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Estimating the Economic Costs of Hydrologic Data Collection

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Abstract. This paper examines the estimation of the economic costs of hydrologic data collection using the concept of opportunity cost. The opportunity cost of operating a hydrologic data collection network is equal to the maximum value the resources used in its operation would have if they were free to be used in another area. A method for estimating the opportunity cost of operating individual stations is developed in this paper. This method is then demonstrated using representative opportunity cost estimates for individual stations in a hypothetical network based on the Victorian hydrologic data collection network, Australia. An important distinction is made between financial costs and economic costs, particularly with respect to their relative suitabilities for use in different applications.

Key words: hydrologic data collection, economic cost, opportunity cost, financial cost, present value

1. Introduction

The operation of hydrologic data collection networks has traditionally depended mostly upon public funding, as noted by Snorrason (1994). However, increasing concerns regarding accountability and economic efficiency for decisions regarding investment of public funds, and the high level of competition for such funds, have meant that justification of expenditure on data collection has assumed a more important role in ensuring the maintenance of adequate hydrologic data networks. As such, there is an urgent need to assess the economic value of hydrologic data as an input to decisions affecting allocation of resources to data collection. This has been clearly recognized in the *Report on Water Resources Assessment* by the World Meteorological Organization and the United Nations Educational, Scientific and Cultural Organization (WMO/UNESCO, 1991) and is particularly relevant in Australia where the water industry is becoming increasingly driven by commercial imperatives (see, for example, Ruprecht and Chester, 1994).

An essential part of any assessment of the economic efficiency of a data collection programme necessarily involves estimating the input of resources (i.e. cost) required for its operation. This paper presents a technique which has been developed to enable estimates of the impact of expansion or contraction of network operation on the associated real economic (as opposed to purely financial) costs.

These economic resource costs will not be the same as the financial costs allocated to each station by the collection agency due to the differing treatment of joint costs shared between stations. This is an important point which has not been well recognized in the literature. Joint costs are those fixed costs of operating the network which will be incurred whether or not the network is scaled up or down by small numbers of stations (relative to the overall network).

The relevant economic cost estimates relate to the marginal cost of operating a data collection network. The marginal cost indicates the effect (in terms of *avoidable* costs) of scaling the network up or down by small numbers of stations relative to the overall network considered. Marginal cost measures can be compared to the expected change in economic benefits of data collection from increasing or decreasing the size of the network, allowing an economic assessment of the desirability of such changes to be made from the point of view of society as a whole. However, in relation to actual funding of data collection programmes some particular (often arbitrary) allocation of joint costs must be made for estimation of the *financial costs* of operating each station. Even though the financial cost estimate for a particular station does not represent the real avoidable cost of operating that station (as discussed by Stubbs *et al.*, 1980, pp. 56–59, in relation to provision of public transport), the practical reality of operating the data collection network means that the joint fixed costs must still be covered and therefore that these costs must be shared for administrative and funding purposes between stations.

Existing approaches to calculating the costs of data collection give little indication of a true break-up of real economic costs between stations in the network, and thus do not help the decision maker who is looking to compare the costs and benefits of data collection at each existing and proposed station. This paper attempts to fill this gap by presenting a method to determine the opportunity (or avoidable) costs associated with operating each station from financial records held by the data collection body. The work reported here is part of a project involving the development of an overall methodology for economic evaluation of hydrologic data networks (see Pretto *et al.*, 1996).

2. Approaches to Estimating Costs of Data Collection

2.1. EXISTING APPROACHES

Little has been reported in the literature on estimating the cost of operating individual stations in a hydrologic data collection network. The focus of research has tended to be on the evaluation of benefits arising from data collection. Cost estimation has generally been either ignored or treated summarily in such studies. For example, Cloke and Cordery (1993) determined the total cost of running a network for various lengths of time and compared this to the economic benefits arising from the use of hydrologic data to illustrate the value of the network. While useful for assessing the economic efficiency of the network as a whole, this approach tells us nothing of the net economic worth of individual stations in the network because no attempt is made to measure the economic costs and benefits associated with operating each station individually. As a result, such methods provide no information as to which stations should be continued, which discontinued and where new stations should be established.

Another approach has been to take the cost of running the network as given and set out to determine the network configuration which will yield the greatest amount of information given a fixed data collection budget. This ‘cost effectiveness’ approach (see, for example, Matalas, 1969) does not, however, allow determination of a network configuration which maximizes the net economic benefits gained from data collection.

Moss (1970) constructed a cost function relating the cost of obtaining streamflow data from a site to the cost of constructing the gauge, the number of discharge measurements made per year, the cost of each discharge measurement, the number of years of measurement and overhead costs. Although this presents a comprehensive theoretical structure for estimation of costs of the future operation of each station in a hydrologic data collection network, no general procedure for estimating the parameters in the individual station cost functions using the information typically available in practice is given.

Another approach to representing costs of hydrologic data collection suggested by Wain *et al.* (1992) is to estimate a production function relating the economic resource inputs required for data collection (typically lumped into the categories of labour and capital) to the output of hydrologic data. Theoretically, such a production function could be used to illustrate the substitutability of inputs used in the production of hydrologic data and the subsequent effects on data output. By incorporating information on the costs of each input, the costs of operating the network at different levels of output and for different combinations of inputs could be derived. One way of doing this would be to construct an aggregate production function for the entire data collection network, similar to the approach taken for fitting production functions to major industries in India by Murti and Sastry (1957). However, due to the unique combination of inputs each station needs for collection of the required data, such an aggregation over the whole network would tell us little about the inputs required to operate individual stations.

Constructing individual production functions for each station would also be of little value. In practice, for any particular station there will be specific combinations of inputs required to collect data given the local conditions and the equipment and measurement techniques available. Data collection agencies are already under pressure to minimize the costs of data collection at each station, and thus the combination of equipment and measurement technique giving the most efficient use of input resources will be chosen on a station by station basis. Once this choice has been made, the notion of substitutability between inputs is of little practical relevance, due to indivisibility of most of the inputs. Thus the usefulness of a production function approach is greatly reduced by practical considerations. As a result, the production function approach has not been pursued. Instead, the more direct approach of using existing cost information for individual stations (or estimated cost information for proposed stations) has been used.

2.2. MEASURES OF STATION COSTS

Two main methods of estimating station costs can be identified, these resembling the concepts of average and marginal costs. These are proportional cost and opportunity cost respectively. Proportional cost includes administrative allocations of joint fixed costs between stations, whilst opportunity cost represents the avoidable, or marginal, cost of operating individual stations.

2.2.1. *Proportional Cost*

This measure reflects the proportional shares of total costs for the data collection organization which are allocated by that organization to each station. It does not represent the change in total costs that would be realized if a station were to be closed. Instead, it is a weighted average cost amount used to allocate total costs (including fixed overheads) for the organization to each station. The basis for this cost allocation is often essentially arbitrary (for example, a simple average cost over all stations may be used), although it is intended as a mechanism for distributing financial costs which must be covered by revenue or budget inputs to each station, and thus for identifying the input required from each station to finance the operation of the network as a whole. This figure is typically used by a data collection agency as a basis for financial budget preparation in order to account for network funding, or to allow estimation of the amount to charge clients for the collection of data from a given site.

The basis used for cost allocation in the proportional station costs calculated in this work (following the practice used for the Victorian streamgauging network in Australia) is to use a weighted average based on budget estimates of person hours required to operate each station. Thus the total financial annual cost (proportional cost) of operating station *j* (TAC_j) is calculated as

$$\mathrm{TAC}_j = \mathrm{TH}_j * C \quad (1)$$

where TH_j is the total estimated person hour requirement for operating the station and *C* is the charge out rate per person hour which covers all the data collection organization's costs. This approach is somewhat less arbitrary than using a simple average cost approach as it acknowledges the differences in input resource requirements at different stations. This allows a fairer targeting of stations in terms of funding for recovery of the costs of operating the network.

2.2.2. *Opportunity Cost*

The opportunity cost of operating a station refers to the costs incurred through continued operation of a station which would not be incurred if the station were closed. Some of the costs allocated to a given station under the proportional cost method will not be completely eliminated by the closure of that station and so would not be included in an opportunity cost estimate. These are the joint fixed costs and include, for example, administrative and infrastructure overheads, equipment and instrumentation external to data collection sites and some travelling costs. The methodology developed in this paper calculates the annual opportunity cost of operating station *j* (AOC_j) as

$$\mathrm{AOC}_j = \mathrm{AVC}_j + \mathrm{ACC}_j \tag{2}$$

where AVC_j is the annual variable cost and ACC_j is the annual opportunity cost of capital for the station.

The opportunity cost of operating a station is the economic resource cost, which is the correct measure for determination of the marginal economic cost of operating the network. This is because the opportunity cost of operating a station represents the extra economic cost incurred by adding one more station to the network or the economic cost that would be saved by reducing the network by one station.

3. Network Costs

The economic cost of operating a hydrologic data collection network can be divided into four categories:

- labour costs;
- capital costs;
- material and other costs;
- external costs.

3.1. LABOUR COSTS

Labour is the biggest cost faced in this industry. Based on standardized operating criteria, the use of electronic monitoring and recording devices has generally increased labour hours spent in the field while reducing office labour hours spent processing and storing data. The input of labour for operating a particular site is calculated by estimating the time spent and number of staff members involved in collecting and analysing data from the site, plus time spent on site maintenance.

3.2. CAPITAL COSTS

3.2.1. *An Existing Station*

When determining the capital cost of an existing station, we focus on the value the physical capital (instrumentation and equipment) used at that station would have in its next best use. Therefore, only equipment which is salvageable from the site is used to determine the cost of capital of the existing station. The remaining investment in the site is treated as a sunk cost.

Monitoring equipment located at a given site can often be removed and used at a new or existing site, or added to inventory stores to provide backup in case of equipment failure at other sites. In some cases even the housing for the equipment can be relocated for use at other sites. This reduces, or postpones, the need to expend financial capital on the purchase of new instrumentation and equipment. As such, the opportunity cost of keeping the equipment at its current site equals the potential return yielded by investing this financial capital in its next best alternative use. If the equipment is not suitable to be used at another station or to be added to inventory stores, then its opportunity cost is its scrap value.

3.2.2. *A Proposed Station*

To calculate the capital cost of a proposed station, we must focus on the return that could be gained from investing financial capital elsewhere in the economy rather than tying it up in the establishment of a new monitoring station.

In the case of a proposed station, both the salvageable and non-salvageable components of the set-up cost are relevant. The non-salvageable aspect of the initial investment in the site is not yet a sunk cost, as it is in the existing site case. As a result, both should be taken into account when calculating capital costs. This is because the owners of the financial resources would desire a return on both these costs, as their resources could have been used profitably elsewhere in the economy. The irrecoverable cost of the relocation of equipment and instrumentation from existing stations (where relevant) must be included as part of the non-salvageable cost for the proposed station.

3.3. MATERIAL AND OTHER COSTS

Included in material and other costs are materials used up in the measurement, recording and processing of hydrologic data. Included here are vehicle operating costs, office and stationery supplies, some investment in instrumentation and minor plant and equipment and any other items that do not form part of capital stock. This category also includes non-material costs such as electricity and rent.

3.4. EXTERNAL COSTS

This category includes the costs to society generated by constructing and operating a data collection station which impacts negatively on other parties without compensation (i.e. these costs are not borne by the data collection agency). Although no attempt has been made in the work presented here to include estimates of external costs in the overall economic costs of establishing and operating data collection stations, their existence is identified for the sake of completeness.

As an example, the building of any artificial structure, such as a weir, on a stream to aid in the measurement of streamflow may adversely affect environmental values associated with the stream. If the aesthetic, environmental and ecological attributes of a stream are valued by society, then any structure which adversely affects these should include in an assessment of its economic cost an estimate of the loss in this value. Although arriving at an economic cost for these externalities may prove difficult, they should still be borne in mind by decision makers as being potentially significant factors in assessing the overall cost to society of establishing and operating data collection stations. In such cases, these costs must also be weighed against the potential value the data collected may have as an input to processes aiding the preservation of environmental values.

4. Station Costs

4.1. COST OF ESTABLISHING A STATION

The costs of setting up a new station include the cost of labour and materials incurred in:

- constructing and remodelling the site for measurement purposes;
- installing housing for equipment and instrumentation;
- installing equipment and instrumentation.

4.2. OPERATING COSTS

Included here are all costs of maintaining and operating a station which would not be incurred if that station were closed. This includes all activities required to:

- read and maintain monitoring equipment at stations;
- carry out general maintenance of gauging station sites;
- perform flow measurements periodically and in response to need;
- collect water quality samples;
- download data collected in the field;
- convert stage measurements to discharge estimates using a rating relationship;
- carry out appropriate analysis and error checks of the data collected;
- prepare data for presentation and storage;
- update and check the rating relationship;
- administer and manage the organization of data collection from the station.

4.3. VARIATION IN STATION COSTS

The opportunity cost of operating a station in the network for an additional year will vary between stations due to the different levels of resource inputs they need to obtain the required data at a given level of accuracy. Differences in levels of resource inputs required between stations are due to differences in:

- the types of data required at different sites;
- the accuracy of data required at different sites;
- the frequency of sampling/measuring and maintenance visits to obtain the required data at different sites;
- the difficulty of obtaining an accurate measurement at different sites;
- the ease of access to different sites.

As a result of this non-homogeneity of stations in relation to resource inputs required in real data collection networks, the cost structure of each station is best determined individually.

4.4. CLOSING A STATION

Where a station is closed, all salvageable equipment and instrumentation (and housing where applicable) are removed. Non-salvageable equipment and structures (for example, float wells and artificial controls or weirs) are generally left in place. The closure of one station in the network will result in the proportion of total costs allocated to each remaining station increasing. This is due to the shared nature of the joint fixed costs discussed above. As an example, consider travelling costs. Closing a station may not have much effect on overall travelling costs if the closed station is located in the vicinity of other operating stations which are monitored in the same trip. For such cases, the saving in real economic costs from closing a station (which equals the opportunity cost of operating the station) will be less than the station's allocated proportion of total network costs. To further reduce or eliminate such costs would require the closure of a number of stations in close proximity.

This applies to all costs which are considered as joint fixed costs. These costs are still incurred whether or not individual stations continue to operate. Although the opportunity cost is the cost which should be considered when making decisions regarding the economic cost to society of continuing to operate a station, the proportional cost (which includes allocation of joint fixed costs to each station) is still important in relation to network funding. Both opportunity cost and proportional cost estimates therefore serve useful (although different) purposes, the former for efficient allocation of society's economic resources and the latter for identifying the level of funding contribution required from each station to fund the operation of the network as a whole.

5. Station Opportunity Cost Estimates

In this section a methodology for estimating the opportunity cost of operating individual stations in a hydrographic network is developed and applied to hypothetical network cost figures for a hypothetical network. For convenience, representative cost figures based on the Victorian hydrologic data collection network are used.

This methodology should be applicable to any hydrologic data collection network by substituting the relevant network costs into the analysis.

5.1. ANNUAL VARIABLE COST OF OPERATING A STATION

To determine the variable cost of continuing to operate a data collection station for an additional year we need to decide which network cost components would be affected by the closure of the station. To achieve this, the person hour break-up figures for each station, as estimated by the responsible data collection agency, will be used. While these figures do not give an exact estimate of station costs, they provide the best available guide to each station's share of total costs. The person hour figures used in this paper are, for illustrative purposes, based on general figures for stations in the Victorian hydrologic data collection network. The annual variable cost is calculated as

$$\mathrm{AVC}_j = \mathrm{VC} * \mathrm{VH}_j \tag{3}$$

where VH_j is the estimate of variable person hours required to operate the station per year and VC is the true variable cost per person hour.

5.1.1. *Determination of Variable Person Hours*

Determining which categories of person hours attributed to the station which would be eliminated (or avoided) by its absence from the network involves classification into fixed and variable person hours. Variable person hours are those that are eliminated when a station closes, whereas fixed person hours are unaffected by such a closure.

Table I shows the break-up of person hours between stations and between work categories for 17 stations in the hypothetical network considered. The format and information shown are based on the general type of budget estimate information used for stations in the Victorian network. Based on the four broad person hour categories listed in Table I, variable person hours can be calculated as

$$\mathrm{VH}_j = a * \mathrm{FIELD}_j + b * \mathrm{OFFICE}_j + c * \mathrm{OPOH}_j + d * \mathrm{TRAVEL}_j \tag{4}$$

where *a*, *b*, *c* and *d* are the proportions of field, office, operating overhead (OPOH) and travel person hours respectively which are variable.

Field and Office Hours. The person hours entered under the work category *quantity* represent the input required to carry out water quantity measurement at each station. Similarly, the work category *quality* refers to the collection of water quality data (for example, temperature, pH, salinity, dissolved oxygen). For both categories, person hours have been split into field and office hours. The former are assumed to be 100% variable, as closing a station would eliminate all field work associated with

Table I. Person hour requirements for stations in the hypothetical data collection network considered. Variable person hours are in brackets where they are different to the sub-total for a work category. Refer to the text for details regarding division of person hours into variable and fixed components

Station	Time requirement (Person hours)						Total hours	Total variable hours
	Quantity		Quality		Operating overheads	Travel		
	Field	Office	Field sampling	Office analysis				
A	63.1	21.0	11.2	5.6	22.0 (1.1)	36.8 (0.0)	159.7	102.0
B	63.1	20.9	0.0	0.0	24.0 (1.2)	41.0 (0.0)	149.0	85.2
C	50.1	14.9	0.0	0.0	17.0 (0.85)	35.0 (0.0)	117.0	65.9
D	37.0	12.0	9.6	4.8	14.0 (0.7)	38.0 (0.0)	115.4	64.1
E	39.2	11.8	9.6	6.0	13.0 (0.65)	28.6 (0.0)	108.2	67.3
F	65.1	19.9	10.8	4.8	18.0 (0.9)	28.8 (0.0)	147.4	101.5
G	108.8	30.2	12	4.8	29.0 (1.45)	56.0 (0.0)	240.8	157.3
H	37.6	8.4	0.0	0.0	9.0 (0.45)	18.0 (0.0)	73.0	46.5
I	65.1	19.9	0.0	0.0	19.0 (0.95)	25.0 (0.0)	129.0	86.0
J	60.3	16.7	0.0	0.0	20.0 (1.0)	32.0 (0.0)	129.0	78.0
K	71.0	21.0	10.8	6.0	19.0 (0.95)	39.8 (0.0)	167.6	109.8
L	77.7	23.3	13.2	4.8	23.0 (1.15)	43.2 (0.0)	185.2	120.2
M	40.5	13.5	0.0	0.0	11.0 (0.55)	26.0 (0.0)	91.0	54.6
N	48.3	16.7	10.8	4.8	15.0 (0.75)	29.0 (0.0)	124.6	81.4
O	68.7	20.3	0.0	0.0	20.0 (1.0)	38.0 (0.0)	147.0	90.0
P	78.6	23.4	0.0	0.0	21.0 (1.05)	24.0 (0.0)	147.0	103.1
Q	39.5	10.5	0.0	0.0	12.0 (0.6)	24.0 (0.0)	86.0	50.6

operating that station. Office hours will also be treated as 100% variable here as, for the Victorian network, budget estimates of these include only office time spent analysing and recording the data collected from the particular station concerned. Thus both *a* and *b* in Equation (4) are equal to 1.0. This is purely based on the budget estimate practices used in Victoria and may therefore not be applicable for other networks. If such is the case, an estimate of the proportion of office hours which can reasonably be considered variable will need to be made.

Operating Overheads. This category includes person hours spent on operating and maintaining the network which are not directly assignable to individual stations. Included here, for example, are time spent maintaining vehicles and time spent preparing measuring equipment for station visits. Based on experience within the Victorian network, it will be assumed here that 5% of the hours in this category are variable, reflecting the fact that most of the work involved would still be necessary if one station were closed. Thus *c* in Equation (4) is equal to 0.05.

Travel Hours. Station visits are made in runs which consist of visits to several stations in one 'loop shaped' trip. As a result, the closure of an individual station will generally have little effect on travel time on its own, so this category is treated as fixed (*d* is 0.0 in Equation (4)). This fixed cost assumption can be altered in the case of a number of stations being closed on the same run which would reduce overall travel time involved in operating the network.

5.1.2. *Variable Costs per Person Hour*

The variable cost per person hour is calculated as

$$\text{VC} = [x_1 x_2 + (1 - x_1) x_3] C \tag{5}$$

x_1 is the proportion of the charge out rate (*C*) which covers regional office costs and $(1 - x_1)$ is the proportion of *C* which covers head office costs, including any central processing of the data. x_2 and x_3 are the proportions of regional office and head office costs respectively which are variable.

To arrive at the cost split between head office and regional offices, the budget for the data collection agency must be consulted. Here it will be assumed that 25% of total budgeted costs come from the head office and the remaining 75% from regional offices. Hence, x_1 is equal to 0.75.

To determine the proportions of budgeted costs for the regional and head offices that are variable, budgets detailing individual expected expenditures must be examined. Each budget entry is examined with respect to whether it should be considered a fixed input to operating the network or a variable input. Using representative hypothetical budgets as shown in Tables II and III, 80% of the regional office budget and 20% of the head office budget have been assumed to represent variable costs. Thus x_2 is equal to 0.8 and x_3 is equal to 0.2. To obtain these estimates, it was assumed

Table II. Representative regional office budget

	Total	Training and management	Variable costs
Budgeted costs			
Total salaries	$430 000	$58 000	$372 000
Materials	$18 000	$1 000	$17 000
General office supplies	$1 000	$1 000	$0
Capital equipment and instrumentation	$10 000	$0	$10 000
Freight and cartage	$1 000	$0	$1 000
	$460 000	$60 000	
Other fixed costs	$40 000	–	–
Total	**$500 000**		**$400 000**
Total variable costs as a proportion of total budget:	$400 000/$500 000 = 0.8		

Table III. Representative head office budget

	Total	Training and management	Variable costs
Budgeted costs			
Total salaries	$500 000	$180 000	$320 000
Materials	$18 000	$700	$17 300
General office supplies	$1 000	$300	$700
Capital equipment and instrumentation	$11 000	$1 000	$10 000
Freight and cartage	$70 000	$28 000	$42 000
	$600 000	$210 000	
Other fixed costs	$1 350 000	–	–
Total	**$1 950 000**		**$390 000**
Total variable costs as a proportion of total budget:	$390 000/$1 950 000 = 0.2		

that all salaries except those for training and management are directly dependent on the number of stations operated (i.e. they are variable costs). This means labour hours would be reduced if the number of stations were reduced.

In the example presented here, C is arbitrarily assumed to be $80 per person hour. Therefore, from Equation (5), the estimate of variable cost per person hour to be used is

$$\mathrm{VC} = [0.75 * 0.8 + (1 - 0.75) * 0.2]80 = \$52 \text{ per person hour} \quad (6)$$

5.1.3. *Variable Cost Estimate*

To illustrate the calculation of annual variable cost, consider station A from Table I. From Equation (4), the annual variable person hour requirement is

$$\begin{aligned} VH_A &= 1.0 * FIELD_A + 1.0 * OFFICE_A + 0.05 * OPOH_A + \\ &\quad 0.0 * TRAVEL_A \\ &= 1.0(63.1 + 11.2) + 1.0(21.0 + 5.6) + 0.05(22.0) + 0.0(36.8) \\ &= 102 \text{ person hours per year} \end{aligned} \quad (7)$$

Then, from Equation (3), the annual variable cost of operating station A is

$$\begin{aligned} AVC_A &= VC * VH_A \\ &= 52 * 102 \\ &= \$5304 \text{ per year} \end{aligned} \quad (8)$$

The annual variable cost estimates for operating each station in the hypothetical network are shown in the third column of Table IV.

5.2. ANNUAL OPPORTUNITY COST OF OPERATING CAPITAL

There is an opportunity cost of tying-up financial capital in the equipment used at a station (i.e. as operating capital). If this equipment can be used productively at another site or added to inventory stores, then the value of the alternative use should be included in the opportunity cost figure. For the hypothetical network considered here, it will be assumed that all salvageable equipment can be re-used at other sites. The annual opportunity cost of capital at a station can be calculated as

$$ACC_j = i * SV_j \quad (9)$$

where *i* is the required real rate of return on operating capital and SV_j is the value of salvageable equipment at station *j*.

Explicit values for equipment used at each station may not be readily available. However, for the Victorian hydrologic data collection network the cost of equipment for a new station (including data loggers, instrumentation and gauges) is generally in the range from $5000 to $6000 (1995 Australian dollars) and so an average figure of $5500 will be used as an estimate of the value of equipment employed in each station and as the basis for estimating the cost of operating capital for each station. For example, from Equation (9), if a requirement for a 5% per annum real

Table IV. Station costs and present values of future opportunity costs

Station	Total variable person hours	Annual variable cost	Annual opportunity cost (r = 5%)	Present value (5 years) (r = 5%)	Present value (10 years) (r = 5%)	Present value (5 years) (r = 2%)	Present value (10 years) (r = 2%)	Present value (5 years) (r = 8%)	Present value (10 years) (r = 8%)
A	102	$5304	$5579	$24 154	$43 080	$25 519	$48 632	$22 934	$38 543
B	85	$4420	$4695	$20 327	$36 254	$21 352	$40 691	$19 405	$32 611
C	66	$3432	$3707	$16 049	$28 624	$16 695	$31 816	$15 460	$25 981
D	64	$3328	$3603	$15 599	$27 821	$16 205	$30 882	$15 045	$25 284
E	67	$3484	$3759	$16 275	$29 026	$16 940	$32 283	$15 667	$26 330
F	102	$5304	$5579	$24 154	$43 080	$25 519	$48 632	$22 934	$38 543
G	157	$8164	$8439	$36 536	$65 164	$38 999	$74 322	$34 353	$57 734
H	47	$2444	$2719	$11 772	$20 995	$12 038	$22 942	$11 515	$19 352
I	86	$4472	$4747	$20 552	$36 655	$21 597	$41 158	$19 612	$32 960
J	78	$4056	$4331	$18 751	$33 443	$19 636	$37 421	$17 951	$30 169
K	110	$5720	$5995	$25 955	$46 292	$27 479	$52 368	$24 595	$41 334
L	120	$6240	$6515	$28 207	$50 307	$29 930	$57 039	$26 617	$44 823
M	55	$2860	$3135	$13 573	$24 208	$13 999	$26 678	$13 176	$22 143
N	81	$4212	$4487	$19 426	$34 647	$20 372	$38 823	$18 574	$31 215
O	90	$4680	$4955	$21 453	$38 261	$22 577	$43 027	$20 443	$34 356
P	103	$5356	$5631	$24 379	$43 481	$25 764	$49 099	$23 142	$38 892
Q	51	$2652	$2927	$12 672	$22 602	$13 019	$24 810	$12 345	$20 748

rate of return on operating capital is assumed, the annual operating capital cost per station can be calculated as

$$\begin{aligned} \mathrm{ACC}_j &= 0.05 * 5000 \\ &= \$275 \text{ per year} \end{aligned} \tag{10}$$

Once again using station A for illustrative purposes, the annual opportunity cost of operating station A is then calculated by substituting from Equations (8) and (10) into Equation (2)

$$\begin{aligned} \mathrm{AOC_A} &= \mathrm{AVC_A} + \mathrm{ACC_A} \\ &= 5304 + 275 \\ &= \$5579 \text{ per year} \end{aligned} \tag{11}$$

The results for all stations in the hypothetical network for a required real rate of return of 5% are shown in the fourth column of Table IV. An important assumption here is that depreciation has been ignored and that the equipment at each station has an infinite life. This assumption is made here to simplify the analysis presented and can be easily altered to incorporate a finite life for all equipment.

5.3. PRESENT VALUE OF FUTURE COSTS

Present value is a concept which is used to analyse projects which incur costs and benefits over a period exceeding one year. Future benefits and costs are adjusted by the application of a discount rate to give an equivalent present value of the future time stream of benefits and costs.

In the case of a hydrologic data collection station, the present value of future costs represents what must be forgone in today's terms to keep a station open for a given number of years. To calculate the present value of future costs of operating the stations in the hypothetical network, time horizons of 5 and 10 years have been used and *real* discount rates (*r*) of 2, 5 and 8% have been adopted as being within the range of expected market rates of return. The results are shown in Table IV. For assumed values of *r* equal to 2 and 8%, the annual opportunity cost of operating capital has been calculated using an assumed real rate of return on capital of 2 and 8% respectively. It can be seen that the present value cost estimates produced are quite sensitive to modest variations in the discount rate. This is an important observation given that the range of discount rates used here would be expected to be quite relevant in relation to economic analysis of real hydrologic data collection networks.

6. An Illustrative Example

To illustrate the differences between estimating the cost of operating a station using the opportunity cost methodology developed here and the proportional cost

Table V. Comparison of the present values of the costs of collecting data at stations A and R estimated using the proportional cost and the opportunity cost methods

Station	Cost estimation method	Present value of station cost					
		Operation over next 5 years			Operation over next 10 years		
		r = 2%	r = 5%	r = 8%	r = 2%	r = 5%	r = 8%
A	Proportional cost	$60 219	$55 313	$51 011	$114 762	$98 653	$85 728
	Opportunity cost	$25 519	$24 154	$22 934	$ 48 632	$43 080	$38 543
R	Proportional cost	$37 520	$35 001	$32 792	$ 65 526	$57 255	$50 618
	Opportunity cost	$15 696	$15 163	$14 677	$ 27 829	$25 241	$23 101

approach, two cases will be investigated. The first involves closing station A in the hypothetical network, the second opening a new station (station R).

6.1. CLOSING STATION A

6.1.1. *Proportional Cost Method*

From Table I, the total person hour requirement at station A is 159.7 hours. Substituting this figure and the assumed value for C into Equation (1) gives an annual proportional cost of operating station A as

$$\begin{aligned} \mathrm{TAC_A} &= 159.7 * 80 \\ &= \$12\,776 \text{ per year} \end{aligned} \tag{12}$$

Applying real discount rates of 2, 5 and 8% over both 5- and 10-year periods of network operation in the future, the present values of the proportional cost of operating station A are shown in Table V.

6.1.2. *Opportunity Cost Method*

As calculated in Equation (11), the estimate for the annual cost saving from closing station A at an annual real rate of return on capital of 5% is:

$$\mathrm{AOC_A} = \$5579 \text{ per year} \tag{13}$$

This represents the sum of the annual variable and annual operating capital costs. The present values of cost savings from closing the station estimated using the opportunity cost method are also shown in Table V. In relation to the figures presented in Table V, it must be noted that for assumed values of r (the discount rate) equal to 2 and 8%, the annual opportunity cost of operating capital has been calculated using an assumed real rate of return on capital of 2 and 8% respectively.

6.2. OPENING STATION R

Where a new station is proposed, an estimate must be made of the person hour requirements for operating that station. An estimate of the sunk cost of setting up the station is also required. These estimates will typically be made by the responsible data collection agency, for example when preparing quotations for establishing and operating proposed data collection stations. For station R, assume that

total variable person hours (VH_R)	=	53 hours per year
total fixed person hours (TH_R - VH_R)	=	29 hours per year
sunk cost of setting up (SC_R)	=	$2300
value of salvageable equipment (SV_R)	=	$4300

The estimate of required person hours includes a consideration by the agency of the alteration in allocation of joint fixed costs to each station in the network resulting from the inclusion of the extra station. With the only change to network operation being the opening of station R in this case, the allocation of a proportion of the joint fixed costs of the network to the new station (represented by the total fixed person hours of 29 hours/year) results in a slight reduction in the level of fixed costs allocated to all the other stations. This reflects the fact that station R must share the burden of funding the network as a whole.

6.2.1. *Proportional Cost Method*

From Equation (1), the proportional annual cost of operating station R is

$$\begin{aligned} \mathrm{TAC_R} &= \mathrm{TH_R} * C \\ &= (53 + 29) * 80 \\ &= \$6560 \text{ per year} \end{aligned} \tag{14}$$

However, to this annual operating cost must be added the initial outlay in setting up costs (IC_R) where

$$\begin{aligned} \mathrm{IC_R} &= \mathrm{SC_R} + \mathrm{SV_R} \\ &= 2300 + 4300 \\ &= \$6600 \end{aligned} \tag{15}$$

Treating the initial outlay as a cost incurred at the beginning of the first year (and thus not discounted), the present value of the proportional cost of establishing and operating a new station *j* ($\mathrm{PVPC}_{(j)n}$) for a period of *n* years is

$$\mathrm{PVPC}_{(j)n} = \mathrm{IC}_j + \mathrm{PV}(\mathrm{TAC}_j)_n \tag{16}$$

where $\mathrm{PV}(\mathrm{TAC}_j)_n$ is the present value of the proportional cost of operating station *j* for *n* years. The results of applying Equation (16) to station R are shown in Table V.

6.2.2. *Opportunity Cost Method*

From Equation (3), the annual variable cost of operating the new station is

$$\begin{aligned}\mathrm{AVC_R} &= \mathrm{VC} * \mathrm{VH_R}\\ &= 52 * 53\\ &= \$2756 \text{ per year}\end{aligned} \tag{17}$$

From Equation (9), the annual opportunity cost of the operating capital which would be tied up in salvageable equipment at the station (assuming a 5% per annum real rate of return and infinite equipment life as above) is

$$\begin{aligned}\mathrm{ACC_R} &= i * \mathrm{SV_R}\\ &= 0.05 * 4300\\ &= \$215 \text{ per year}\end{aligned} \tag{18}$$

Therefore the total annual opportunity cost of operating station R for a 5*% real rate of return on capital* is, from Equation (2)

$$\begin{aligned}\mathrm{AOC_R} &= \mathrm{AVC_R} + \mathrm{ACC_R}\\ &= 2756 + 215\\ &= \$2971 \text{ per year}\end{aligned} \tag{19}$$

An initial outlay of the sunk cost of setting up the station ($\mathrm{SC_R}$ = \$2300) is assumed as being incurred at the beginning of the first year of operation. However, unlike the case for the proportional cost method, the cost of purchasing the salvageable equipment for the station is not included in this initial outlay, as it is assumed in this example that the equipment retains its value over the periods considered. The only opportunity cost incurred on it is the opportunity cost of the financial capital which it ties up. Therefore, the present value of the opportunity cost of establishing and operating a new station *j* ($\mathrm{PVOC}_{(j)n}$) for a period of *n* years is

$$\mathrm{PVOC}_{(j)n} = \mathrm{SC}_j + \mathrm{PV}(\mathrm{AOC}_j)_n \tag{20}$$

where $\mathrm{PV}(\mathrm{AOC}_j)_n$ is the present value of the opportunity cost of operating station *j* for *n* years. The results of applying Equation (20) to station R are shown in Table V, with the opportunity cost of operating capital being calculated using an assumed real rate of return of 2 and 8% for assumed *r* values of 2 and 8% respectively.

6.3. ADVANTAGES OF OPPORTUNITY COST APPROACH

When assessing the potential costs and benefits to society of continuing to operate station A or of establishing station R, the important measure of cost is opportunity cost. The potential additional benefits (or loss of additional benefits) must be compared to the potential *extra* cost (or cost *saving*) relating to any decision regarding opening or closing stations. The key concept here is the necessity to compare marginal economic costs to marginal economic benefits. We need to make an estimate of the *changes* in overall costs and benefits resulting from any decision as a basis for assessing the economic impact of that decision.

In this context, the proportional cost estimates shown in Table V significantly overestimate the real additional economic costs *to society* which would be incurred by continuing to operate station A or setting up and operating station R. This results from the incorporation of the joint fixed costs of operating the overall data collection network into the proportional cost estimates, and is consistent with the observation made by Stubbs *et al.* (1980) in relation to transport economics that the opportunity cost of a unit of output at the margin will be less than the average cost of producing the output where joint fixed costs exist. Providing that large sections of the network are not to be closed (as assumed in the example used), these fixed costs would still actually be incurred whether or not station A or station R were to be operated. Thus the opportunity cost estimates as given in Table V provide a more realistic reflection of the actual changes in economic resource inputs to operating the network which would result from the proposed changes to the network *at the margin*.

It is important to emphasize that, despite their unsuitability for estimating economic resource costs, the proportional cost estimates do represent the actual financial costs which must be allocated to each station as a basis for funding the data collection network. This highlights the fundamental difference between the use of economic cost estimates to make decisions about efficient allocation of society's economic resources, and the use of financial cost estimates to ensure that actual funding for the network is provided. Financial cost estimates must *not* be used as an input to decision making regarding efficient allocation of economic resources. Equally, economic cost estimates are totally inappropriate for use in relation to funding requirements for stations.

In situations where the scope of changes in network size will result in changes in the overall fixed network costs, the potential changes in these fixed costs must be estimated and included in the estimation of the opportunity costs of operating alternative networks. In economic terms, this is equivalent to a shift from the concept of costs in the *short run* (for which the joint fixed costs always remain fixed) to costs in the *long run* (for which all joint fixed costs can vary due to significant changes in the overall size and structure and operation of the network). This would be the case, for example, where significant expansion or contraction of existing data collection networks is being considered. In the work presented here, only a short run analysis has been considered.

7. Conclusion

A relatively simple methodology to enable estimation of the marginal economic cost of operating stations in a hydrologic data collection network has been presented. Application to a hypothetical network typical of components of the Victorian network in Australia was used to illustrate the methodology. The methodology involves making individual station cost estimates based on analysis of typically available network and station time requirement and cost figures. The resulting estimates represent the opportunity costs to society of continuing to operate individual stations (or of setting up and operating new stations) and thus provide a more relevant measure for economic analysis of changes in costs associated with network alterations than simple average (or proportional) cost estimates. Relevant station cost estimates are necessary where decisions are being made as to the overall economic value to society of operating particular data collection stations within a network.

If the economic costs of station operation are not adequately quantified and financial cost estimates are used instead, in the context of an economic analysis the costs will be overestimated. Where decisions are being made as to whether or not particular stations should be operated based on economic considerations, this would generally lead to smaller numbers of stations than would actually be desirable in terms of net marginal economic benefits over costs to society in general. The real difficulties in making estimates of the opportunity costs of operating data collection stations are extracting and combining the relevant information from the network records typically available in practice. These records are tailored to meet specific administrative, financial and accounting requirements and thus to calculating financial costs rather than real opportunity costs.

It must be understood that although opportunity cost estimates should be used for analysis of economic resource allocation, they are not applicable to determining the financial costs of operating data collection stations which must be met through funding. The appropriate estimate to use in this context is the proportional cost, which incorporates an allocation of the joint fixed costs of operation of the data collection network to each station. To enable adequate funding of the network these fixed costs must be shared by all stations even though closing any particular station on its own would not bring about any reduction in overall fixed costs.

An important consideration in the application of the methodology developed here is that allowance must be made for the inherent uncertainties involved in estimating the various cost components. Of particular significance in this respect will be the assumptions affecting the estimate of variable costs per person hour and especially the choice of discount rate used in reducing future costs to present values. Variations in these parameters will result in potentially important impacts on the eventual results of overall analysis of benefits and costs of future network operation. However, given the information typically available upon which to base station cost estimates, the methodology developed here does allow plausible estimates to be made. Where any analysis of the costs and benefits of continuing to operate stations is being performed, a range of outputs should be investigated covering the expected relevant range of factors (such as the discount rate) which have a significant effect on the outcome. This is of course true for any analysis involving assessment of unknown future scenarios.

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