood protection works

Basis of benefit assessment
Specialist literature indicates that the value of streamflow data may be estimated as 4-5% of flood protection scheme cost.

Data required
Scheme cost = £22 million
Highest gauging at Ballathie is marginally in excess of MAF
Mean catchment area ratio is 0.95
5 year period scanned for projects of this type

Calculation of potential benefit
4.5% of reported scheme cost of £22 million = £1 million

Scaling for data accuracy
As highest gauging is in excess of MAF, Chapter 7 indicates that scaling factor of 1.1 should be applied.

Scaling for data representativeness
Ratio of catchment areas gives scaling of 0.95.

Scaling for period of record
Ballathie GS record length = 46 years, scaling factor 1.1

Scaling for period of benefit
As with the A34 infrastructure investment, it is proposed to distribute this benefit over 5 years, i.e. scale by 20%.

Component benefit assessment
Assessed as £1,000,000 * 1.1 * 0.9 * 1.1 * 0.2 = £217,800 pa

This is based on data from one gauging station only. An increase in benefit could be achieved with sole reference to a site more immediately upstream of the point of investment/benefit (Perth).

9.4 Foyle Catchment Case Study Worked Example

9.4.1 Construction of bridges and culverts

Benefit
Identify benefit type

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in literature. The literature confirms that typical benefit values can be derived from construction costs.

Data required
Project costs
Gauging station(s) used for the assessment, details of catchment areas etc.
Gauging station classification
Length of period scanned for projects of this type

Calculation of potential benefit
Data are available for the total expenditure incurred on upgrading/constructing bridges and culverts in the Foyle catchment in the two financial years spanning the period 1995 to 1997. Typical benefit values are 1% of the total construction cost.

Scaling for data accuracy
As this case study relates to a DoE(NI) catchment reference to Chapter 7 provides details of data accuracy scaling based on details of high flow gaugings. As the high flows are the main source of data for the design specification, the scaling for this category is the most appropriate. (Note that no data were available for the case study evaluation)

Scaling for data representativeness
As the projects were all undertaken within the Foyle catchment, and no further details are available, it is not possible to determine individual scaling factors for data representativeness for each bridge etc. Should this be necessary, the approach presented in 9.2.6 for the Bollin catchment should be applied, namely individual ratios for each project used to determine the scaling factors.

Scaling for period of record
Section 7.3 provides details of scaling factors to be applied for record length.

Scaling for period of benefit
As data were only provided for a two year period the results are to be scaled for this period.

Component benefit assessment
Base value benefit scaled for data accuracy, data representativeness, period of record and period of benefit.

Note that this benefit compares to an estimated total operating cost of £1,900 per annum for the network of five stations covering the above catchments.

Test catchment
Foyle

Benefit
Improved design of bridges and culverts

Basis of benefit assessment
Hydrometric data provide for the avoidance of over-design and under-design costs by reducing uncertainty, as reported in the literature.

Data required
Details provided below.

Calculation of potential benefit
Construction costs of projects undertaken over two years between 1995-1997 are as follows:

Catchment	Title/Bridge	Client/Consultant	Est Cost
Roe	Limavady By-pass Curly Bridge	DOE Roads	£500k
Roe	Repairs to Roe Bridge	Translink/FMcI	
Faughan	Repairs to Faughan Bridge	Ferguson McIlveen	£250k
Fairywater	Bridge re-decking	DOE Roads	£55k
Camowen	Footbridge	Community Assoc.	£40k
Foyle	Community platform millennium project	3rd millennium bridge company	£100k
Roe	Disabled anglers' footbridge	Community Assoc.	£50k
Fairywater	Moorfield Bridge	DOE Roads	£50k
Burndennet	Burndennet Bridge	DOE Roads	£300k
TOTAL			£1,345k

It can thus be seen that the total construction costs are estimated to be £1.345 million. The literature indicates that 10% of these costs are likely to be sensitive to hydrometric data, and that in turn 10% of this equates to the typical benefit. Consequently, potential benefit is calculated to be £13.45k.

Scaling for data accuracy
No scaling factors can be derived at this time ($\Rightarrow ?_1$).

Scaling for data representativeness
Similarly, unity is assumed to be the case as no alternative data were available.

Scaling for period of record
Again, no data are available, but individual factors could be obtained ($\Rightarrow ?_2$).

Scaling for the period of benefit
As the data apply to a two year period, a scaling of 0.5 is applied.

Component benefit assessment
Assessed as £13.45k $* ?_1 * 1.0 * ?_2 * 0.5 =$ £6,725 $* ?_1 * ?_2$ pa.

9.5 Combining Quantitative Benefit Assessments (Bollin Catchment)

The component benefit assessments for the Bollin catchment, making up most of the examples above, can be combined to produce a total quantitative benefit assessment.

In Section 7.5, a distinction was made between inherently annual benefits and investment decisions. This distinction is maintained here, although the computation of benefits in Sections 9.2-9.4 has already undertaken the translation of investment decision benefits into annual representations, by applying a 20% period of benefit scaling (for a 5-year term) prior to reporting scaled benefits.

The data are handled thus:

Sum estimates for all inherently annual benefits:

Bridge and culvert maintenance	955
Quarry Bank Mill HEP	16,739
Abstraction licensing/low flow alleviation	6,388
Pollution control consenting	21,362
Sub-total (£ p.a.)	**45,444**

Sum annualised estimates for all investment decisions:

Manchester Airport extension	305,394
A34 by-pass	83,790
Sub-total (£ p.a.)	**389,184**

Add 2 sub-totals together to obtain annual benefit (£ p.a.): 434,628

The total quantitative benefit seems large in the context of the possible range of values which might be yielded for a catchment, and the benefit attributable to the Manchester Airport project assumes a dominant position, accounting for 70% of the total. Consideration of the results of an annual equivalent factor assessment therefore appears warranted.

The two investment decision benefits are subject to an AEF assessment as follows, using a 6% discount rate and 100-year design periods:

$$AEF = i/(1-((1+i)^{-N}))$$

where i = discount rate (as a fraction of 1)
N = design life of project

Manchester Airport extension

AEF = $0.06/(1-((1+0.06)^{-100})) = 0.06018$

So annual benefit on lumped benefit of £1,526,970 = 1,526,970 * 0.06018 = £91,893

*(Lumped benefit is as given in Section 9.2 (p.61), but with no period of benefit scaling applied, i.e. £1,720,000 * 0.95 * 0.89 * 1.05 ~~* 0.20~~ = £1,526,970 pa)*

A34 by-pass

AEF = $0.06/(1-((1+0.06)^{-100})) = 0.06018$

So annual benefit on lumped benefit of £418,950 = 418,950 * 0.06018 = £25,212

*(Lumped benefit is as given in Section 9.2 (p.61), but with no period of benefit scaling applied, i.e. £600,000 * 0.95 * 0.7 * 1.05 ~~* 0.20~~ = £418,950 pa)*

In this case, assuming the 100-year design lives and 6% discount rate, the overall benefit assessment can be obtained from:

	£ p.a.
Sum of inherently annual benefits	45,444
Annualised Manchester Airport benefit	91,893
Annualised A34 benefit	25,212
TOTAL	**162,549**

This value is 37% of that derived with lump summing and division over 5 years for the investment decision benefits. However, it should be regarded as an underestimate, because unknown benefits relating to other projects dating from before the 5-year period scanned (see Section 7.4). The £162,549 and £434,628 figures may be considered as lower and upper bounds respectively for the total quantitative benefit.

In bringing together the various worked examples, some comments can be offered on each, particularly in relation to the assumptions made. These are presented in table form (Table 9.1):

Table 9.1 Summary of example scaled benefits and comments

Catchment	Example	Scaled annual benefit (£ pa)	Comments
Bollin	Manchester airport extension	305,394	Largest single assessed benefit - hydrometric data ideally suited to project
	A34 by-pass	83,790	Lowest scaling factor 0.7 due to location of by-pass
	Bridge and culvert maintenance	955	Very small benefit, but will typically apply every year. Over a wider area (i.e. Cheshire) annual benefit typically £4,600
	Quarry Bank Mill HEP	16,739	Unusual example, with moderate-high benefit value. Similar approach may be applicable to some other benefits - not necessarily exclusive to HEP
	Abstraction licensing/ low flow alleviation	6,388	Conservative assumption that only 10% of benefit comes from the use of hydrometric data. Very dependent on assumption that SW research can be applied elsewhere, and that data representativeness scaling factor is 0.5. Thus, while benefit is large, it is only indicative of the order of magnitude.
	Pollution control consenting	21,362	Assumption that a 20% increase in consent targets will increase treatment costs by 20% unlikely to apply in all cases - specific work relating to STWs may be useful. Only STWs used in case study - industrial discharges could also be assessed.
Tay	Perth flood defences	218,000	Very large benefit based solely on one large project
Foyle	Bridge and culvert design	6,730	Still to be scaled for period of record and data accuracy

Finally, the interaction of the various scaling factors can be represented in a tabular format as a condensed summary of the interaction of factors affecting the Bollin quantitative benefit assessment (Table 9.2).

Table 9.2 Summary of base value, scaling and component benefit values - Bollin catchment

Benefit	Base value (£)	Accuracy scaling	Representativeness scaling	Period of record scaling	Period of benefit scaling*	Component benefit value (£)
Manchester airport extension	1,720,000	0.95	0.89	1.05	0.20	305,395
A34 by-pass	600,000	0.95	0.70	1.05	0.20	83,790
Bridge and culvert maintenance	6,000	1.03	0.15	1.03	1.00	955
Quarry Bank Mill HEP	21,470	0.83	0.90	1.05	1.00	16,739
Abstraction licensing/low flow alleviation	12,403	1.00	0.50	1.03	1.00	6,388
Pollution control consenting (Hale)	12,885	1.10	0.70	1.00	1.00	9,921
- (Alderley Edge)	12,617	1.10	0.05	1.00	1.00	694
- (Knutsford)	12,302	1.10	0.12	1.00	1.00	1,624
- (Bowdon)	10,398	1.10	0.70	1.00	1.00	8,007
- (Mobberley)	10,152	1.10	0.10	1.00	1.00	1,117
Pollution control total						21,362
				Overall total		**434,628**

** period of benefit scaling introduced to allow scaling for investment decision benefits (scaling by 20%) - otherwise value is 100%, i.e. no scaling applied.*

This table has been extracted directly from a spreadsheet, and illustrates the potential for development of a tool which could allow the effects of network changes to be assessed.

Note that the high values for the investment decision benefits have been used in this instance. Where annualisation is implemented, the results of annualisation should be shown in the base value column, exclusive of the effects of other scalings which can be handled in their own columns. In such cases, no period of benefit scaling should then be used.

9.6 Discussion

Undertaking an assessment of quantitative benefits for the Bollin catchment has illustrated the large influence which is exerted by major capital projects: true whether a crude 5-year averaging or an annualisation process is used. Although no cost data have been presented here, assuming an annual running cost for the three stations of approx. £3k each (Environment Agency source), it can be seen that the level of benefit being derived (estimated at between £163 and 435k pa) is vastly in excess of annual costs. It should be noted that these benefit figures are the best representation possible of the actual level of benefit being derived from the Bollin gauging network, per annum, at the present time. It should further be noted that, because of the limitations of the methods by which benefits can be represented quantitatively, there are expected to be further benefits (e.g. operational benefits to Environment Agency staff) which are not represented in the figures given. The checklist approach, outlined in Chapter 5, is designed to allow formal recognition of such other benefits although, in focusing on the primarily economic priorities of this research project, such a checklist for the Bollin is not presented here.

These results therefore give an assessment of the benefit being derived from the Bollin network. The underlying methods also allow for assessments of the effects of network changes, e.g. the enhanced benefits which would accrue in serving pollution control/consent-setting requirements, by installing another gauging station on (say) the Mobberley Brook and thus increasing data representativeness scalings.

While in all cases the component benefit values indicate the level of benefit being derived from the network, these may or may not be marginal benefits for each extra year of record - depending on the benefit type. Considering the list of benefit types identified in Section 6.2, a clear division of types can be made. Some benefits accrue at a given level because of the need for real-time (or near-real time) data: the benefits accrue because of the availability of *this year's* data. These are:

1. Avoidance of excess pollution control costs
2. Improved determination of abstraction licenses/avoidance of low flow problems
3. Reduction of flood damages achieved through telemetry-based flood warnings
4. Avoided pumping costs achieved by use of telemetry hydrometric data

The computed benefits will not accrue if this year's data are not available. On the other hand, however, where historic data are of value, benefits can be accrued even if a station now closes (although subjective arguments can be made about uncertainty in the continued streamflow characteristics of a site). These uses are:

1. Improved design of bridges and culverts: major new investment/major repairs
2. Improved design of flood protection works
3. Avoidance of costs of unsound hydro-power investment

This distinction needs to be borne in mind when considering any changes to a network.

A strong contrast must be noted between the results for the Bollin and those emerging for the Foyle. It was only possible to identify one type of benefit where quantitative benefits could be estimated, namely for improved bridge/culvert design, yielding an estimated value of approx. £6k. It is thought that a further quantitative benefit assessment should be possible for pollution control, perhaps in the order of £10k, but data have not been forthcoming for this work. For seven gauging stations in the Foyle catchment, total system costs may not compare favourably with benefits of this order if the unit cost is close to the £3k pa mentioned above, but Northern Ireland sources indicate that realistic costs would be closer to £1k pa, as a result of lower overhead and other costs. It is likely that for this network, total quantifiable benefits and costs are of a similar magnitude. However, these benefit assessments will take no account of other important uses of hydrometric data in the catchment, such as servicing fisheries interests or a semi-formal flood forecasting system (again, no quantitative benefit assessment has been possible).

In summary, this chapter has shown how the various parts of the methodology integrate in an overall framework, and the relative magnitudes of effect produced by each. Amongst base values, major capital projects have been seen to generate very large benefit values, based on reported literature, in comparison with others. Amongst scalings, the most marked effects have been generated by the very low scalings which can be generated for data representativeness - a point which may warrant some further study. And while the emphasis of this work has been on quantitative methods, the user must be aware of the importance of benefits which cannot be subject to such treatment - even though perhaps relating to such important uses as statutory reporting, the support of navigation or conservation projects.

By using a commentary with each worked example, much relevant background has been provided to help the user gain an appropriate insight to the methods used. Ultimately, the application of these methods is in the hands of users, and it is hoped that all of this information will be of value.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Summary and Evaluation of Results

This report has described in detail the progress and results of a large programme of research. The notion of benefits arising from the collection of hydrometric data has been examined at length: benefits may arise from the ability to use either real-time or historic hydrometric data, they are sensitive to a large number of controlling factors but, in all cases, they are those which can be identified by reference to the uses made of them. At the start of the project, it was immediately apparent that it would be possible to represent some benefits in a quantitative framework, while others would be amenable only to qualitative methods.

The study began with a review of the available literature. It was found that a large literature exists, dating from the 1960s onwards, and over 100 papers were directly consulted. Some studies have used economically-rigorous methods for assessing benefits, others have been based on purely qualitative methods, and some have used a quantitative framework but without building on any economic theory. Most studies related to assessing the benefits of data in relation to just one particular type of benefit, e.g. the design of flood defences, and none provided a coherent methodology which could be used for the evaluation of a full range of benefit types within any given catchment area. To do so was the task of the research being undertaken.

A survey of data users was undertaken, with a view to assessing the full extent of their usage and identifying information on the benefits they derived. The survey of uses was very successful, with many unexpected uses being identified, and the main areas of benefit are described in Chapter 3. Little information of direct economic relevance was obtained, but answers to more general questions regarding decisions made under different levels of data availability were useful. These chiefly concerned decisions in relation to abstraction licensing and consent setting and, while may respondents were reluctant to deal with hypothetical questions, precautionary principles were found to apply.

The chief focus of the research has been the development of methods for assessing benefits, and the background work described in the preceding paragraphs was useful in informing this activity. Both quantitative and non-quantitative methods were developed, with most emphasis being directed towards the quantitative methods - in line with the overall aims of the study. Chapter 6 details a range of bases on which quantitative methods were developed, according to the various types of relationship between hydrometric data and benefit: avoided losses, production functions, etc. Each type of benefit had its own specific requirements in terms of input data and the method to be used in assessing *base benefit values* - those which would apply under typical data availability conditions. Methods were developed so that these base values could then be scaled to reflect local conditions - by the introduction of scaling factors for data accuracy, representativeness, and period of data record (Chapter 7). Application of these scaling factors allows realistic hydrometric data values to be produced such that, for example, low hydrometric accuracy or representativeness deriving from one site might be used as a stimulus for directing resources elsewhere, or for justifying appropriate investment.

Not all benefits can be represented by the application of quantitative methods, e.g. assessing the value of data used in determining the loading of pollutants to sea from the outfall of a catchment (a statutory requirement of the Oslo and Paris Commissions - "OSPARCOM"), or for detecting the effects of climatic changes or assisting studies of resource use sustainability. Therefore, a *checklist* approach was also developed for the comprehensive identification of all benefits, whether amenable to quantitative assessment methods or not (Chapter 5). The report recommends that the results of applying quantitative and non-quantitative methods are complementary, and that managers should assimilate the results of each within a framework appropriate to their own decision-making needs (Chapter 4). These might include an assessment of the overall benefits of a network, a review of the effects of a proposed network change, or an assessment of the effects of altering the hydrometric performance of a station.

It is emphasised that, because of the hydrological connections between one part of a catchment and another, and the catchment basis on which data are used, a catchment or network basis is the most appropriate to the task of assessing benefits, i.e. they cannot be assessed for one station in isolation from others. Where the effects of adding or removing one or more stations from a network is to be considered, or where upgrading/downgrading hydrometric performance, the effects should be identified by comparing overall network benefit in one scenario (typically the current situation) with overall network after the introduction of change. Sources of information necessary for application of the methods are described in Chapter 8, as an aid to implementation, and the quantitative methods are illustrated and explained in a practical context in Chapter 9. Sometimes, network considerations are important at a national scale, particularly when attempting to identify changes in regime as a result of climatic behaviour. Section D of the checklist addresses this point, and recommends its integration into decision-making processes (see Chapter 5).

In evaluating this research, a number of salient points emerge as key strengths and weaknesses.

Strengths:
1. A formal method has been developed for the recognition of all benefits deriving from hydrometric networks.
2. Formal methods have been developed for quantifying many benefit types as base values, and for adjusting these to reflect local conditions with respect to data accuracy, representativeness and period of data record.
3. Methods have been presented which will allow the effects of network changes to be illustrated.
4. The literature reviews and survey of data usage give a detailed context in which this work has been developed.

Weaknesses:
1. Scalings for data accuracy, representativeness and period of record are arbitrary, although the methods for their application do provide for consistency.
2. Accordingly, the quantitative benefit values deriving from application of these methods can only be approximate.
3. The benefit quantification methods developed are not applicable to all types of benefit: some can be addressed only by non-quantitative means.
4. No direct method of translation is provided to express the value of benefit types, which depend only on historic data, as marginal benefits.

Beyond these general points, it is also instructive to consider the progress made by the research in relation to the eight inherent problems which were identified by the Project Board at the time of issuing tender invitations for this research (and listed in Chapter 1). Each is considered in turn (they appear in full within Appendix I, Section 4, and are abbreviated here).

Problem: It is difficult to translate the benefits of data into economic terms.
Progress: Substantial progress has been made here, through the development of economically-based quantitative methods.

Problem: There may be a wide range of potential benefits from additional data, ranging from very specific requirements ... to much less well-defined benefits.
Progress: Quantitative methods have been developed for many specific benefits. However, where less easily definable benefits occur and are locally important, the checklist approach ensures that these are recognised. This report also refers to some of the more important general benefits which are true of hydrometric data collection as a whole.

Problem: The true value of data may not always become apparent for years. Data [have in the past] been used for purposes that could not have been foreseen when a station was built.
Progress: It could be argued, in general terms, that the value of any resource is always a function of time. It is only possible to address this fundamental problem superficially: in the checklist, a consideration of possible future needs is recommended and, more generally, every reader of this report is urged to recognise the unquantifiable value of having historic information with which future needs may be serviced. The maintenance of a programme of baseline monitoring on a regional basis is essential to quantifying the effects of future changes (e.g. from land use, climate, water resources usage).

Problem: Some users need real time data while others need historic data [and the benefits derived will depend on a user's type of need].
Progress: This is often explicitly recognised in the methods developed for assessing benefit. Where the benefit value is a function of record length, guidance is provided for a scaling to be applied. However, if it can be demonstrated that the benefit is not affected by record length at all, the flexibility is provided for this scaling to be set at 100%, i.e. no change (Chapter 7). More importantly, the distinction between real-time and historic data need underlies differences in the translation of measured benefits to marginal benefits reflecting the added benefit of an extra year's data.

Problem: Estimates can always be made, based on theoretical models or existing data at another site. [Benefits of data use must be just that - they must give no credit for the use of estimates which could otherwise be generated.]
Progress: Estimates can indeed always be made, but their use comes with dangers of large uncertainties in flow parameter estimates. The use of observed data reduces these. Having developed methods for the derivation of base values, steps have been taken to ensure that where observed data are of little benefit because of poor accuracy, representativeness or short records, then component values are low. This is considered to be a pragmatic response to the problem identified.

Problem: The levels of accuracy may be different for different parameters [and] ... benefits will therefore probably need to be assessed for each potential data use.
Progress: In the quantitative methods presented, benefit types are assessed separately, and separate, appropriate scalings ensure that benefits do recognise data utility in a context-specific way.

Problem: The selection of the site for [a gauge] is controlled by many practical constraints other than just the need for data. [Data produced by the gauge may not be as appropriate to the perceived need as intended.]
Progress: This is deliberately recognised by the data representativeness scaling.

Problem: Costs of feasibility studies for major sites such as gauging stations are already high, and additional costs caused by unnecessarily complex benefit assessments would not be welcome. Any proposed methods should be as simple as possible to apply, and flexible and robust enough to accommodate the many and varied aspects of site selection.
Progress: The methods presented in this report are designed to be of general applicability, and robust through a relatively simple structure. However, it is inherent in their approach that benefit assessments will always be approximate. Only locally specific empirical research can provide for the needs of higher precision.

The authors consider these responses to confirm the value of the methodology developed, and recognise the valuable contribution made by the Project Board in its evolution.

Nonetheless, it is recognised that there are a number of difficulties which will continue to frustrate progress in this sphere for the foreseeable future:

1. It seems most unlikely that it will ever be possible to develop a framework to express all benefits in an economic framework and thus allow complete comparison of costs and benefits.
2. Even in relation to those benefit types where economically sound valuation techniques are well established, there is (at least in the UK) a great reluctance on the part of consultants to pay any more than small handling charges for the supply of hydrometric data. Market conditions do not apply, cannot be expected to do so in the future, and therefore (with 1. above) make the prospect of market-led network change impossible.
3. Some general benefits of fundamental importance to the work of environment agencies will continue to be unquantifiable in the future, e.g. the value of a detailed scientific awareness of the state of the environment, in underpinning the authority of regulators in a policy context. It is likely to fall to hydrometricians to argue this point from time to time, if reviews of monitoring networks threaten to undermine the credibility of their own organisations.

10.2 Recommendations for Research and Implementation

In Chapter 7, it was noted that scaling ratios applied to base benefit values were often arbitrary in their derivation. It is therefore suggested that further research in this sphere would be of considerable assistance in enhancing the utility of the methodologies presented. If it is possible to derive some more objective basis for the scaling values to be used, it will in turn be possible to add utility to the results of applying the methodologies. One particular area worthy of further consideration is representativeness scaling, since no allowance has been made for representativeness in terms of catchment characteristics rather than simple geographical nearness. However, it is suggested that large amounts of empirical information would need to be collected to underpin the development of any of the scalings proposed, and no opinion is offered in relation to the viability of any such research. Additional scaling factors, beyond those used in this report, may also warrant consideration.

Further work would also appear to be warranted in relation to separating marginal benefit values from values expressing the overall level of benefit being received in a given type. This would need to be done in conjunction with further refinement of the requirements for such information.

Some practical steps can be taken by environment agency staff in the interests of supporting future benefit assessments. Where not already in place, logging systems should be established so that requests for data are recorded - specifically covering:

1. date requested;
2. the records used;
3. periods of record;
4. data user;
5. data use;
6. notes.

These systems could be of considerable future value in demonstrating the value of hydrometric monitoring, and need not involve any excess of detail which could be seen to impose unduly on staff resources. Staff should be particularly encouraged to discuss data requests with users involved in projects which are either capital-intensive (in which case it would be useful to know how the data would be used and what benefits would arise from their use), or non-standard (helpful in illustrating breadth of use/identifying new uses). Such information should be noted on log sheets. These comments should apply equally to all types of environmental monitoring - not just surface water hydrometry.

In the interests of ensuring that monitoring networks are responsive to user needs (and at the risk of stating the obvious), it is important that the methods outlined here are applied to networks in practice. In Environment Agency regions, Service Level Agreements (SLAs) are made annually as a means of defining the link between hydrometric service providers and users. This seems too short an interval for benefit assessments, considering the staff effort that is likely to be required and considering that substantial changes are unlikely to occur so quickly. However, it is suggested that every five years may be a more sensible interval at which to review networks in this way.

One element of the terms of reference for the study was to endeavour to develop methods which would allow transfer to other types of environmental monitoring. It is hoped that by having developed structures which are both transparent and modular, they will be amenable to application to other types of monitoring. However, the benefit types will differ since river flow data are, as a rule, used for different purposes to those for (say) air quality or other types of environmental data. Therefore, as would be anticipated, there would be a research need to investigate the types of benefit, the level of base values to be expected for each, and the value of scaling which could be used to reflect local conditions. Some effort would also be required in relation to the definition of the local units in which network evaluation took place: river catchments would not always be applicable, but it would be advantageous to identify coherent geographical units which could be taken as direct analogues. Nonetheless, the general form of an evaluation procedure may be as illustrated in Figure 10.1, based on Figures 4.1 and 6.1 in this report.

a)

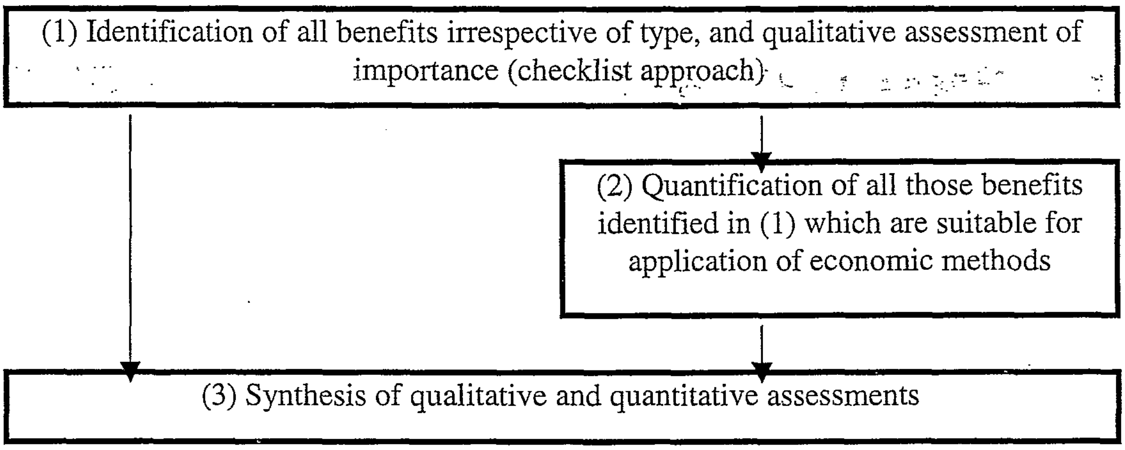

Figure 10.1 Proposed general form of method applicable to assessment of benefits from any type of environmental monitoring network: (a) relationship of quantitative and non-quantitative methods

(continued)

b)

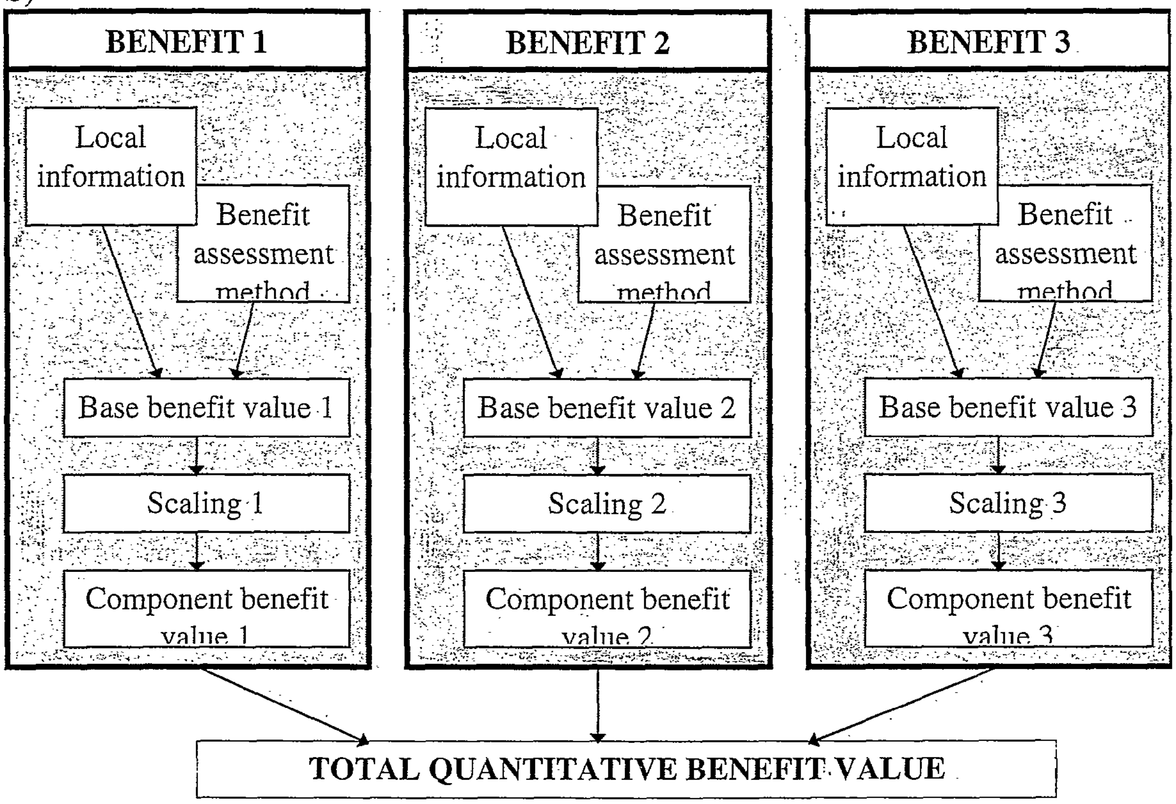

Figure 10.1 (b) detail of quantitative methods. Scalings to combine representation of as many local factors as apply.

10.3 Recommendations for Format and Contents of a Future R&D Note

A manual in the form of a future R&D Note will need to fulfil many roles if it is to successfully allow users to implement these procedures in practice. Amongst other things, it should be:

- informative, giving sufficient background to the methods that the user can apply them with the benefit of a reasonable understanding;
- accessible, avoiding "information overload" which would over-burden the reader;
- explicit, so that procedures can be followed exactly and reliably;
- comprehensive, so that guidance is offered for all possible situations.

It is recommended that the content of such a manual should include the following:

1. Some background to the theory involved in this research: it would be dangerous for the user to collect data and apply them in the methods without having an understanding of why certain methods are applied, or what assumptions were being made.
2. Guidance on the sources of information required, with precise definitions of the variables for which data are to be collected.

3. Some definitions for the technical vocabulary necessary - e.g. base value, similar to those in the Glossary to this report.
4. Flow charts to guide the user through the various stages of the procedures to be implemented.
5. A checklist with which to undertake a comprehensive review of all benefits.
6. Proformas or other suitable tools with which to implement all the quantitative methods described in Chapter 6. Also tools with which to assess scalings to be applied to base values.
7. Guidance on the frequency/timeliness of application of these methods, and on how to interpret the results (e.g. how to combine results of quantitative and non-quantitative assessments).
8. Guidance on the identification of unquantifiable benefits - those which should attend any decision-making based on the results of applying these methods.

In terms of the format of the manual, it is essential that there is sufficient paper-based support for the user, in the form of instructions, background information, sources of information, etc. However, the optimum format for the delivery of the core methods of benefit assessment is less clear. Paper-based or electronic methods are both possibilities.

The complexity of methods developed in this research programme is such that the development time and costs, for a fully-functional PC software application, would be considerable. However, one possible route to consider is the development of an expert system, which could interrogate the user in a PC environment, and which could be reasonably easily constructed. An application based on a data entry interface to a spreadsheet or database programme, may be more straightforward and less costly, and might offer an effective means of guiding a user through the stages of a perhaps otherwise daunting procedure. Both of these would require the skills of a suitably qualified person to develop the procedure in the future, however. A paper-based solution certainly demands no problematic prerequisites, but may be the most mundane to use. An exchange of views with the Project Board may be most helpful at this final stage, as a means of pointing more clearly towards a suitable path forward.

10.4 Final Conclusions

By way of final conclusions, it can be seen that the research has achieved considerable progress in developing methods by which the benefits of hydrometric networks can be evaluated. A wide range of types has been covered, using a diverse set of economic methods for evaluation. Through the application of the methods in a number of case studies, the value of the concepts has been illustrated. However, opportunities for strengthening the methods have been identified, particularly the scope for research into means by which the scaling mechanisms can become more objective. With the experience of developing the methods, and attempting benefit assessments for real catchments, the need to re-focus on the specific applications for these methods has been recognised, and further work in this sphere will help in the application of these methods to user requirements. The authors hope that the report will act as a stimulus for further research and development of methods for assessing data benefit, and that this work will usefully add to established methods of assessing hydrometric data utility.

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(Note: separate reference lists appear in Appendices II and III)

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APPENDICES

I Terms of reference
II Hydrological literature review
III Economics literature review
IV Full set of blank questionnaires
V Economic aspects of questionnaire survey responses
VI External data usage - results of interviews
VII Specimen checklist
VIII Alternative methodological approaches

APPENDIX I

Contract for the provision of a National R & D Project

Evaluating Benefits of Hydrometric Networks

<u>SECTION A: SPECIFICATION</u>

1. Introduction

The National Rivers Authority (NRA) is a major environmental protection agency charged with safeguarding and improving the natural water environment. The Authority's main responsibilities are:-

i) The control of pollution and improvement in quality of rivers and coastal waters.

ii) The management of water resources.

iii) The protection of life and property from flooding.

iv) The conservation of the natural environment including the development of fisheries.

v) The promotion of river based recreation.

The Authority has a National Research and Development Programme, aimed at improving the effectiveness and efficiency of the NRA's services. It is co-ordinated by Head Office with individual projects managed from the Regions.

2. Background

Hydrometric data (river flows and levels, groundwater levels, rainfall and other climate data, etc.) are collected and used extensively by the NRA, River Purification Boards and the DoE(NI) in the UK and by river authorities throughout the world. The costs of running these networks can be calculated reasonably easily but at present there are no objective and consistent methods for assessing the economic benefits of the data. These methods are needed firstly to assess whether or not existing networks should be enlarged or contracted, and secondly to examine the justification for the expense of proposed sites – which, in the case of gauging stations, can be considerable.

Hydrometric data are obviously essential for the efficient development and management of water resources and flood defence projects, for flood warning and for the estimation of dilutions and loads in the assessment of water quality. Various studies have been carried out to show the high overall benefit of a good hydrometric network.

However, it is not so obvious how extensive the networks need to be to provide an adequate or optimum service. In addition, neither is it obvious how to demonstrate that a proposed new gauging station will provide value for money as there are no generally accepted methods of quantifying the increased quality of data availability, nor for assessing the benefits that the data will provide. A new gauging station can be a major expense and there is an increasing demand to justify spending decisions. In a climate of conflicting demands on limited budgets, the NRA and other river authorities need to know:

- whether or not a proposal for any new site can be economically justified

- that the existing hydrometric networks are providing value for money

- and that the data they produce are needed.

At present there is no effective or generally accepted method of providing the answers to these questions.

3. Objectives

Overall Objectives:

To work towards the development of standard practicable procedures to assess the benefits of data from gauging station networks and individual sites, so that comparison can be made with the costs of running the networks and individual sites. The procedures should be adaptable to other types of hydrometric and environmental monitoring networks.

Specific Objectives:

1 To review the literature and current practice in Britain and around the world on:

  - the assessment of the benefits of hydrometric data from both entire networks and individual sites
  - methods of reviewing the size of hydrometric networks
  - methods of assessing the costs and benefits of individual existing and proposed sites

2 To develop an assessment framework and new methods of assessment of the benefits of hydrometric data from both networks and individual sites.

3 To produce proposals for the format and contents of a future R&D Note in the form of a manual containing practicable procedures that would be flexible and modular to allow for future updating that can be used to undertake the following:

- review the size of a hydrometric network – can even better value for money be achieved by enlarging or reducing the network?

- identify the best network density

- assess the benefits of data from an individual site

- assess the potential benefits of a proposed site, taking into account data and estimates already available

4 To produce a specification for the further work required (if any) to acquire the data and information necessary for the future production of the manual.

5 To test the proposed methods on a representative range of case studies.

6 To produce a draft Project Record and R&D Note.

7 To produce a final Project Record and R&D Note.

4. Methodology

Approach

Overall Approach:

To review available methods of assessments of the benefits of hydrometric networks, decide if any are suitable for our needs, and if note, develop new methods, and produce procedures to implement these.

Detailed Approach:

a Briefly review the literature and current practice in Britain and around the world on the following:

- the assessment of the benefits of hydrometric data from both entire networks and individual sites
- methods of reviewing the size of hydrometric networks
- methods of assessing the costs and benefits of individual existing and proposed sites

b Develop practicable methods of assessing the full social benefits of the data from hydrometric networks and individual sites, for use in comparing with the costs of running hydrometric networks and installing additional sites. Standard methods of assessment of costs of hydrometric networks are being developed by the NRA, and may only need slight modification to make them compatible with the methods developed for benefits assessment. Bayesian and non-Bayesian methods, including environmental valuation studies, should be considered for the assessment of the economic benefits of data, taking into account what data are already available. This may include consideration of the use of benefit transfer approach, if appropriate.

c Produce an interim report reviewing methods of assessing costs of installing and running networks and individual sites, and the possible methods of assessing the benefits of the data collected by hydrometric networks and at individual sites. Account should be taken of the different levels of benefits provided by different degrees of reliability and accuracy achievable at hydrometric sites. Recommendations for the most suitable methods should be made together with an outline of how they would be applied in the assessment of a proposed site and in the review of a hydrometric network.

d Produce a specification for the format and contents of a future R&D Note in the form of a manual (the actual manual will not be produced as part of this project) containing practicable procedures that are flexible and modular to allow for future updating that could be used to undertake the following:

- review the size of a hydrometric network
- assess the benefits of data from an individual site
- assess the potential benefits of installing a proposed site

It is envisaged that modules within the procedures will deal with benefits assessment of data for different business areas. One module may contain the procedures for assessment of costs. The methods developed should be based on sound environmental economics principles but should be capable of application by hydrological staff.

e Ensure that the procedures that are developed take into account other developments within the NRA, such as catchment management plans, which could possibly be used as the basis of the assessment of present and likely future need for hydrometric data. The modular nature of the procedures should reflect the business needs of the organisation for the data – so the benefits of a proposed gauging station might be assessed by modules specific to Flood Warning, Water Resources, Flood Defence, Water Quality, Pollution Control, Licensing and Consents etc. The potential benefits of better interlinking of hydrometric and other data such as water quality and biological parameters may need investigation.

f Test the proposed procedures on agreed representative example networks and sites. Probably three of each will be sufficient. Examples will need to be included in the procedures manual, to assist in its use.

g Produce a draft and final R&D Note which is likely to cover the background to the study, previous work, discussion of possible approaches, recommendations for the methods to be adopted, description of the procedures, example applications, recommendations for further work, and discussion of the potential for application of the techniques beyond gauging station network review.

h Produce a draft and final Project Record detailing all the information relating to how the project was carried out and containing any information and data which would be necessary to anyone continuing the work in the future.

Inherent Problems:

No simple assessment of benefits of hydrometric data has been produced before due to the inherent problems associated with the task, amongst which are:

- it is difficult to translate the benefits of data into economic terms.

- there may be a wide range of potential benefits from additional data ranging from very specific requirements such as being able to monitor an abstraction licence, to much less well defined benefits such as being able to estimate flows in neighbouring ungauged catchments more accurately.

- the true value of data may not always become apparent for many years. The assessment of benefit of data must include some assessment of the need for the data. However, in the past, data has been used for purposes that could not have been foreseen when a station was built. When a need for long periods of data becomes apparent it is usually too late to build a station.

- some users need real time data while others need 'historic' data eg flood warning and abstraction monitoring need real time data while flood defence design needs long records of high peak flow measurement. A new gauging station will be of benefit immediately to users of real time data, but it will only gradually become of benefit to users of long term records who might need to monitor gradual changes in the catchment or to analyse extreme events – droughts and floods.

- estimates can always be made based on theoretical methods or existing data at another site. The benefit of additional data must therefore be calculated on the difference between the level of accuracy achievable using existing data and the increased level of accuracy provided by the new site. This implies that the accuracy with which a particular parameter at any location, not only hydrometric sites, can be estimated with the available data, needs to be known. GIS may have uses here.

- the levels of accuracy may be different for different parameters eg a gauging station may be very good at measuring low flows but very poor for flood flow estimation. The benefits therefore will probably need to be assessed for each potential use of the data. Alternatively, assessment may be made of the benefits of the increase in accuracy with which each parameter could be measured or estimated from the data from a proposed site eg real time flow, mean annual flood, 50 year flood, 95 percentile flow etc at a gauging station.

- the selection of the site for a raingauge weir is controlled by many practical constraints other than just the need for data. The viability of sites is controlled by physical conditions eg suitable gradient in the river for a gauge weir, degree of exposure of a raingauge, owners' permission, liability to vandalism, etc. The site that is eventually selected may be a great distance from the one originally envisaged, and the benefits of the data may therefore not be as great as intended.

- costs of feasibility studies for major sites such as gauging stations are already high and additional costs caused by unnecessarily complex benefits assessments would not be welcome. Any proposed methods should be as simple as possible to apply and flexible and robust enough to accommodate the many and varied aspects of site selection.

5. Monitoring

The project will be monitored by the Project Leader and Assistant R&D Co-ordinator. Monthly progress reports will be provided by the contractor. A meeting will be held to discuss the interim report.

6. Targets and Timescales

Outline programme in relation to Section 4 above.

Item		Month
1	Complete review of existing literature	3
2	Complete discussions with useful contacts	3
3	Complete development of recommendations for methods and procedures	5
4	Complete Interim Report on methodology	6
5	Project Board meeting	7
6	Project Board approval to continue development of draft methods and procedures	7
7	Test draft procedures	9
8	Draft R&D Note and Project Record circulated	10
9	Complete Final R&D Note and Project Record	12

7. Summary of Output Requirements

Final outputs are as follows:

R&D Note: clear and concise report to summarise findings and make recommendations for the format and contents of a manual containing practicable procedures for the assessment of the benefits of hydrometric networks and sites. The specification for any further work, if needed, to acquire the data and information necessary for the production of the future manual should be included.

Project Record: This document records all information collected during the lifetime of the project and is a complete account of the work undertaken.

Report Type	No. of copies	Date of completion	Produced by
A. Short Term			
Progress Reports	6	Monthly	Contractor
Interim Report	20	Month 6	Contractor
Draft R&D Note	20	Month 9	Contractor
Draft Project Record	1	Month 10	Contractor
B. Final Outputs			
R&D Note*	50	Month 12	Contractor/EA
R&D Project Record	4	Month 12	Contractor

*Contractor to supply one copy of the R&D Note on disk in WordPerfect 5.2 for Windows format

NB Unbound masters of all final outputs will be required.
All R&D outputs must be produced in accordance with 'NRA R&D Guidelines to Reporting' (see Appendix B – for summary of guidelines).

8. Information to be Supplied by the Contractor

- A full method statement. This must include a detailed programme of work together with details of services to be provided by the Contractor.
- Details of proposed project management, including details of any proposed sub-contracting arrangements.
- CVs of all staff.
- CVs of any sub-contracted staff.
- List of all experience which may be relevant to this work.
- Completed Financial Cost Statement – this will form Schedule I of the Contract documents in due course.
- Supply details of any prior intellectual property rights you may have in connection with this study – this will form Schedule III of the Contract document in due course.
- Completed Form of Offer (Reply form) – Appendix A

Please note that the full method statement, details of project management, and details of sub-contracting arrangements will form Schedule II of the Contract documents in due course.

NB PLEASE SEND TWO COPIES OF YOUR TENDER SUBMISSION

APPENDIX II

AN HYDROLOGICAL LITERATURE REVIEW

Historical context

Despite the example set in river gauging internationally by countries such as Switzerland, Austria and the United States, early gauging in the UK was very limited, with some of the earliest stations being privately funded in the Scottish Highlands by Captain W. N. McClean. Pressure for formalised systematic runoff measurement grew in the early 1930s as a result of a severe drought and a memorandum from the British Association which urgently called for the establishment of an Inland Water Survey to systematically monitor water resources. In 1934 the Minister of Health announced that such a survey should be undertaken, and after the war the 1948 River Boards Act required schemes to be drawn up and implemented, with the formation of River Purification Boards in Scotland following in 1951. The 1963 Water Resources Act then created River Authorities and created a new authority, the Water Resources Board (Lees, 1987). This Act, along with the stimulus provided by grant-aid, produced a rapid increase in the size of the network and although some 'contraction' did occur later in England and Wales (Scotland's less dense network continued to be developed), the UK now has a relatively dense network, comparable with Western Europe but weakened by its inferior length of record compared to most developed countries; in Sweden records started in 1870 and in Hungary even earlier (Evans, 1984).

Europe and funding

Across Europe, governments or state authorities hold the responsibility for data collection and site maintenance although six countries (Belgium, Denmark, Germany, The Netherlands, Spain and Sweden) sub-contract site maintenance and three (Belgium, Denmark and Germany) sub-contract data collection (Rees and Dixon, 1994). In the UK, most aspects of hydrometric surveying are retained 'in-house' due to two factors (Fawthrop and Streeter, 1996); the limited external market, and a recognition that externalisation would jeopardise the synergy and integration between hydrometry and many other activities. Looking to the future, the gathering of hydrometric data can be seen in a more global context; for example in Switzerland a more global approach has merged hydrological data with meteorological and geological data as basic elements of global environmental observation (Emmenegger, 1990). In terms of funding, many hydrological services are meeting or have met the challenge of deriving an income for the services they provide, although it is important that some of the returns available in the commercial world can be fed back to ensure the continued improvement of the service and its infrastructure rather than extra income being returned to government coffers. It is also notable that in today's world a hydrological service that supports itself from the fees it earns might be an obvious target for privatisation (Rodda, 1990).

Hydrometric Data

Numerous studies such as those by Scott (1987), Black et al. (1994) and Black and Cranston (1995) have demonstrated the broad range of uses of hydrometric data, the latter describing the evolution of data usage in Scotland and highlighting new and anticipated uses of data being produced by the existing network. In the 1994 review of the Northern Ireland hydrometric network, Black et al. identified 13 distinct data uses from interviews with the Department of the Environment for Northern Ireland's Environment Service and the Department of Agriculture for Northern Ireland (Black et al., 1994, p17):

1. residual/prescribed flows/levels
2. river regulation/transfer schemes
3. abstraction point spillage protection
4. catchment yield assessment
5. flood forecasting
6. flood design studies
7. water sampling to meet PARis COMmission guidelines
8. assimilative capacity
9. consent standards
10. transmission of data to National River Flow Archive
11. ecological studies/recreational monitoring
12. benchmark monitoring
13. hydrological studies

Of these uses only one station (the station nearest Belfast) could claim 11 uses for its data, and those stations whose data had the most uses were generally the lowest gauges on major catchments. Stations whose data had few uses were often level-only stations. Scotland's data usage, although similar (Black and Cranston employed the same 13 data use categories), has been strongly influenced by the development of HEP - much of Captain W. N. McClean's early gauging was aimed at assessing HEP potential. Water quality assessment then became a driving force for the opening of new stations in the late 1950s/early 1960s, followed by research projects (forestry - Balquidder; acidification - Loch Dee) and more recently the development of telemetry-based flood warning schemes. New technology has enabled more remote stations to be opened and can allow data to be collected at only one extreme of the flow duration curve to meet specific needs. Although both these reviews noted the lack of representation of smaller catchments, the potential of Scottish historical flow data with respect to climate change impacts was considered valuable and the increasing multifunctionality of the network praised.

Network efficiency and operation

It is becoming ever more important that networks are efficient in their collection of hydrometric data, and are able to justify the levels of expenditure spent on them. This issue influences network design, operation and can bring about the contraction of a network. There are many approaches to network design (for example Moss, 1987; comparison of specific technologies by Moss and Tasker, 1991; entropy approach of Yang and Burn, 1994) but inevitably maximum information can only be achieved by a dense expensive network. As a less dense network leads to a loss of information, the best solution is found if the sum of information loss and network costs shows a minimum (Van der Made, 1990). In terms of network rationalisation, Burn and Goulter (1991) described a methodology to reduce a network and increase its effectiveness by searching for redundant information. They used a hierarchical clustering algorithm to identify groupings of stations and then selected one station from each group to be retained as a member of the reduced network (incorporating station specific information such as the user's judgement and experience).

There is also a variety of work concerning the operation of a network to maximise the quality of the data and minimise the time and expenditure required to collect it. Pelletier (1988) documented the main uncertainties in the determination of river discharge and Mades et al. (1990) presented a technique for assessing instrumentation systems in terms of cost effectiveness. Kitandis et al. (1984a) considered the cost effectiveness of direct discharge measurements as a means of increasing the accuracy of data, and also studied (1984b) the effects of visitation frequency and instrument reliability on data accuracy. On a more practical note, Pelletier and Simonovic (1988) and Simonovic et al. (1988) tackled the problem of optimal field operation of a hydrometric network using a travelling salesman algorithm modified to solve the 'Travelling Hydrometric Technician Problem'. They produced an algorithm compatible with the capabilities of personal computers which could be used to:

1. compare stations according to their relative importance
2. plan emergency network operation
3. determine the cost effectiveness of a particular stream gauging programme.

Cost benefit analysis and hydrometry

It has been recognised that more than just a qualitative valuation of the benefits of streamflow gauging is required to justify its significant cost to countries worldwide. Studies have therefore considered either the value of hydrometric data from a network generally, or for a specific purpose (see below). A cost benefit approach has also been used to assess the planning of networks and the ability to improve data quality from a network. Wilson (1972) evaluated the relative value of three broad categories of hydrometric data: mean discharge, flow dependability and flood data. By considering the effects of network intensification/development he highlighted the latter two categories as producing the largest portion of benefits. Watt and Wilson (1973) were able to identify a parabolic relation between cost savings (such as costs of hydraulic structures or future damages avoided) and data accuracy suggesting that data improvement beyond a certain point would no longer be economically attractive. Estimates of the costs and benefits of data with respect to specific uses are inherently more accurate, and this approach has provided the basis of Service Level Agreements between NRA (now Environment Agency) data providers and internal customers since 1993, to provide a framework to link costs, benefits, quality assurance and network reviews (Fawthrop and Streeter, 1996). A number of authors have produced the following cost benefit estimates for specific data uses.

1. *Reservoirs/storage*

Increased hydrometric data reduces the uncertainty involved in estimating required storage. Uncertainty leads to either underdesign (frequent water shortages occur) or overdesign (capital unnecessarily tied up), so the availability of long records is desirable. However, although this uncertainty decreases as the record length increases, the coefficient of variation (CV) of annual flows represents the most significant streamflow parameter determining reservoir design storage (Adeloye, 1995; 1996), because an increased annual CV either reduces the mean flow (thus increasing storage requirement) or increases the standard deviation (thus requiring more storage to deal with the ensuing large fluctuations in streamflow). Nevertheless, the length of streamflow data record has an enormous influence on the accuracy of reservoir capacity estimates especially for record lengths of 20 years or less, and Adeloye (1990) was able to demonstrate that this relationship approximately obeys the inverse-square-root law. Longer data records are also valuable as they are more likely to include critical periods which cannot be synthetically generated from shorter records (Barlishen et al., 1989).

The ratio of benefits to costs will depend on the amount of data already in hand, the length of the extra sample of data to be collated and the number of sites at which data are to be collected (Cloke and Cordery, 1993). It is clear though, that 'even for those streams which occur in the relatively stable hydrological regimes of Europe, large sampling errors are associated with reservoir capacity estimates obtained from short streamflow data records' (Adeloye, 1990, p234). This means that a 6-year data record implies 30% error in capacity estimates and even a 20-year record implies 15%, so financially the cost of under- or overdesign will depend on the size of the storage. By determining storage sizes from a range of record lengths, Cordery and Cloke (1990) were able to estimate the variation in capital cost of the designed structures. Further work (Cloke and Cordery, 1993) subsequently demonstrated that if data collected from all 500 stations in New South Wales was to be used for no purpose other than storage design the benefits and costs would become about equal once records had been collected for about 80 years. It also noted that other data uses would ensure a benefit cost ratio greater than one for the foreseeable future even if the network was greatly expanded. Even after reservoir design is complete, hydrometric data is extremely valuable; in reservoir operation it was found that policies that employed more complete hydrological information performed significantly better (Tejadaguibert et al., 1995).

2. *Low flows*

There is little work regarding the value of flow data in dealing with low flows. Willis and Garrod (1995) evaluated a low flow alleviation scheme on the River Darent in Kent, and identified five principal benefits of alleviating low flows as recreational, commercial, educational, amenity value to residents, and passive values to non-residents. With £7.2 million spent on capital works, £5 million on a pipeline and £1 million on riverside boreholes in this catchment (the latter two both to augment water in the Darent), the percentage error associated with a short record could amount to a significant sum financially. The economic value of water in a watercourse could also be re;lated indirectly to data value, and studies such as Bilsby et al., Postle and Moore, and Gautam and Steinback (all 1996) have considered the value of recreational fisheries, linking changes inenvironmental quality to recreation gains and losses. However, the value attributable to the use of hydrometric data in these situations in difficult to define.

3. *Flood protection*

The use of hydrometric data is most obviously valuable now that online data can be used in flood warning systems enabling the organisation of emergency services, closure of road and rail links, issuing of warnings to public services and companies and the issuing of warnings to the population at large including the possibility of evacuation (Roche, 1990).

In terms of the design and construction of flood protection schemes, Mawdsley et al. (1990) studied three small schemes in England, and estimated the data value to be approximately 4-5% of construction costs. This produced benefit cost ratios of 1.0, 0.37 and 0.05; in only one case were the data considered worth collecting if this application was the only use of the data. Cordery and Cloke (1994) used streamflow records, a damage-height relationship and a height of protection-cost relationship for three sites in Australia, and devised a flood mitigation strategy from a sample of the record. This was then compared to a strategy devised from the same data plus data from the following years to produce firm conclusions:
(a) that gauging stations should be installed *now* in regions where there is likely to be a demand for flood protection works in the future;
(b) that collected data are so valuable for project planning that there is a need for considerable public investment in installation and operation of stream gauging stations to collect and archive high quality data.

4. *Pollution*
Quantification of the value of streamflow data for water pollution control was worked towards by Adeloye and Mawdsley (1990) but no clear result was achieved as the authors were wary of ignoring intangible benefits and producing low data value estimates. Nevertheless, 'the indication from the error characteristics presented...is that the data are likely to have value in the application' (p407).

5. *Bridges*
Cordery and Cloke (1990) considered the design of crossings of small streams and in their evaluation included the following;
(a) capital loss/saving due to overdesign/underdesign
(b) cost/saving of damage to structure due to overdesign/underdesign
(c) cost/saving of delays and extra travel distance when the road is closed.
This produced a benefit cost ratio of 92 for the years between 1958 and 1987 which would fall to 22 if the cost of all data collection were included.

6. *Groundwater*
Despite a lack of quantitative work on the value of groundwater data, monitoring has been intensified in recent years due to an increase in problems such as contamination, overabstraction and their environmental consequences (Zhou, 1996). The high cost of groundwater data collection must be justified by the fact that all processes of interaction between the groundwater system and the environment can be observed only by a monitoring network, allowing applications such as detecting the impacts of climate changes and human activities on groundwater quantity and quality.

Moss (1996) provides a useful overview of worth of data studies such as those described above. On a methodological basis, he identifies three approaches which have been employed:

- *Hypothetical studies* use synthetic data series and theoretical approaches to the worth of data to assess how benefits vary with length of record available;
- *Ex post facto studies* explore the worth of real streamflow data after they have been collected; and
- *Preposterior studies* attempt to estimate the worth of data before collection, by using Bayesian Decision Theory, but require simulations to overcome otherwise insurmountable computing demands.

The relative merits of these approaches will be discussed in the fnal section of this review.

Network evaluation

Whilst the above case studies cover specific data uses, there are a few cases of broader network evaluation worthy of comment. Studies by Cordery and Cloke have already been mentioned, but their work on Australian gauging went beyond the quantification of benefits of data per usage to estimating the benefits of the whole data collection programme for New South Wales. Their 1990 paper relied on assessing what were considered to be the two most significant uses of data; the design of crossings over small streams and the design of storages. From these two data uses it was estimated that the benefit cost ratio for the network considered was at least 27 and probably greater than 30. A more complete evaluation was conducted by the same authors in 1992 (Cordery and Cloke, 1992a; 1992b), where the cost in each data usage case was taken as the cost of collecting and archiving data from the complete network of stations, and related to benefits in a range of categories. The following results were produced (1992a, p275):

data use	estimated benefit/cost ratio
crossing of minor waterways	0.8
flood mitigation	0.1
sizing of water storages	1.7
major structures	2.0
urban drainage	>4
others	>0
minimum total benefit/cost ratio	9

An evaluation of the U. S. Geological Survey stream gauging programme (Thomas Jr et al., 1990) used nine categories of data use: regional hydrology (3227 stations), hydrological systems (3564), legal obligations (238) planning and design (938), project operation (2447), hydrological forecasts (2437), water quality monitoring (2307), research (603) and other uses (609). It calculated that the data from each gauging station had an average of 2.6 uses, and of the 1252 stations with only a single data use it identified 60 as not having sufficient justification to continue their operation. A further 69 stations being operated for short term special projects were identified as not having sufficient justified data uses beyond completion of their respective studies; in all about 2% of stations were recommended for discontinuation. Analysis found the network to be cost effective and concluded that (a) the standard error of the streamflow records could not be significantly reduced by changing operating practices given the present budget and (b) the present budget could not be significantly reduced and still maintain the current level of accuracy of streamflow records.

A more subjective, qualitative audit approach was used to evaluate the hydrometric network of New Brunswick in Canada by Davar and Brimley (1990). They modified the priority considerations of Wahl and Crippen (1984) to produce these four groupings for each station to be scored under:
(a) site characteristics
(b) identified client needs - regional hydrology
(c) identified client needs - operational hydrology
(d) regional importance of water resources

A scoring structure from 0 to 10 was developed so that the higher the total station audit points accumulated by a particular station, the higher is the relative value of benefits derived from that station. Therefore the scoring was only an ordering of relative worth and no economic value attributed to stations. Although the framework was subjective, it was found to be a useful integrating tool, and the provision of objective guidelines for the assessment procedure helped prevent the subjectivity being too detrimental. However, as in most of these evaluations, current values are all that are used in the decision making process as the future worth of data is difficult to predict. There is also the issue of comparing different data uses, as some might be considered more important than others, whilst some tasks which use hydrological data might be achievable without it by other means.

A growing importance in the value of water as a potentially sustainable resource has not been enough to maintain hydrological networks and the services that operate them in many countries. Worldwide hydrometric observation is deteriorating, especially when compared to global meteorological data, at a time when the global demand for water is accelerating (Rodda et al., 1993).

Future technologies

Hydrometric data collection may in the future become less reliant on ground-based measurements. The growth of remote sensing in hydrology has seen the introduction of remotely-sensed data being used in precipitation estimates, soil moisture measurements, snow water equivalent and snow extent assessments, seasonal and short term snowmelt runoff forecasts, and surface water inventories. In the next decade these might be joined by remote measurements of land cover, sediment loads, erosion, groundwater and areal inputs into hydrological models (Rango, 1994). The impact of remote sensing is also likely to be great because of its ability to provide spatial rather than point data, on a global scale and even for remote and inaccessible regions of the Earth (Engman, 1996). The transmission of hydrological data by satellite is also a valuable cost effective and reliable method of data collection, and for areas where no hydrological data are available there is the chance to estimate runoff (for example two techniques described by Kruger et al., 1982). However, progress in these fields has been hindered by the lack of dedicated hydrological satellites (Barrett and Herschy, 1989). Presently sensors with good resolution in space (Landsat, SPOT) are able to provide information on slow hydrological processes such as snowmelt, ice, land use, and model parameters, and those with good resolution in time (GOES, Meteosat, GMS) cover dynamic processes such as rainfall, runoff and floods (but not in detail as spatial resolution is poor). It is evident that what hydrologists need is good resolution in space *and* time (Schultz, 1988).

Discussion

This review has illustrated a considerable amount of interest in the subject of assessing hydrometric data benefits. More than 50 papers are cited, and more than 90 have been consulted. The great majority of this literature (85%) has been published since 1986, notwithstanding the fact that some useful principles had been established in the 1970s. This could be interopreted as an indicator of the importance now being attached to assessing the justification for expenditure on hydrometric monitoring - a trend found in many other fields of activity around the world.

The case studies above have reported a wide range of values for hydrometric data. In single-application assessments, Mawdsley et al. (1990) reported a benefit cost ratio of only 0.05:1for one small flood defence project (ie benefit<<cost) while, at the other extreme, Cordery and Cloke (1990) have found a benefit cost ratio as high as 92:1 for the collection of data and their application to flood estimation in small crossing design methodologies in New South Wales for a 30-year period. Even a more conservative assessment in the latter studyproduced a ratio of 22:1. Cordery and Cloke (1992a) have also been active in the field of assessing benefits for all types of data use. They stress that some benefits are not quantifiable but, on the basis of adding benefits for all those uses which can be lent to such treatment, a minimum ratio of 9:1 can be justified. Earlier work for the UK by CNS Scientific & Engineering Services (1991) found that ratios in the range 1.2:1 to 7:1 were appropriate for that country, depending on methods used.

It can be seen therefore that a significant range of values have been attached to hydrometric data, depending on the type of application, characteristics of the study in question and assessment of existing data - amongst others. The useful overview by Moss (1996) cited above reminds the reader that different approaches can be employed in a given situation, and each of these has its own inherent assumptions. Not least amongst these are the assumptions that past streamflow observations can be used to estimate statistical properties of future distributions of values within given levels of uncertianty, notwithstanding increasing signs of vulnerability of flow behaviour to changes in climate, and the constant possibilities of land use change impacts. Also, it is regularly observed in the literature that no study can quantify all the benefits accruing from the collection of data, e.g. what is the conservation benefit of operating a gauging station which allows flow to be maintained to provide a safe habitat for a rare ecosystem?

The risk of inconsistencies between one approach and another, coupled with the recognition that some benefits cannot be quantified, has led some workers to prefer qualitative or subjective methods in the assessment of benefits. One example is the work of Davar and Brimley (1990) in Canada, where points are awarded under a number of headings in order to produce an expression of relative worth. If unquantifiables were to be regarded as as important in a given area, or serious reservations were held regarding methods of quantification, this might be an appropriate approach for some studies.

This review has set out the main areas of work reported on assessing the value of hydrometric data. In the context of the wider Environment Agency/SNIFFER-sponsored study in which it arises, results of a survey of data users, and further work on assessing alternative approaches to quantification, are now awaited before proceeding further.

Acknowledgements

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APPENDIX III
BENEFIT ESTIMATION METHODS FOR HYDROMETRIC DATA

By Ceara Nevin

Introduction - Environmental Decision Making, Data Collection and Cost Benefit Analysis

The environment is composed of a number of complex interacting systems. A symptom of this complexity is that it can take a long time to obtain enough information to develop an understanding. One response is to design [and maintain] a network of sites where measurements are made, 'in order to encourage understanding and provide an indication of future change' (Burt, 1994). This proposal, in addition to the comment in the Government's 1990 white paper on the environment - that without good monitoring activities 'environmental policy decisions cannot be based on the best of scientific and technological analysis' (H.M.S.O. 1990) - appears to support the continuation of environmental data collection.

When evaluating any project concerning the environment, such as the structuring of a data collection network, financial costs however must be assessed and compared with environmental benefits obtained.

This estimation of costs and 'monetary' benefits of an environmental improvement can justify project expenditure or exhibit to decision makers that the project is not worthwhile (Ramchandani, 1989).

Cost Benefit Analysis, a quantitative analytical method, was originally developed for performing economic evaluations of alternative US federal water supplies. As a consequence of its capacity to assign monetary values in a non-market situation, it has been accepted by government in both project and policy decision making.

There are several approaches to the use of cost benefit analysis in the evaluation of hydrometric data, a combination of which are examined in this report:

- *Detailed* - data from one or several specific observing stations is related to a specific project or to a set of similar water resources projects e.g. flood protection schemes.
- *General* - Overall data from a country/region/network of stations is assessed in relation to a data use [not necessarily project specific].

Part 1 - Detailed Approaches to Cost Benefit Analysis

Part one involves the identification of indirect benefits of data collection as outlined in the literature review and the discussion of how these may best be valued using cost benefit analysis. For clarity, the discussion has been structured in sections. While each section represents an individual benefit, in order to provide a comprehensive approach and exhibit the links between benefits, some overlap exists.

1. Indirect Benefit: Water Quality Improvement

1.1. Benefit Category: Water quality improvement in terms of an improvement in both surface and groundwater[1] abstracted for potable supply.

1.2. Relationship of Benefit to Data Collection: The collection of hydrometric data encourages more accurate estimation of a river's assimilative capacity and in turn the more efficient issue of pollution consents to industry through avoiding the risk of over/under provision of water treatment capacity (Crabtree et al, 1996. Black et al, 1994).

1.3. Economic Valuation of Water Quality Improvement for Potable Supply

1.3.1. Avoidance Costs/Averting Expenditure Actions

Theoretical explanations of this approach are based on the production function theory of consumer behaviour. It is suggested that costs incurred by households, firms or Government to avoid exposure to a water contaminant, can be used as an empirical measure of the pollution costs imposed on society (Courant & Porter, 1981).

In addition to actual expenditure Abdulla et al included an evaluation of the amount of time required for averting actions, based on the estimated wage of the respondent (Abdulla et al. 1992). In that study total 'averting actions' were defined as including; increased bottled water purchases for individuals buying it prior to pollution, bottled water purchases by new buyers, installing home water treatment systems, hauling water from alternate sources, and boiling water. A key assumption however within the averted expenditure approach is that averting actions *perfectly* substitute for reduction in pollution (Courant & Porter, 1981).

The construction of regression models with this method is useful to identify household and contaminant factors influencing expenditure. Raucher attributed influence to the contaminant's health risk, the extent of the public's awareness, type of water supply and presence of children (Raucher, 1986).

Averted expenditure studies by organisations (e.g. firms and Government/local authorities) have generally focused on the capital and operating cost associated with water treatment. Care must be taken however in the event of considering costs to both firms and households in the same CBA study that double-counting does not occur, as households, in addition to firms, can benefit from a firm's water treatment activities.

The averting expenditure method provides a lower bound estimate of total costs imposed by pollution. The divergence arises as some consequences of water pollution cannot be averted entirely through expenditure (Courant & Porter, 1981). In an attempt to address this properties of the utility function in addition to those of the household's production function should be examined. Despite this limitation however, and the failure to consider non-use values the approach has been used effectively on its own and as an 'anchor' for *willing to pay* values within contingent valuation (Abdulla, 1994).

Benefit Transfer: Benefit transfer may reduce the financial cost and time of carrying out a cost benefit analysis, in reducing the primary research involved. It has been defined as 'the process of taking a value or benefit estimate developed for a previous project or policy decision and transferring it to the proposed project or policy decision' (Postle & Moore, 1995). Several concerns have been highlighted however in relation to the validity of this approach and as a result its use is limited, according to Postle and Moore, to the estimation of orders of magnitude

The site specific and household factor influences upon averted expenditures, as related to Raucher in the discussion, may imply that benefit transfer is difficult (Raucher, 1986).

1.3.2. Contingent Valuation

The gross monetary value of any market good or service has two components: financial value and consumer surplus. Averted expenditure approaches concentrate on the averted *financial* *cost* of goods through a focus on consumer's *actual* expenditure. The amount which consumers are *willing to pay* may be greater, this difference being known as consumer surplus. The contingent valuation (CVM) approach to CBA attempts to capture both this consumer surplus and financial value to reflect the total utility derived from improved drinking water quality.

Contingent valuation involves the structuring of artificial markets, designed to directly elicit measures of consumer surplus through individuals' WTP[2] (Bergstrom et al, 1990). Such a market, for improved drinking water quality, with relevant payment mechanisms could be applied either within a controlled setting, or in the field. Artificial markets are divided into two broad categories: those that involve actual monetary payments for non-market goods, and those that do not (Bergstrom et al, 1990).

Jordan and Elnagheeb used a CVM study to estimate total WTP for improvement in drinking water quality in Georgia (Jordan & Elnagheeb, 1993), while Desvouges et al have looked specifically at the option value relating to water resources (Desvouges et al, 1987). Stevens et al [although not referring directly to water resources] argue that ignoring the non-use values in CBA can underestimate the total value from such an environmental resource by up to 75% (Stevens et al. 1993).

1.3.2.1. Limitations of CVM: Gregory et al believe that CVM, as applied to measuring improvements in drinking water quality and recreation uses (Gregory et al, 1993), are fundamentally flawed for a number of reasons:

1. Assigning monetary values imposes unrealistic cognitive demands upon respondents, as one is dealing in an artificial market situation.
2. The observed disparity between WTP and WTA, as discussed below.

Kahnemann and Knetsch also found that when individuals assign a monetary value in an artificial market situation, they seemed unable to distinguish between the relevant 'good', and their 'sense of moral satisfaction' associated with contributing to a good cause, e.g. the improvement of water quality for society (Kahnemann & Knetsch, 1992).

Bowers expressed concern that the use of WTP within contingent valuation [as a consequence of WTP being a function of income and wealth] implied the acceptance of the pattern of WTP as given by society's existing distribution of income, even if inequitable (Bowers, 1993). The use of WTA compensation as an alternative has been found however to elicit much higher responses (Hanley & Spash, 1994).

The payment mechanism may also influence results. The choice of water rates for the measure of willingness to pay for water quality improvement, for example, will encourage responses which reflect peoples' attitudes towards the role of public investment or private water company profits, and not the importance of improved drinking water quality (Green & Turnstall, 1991).

Support for the reliability of contingent valuation in estimating water quality benefits comes from Loomis' study however, where test-retest results for willingness to pay to preserve Mono Lake in California, over a nine month period, remained relatively stable (Loomis, 1989).

1.3.3. Hedonic Pricing Method

The Hedonic pricing method uses surrogate measures e.g. variation in house prices, as an indication of the value of a change in water quality.

Garrod and Willis (1992) found that the proximity of open water to a property increased its value by 5%. However, this also highlighted several bases for concern with this method including that:

1. House prices represent a unique *combination* of characteristics, yet HPM centres on an individuals ability to isolate and estimate the value of particular attributes independently. To aid this valuation economists also require a great deal of regionally and nationally adjusted data.
2. The HPM will only reflect household's marginal WTP for a particular attribute if the *measured* level of the attribute corresponds to the *perceived* level by the consuming household.

Ramchandani has commented that this method tends to be inaccurate for valuing water quality improvements, and is more suitable for air or traffic quality changes (Ramchandani, 1989).

2. *Indirect Benefit: Enhanced Recreation from Water Quality Improvement*

2.1. Benefit Category: An improvement in water quality relating to improved recreational uses[3]. Green et al believe that the benefits of water quality improvement in the UK will mainly arise from increases in the amenity and recreational value of rivers, rather than from the abstraction of water for potable supply (Green et al, 1989). In this context improved water quality leads to:

a) a reduction in incidences of low dissolved oxygen resulting from the bacterial degradation of organic materials and heavy sediment loads, which make it difficult for fish to live (Kneese, 1984). This reduction leads to increases in the total availability i.e. *quantity*, of recreational freshwater fishing. Clean water also leads to an increase in *quality* of fishing, ensuring the presence of more game fish such as trout (Patrick, 1991).
b) an upgrade in the status of a river's quality e.g, from fishable to swimmable, thus opening up other in-stream uses (Feenberg & Mills, 1980).

2.2. Relationship of Benefits to Data Collection: The relationship of water quality improvement to data collection is explained in paragraph 1.2.

2.3. Economic Approaches to Evaluating Recreation Benefits

2.3.1. Travel Cost Method

The Travel Cost Method is argued by some to be the most appropriate approach within CBA to value *user* benefits from recreation (Ramchandani, 1989). Similar to CVM it is a non-market valuation technique, but here travelling expenses [financial costs + time spent] are used as a proxy for the price of visiting outdoor recreational sites (Hanley et al, 1997). These costs are then used in formulating the recreation demand equation which is used in turn to estimate consumer surplus for visits.

The process initially involves the collection of economic and demographic data through visitor surveys which is incorporated in the estimation of a statistical relationship between visits and the cost of visits.

Opinions tend to differ between authors on how precisely demand for recreation should be defined, the variables which should be included in the evaluation, and how (Davis & O'Neill, 1991). Gautam and Steinback identified the historical daily average catch rate as an important explanatory variable for 'quality of fishing experience' in their valuation of recreational fishing in North East America (Gautam & Steinback, 1996).

In Davis and O'Neill's evaluation of recreational angling using the TCM in N. Ireland, the mode of transport used was considered, in addition to the extent to which recreational activities other than angling were pursued during the trip (Davis & O'Neill, 1991). This is a useful approach as it permits an estimation of the *proportion* of the cost of the trip attributable to angling in isolation to other uses to be estimated.

It was argued by Green and Turnstall that an increase in water quality would attract new visitors away from *other* substitute sites (Green & Turnstall, 1991). Cesario and Knetsch included a factor reflecting 'competing opportunities' provided by all other sites in their zonal travel cost model (Cesario & Knetsch, 1976).

The TCM generally leads to an underestimation of water quality / flood alleviation benefits as total recreational benefits only represent the additional value to existing users (Brookshire & Smith, 1987).
The overall validity of the travel cost approach has been recently questioned however in a paper by Green. It showed that the fundamental assumption underlying the validity of TCM is not always the case, this assumption being that the value of visits undertaken from distant origins is greater than for origins nearer the site, because the travelling costs are greater (Green, 1990).

2.3.1.1. Hedonic Travel Cost Method: This involves the estimation of benefits from enhanced recreation from water quality improvements on a 'per recreation/fishing day' basis (Bockstael et al, 1987), through the regressing of individuals 'total cost [Cmij] of visiting a site [j] on the characteristics of the site [bj]:

$$Cmij = f^{i} [bj]$$

It is assumed here that the costs of visiting a particular site and the characteristics of the site are similar, for all individuals living within the same area, the variation stemming from the *different* sites visited by people from the same area. The distinction therefore, between this and the standard TCM model, is that here recreational benefits relating to improved water quality are estimated from the demand for site characteristics, and not that for recreation trips (Dasgupta & Pearce, 1977).

2.3.1.2. Random Utility Model: The appeal of this model to value enhanced recreation relates to the collection of travel cost and characteristics data for a number of substitute sites in an area. The probability that an individual will visit site i rather than j is then calculated, depending on the costs of visiting each site and their characteristics, relative to the characteristics in the individual's set of alternatives offering maximum utility. The welfare effects of changing a characteristic can then be calculated (Braden & Kolstad, 1991).

Benefit Transfer: In adopting a travel cost approach Gautam and Steinback assumed that sites within the same region were likely to be fairly homogenous in terms of catch rates, travel costs and distances to sites (Gautam & Steinback, 1996), possibility facilitating benefit transfer. Radford adopted an homogenous functional forum for all rivers in a region as differences in observed mean per capita values across rivers in a similar area were found not to be significant (Radford, 1991).

2.3.2. Contingent Valuation

Similar to TCM, contingent valuation employs an economic and demographic survey. In contrast however, it facilitates the estimation of nonuser benefits in relation to an improvement in recreation.

It has been suggested that the values expressed by respondents who do not engage in in-stream recreation should be almost purely intrinsic in nature, implying that calculating the average WTP amount for them allows an approximation of the intrinsic benefits accruing to

all individuals from the enhanced availability and quality of recreational use. Adopting this assumption Kneese subtracted non-recreationalists' WTP from recreationalists' WTP [deemed equal to total user values] and concluded that intrinsic value, apart from constituting 100% of non-user value, constitutes 45% of this total user value (Kneese, 1984).
Green et al sampled *three* groups of respondents in their contingent valuation study of water quality improvements: river corridor users, households adjacent to the river corridor and households located at least two miles from an accessible river corridor, with the total value then estimated as (Green et al, 1989):

[No. of visits * value of increased pleasure per visit] + non-use value of improvement

Earlier in this paper Gregory et al commented that requiring respondents to assign a monetary value within the non-market CVM placed excessive cognitive demands upon the respondent (Gregory et al, 1993). Kneese has proposed a solution to another cognitive difficulty for individuals in this context, i.e. to be aware of the *existing* water quality, and the water quality improvement *needed* for specific recreational uses (Kneese, 1984). He proposed that these levels be described in words and depicted graphically by means of a 'water quality ladder', which can also ensure that different people perceive existing and required levels in a similar way.

Benefit Transfer: In the FWR water quality manual a CVM survey was especially commissioned to develop 'standardised' values for the benefits to anglers associated with water quality improvements, a summary of which is given below (FWR, 1996).

Table 1: Summary of monetary benefits attributed to an increase in water quality for angling

Angler Type	*Value (£ per person per trip)*	*From**	*To***	*Method*
Coarse	3.86	No fishing	C3	CVM
	4.07	No fishing	C2	CVM
	6.21	No fishing	C1	CVM
	6.51	No fishing	T3	estimate
	7.58	No fishing	T2	estimate
	11.86	No fishing	T1	CVM
	15.83	No fishing	S1	CVM
Non-migratory salmon	7.16	No fishing	C1	CVM
	8.92	No fishing	T3	CVM
	10.39	No fishing	T2	CVM
	16.28	No fishing	T1	CVM
	22.65	No fishing	S1	CVM
Migratory salmon	11.58	No fishing	C1	CVM
	11.95	No fishing	T2	estimate
	18.70	No fishing	T1	CVM
	25.66	No fishing	S1	CVM

* Water quality where fishing cannot be carried out.
** Improved water quality level.
Source: Adapted from FWR (1996).

3. Indirect Benefit: The Generation of Hydroelectric Power

3.1. Benefit category: The generation of hydroelectric power contributes to 10% of the energy requirements of Scotland alone (SEF, 1996). The development capacity of hydroelectric power can be assigned a monetary value on the basis of £ per MW.

3.2. Relationship of benefit to data collection: This may be explained through the importance of forecasting seasonal flow changes on the effective operation of a hydroelectric plant as highlighted by Monokrovich (Monokrovich, 1990). At such plants throughflow is increased leading up to an expected surge of water or flood with a view to releasing some of the reservoir's capacity so that it can hold this water. If such forecasts are inaccurate or absent the throughflow regimen is calculated using the average high water inflow volume. If the actual inflow is greater, the lost production due to excess water discharged must be compensated by energy generated using fossil fuel.

3.3. Economic Approaches to Valuing Benefits from Hydroelectric Power Generation

3.3.1. Opportunity Cost Approach

Monokrovich calculated data value on the basis of the increased energy output from more accurate data. Assuming accuracy levels of 80-85% the lost production opportunity was calculated where:

$$R = U^* \, Wdis$$

R = Lost production
U = Difference in cost price of thermal station electricity and hydropower electricity
Wdis = Energy lost, being a function of volume discharged and the pressure head at which power is produced.

Monokrovich found that with this assumption of 80-85% accuracy a further increase of 5% gave an additional energy output of 1.4-1.9%, which could be equated to MW, and in turn valued at the market rate, resulting in an annual benefit of 100,000-140,000 roubles. The overall value of data was considered dependent on the actual capacity of the hydroelectric scheme.

4. Indirect Benefit: Enhanced Flood Protection

4.1. Benefit Category: The benefits from avoided losses due to flood protection. Flood damages can be either direct or indirect, depending or whether the damage is the result of direct contact with the flood waters or whether the losses result from disruption of economic activity as a consequence of flooding i.e. indirect flooding.

Benefits are further subdivided into tangible and intangible. Tangible benefits are measurable in monetary terms, while intangible are more difficult to attribute a monetary evaluation to e.g. greater security against loss of life, and enhancing environmental quality (Kuiper, 1971), or costs of dislocation to family life (Thampapillai & Musgrave, 1985).

4.2. Relationship of Benefits to Data Collection: Decisions concerning the implementation of flood mitigation schemes, according to Cordery and Cloke, are dependent on the accuracy of avoidable information. As the data length increases 'the inherent uncertainty of the characteristics of the stream flows decreases and confidence in estimates of the size and frequency of expected flood increases' (Cordery & Cloke, 1994).

4.3. Economic Approaches to Evaluating the Benefits of Flood Protection/Flood Warning Systems

4.3.1. Hedonic Price Method

Penning-Rowsell et al examined several US applications of HPM to flood alleviation benefit assessment and found little consistency in terms of explanatory variables included (Penning-Rowsell et al, 1992). This casts doubt on its validity.

Miyata and Abe applied this technique to valuing flood control benefits for the Chitose basin in Hokkaido, Japan (Miyata & Abe, 1994). A reduction in the variable, annual expected depth of flood water (AEDFW), was used to represent the resultant improvement in regional safety. This variable, in addition to a number of other variables was incorporated into two land price functions for suburban and urban areas:

$AEDFWi = \int_0^{\infty} P(Q) * Di(Q)dQ$	AEDFWi = annual expected depth of flood water in square I [1km grid squares] P(Q) = probability of occurrence of volume of discharge Q Di(Q) = expected depth of flood water in square i associated with volume discharge Q
Urban $1nLP_1 = 4.9231 - 0.0041X_1 + 0.0035X_2 + 0.0001X_3 + 0.1069AEDFW - 0.5952D_1 + 1.0988D_2 + 0.1424D_3 + 0.3520D_5$ Suburban $1nLP_2 = 3.7401 - 0.0116X_1 + 0.0003X_3 - 0.2010AEDFW + 0.4032D_4$	LP_i = land price per $1m^2$, X_1 = travel time between the nearest railway station to Sapporo station[the capital], X_2 = number of workers in a square, X_3 = population within a square, AEDFW = annual expected depth of flood water, D_1 = dummy for expected residential area, D_2 = dummy for commercial area, D_3 = dummy for gas supply, D_4 = dummy for water supply, D_3 = dummy for drainage availability, ln = natural logarithm.

The annual average cost considered was defined as:

$$c = \left(i + \frac{i}{(1+i)^n - 1}\right) * I$$

where c = annual average cost, i = interest rate (4.5%), n = number of years, and I = total investment for the project.

The increase in land prices found with a reduction in AEDFW represented the benefit of a flood control project. The largest benefit cost ratio was that found for Eniwa city at 1.99, which when limited to the consideration of direct damage avoided, in order to avoid the possibility of double counting, fell to .74. The overall benefit in suburban areas was greater than in urban areas due to a greater flood area, however the urban unit benefit was much greater i.e. 44 times that of suburban units. Table 2 exhibits the similarities across Japan in terms of the % of overall damage accounted for by annual average expected damage types.

Table 2: Reduction in the annual average expected damage type estimated as a % of overall damage

Damage Type	*Ebetsu*	*Chi-tose*	*Eniwa*	*Hiro-shima*	*Nanp-oro*	*Naga-numa*	*Total*
Property-	**13.7**	**25.6**	**12.6**	**16.9**	**27.1**	**38.3**	**14.6**
Houses	4.4	5	4.6	2.1	4.1	4.1	4.5
Furniture	3.3	3.4	2.3	1.6	2.5	2.3	2.3
Agricultural capital stocks	0.1	0.3	0.1	0.1	0.49	0.9	0.6
Agricultural inventory stocks	0	0.06	0.02	0.02	0.08	0.2	0.03
Other industrial capital stocks	2.1	0.85	2.9	5.5	1.3	0.3	2.8
Other industrial inventory stocks	1.4	0.2	1.5	1.5	1	0.3	1.4
Rice	2	6	1	4.9	17.2	28.7	3
Dry fieldcrops	0.44	9.9	0.16	1.2	0.4	1.6	0.4
Public Facilities-	**22.5**	**19.4**	**22.9**	**21.7**	**19**	**16.1**	**22.3**
Roads and bridges	2.7	2.3	2.7	2.6	3.9	3.3	2.8
Agricultural facilities	11.5	9.9	11.7	11.1	9.8	8.3	11.4
Agricultural land	0.08	0.06	0.09	0.08	0.06	0.05	0.09
Railways	1.96	1.7	1.99	1.9	-	-	1.8
Urban facilities	0.8	3.3	3.85	3.7	3.2	2.7	3.8
Telecommunication facilities	0.34	0.3	0.34	0.3	0.28	0.2	0.33
Power facilities	2.1	1.8	2.1	2	1.8	1.5	2.1
Indirect Damage-	**63.7**	**55**	**64.5**	**61.3**	**53.9**	**45.6**	**63.1**
Cost of emergency measures	2.1	1.8	2.2	2.0	1.8	1.5	2.1
Reduction in production	19.7	17.4	19.9	18.9	16.7	14.1	19.5
Repercussive effects on production.	15.6	13.52	15.9	15.1	13.2	11.2	15.5
Cost of traffic suspension	6.1	5.3	6.2	5.9	5.2	4.4	6.1
Increase in living costs	10.7	9.2	10.8	10.3	9.0	7.6	10.6
Others	9.4	8.1	9.5	9.02	7.9	6.7	9.3
Total	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Source: Adapted from figures as reported by Miyata & Abe (1994).

Contrary to Penning-Rowsell's findings the above tables shows similarities across cities in % of total damages accounted for by each category. Examining benefit by type of damage, across cities indirect benefits were found on average to be 1.4 times direct benefits.

4.3.2. Avoided Damages Method

Potential damages avoided due to a flood protection scheme which Hueting attributed a monetary value to included loss of agricultural protection, damage to urban areas, temporary reduction in economic activities, costs of clean up, annual expenditures relating to emergency measures and health effects (Hueting, 1992). Cordery and Cloke similarly identified losses as the sum of items such as damage to property and infrastructure and disruption to businesses and transport routes (Cordery & Cloke, 1994).

4.3.2.1. Evaluating Agricultural Benefits i.e. avoided damages: This is on the basis of a farm survey (Penning-Rowsell et al, 1992) within the benefit area determining land use, soil type,

and flood experience of the land. An assessment is then made of the change in the value of output using adjusted[4] product prices.
4.3.2.2. Evaluating Urban Flood Protection Benefit: The unit loss method, developed initially by Penning-Rowsell and Chatterton was adopted by Parker et al to provide standard/average or site survey loss data for residences, businesses, and general utility loss (Parker et al, 1987). Accurate loss data can be derived initially from detailed studies of 'representative' samples of land uses and activities. On completion of this stage, only outline survey data is then needed in each project area rather than a complete modelling exercise. An advantage of this unit loss method is that losses can be built up or aggregated initially from individuals, to regions, and nationally. The suitability of this method is limited however to estimating direct losses and not changes which are likely to occur throughout the economy.

4.3.2.3. Evaluating intangible flood protection benefits i.e. intangible losses avoided
Qualitative Evaluation: This is the description of intangible benefits and costs comprehensively and clearly without attempting to assign a monetary value.

Bootstrapping: Bootstrapping is a method of deriving equivalent monetary values for unquantified losses, based on an extensive interview survey with flood victims (Green et al, 1989. Penning-Rowsell et al, 1992). A schedule for such surveys has been developed by Middlesex university and validated through 2000 interviews with flooded households.

Green's approach is illustrated in a number of steps:
1. Respondents were asked about the financial value of their losses and to rate the overall severity of the flood in terms of its impact on household life, and the relative severity of each of individual impacts. Scores on a scale of 1-10 are illustrated in table 3, 10 representing very severe damage and 1, least severe.
2. Table 3's subjective severity judgements for one of the two direct damages (i.e. fabric of the house, and its contents) were regressed[5] on a number of independent variables including financial magnitude of direct damage.

Table 3: Relative severity of different impacts or flooding as assessed by those who reported experiencing each impact

Damage	*Swalefcliffe*	*Uphill*	*Southgate*
Damage to house structure	5.0	5.0	3.0
Damage to replaceable contents.	9.0	7.0	0
Loss of memorabilia.	10.0	7.0	-
Health effects.	7.5	5.0	2.0
Stress of the flood itself.	10.0	n/a	6.5
Evacuation.	10.0	6.0	-
Disruption.	10.0	10.0	6.0

[n/a = not asked. - = no household suffered impact]
Source: Adapted from Green et al, 1989.

3. Monetary equivalent values for unquantified impacts were derived though:
    - an equation invented to express subjective severity in terms of pounds, see below.
    - insertion of subjective severity judgements for each of the unquantified impacts into equation.

$$\text{Log(subjective severity)} = 0.30\log(£) + 0.01$$

$(r = 0.75; F = 74.90; p <= 0.001)$

4.3.2.4. Evaluating Environmental Benefits i.e. environmental flood losses avoided
The benefits from saving environmental functions can be estimated through a 'collective political decision' by experts as referred to by Hueting (Hueting, 1992), contingent valuation or shadow prices.
With the shadow prices approach the potential loss avoided is estimated as the cost of creating or recreating exactly the same ecosystem elsewhere, e.g. the loss of an area of marshland would be valued as the cost of buying the same area and type of land elsewhere, and then establishing the same ecosystem (Penning-Rowsell et al, 1992). Indirect environmental benefits have been found to be well in excess of direct benefits, in this case, approximately double direct damages.

5. Indirect Benefit: Enhanced Flood Warning Systems

5.1. Benefit Category: Flood damages are a function of water depth and warning time, defined by Day in the equation (Day et al, 1969):

$$E(D) = \sum_{i-1}^{n} PiDi$$

Pi = probability of a flood within the 'steps'/recurrence intervals i and i - 1
Di = community damage associated with flood level at top of step i, a function of the warning time, type of action and response to the warning.
E(D) = expected annual loss
n = number of contour steps to approach floodplain limit, also representing the recurrence interval

Damage losses may be avoided through improved flood warning systems.

5.2. Relationship of Benefit to Data Collection: Increased length or accuracy of data leads to more precise flood warning schemes.

5.3. Economic Approaches to Evaluating the Benefits of Enhanced Flood Warnings
The approach adopted by Walsh and Noonan to assessing the contribution of weather data to flood warning may also be applied in relation to directly evaluating that of hydrometric data (Walsh & Noonan, 1990). The steps involved in this approach are outlined below, the assumptions upon which it was based including that:
- the weather radar network was operational 95% of the time.
- there would be a 70% response rate by occupants to warnings. Weather/flood warnings are of no value without good communications to the public.
- the availability of suitable flood forecasting/warning models, using radar (or in our case hydrometric data) as an input.
- benefits only relate to flood damage reduction.

1. Identification of sites where radars could provide greatest flood warning benefit. All flood data was collected on property at risk within England and Wales, flood damage assessment based on Penning-Rowsell and Chatterton's methods.
2. Classification of risk to property in terms of three categories of frequency of occurrence (1 in 10 yrs, 1 in 10 - 1 in 50 yrs, 1 in 50 yrs) plus catchment response times.
3. Conversion of single flood event data (from step 1) to average annual benefit using factors derived from derived from assumptions damage levels for differing flood events, see annexe 1and table 4 below.

Table 4: Factors to multiply single event damage reduction to give average annual benefits.

Category	*Event*	*Multiplying factor*
A	Flooding more frequent than 1 in 10 years	0.25
B	Flooding frequency between 1 in 10 and 1 in 50 years	0.07
C	Flooding less frequent than 1 in 50 years	0.02

Source: Adapted from Walsh & Noonan. (1990).

4. Derivation of weighting factors based on catchment response time of 4 hours. When response times were between 6 and 9 hrs radar was assumed to be of some value, and to be very useful for response times between 3 and 6 hrs, table 5.

Table 5: Weighting factors to give benefit due to radar

	No existing F/W scheme				*With existing F/W scheme*			
Times of response (Hrs)	0-3	3-6	6-9	>9	0-3	3-6	6-9	>9
Without 'Frontiers'*	0	0.8	1.0	1.0	1.0	0.6	0.2	0.05
With 'Frontiers'	1.0	1.0	1.0	1.0	0.9	0.75	0.2	0.05

* radar operating in conjunction with additional rain forecasting system.
Source: Adapted from Walsh & Noonan. (1990).

The most updated figures available using Walsh and Noonan's method calculate benefits, on the basis of giving a 4 hr. warning, to be £1.56m per yr, rising to £3.84m when data is combined with 'frontiers' data, implying benefit cost ratios of 3 and 5 respectively.

Benefit Transfer: The extent to which both standard and average data are available for flood damage has facilitated the transfer of flood alleviation benefits.
The term standard depth damage is reserved for data assembled from secondary sources. Average data is used to denote data derived from previous site surveys, averaged to give a generalised indication of flood damages for property types. UK damage data to residences/commercial units is frequently updated in the Flair report, by Middlesex University. Table 6 outlines different types of currently available data.

Table 6: Different types of flood damage data available and their characteristics

Types of Data	*Examples*
Standard Data • Based on specified simplifying assumptions regarding flood characteristics, e.g. velocity effects are minimal. • Based on specified costing approach e.g. use of average remaining values. • Based on a synthesis of data from multiple primary and secondary sources including loss adjustments. • Assumed to be transferable throughout U.K.; may incorporate national secondary data sources based on sample surveys. • Available where damage characteristics are likely to be very similar because properties or services are similar.	Direct depth damage data for residences Emergency Services cost data
Average Data • Based on assessments of flood loss potential from a large number of cases/properties using e.g. business site survey interview schedule. • Based on specified costing approach but also relies on property manager's estimated. • devised where there is relatively high variability between damage sensitivity of properties and where standard data cannot be devised. • transferable within the UK but cannot be expected to take full account of uniqueness of properties.	Direct depth damage data for industry Manufacturing flood loss data
Site Survey Data • Loss data collected by 'one-off' site surveys using, e.g. business site survey interview schedule. • Most reliable where properties or locations have unique damage characteristics.	

Source: Adapted from Parker et al. (1987).

6. Indirect Benefit: Recreation Benefits from Enhanced Flood Protection/Flood Warning Systems

6.1. Benefit Category: In addition to improved water quality, recreational benefits also accrue to more effective flood warning / flood alleviation measures. The difference lies in that in the case of water quality improvement, benefits relate more to an increase in the quality *and* quantity of recreational uses, while the latter concentrates on the benefits stemming from increased amenity land saved from flooding, through flood warning systems and better design of flood mitigation measures.

6.2. Relationships of Benefits to Data Collection: As hydrometric data increases, 'the inherent uncertainty of the characteristics of the stream flows decreases and confidence which aids the design of flood mitigation measures and issue of flood warnings increases (Cordery & Cloke, 1994). More effective flood warning procedures avoid the loss of amenity land through flooding.

6.3. Economic Approaches to Evaluating Recreation Benefits from Enhanced Flood Protection/Flood Warning

6.3.1. Travel Cost Method

Section 2 offered a discussion of this method in relation to improved water quality. Penning-Rowsell et al in their evaluation of coastal flood protection proposed that in addition to the loss of enjoyment that may follow due to flooding, the possibility that users will decide to transfer their visits to an alternative site should also be taken into account, in total economic loss, illustrated in figure 1.

Figure 1: Estimating total economic loss in terms of recreation from flooding

1. $B_1 = Eo - E_1$
2. $B_2 = (Eo - Ea) + (Ca - Co)$

Eo = Value of enjoyment of today's visit/a visit in current conditions
E_1 = Value of enjoyment per visit after flood
Ea = Value of enjoyment per visit at the alternative site visited after flooding
Ca = Cost incurred in visiting the alternative site after flooding
Co = Cost incurred in visiting the present site.
B_1 = Benefit when economic loss is measured by the loss in enjoyment only
B_2 = Benefit when economic loss is measured by the difference between enjoyment at the site plus any increase in cost involved in visiting the alternative site.

Source: Penning-Rowsell et al. (1992).

Similarly to the case with water quality, the travel cost method generally leads to an underestimation of flood alleviation benefits (Brookshire & Smith, 1987). While Green et al however questioned the validity of the approach in relation to water quality improvement benefits, Penning-Rowsell et al propose TCM as a 'sound basis' for the use of CVM in relation to recreational benefits of flood alleviation (Penning-Rowsell et al, 1992).

6.3.1.1. Hedonic Travel Cost Method: This method, described in section 2, may also be appropriate in valuing the recreational benefits from more effective flood alleviation.

Benefit Transfer: The 'per recreation day' standard values as attributed with the hedonic travel cost model, may be suitable for equating with days lost due to flooding in similar catchments.

Part 2 - General Approaches to Cost Benefit Analysis

The aim of this report is to consider economic approaches which provide a clear evaluation of the worth of hydrometric data. This has been attempted essentially in a piecemeal fashion by valuing the indirect benefits of data collection, as outlined, and proposing that they then be apportioned to hydrometric data in a quantitative way. In parallel to this it may be useful to consider a more general approach which examines the relationship between data collection and risk reduction.

Evaluating the Collection of Hydrometric Data Directly Through its Relationship to Risk/Uncertainty Reduction

Introduction - A Distinction Between Risk and Uncertainty

Environmental decision making, according to Faucheux and Froger, will always be in the context of uncertainty in addition to complexity (Faucheux & Froger, 1995). Forecasts which concern hydrometeorologic phenomena were highlighted by Krzystofowicz as 'inherently uncertain'. This uncertainty he categorised as: 'natural uncertainty' which stems from the nature of hydrological systems and 'forecast uncertainty' stemming from the processes involving the interpretation of this data (Krzytstofowicz, 1983).

Dasgupta and Pearce also classify uncertainty in project evaluation in terms of its source in an attempt to emphasise the need to modify the standard methodologies of CBA, as discussed in part one, to incorporate this (Dasgupta & Pearce, 1972).

In adopting a suitable economic approach to evaluate the worth of hydrometric data however, it is important to distinguish between the terms *risk* and *uncertainty*. The crucial factor for Dasgupta and Pearce rests on the availability of information. If probabilities can be assigned to specific outcomes the situation is defined as risky, and if consequences cannot be identified with any likelihood the situation is deemed one of uncertainty (Dasgupta & Pearce, 1972). Similarly Vercelli refers to risk as being based on 'a reliable classification of possible events' with uncertainty referring to 'events whose probability distribution does not exist or is not fully definable for lack of reliable classification criteria' (Vercelli, 1991).

Finally, Fauchaux and Froger identify all the interactions between the economic system and the environment as being under *strong uncertainty*, on a scale of certainty to ignorance. This is described as a distribution of 'non-additive probabilities and/or by a plurality of probability distributions which are not fully reliable.' (Fauchaux & Froger, 1995).

1. Dealing With Environmental Uncertainty Within an Economic Framework

Traditionally, several approaches have been adopted in dealing with uncertainty, summarised by Zerbe and Dively (Zerbe & Dively, 1994):

1. Ignore uncertainty, appropriate where it is small, time span of importance is short or where CBA is only a rough estimate.
2. Reduce it to levels where it can be ignored by gathering additional data or more accurate information.
3. Recognise uncertainty and factor it into analysis with the introduction of sensitivity analysis, simulation or decision trees.
4. Adding a risk premium to the discount rate (Parker et al, 1987).

Adding a risk premium to the test discount rate is an unsatisfactory method as increasing it also reduces the effective time horizon for the scheme i.e. the higher the discount rate the closer is the date when benefits or costs accruing will be zero. The most preferred method for coping with uncertainty, according to Parker et al is sensitivity analysis which may be relevant in our case for the apportionment of indirect benefits to data collection.
The following general approaches rely on the second method above, the collection of additional data and its relation to error (equated to risk) reduction.

1.1. Data Collection and its Relationship to Error Reduction

This is based on the assumption that the benefits from increased hydrological information [Bh] are related to the % standard error [Eh] affecting the hydrological parameter:

$$Bh = f[Eh]$$

It is proposed that the *cost* of decreasing the standard error ΔC_{eh} by ΔEh, can be estimated in terms of the variables:

1. Increased frequency of measurement [ΔNm]
2. Increased number of stations in the study area [ΔNs]
3. Additional number of years in operation [ΔNt]
4. Better interpolation technique [ΔCi]

Precise relationships are illustrated in the box 1.

Box 1: Relationship of data collection to error reduction

Cost of decreasing error: $\Delta C_{eh} = f(\Delta Nm, \Delta Ns, \Delta Ne, \Delta Ci)$
Marginal benefit of decreasing error: $\Delta Bh/\Delta Eh = f(Eh - \Delta Eh) - f(Eh)/\Delta Eh$
Marginal cost of decreasing error: $\Delta C_{\Delta eh}/\Delta Eh = f(\Delta Nm, \Delta Ns, \Delta Ne, \Delta Ci)/\Delta Eh$

Source: Adapted from McMahon & Cronin (1980).

This method is generally applied to data evaluation on planned water resource projects in respect to a particular region or network.

Edgar et al. suggested early on that the adequacy of hydrologic data [i.e. which encompasses hydrometric data] in economic terms, centred upon the marginal cost associated with improving the data being just equal to the marginal benefit resulting from the improvement in information relating to potential flood damages for example, and reduction in error implied as a result (Edgar et al. 1973).

McMahon and Cronin's marginal economic analysis approach focused on developing statistical relationships of increasing/reducing uncertainty(exhibited through differing errors) to the construction costs of dams/reservoirs, culverts/bridges, regulation measures, and hydropower operations and examining which had the greater influence (McMahon & Cronin, 1980). It supported the continuation of data collection in that the disbenefit of a 20% reduction in the Canadian data collection network was greater than the relative benefit in continuing data collection activities.

1.2. Non-Bayesian Decision Theory

An appropriate way to assess the value of data collection is to estimate the value of the next data sample. This involves:

1. The definition of a benefit/error function, similar to the error reduction approach
2. Translation of benefit/error function to a benefit/length of record function
   a. Simulation of long period of record
   b. Splitting this into sections [Ts]
3. The separate use of each section for designing the project and benefits calculated [Bs]
   a. Bs is compared with benefits from using a long period of record [Bl].
   b. The difference [$\Delta Bs = Bl - Bs$] can then be attributed to the additional period of record [$\Delta Ts = Tl - Ts$].

In assessing the value of data to flood mitigation planning, Cordery and Cloke divided available streamflow data for N.S.W into small sample sizes [10 years] to estimate design flood levels which were then used to develop damage frequency relations (Cordery & Cloke, 1992). Levee construction costs to each sample's design level were calculated, which allowed the difference in benefits between different design levels to be estimated. This allowed the value of 10 extra years of data given that 20 years are available, for example to represent the difference in overall benefits. The situation was simulated using data from an existing monitoring station for which a long record was available. Assuming that flood mitigation protection measure planning was the only use, benefits were up to eighty times the cost of annual data collection at the site.

In 1993 the value of streamflow data for flood estimation for minor structures was assessed by examining the improvement in design flood estimation during the period 1958 to 1987 (Cloke et al, 1993). It was assumed that design floods estimated in 1987 incorporating the most recent methodology, and longest record length 'would be the closest to the intended or true design value'. Hence benefits were related to the avoidance of additional costs resulting from underdesign/overdesign, variables considered including flood damage cost, flood durations, average number of vehicles affected [annual average daily traffic values], detour distances [assuming that traffic affected would choose to detour], traffic detour costs [allowing for occupants' time, and vehicle depreciation, maintenance and fuel costs and frequency of overlapping. Relevant costs were those from collecting streamflow data.

As early as 1965 Linsley also identified that cost savings could not be related in a linear fashion to data accuracy (Linsley, 1965), while Cordery and Cloke, in 1993 found a similar nonlinear relationship with regard to reservoir storage design, i.e. that the present worth of collecting the 'next' sample of data is much smaller than the present worth of collecting the 'previous' sample of data (Cloke & Cordery, 1993).

Overall Cloke and Cordery concluded that benefit cost ratio depended on the amount of existing *and* additional data, and the number of sites at which data are to be collected.

Table 7: Formulae for use in benefit cost study for minor waterway construction

Underdesign Cost Estimation $C_u = (R_u.N.C_{fd}) + C_T$ $C_t = R_u.N.E_u.T_u.[(D.C_v) + (O.C_p.D/S)]$ C_u = total costs resulting from underdesign during design life $. C_{fd} = average flood damage costs per structure during design life $ C_t = costs resulting from traffic disruption 4 C_v = vehicular costs, $/km D = average detour distance, km S = average vehicle speed, km/hr O = average vehicle occupancy T_u = average no. of vehicles delayed, in addition to design intention by underdesign E_u = extra flood overlappings during design life N = no. of structures in region R_u = ratio of underdesigned structures to total sampled	***Underdesign Savings*** $S_u = R_u.N.S_w$ S_u = total savings resulting from underdesign S_w = average savings per structure from reduced capital expenditure for structures underdesigned, $
Overdesign Costs $C_o = R_o.N.C_a$ C_o = total costs resulting from overdesign, $ C_a = average cost per structure of unnecessary capital expenditure due to overdesign of structure, $ R_o = ratio of overdesigned structures to total sampled.	***Overdesign savings*** $S_o = (R_o.N.S_a) + S_t$ $S_t = R_o.N.E_o.T_o.[(D.C_v) + (O.C_p.D/S)]$ S_o = total savings resulting from overdesign during design life, $ S_a = average savings in flood damage during design live per structure from reduced overlappings, $ S_t = savings resulting from reduced traffic disruption, $ E_o = reduction in flood overlappings during design life T_o = average reduction in vehicles delayed due to overdesign

Source: Cloke et al. (1993).

Benefit cost ratios for a programme of data collection relating to minor waterway crossing design were estimated as 120, 21, 4.4 and -0.25, for discount rates of 0, 4,7 and 10% respectively. These could be considered conservative estimates however, taking all program costs into account but relating benefits to just one use. Equivalent monetary benefits ranged from $3900m to $350m with 0 to 7% discount rates.

Similar to Cloke et al's 1993 study, Ramirez et al examined the effect of additional information on better flood alleviation designs in Rushford Minnesota, by examining the *ex-post* value of information (Ramirez et al, 1988). The value of information concept (VOI) used in these two approaches was ex post in the sense that the information was on hand when its value was determined. This contrasts with bayesian approaches where the exact information to be received is unknown at the time its potential value is assessed. New estimates with 28 years additional data showed a reduction in avoided damages from $30,750 to $21,420, and as a consequence a reduced b/c ratio of .87

The value of increased data collection at two observation stations on the Lapuanjoke river in Finland was calculated by the value of land which could be used due to decreased uncertainty on the area at risk from flooding i.e. an extra 80ha, see table 8 (Laitinen & Puupponen, 1996). It was found however that benefits stabilised after 40 years.

Table 8: Uncertainties of HQ150* and benefits of data

Period (yrs)	*HQ 1/50* *Station 1. (m_3/s)*	*Station 2. (m_3/s)*	*Benefits (million FIM)*
10	210-500	96-228	0
20	240-430	109-196	4,8
30	290-410	132-187	6,4
40	290-400	132-182	8,0
50	295-395	134-180	8,0
60	310-395	141-180	8,0

* lowest limit of elevation permitted for construction on floodplain.
Source: Laitinen & Puupponen. (1996).

Benefit Transfer: Hydrometric data are used very differently for specific investment project. Cordery and Cloke found also that even for similar project types, from site to site benefits varied depending on size of basin upstream, of the site, local topography, flooding frequency and the number and damage susceptibility of the properties to be protected (Cordery & Cloke, 1991).

1.3. The Use of Bayesian Decision Theory

The application of decision theory to evaluating the worth of data involves a number of steps:

1. A set of initial existing data e.g. time series/probability distribution], known as the 'prior' is used to design the water resource project in question e.g. flood control.
2. The times series/probability distribution is modified over time with new data, known as the 'posterior'
   a. the 'prior' estimates are revised using Bayes' theorem, improving information and reducing error, illustrated in box 2:

Bayes rule/theorem

$$P(ai/c) = \frac{P(ai)\,P(c/ai)}{Ei\,P(ai)\,P(c/ai)}$$

ai = a priori probability estimates
c = new information

3. Calculation of the expected opportunity loss [EOL], which is represented by the difference between additional benefits due to better design and additional costs due to acquisition of additional information. The optimal design is that which minimises XOL. XOL, however, cannot be calculated until all possible outcomes for additional measurements and corresponding posteriors are examined.

In Simpson's 1987 review of methodologies for estimating the value of streamflow data, bayesian decision theory, in providing a method to 'pool or update' information was deemed superior to earlier methods, such as generating synthetic records through identifying statistical distributions (Simpson et al. 1987).
Davis, Kiesel and Duckstein's early paper also illustrated the application of bayesian decision theory in assessing the value of additional data by incorporating it into engineering decisions on flood levee design on the Rillito Creek floodplain (Davis et al. 1971).

Adeloye suggested a bayesian approach to evaluating the worth of hydrometric data for reservoir capacity in examining the 'dependent' relationship which exists between reduction in uncertainty (equated to temporal error, see figure 2) and costs of reservoir over/under design (Adeloye, 1995). Due to the complexity however in defining such a relationship for each error type, Adeloye proposes the use of Monte Carlo simulation.

Figure 2: Breakdown of Total Data Error

$$e = \sqrt{(e^2_g + e^2_t + e^2_s + e^2_m)}$$

e^2_g = Gauging error due to flow measurement
e^2_t = Temporal error due to short data record length
e^2_s = Spatial error due to data transferred from a measurement location to the location of the project
e^2_m = Model error due to assumptions concerning the nature of the random hydrological process.

Source: Adapted from Adeloye 1995.

Adeloye found that when the length of data record was increased fourfold, the temporal error was only reduced by 50%, and with an eight fold increase the error was reduced by a factor of 2.8.

1.3.1. The Suitability of Bayesian Decision Theory Within an Environmental Decision Making Framework

On closer examination of the nature of both bayesian methods and environmental decision making it becomes apparent however that, despite widespread application, they may be somewhat incompatible:

1. The process of developing equations to reflect all possible interactions among variables, and assigning different probabilities of outcome is very time consuming (Zerbe & Dively, 1994), and expensive. This also implies that the assignment of objective probabilities to established outcomes is justified, implying in turn, the existence of a risky situation, and not one representative of environmental uncertainty, as defined (Dasgupta & Pearce, 1972).
2. This is essentially a project specific approach relying on the availability of detailed project specific costs.

In 1977 Klemes highlighted that when using hydrometric data as a decision basis in reservoir design one must remain aware that one is dealing with a 'complete random process' (Klemes, 1977), while Davey believes that while historical extreme flood events give a useful guide to the possible size of maximum floods, the fact that several recorded floods have exceeded maximums set highlights the potential extreme responses. Machina suggests that such traditional theories of decision making, as bayesian may need to be reversed with the occurrence of different forms of uncertainty (Machina, 1987).
If bayesian decision theory was to be adopted its use would be dependent on a large number of simplifying assumptions (Cloke & Cordery, 1993).

Part 3 - Valuing The Hydrometric Data Collection *Network*

1. Network Approach to Data Evaluation

Mawdsley et al examined the value of data for the design of flood protection schemes with respect to a gauge network in NE England.
Historic data was used to assess the effects of obtaining further data rather than expectations based on all possible future flows.

The general principle behind this approach was the assessment of the opportunity loss of making a wrong decision given imperfect data. According to Mawdsley the value of existing data is represented by the difference between the opportunity loss of decision making in the design of a flood protection works without any data, and that with hydrometric data[6] (Mawdsley et al. 1990):

$$\text{Data Value} = EOL_{yo} - EOL_{y}$$

Yo = data available in the absence of a gauge. In the absence of data other information would be used to make the decision e.g. rainfall information, or simulated data.
Y = data available with the gauge

To assess the expected opportunity loss for a given level of data, an opportunity loss function was obtained which is a function of the error in the estimate of the design parameter (e), and a probability distribution of the error p(e) is also required, which was then combined to obtain:

$$EOL_y = \int OL(e)p(e)de$$

By considering all contributing errors in the data, the probability distribution of the error in the design was estimated, the errors being classified into four groups i.e. gauging, temporal, spatial and model.
With application of this method to three network case studies, see table 9, Mawdsley found data value increased at a diminishing rate, whereas annual costs varied relatively little after installation.

Table 9: Value of hydrological data for flood protection only in three case studies

Values/Scheme	*Morpeth*	*Stokesley*	*Croft*
No: of gauges	1	2	3
Station years of data	10	24	54
Cost of scheme	£172,000	£325,000	£90,000
EOL [base level]	£10,650	£14,950	£1,100
Value of gauge data	£7,910	£12,350	£3,980
Cost of data for station year	£758	£1,378	£1,378
Value of data per station year	£791	£515	£74
Values as % of scheme cost	5	4	5
Benefit/cost ratio	1.0	0.37	0.05

Source: Adapted from Mawdsley et al. (1990).

The value of data was shown to be 4-5% of construction costs of the flood protection scheme for the lengths of data available considering flood protection as the only application of the data. The relatively low benefit/cost ratio for the flood protection schemes may have been caused by their small sizes. If a bigger scheme was undertaken and the 4-5% value was still correct, then the benefit/cost ratio would increase.

2. The Audit Approach

The audit approach, developed by Davar and Brimley, has been used to identify areas where improved network performance could be achieved without any additional resources, and to provide a guide by which to assess the impacts of any decision (Davar & Brimley, 1990).

Contrary to cost benefit analysis however, no monetary value is assigned to benefits. Instead the total set of existing and proposed stations are prioritised or ranked in order of performance on a number of considerations:

1. A survey identifies users' needs
2. Uses are rated on the basis of % benefit attributable to data
3. A set of priority considerations/criteria is outlined i.e. site characteristics, identified client needs [in terms of hydrology and operational] and a region's importance for water resources.
4. Individual gauging stations, organised on a catchment basis are assessed, by a number of water resource experts and managers, in terms of the extent to which they reflect priority considerations, see table 10.
5. The higher the total station audit points accumulated by a particular station, the higher the relative value of benefits derived from that station.

Table 10: Example of network evaluation audit for New Brunswick

Priority Consideration - Site Characteristics	*Available Points*	*Maximum Score Possible*	*Rationale for Score*
Mean annual flow • less than $25m^3/s$ • $25 - 125m^3/s$ • greater than $125m^3/s$	 2 4 6	6	Large drainages provide more representative samples for province as a whole.
Water level only		3	These stations provide less info. than flow stations.
Quality of record		15	The better the quality of record the greater the information value.
Period of record (years) • 0 - 5 • 6 - 10 • 11 - 15 • 16 - 25 • 26 - 40 • greater than 40	 7 5 3 7 10	10	Short records need to be extended to establish a record. Once record is established it is of decreasing value, with exception of very long records, which become valuable for index purposes.
Proximity to climate station		5	Stations whose record may be readily related to comparative meteorological data have added information value.

Source: Adapted from Davar and Brimley. (1990).

The audit approach offers an approach also to identifying redundancy in gauging stations, in assessing stations on the basis of such criteria, as outlined above, in addition to marginal costs. The priority considerations for site characteristics could also be based on responses from user surveys.

Review Conclusion

The above review examines potential approaches to valuing hydrometric data in three parts:

1. Detailed approach to cost benefit analysis
2. General approach to cost benefit analysis
3. Valuing the hydrometric data collection network

A two step procedure was suggested in relation to part 1, where indirect data collection benefits e.g. flood protection, could first be quantified and then apportioned to actual hydrometric data. For comprehensive coverage of these indirect benefits, both tangible and intangible (para 4.3.2.3.), a combination of primary survey techniques would be required implying considerable investment in time and money. In an attempt to avoid this, benefit transfer was also discussed, as useful in approximating values, if reliant on the availability of existing updated values.

General approaches value the worth of hydrometric data through its relationship to risk/uncertainty reduction. Such approaches, as outlined in part 2, have been used extensively in recent years with regard to investment planning. The difficulty in applying these techniques for our purposes however stems from their project specific nature which prevents the transfer of benefits, possible in part 1.

Finally, part 3 proposes a more holistic approach, focusing on the valuation of the data collection network, with the potential to then narrow down specific stations. The audit approach (part 3, section 2) in particular is highlighted as offering a possible 'user friendly' solution to the valuation issues faced by Environment Agency and S.E.P.A officers across functions, however its effectiveness, as will be discussed in Hanley's forthcoming paper, may rely on its use in association with further statistical techniques to develop an efficient *framework* for economic valuation.

Annexe 1

<u>Determination of multiplication factors to convert benefits of flood warning from single events to average annual benefits</u>

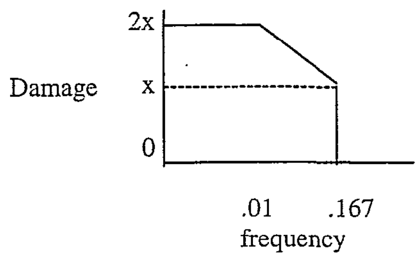
A) <u>Flooding more frequent than 1 in 10 yrs</u>:

In this category of flood risk zones it was assumed that protection was given up to approx. 1 in 6 year frequency, with damage doubled for a 1 in 100 year and less frequent events.

- assume single event damage reduction = £x
- average annual benefit (area under curve)

$$= 2x * .01 + \frac{2x + x}{2} (.167 - .01)$$

$= 0.255x$, i.e. .25 = 'frequency factor'



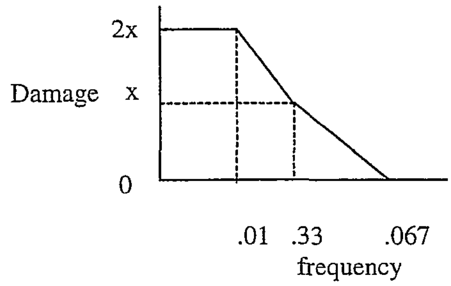
B) <u>Flooding frequency between 1 in 10 and 1 in 50 yrs</u>.

Assume average flood frequency to be 1 in 30 years with flood damage doubled for a 1 in 100 year and less frequent events and with damage reduced to zero for a 1 in 15 year event.

- assume single event damage reduction = £x
- average annual benefit (area under curve)

$$= 2x * .01 + \frac{(2x + x)}{2} (.033 - .01) + \frac{x}{2} (.067 - .033)$$

$= .00715x$, i.e. .07 = 'frequency factor'



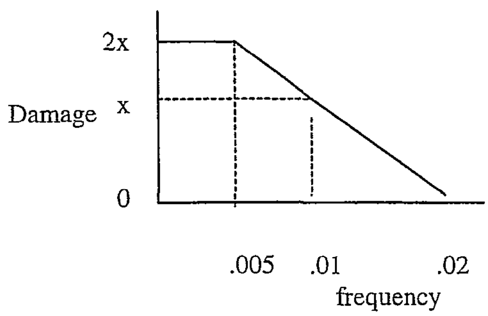
C) <u>Flooding frequency less than 1 in 50 yrs</u>

Assume average flood frequency to be 1 in 100 years with flood damage doubled at 1 in 200 years and less frequent events and with damage reduced to zero at a frequency of 1 in 50 years.

- assume single event damage reduction = £x
- average annual benefit

$$= 2x * .055 + \frac{(2x + x)}{2} (.01 - .005) + \frac{x}{2} (.02 - .01)$$

$= 0.022x$, i.e. .02 = 'frequency factor'



[1] Benefits from groundwater quality improvement are included due to its importance in catchment management, for public and private water supply and for providing base-flow for many surface water systems (Newson, 1995).

[2] Total willingness to pay may be sought from individuals, or alternatively broken down into its components;. current personal use values [current use values], possible future use values [option values], future generation use values [bequest values], non-use values [existence/intrinsic values].

[3] The majority of the 38,000km of watercourse in Britain, are too narrow and shallow ever to support activities in addition to recreational activity (Green & Turnstall, 1991).

[4] Adjustment factors published by the Ministry of agriculture, fisheries and food, 1985.

[5] Assumptions made included that impacts are independent, and that an acceptable regression equation could be obtained.

[6] This implies that Mawdsley believes there remains a level of inherent uncertainty even after the collection of hydrometric data.

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