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If the Price is Right - Development of a Methodology for Valuing Hydrologic Data.

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SUMMARY Increasing restrictions on public funding for hydrologic data collection, and a trend over recent years for data collection activities to be driven by current specific use projects, have highlighted more than ever before the need to systematically assess the value of the benefits derived from the collection of hydrologic data. A most important aspect of this need is to make sensible, realistic estimates of the economic value of such benefits in dollar terms for current as well as for future uses of hydrologic data. Previous attempts to achieve this have been of limited practical application, due mainly to problems associated with assessing *future* data uses, dealing with a multitude of data uses and defining exactly how the benefits of data collection can be measured. This paper outlines the development of a general methodology for the economic evaluation of hydrologic data collection networks, the emphasis being on valuing benefits derived from future data collection as well as on estimating the costs of data collection. This methodology can be used as a tool to aid in determining the level of resources which should be allocated to hydrologic data collection, providing a rational economic justification for the future operation of data collection networks.

1. INTRODUCTION

This paper describes a general methodology for the economic evaluation of hydrologic data collection networks which is currently being developed. The methodology is being applied to a network of 21 streamflow gauging sites in the Goulburn River Catchment in central Victoria.

The development of techniques for estimating the value of hydrologic data has become increasingly important as a result of the continuing escalation in the competition for scarce financial resources. As it is relatively difficult to demonstrate quantitatively the economic benefits of continued data collection, alternative uses for funds for which dollar benefits (and thus returns on investment) can be more readily estimated may tend to be more successful in attracting funds. Where public funding of hydrologic data collection programmes is concerned, poor public perception of the importance of hydrologic data as an issue makes decisions to restrict funding to data collection more politically attractive than restricting funding to many other areas. A problem in this sense is the overwhelming number of other issues of apparently greater public interest. A more commercial approach to the operation of traditionally public funded water resource programmes since the mid 1980's has lead to greater emphasis on encouraging direct beneficiaries to contribute to the costs of collecting the data they use (or benefit from). This further complicates the issue of maintaining adequate levels of hydrologic data collection.

2. DATA VALUATION TECHNIQUES

A most important question to ask is what is needed in an acceptable hydrologic data valuation methodology? A structure is needed within which specific tools can be used to analyse real data collection networks, the output being suitable for guidance in allocating scarce resources to the running of such networks. The overall aim is therefore to have a tool-box which, along with its tools, is appropriate for providing input to a decision making process. This tool-box needs to facilitate the establishment of two key links. The first is between data collection and its effect on reduction in uncertainty in decisions made based on data. The second is the nexus between reduction in uncertainty and the resulting economic benefits.

2.1 The Current Position

The availability of data valuation techniques has been reviewed a number of times, particularly over the last decade (for example, see Simpson and Cordery, 1987 and McMahon et al., 1994). Many useful individual techniques can be identified for valuing data in relation to single, specific uses or projects. Thus a number of the tools which might be needed for inclusion in the tool-box appear to exist, although there are numerous serious problems which tend to substantially blunt their effectiveness in achieving the aim set out in the previous section (McMahon et al., 1994).

Many of the techniques used allow an estimate of the value of past data collection to be made (*ex-post* evaluation), but are of little help in assessing the value of future data collection (*ex-ante* evaluation), as discussed by Cloke et al. (1993). This problem does not hamper analytically based statistical approaches, although these can become mathematically intractable and thus difficult to apply to real networks. Sampling from stochastically generated synthetic data sequences has been used in a number of studies (Dawdy *et al.*, 1970; Moss, 1970; Adeloye and Mawdsley, 1989; Wain et al., 1992) to circumvent both the problems of intractability and of achieving *ex-ante* evaluation. Given the nature of the problems to be addressed, such techniques appear to be the most promising tools currently available within the context of working toward the aim stated above.

Attempts have been made to estimate the economic benefits derived from real data collection networks (see, for example, Acres Consulting Services Ltd, 1977; McMahon and Cronin, 1980; Doran, 1989). However, these tend to rely on subjective judgements and assumptions which are not sufficiently transparent to clearly and formally establish the link between uncertainty and economic benefits. They also tend to ignore factors other than capital costs involved in engineering design applications.

In a theoretical sense, a number of methods do exist which allow estimates to be made of the value of the benefits of data collection. However, the optimism shown in the executive summary of *At What Price Data?* (Gordon, 1993) cannot be extended to the assessment of future data collection in complicated, real world networks.

2.2 The Aim

Although some potentially promising tools are currently available for use in economic evaluation of hydrologic data collection, they are in need of a certain degree of re-shaping and sharpening to better suit them to the task required. Also lacking is an overriding methodology and structure - the tool-box needed to house them and co-ordinate their appropriate application in deriving reasonable inputs to real world decision making processes.

Such a methodology is the aim of the current study, elements of which are described in this paper. It needs to be applicable to real multiple site data collection networks and to multiple data uses and a variety of data types. It must address the problems faced by decision makers in attempting to allocate resources to data collection. What is an economically efficient allocation of resources to hydrologic data collection? What is an efficient allocation of resources available for data collection within a particular network? Which gauging stations should be kept working, which stations would result in least loss of benefits if closed, and at which locations should gauging operations be established (or re-established)?

3. THE METHODOLOGY BEING DEVELOPED

3.1 Overall Structure

The methodology being developed to address these needs is outlined schematically in Figure 1. The aim has been to devise a modular structure, with each module representing a step in the overall process which can be executed by the use of any of number of available methods. This will allow different components of the analysis to be altered to assess the effects of different assumptions and different techniques used. The structure clearly sets out the steps to be followed and thus identifies the points in the analysis at which key assumptions must be made. It is important that these assumptions be specified explicitly to enable meaningful interpretation of the results of any economic analysis of data collection, keeping in mind the limitations in applicability of such results.

The structure of the methodology being developed here helps to keep the assumptions transparent so that interpretation of the results in light of these assumptions is facilitated. Further, this transparency provides an opportunity to criticize the results of the analysis on the basis of the assumptions used and therefore to test the sensitivity of these results to alternative assumptions.

3.2 Specification of Network and Data to be Modelled

Specifying the extent and type of network to be analysed will, in practical situations, depend on the particular requirements at hand. These would usually be expected to relate to the need to coordinate activities within existing networks, in which data collection stations are operated and administered as a distinct group. Such networks will typically correspond to stations within specified river catchments or sub-catchments.

The methodology is applicable to any type of hydrologic data collected (for example, streamflow volumes, peak discharges, rainfall depths). This includes the use of data in real time for operational and forecasting purposes, as well as the use of historical data records for water resources management (including design and planning activities). It is considered important that this broad range of application to different categories of data type and data use be facilitated, as the aim is to develop a generally applicable methodology which considers all the potential benefits of data collection. Techniques developed so far concentrate on the value of historical data records, largely neglecting any formal analysis of real time data use.

This module also includes consideration of alterations in the data collection network which will provide a basis for identifying alternative network configurations to be compared in the analysis. Information specific to the network regarding stations most in danger of being closed, and of locations being considered for establishment of new stations, will guide the specification of the configurations to be analysed. In this way, the number of alternative networks actually assessed will be reduced such that only those configurations relevant to potential future operation will be considered. This significantly reduces the workload required to identify an optimal operation strategy over the time period considered.

3.3 Identification of Data Uses

Once the type of data collection and the corresponding network to be analysed have been identified, the next task involves ascertaining the uses to which those data will be put in the future. This is a fundamental step in the methodology as benefits (and hence value) have no practical meaning unless they relate to specific objectives (as argued by Marglin, 1962). There is little use in estimating the value of hydrologic data collected in the network for data applications which are not relevant. For example, assessing the value of

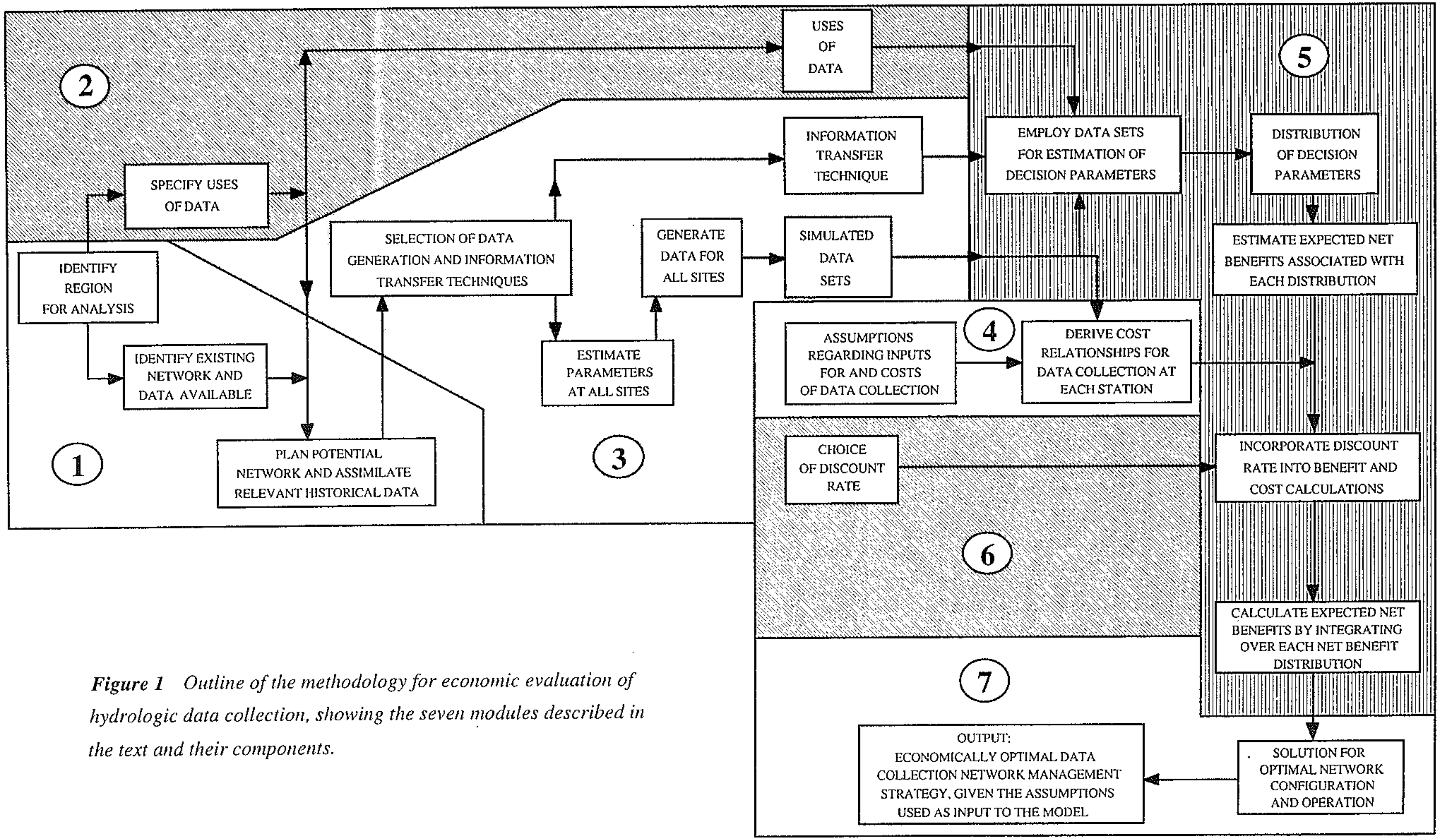

Figure 1 *Outline of the methodology for economic evaluation of hydrologic data collection, showing the seven modules described in the text and their components.*

streamflow data for use in storage reservoir design is of no consequence where that data will never be used for such a purpose. Also, future uses for the data are the only ones considered relevant to the analysis as decisions already made, and which will not be altered, cannot be affected by continued data collection.

For some networks, the uses for the data may be well documented. However, much of the development of hydrologic data collection networks in Australian States in the past has been unrelated to specific data applications. In cases where stations have been established with a specific objective in mind, there will in many instances be alternative useful applications for the data collected which were not considered initially. To identify clearly the range of important uses for the data which must be considered in estimating their value, a survey of data users for the network can be undertaken. In this way, potentially valuable but otherwise unknown (to the economic analyst) data uses can be included in the analysis.

A difficulty in relation to identifying relevant data uses is the problem of future data uses which cannot be envisaged at all from a current perspective. An allowance needs to be made for this in the analysis, although this may be at the level of acknowledging the problem and commenting upon its implications in terms of the results of the evaluation, rather than including it as a factor to be formally analysed.

3.4 Modelling Reduction in Uncertainty

This module involves developing a link between the availability of data and the level of uncertainty associated with the decisions made based on data. In this way, the impact of continued data collection in the network on reducing the uncertainty (due to both bias and variance in the results of data analyses upon which decisions are based) can be quantified. Any technique which suits this purpose can be used, and it would be expected that different applications for data would imply the need for a range of such techniques.

For example, in the assessment being undertaken in the Goulburn region for this study, stochastic data generation and simulation to model the sampling properties of monthly and annual streamflow volumes and of annual peak flows is being used. Replicates of synthetic data sequences for different network configurations and of varying lengths of extension over the current lengths of records available will be generated to produce alternative network operation scenarios. Simplified design and management parameters (decision parameters) representative of decisions to be made based on data will then be estimated for each replicate in each scenario. The result will be a distribution of the derived decision parameters for each network scenario. The reduction in uncertainty associated with estimation of the decision parameters will be represented in these distributions by reduced bias and variance of the estimates as the levels of data increase.

Alternatively, analytical techniques (such as that used by Cloke and Cordery, 1993) could be used where they are amenable to solution. However, these techniques will be less useful for deriving estimates of distributions of decision parameters than for deriving only estimates of means and variances.

There will be types of data and data applications for which modelling using stochastic generation may not be feasible. For example, the use of real time data for operational purposes would require stochastic generation of instantaneous observations (eg. virtually continuous hydrographs and pluviographs). Such a task increases the degree of complexity over the modelling of monthly and annual data. Although stochastic generation of small temporal scale data (eg. six minute rainfall depths - Srikanthan and McMahon, 1985) is possible, its application to multiple site networks may be too cumbersome due to the enormous requirements for handling and analysing data. In such cases, alternative techniques must be found for modelling the reduction in uncertainty from continued data collection. The structure of the methodology facilitates the incorporation of these techniques for analysis where needed.

3.5 Estimation of Economic Costs of Data Collection

Although estimation of the economic costs of data collection is usually considered to be relatively straightforward (eg. Gordon, 1993), it has probably been dealt with much less adequately than the estimation of specific economic benefits of collecting streamflow data. This would appear to be the result of research energy being put into the more difficult investigation of the latter, with the attitude that the former is a fairly trivial and less urgent problem. Data network operation costs have been estimated either for entire networks (eg. Cloke and Cordery, 1993) or as an average over the stations in a network (eg. McMahon and Cronin, 1980). These approaches do not allow the differences between stations in terms of the level of inputs required for their operation to be assessed in relation to the benefits they provide. As a result, the net economic benefit of continuing to run individual stations cannot be assessed.

Wain et al. (1992) suggested the use of a production function approach to model the inputs to data collection as a basis for estimating the economic costs of station operation. A more direct approach, however, was considered to be of more value for this study. This involves the direct estimation of cost functions for individual stations, similar to the method used by Moss (1970) but based on identifying the break-up of network costs to individual station costs by analysis of the actual inputs required to operate each station.

3.6 Linking Reduced Uncertainty with Economic Benefits

This module incorporates the establishment of the second of the key links in the data evaluation methodology. Economic benefits of increased data collection are modelled as the avoidance of costs associated with incorrect decisions made on the basis of imperfect information. This is based on the opportunity loss model approach developed in relation to valuing hydrologic data by Adeloye and Mawdsley (1989) and applied by Wain et al. (1992). For each data application being modelled, the costs of over and under-conservative decisions (represented by decision parameter estimates above and below the true decision parameter based on perfect information) must be estimated. This will be based on information derived from the survey of data users. From these estimates, a relationship between errors in the decision made and the costs of these errors can be made (shown diagrammatically in Figure 2). The opportunity loss is the cost of making an incorrect decision.

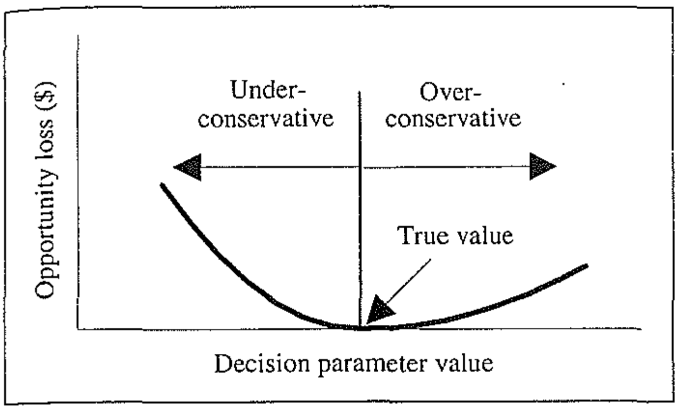

Figure 2 Conceptual representation of relationship between decision parameter error and opportunity loss (cost of errors).

For a particular data application (a), and with x representing the value of the decision parameter, this relationship can be represented by an opportunity loss function $OL(a/x)$ (ie. the opportunity loss for application a given decision x). If the distribution of the decision parameter derived from each network scenario (from Section 3.4) is represented by the probability density function $f(x/s)$, then the expected opportunity loss (EOL) for data application a associated with a particular network scenario (s) can be estimated by:

$$EOL(a/s) = \int_x OL(a/x) f(x/s) dx \qquad (1)$$

The economic benefit for data application a of operating the data collection network in the future according to scenario s ($V(s)$) is calculated as the difference between the EOL associated with the currently available level of data and the EOL associated with scenario s:

$$V(s) = EOL(a/current) - EOL(a/s) \qquad (2)$$

3.7 Discounting and Risk Premiums

Discounting to facilitate meaningful comparisons between benefits and costs incurred at different times in the future is a necessary part of any economic analysis. As Wain et al. (1992) pointed out, the choice of discount rate and of the length of period in the future to be analysed will have substantial effects on the outcome. It is therefore necessary that these choices be made relevant to the expected conditions which will affect the network in the future. A range of reasonable discount rates should be used to determine the sensitivity of the results to this factor. To a large extent, the level of the discount rate may effectively determine the length of period to be analysed, due to costs and benefits many years in the future being discounted to insignificant present values.

A problem which needs to be addressed here is the insignificance in present value terms of benefits accruing to future generations. From the perspective of those future generations, these benefits may be of crucial importance. The problem is one of the intergenerational distribution of benefits and costs. From the point of view of future generations, it may appear to be highly inequitable for preference to be given to past generations in terms of receiving benefits and cost savings. This will be particularly so where adequate compensation for their own reduced level of benefits is not provided.

3.8 Marginal Benefit Cost Evaluation

The benefits (Section 3.6) and costs (Section 3.5) of data collection are discounted and combined to derive the net present values associated with each future network operation scenario. This is effectively a marginal analysis of benefits and costs as it concentrates on the net present value of additional data collection in the future, rather than on the total value of all data collected (past and future). This is important as decisions about future network operation should be made based upon the benefits and costs of successive increments in data collection over the amount of data currently available.

4. APPLICATION TO GOULBURN NETWORK

The methodology outlined is currently being applied to a streamgauging network of 21 sites in Victoria's Goulburn River catchment between Lake Eildon and the confluence of the Goulburn and Broken Rivers. As the study is still in progress, no results regarding benefits and costs of hydrologic data collection in this region have been produced up to this stage.

4.1 Data

The data being considered are monthly and annual streamflow volumes and annual flood peak flows. The annual and monthly flow data are based on 31 full years of daily flow data for all 21 sites in the network, with missing daily flows in the raw data sets having been infilled using linear regression relationships between sites (Duncan and Khouri, 1993).

4.2 Stochastic Data Generation Model

Stochastic generation of streamflow data is being carried by the application of a simple multisite first order autoregressive model, as described by Matalas (1967), to generate annual flow volumes. Flows were modelled with a Normal distribution at eight sites, a two parameter Log-Normal distribution at one site and a three parameter Log-Normal distribution at the remaining twelve sites. Estimation of the model parameters was carried out in the transformed domain (as recommended by Stedinger, 1980, and Stedinger, 1981) rather than using the moment transformation equations of Matalas (1967) and Mejia et al. (1974). It was found that estimation in the transformed domain was more robust, giving a more stable fitted model and good reproduction of the historical statistical parameters. Generation of monthly flows is being carried out by disaggregating the generated annual flows using the method of fragments (Svanidze, 1980; Srikanthan et al., 1984).

4.3 Data User Survey

A survey of over forty users of hydrologic data from the Goulburn network has been undertaken to determine the relevant uses for the data at each site. The survey involved respondents filling out a questionnaire which was analysed to determine the need to interview respondents where further information was required. Based on the information gained from the survey, a list of the important data applications from the point of view of people involved in the use and management of water resources in the Goulburn region was compiled. Overall, the most important data uses relate to applications in water supply planning, flood planning and operation and water quality management in relation to water supply and biological and ecological management and planning. Other important applications identified were research, water supply operation and community education.

4.4 Benefits to be Assessed

Based on the results of the user survey, the methodology is being applied to three of the major data applications. These are the planning and formulation of water resources allocation policies, the planning and design of possible future storages (Department of Water Resources, 1992a) and flood planning and design. Formal economic analysis of the benefits of the hydrologic data for these applications is being conducted following the approach outlined in Section 3.6.

As this paper is concerned with describing the overall data valuation methodology, rather than with details of techniques used to directly value the benefits of data for specific applications, a brief description only of the components of the valuation technique being applied to one of the data uses is given here. The decision parameter being used for water allocation is the yield of the existing system based on a monthly simulation of system operation using synthetically generated data for each network scenario. Costs of errors in the derived yield are assessed as resulting from the costs of greater restrictions of water use (under-conservative yield estimates, ie. too high) and of overall reduction in water allocation (over-conservative yield estimates), allowing estimation of $OL(a/x)$ in equation 1. Replicates of the estimated yield based on replicates of synthetic data sequences for each network scenario provide the basis for estimating $f(x/s)$.

4.5 Costs and Economic Efficiency

The costs of operating each station in the network are estimated by applying the method developed by Goninon et al. (1995), which enables an estimate to be made of the opportunity cost of operating individual gauging stations. This is based on information regarding the actual inputs required for operating each station and the costs of these inputs as assessed by the network operators. Assessment of the net present value of alternative future network operation scenarios will be used to estimate the impacts of closure of existing stations and of recommissioning the five stations in the network which have been closed. Such an assessment will provide some guidance for decisions on the economic worth of allocating resources to data collection in the network.

For data uses where quantification of meaningful economic benefits is found impractical, the methodology allows identification of the importance of the data for such uses and a qualitative assessment to be made of the expected benefits through the user survey. This is important in providing decision makers with adequate information regarding these difficult to quantify benefits, which can be used in conjunction with the net present value estimates to help guide more informed resource allocation decisions. A similar approach has been used previously for the rapid economic assessment of river management works (Department of Water Resources, 1992b).

5. EXPECTED OUTCOMES

The important outcome of the current study will be the establishment of the structure of the data valuation methodology and its application to a real data collection network. This structure will provide a consistent basis for the application of the opportunity loss model to assessment of the value of hydrologic data collection which goes beyond the simple theoretical applications which had been previously carried out. It will also allow the incorporation of alternative models and tools for estimating the economic benefits of data collection. The modular structure of the methodology provides an easy mechanism for dispensing with a tool which has been found not to fit the requirements, and replacing it with a more appropriate tool. This does not affect the overall structure, which remains in place and provides a generally applicable framework.

By clearly identifying the key steps required in the methodology, choosing the appropriate tools for the analysis is aided by highlighting the tasks which need to be performed. The application of the methodology will facilitate assessment of the effectiveness of existing tools for various tasks. Some of the tools will need considerable sharpening, some may need to be replaced. Others will still need to be found. A significant outcome will therefore also be identification of aspects of valuation of hydrologic data which need new tools to be developed for their analysis. A basis for guiding future research into techniques for valuing hydrologic data will be provided.

6. SUMMARY AND CONCLUSIONS

This paper has briefly outlined a general methodology currently being developed for the economic evaluation of hydrologic data collection. The methodology is applicable to real world data collection networks, multiple data uses and multiple types of data. It is being applied to a network of 21 streamgauging stations in the Goulburn River catchment in Victoria. In this application, stochastic data generation is being used to model the reduction in uncertainty due to increments in data and an opportunity loss model is being used to transform this reduced uncertainty to economic benefits. The modular structure allows alternative models to be used where they are considered to be more appropriate.

Once the results of applying the methodology have been analysed, an assessment of the applicability of currently available specific data valuation techniques can be made. This will include identification of data types and data applications which are not yet sufficiently addressed for meaningful quantitative estimates of economic benefits to be made. Thus future research can be directed into addressing these needs.

The fully developed methodology will provide useful input to aiding the decision making process regarding allocation of resources to hydrologic data collection. The need for this input has been heightened by the increasingly commercial approach being adopted in the industry. With the expected increasing importance of funding of data collection by direct beneficiaries in the future, there is potential for application of the methodology as part of the marketing of the benefits of the network to data users. This marketing will also be important in relation to the publicly funded components. Future funding of adequate overall hydrologic data collection will critically depend on being able to demonstrate that the price paid is justified by the benefits derived.

7. ACKNOWLEDGEMENTS

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