Valuing the Environmental Benefits of Urban Water Conservation: Final Report

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Chapter 1

Introduction

This report documents a project undertaken for the California Urban Water Conservation Council (the Council) to create a method to assign economic value to the environmental benefits of raw water savings. The purpose of the environmental benefits (EB) evaluation model is to provide a practical tool with which utilities can estimate the environmental benefits, or costs, associated with a particular Best Management Practice. It is assumed here that the water savings associated with implementation of conservation programs can be quantified, and represented as a reduction in the demand for water from a particular set of supply sources, such as streams, reservoirs or groundwater resources. The reduction in demand from a water supply source may in turn result in a change to the availability of an environmental service provided by that source. For example, reservoirs provide recreational services, streams provide fish habitat, and wetlands provide filtration of surface runoff and species habitat. These environmental services have economic values associated with them, in the sense that individuals or society as a whole are willing to pay to preserve the service, and would expect to be compensated for loss of the service. For clarity, in this report the term environmental value will always be used in the strict sense of indicating a monetized economic value, while the word service is used to refer to the function or beneficial use provided by the environment.

Given an association between water savings at a source of supply, environmental services provided by that water source, and valuation of those services, it is possible to calculate a monetized environmental benefit that results from the water savings. For simplicity we refer in this discussion only to benefits, with the understanding that these can take on negative values to represent costs.

This type of environmental valuation is still relatively new, and there are numerous complications, ambiguities, data gaps and differences of opinion that make the construction of a definitive methodology problematic. For that reason, this study should be considered as a pioneering effort to put together all the required elements in a single coherent framework. It is particularly important to realize that the exercise of assigning economic value to the environment has, to date, targeted very specific activities. There are many services which are of central importance to ecological systems, but are currently given no value simply because they haven't been studied in enough detail. For that reason, the numbers coming out of this work should be taken as first draft, typically lower bound estimates. They are useful primarily as a means of comparing the relative utility of additional availability of water at the margin to different ecological services under current conditions.

The rest of the report is organized as follows: The Background section of this chapter discusses the California Urban Water Conservation Council Memorandum of Understanding and outlines the Council guidelines for the analysis. The Methodology chapter presents an overview of the environmental benefits valuation methodology in general terms, with a focus on explaining the logic behind the model. We identify the quantitative relationships that need to be represented, and describe the information flow from the input water savings, through the intermediate calculations, to the output environmental benefit value. We also discuss the limitations imposed on the actual spreadsheet implementation by the specific requirements for this project, and summarize a list of important issues that have arisen over the course of this work. In the next chapter we discuss Data Sources, review the current state of the literature and outline how the different numbers needed in the calculation could in principle be defined. This chapter is again written in general terms, and outlines the type of information needed for a complete analysis. The actual analysis we present is limited by the data currently available, which is described in detail in the Data Values chapter. This chapter also presents the side analyses needed to convert raw data into the numbers that enter the spreadsheet calculations. In the Appendix, a detailed background discussion of non-market valuation is given. Non-market valuation is the primary method used to assign economic value to recreational activities, and is the basis for developing environmental non-use values.

A separate User Guide provides detailed instructions on how to use the EB spreadsheet model, how to access the variables used in the intermediate calculations, and how to understand the spreadsheet outputs.

1.1 Background

The Council was created by the Memorandum of Understanding Regarding Urban Water Conservation in California (MOU), first signed in 1991 by a group of urban water suppliers, environmental interest groups, and other interested parties. Water suppliers signing the MOU agree to develop and implement comprehensive conservation Best Management Practices (BMPs) using sound economic criteria. Since 1991 over 170 urban water suppliers across California have signed the MOU.

The BMPs and the criteria for their implementation are contained in the MOU, a copy of which is available through the Council's website [15]. There are currently 14 BMPs addressing residential, commercial, industrial, landscape, system loss and leak detection, education, public information, and pricing conservation practices. Not all signatories are expected to implement all BMPs.

1.2 Environmental Benefits and BMP Evaluation

Signatory water suppliers are expected to implement a BMP only when it is cost-effective to do so. For purposes of the MOU, cost-effective means that the present value of expected benefits from implementation equal or exceed the present value of expected implementation costs. The MOU provides the governing language for determining whether a BMP is cost-effective to implement. BMP benefits in principle include water and wastewater utility avoided costs and environmental benefits.

The MOU gives the Council the task of developing guidelines that will be used by all water suppliers in computing BMP benefits and costs. In 1996, the Council adopted its *Guidelines for Preparing Cost-Effectiveness Analyses of Urban Water Conservation Best Management Practices* [16]. These guidelines provide a general analytic framework from which to assess:

1. BMP benefits and costs,
2. guidance on analysis time horizons,
3. use of discounting and selection of discount rates,
4. analysis perspectives,
5. use of sensitivity analysis, and
6. a cursory treatment of certain avoided costs.

The 1996 guidelines do not address the question of quantifying environmental impacts in any detail. The goal of the present study is to provide a uniform methodology for calculating the direct environmental benefits, which have not to date been accounted for explicitly. The method must be theoretically sound and capable of implementation by both small and large water and wastewater utilities in California. A key requirement of the Council is to have a tool that can be used by any member agency, without requiring that agency to provide the necessary environmental data. This imposes fairly strict limits on the level of detail that can be incorporated in this first version of the EB model.

1.3 Guidelines for Environmental Benefit and Cost Methodology

The Council has provided a set of guidelines for the environmental valuation methodology that will enable it to be practically applied in the BMP evaluation process. The following is a partial list of guidelines taken from the Council for development of the methodology:

1. Develop, present, and demonstrate a reasoned approach to the economic valuation and uncertainty of environmental benefits of BMP adoption.

2. Discuss the sources of data and relative certainty/uncertainty behind such estimates.
3. Define accounting perspective (*e.g.* utility, society) and develop a model to evaluate from multiple perspectives.
4. Provide a common set of definitions and terminology to be used for this type of analysis in the industry.
5. Make the underlying assumptions transparent to the degree possible to limit controversy.
6. Focus on what can be quantified, and the range of values. Use scenarios and sensitivity analyses to narrow range of issues that have an actual impact on the outcome.
7. Develop a hierarchy of uncertainty about data, models, assumptions and forecasts. The dimensions of uncertainty include:
   (a) Physical measures, both of quantities and impacts
   (b) Economic measures of values and costs
   (c) Forecasted outcomes including temporal variability
   (d) Political and legal issues
8. Describe how the environmental benefit analysis and model fits into the BMP planning evaluation process, and an integrated resource planning process.
9. Develop a usable guidebook with clear examples, and identified data sources that can be updated readily.
10. Prepare training sessions: Consider the gains from education to allow more complexity versus simplicity of use as a stand-alone tool.
11. Make data input easy. Clearly identify what data are required and where it might be acquired most easily by a water agency.
12. Develop input data templates, and prepare data defaults, preferably with *red flag* data boundaries that identify when further analysis may be required on the data being used. Updates to common data sources and analysis methods shall be part of the model maintenance in the future.

1.4 Accounting Perspective

For environmental impacts, the logically relevant perspective is societal. The water savings for a specific utility are allocated to the raw water sources affected, linked to a particular set of environmental services, and the values associated with those services calculated. It is possible that the water sources will be outside the utility service area. Many services, for example recreation opportunities, species habitat or option values, are not confined to local populations. Others, such as water filtration or local educational use may be proximity-based. Given the interconnectedness of ecological systems, and the fact that many recreational users travel to enjoy environmental services, it would not make sense to confine the benefits analysis to a particular utility's service area. To avoid double-counting of benefits, total consumptive use of water for different environmental services is estimated, and these amounts are used to estimate the probability that a unit of water will contribute to maintaining that service. The valuations provided by the EB model can be used by water agencies to develop cost-sharing programs with other agencies or organizations for whom environmental preservation and restoration is of value.

1.5 Integration with the Avoided Cost analysis

Concurrent with the EB project, the Council has also sponsored the development of a detailed spreadsheet model for calculating infrastructure Avoided Costs (AC) [17]. The 1996 guidelines did not address utility avoided cost calculations in detail, nor provide water suppliers with the theoretical underpinnings and practical methods needed to make such calculations. Infrastructure avoided costs can make a substantial contribution to the overall cost-effectiveness of BMPs. The AC model is intended to provide a standardized methodology for calculating this contribution. To facilitate their use, the EB and AC models are designed to have consistent data definitions and to be able to exchange data inputs and outputs, although some differences are unavoidable. The key point is that both models are meant to describe BMP impacts of the *same* programs for the *same* system. They must therefore use the same system description and identical assumptions about the time frame for the analysis, energy costs, discount rates *etc.* The two models are designed to ensure this consistency is maintained.

The AC model deals with *water system components*, which is a more general category than water sources, and includes such things as treatment facilities and conveyance systems. Because it is more comprehensive, the AC model is used to set up the water system description and define the various accounting inputs. For simplicity, the complete set of system components is imported from the AC into the EB spreadsheet, but only those corresponding to raw water withdrawals are dealt with in the EB model. For these components, the user must provide additional information needed by the EB model but not supplied from the AC spreadsheet. The raw water system component must be associated with a *water source type*, and it must be assigned to a *hydrologic region* (see chapter 3 for more detail on the data inputs). These associations allow a raw water system component to be linked to a set of specific environmental impacts.

The EB spreadsheet also imports information on the planning horizon, energy costs, season definition, seasonal water savings in the base year, and the projection of water savings over the analysis period. However, the EB model calculates the benefits for each raw water system component on a per-unit-volume basis, so the actual quantity of water saved is not really needed as an input. What is needed for the EB model is a distribution of water savings over months, as many of the environmental impacts are sensitive to the time of year. By default this is computed by combining the seasonal savings with the definition of seasons by month (see section 2.3 and chapter 3 for more detail). It is also possible to input the monthly savings directly to the EB model. The on-margin probabilities are also imported from the AC model, and used to compute the annual aggregate environmental benefits over all raw water system components for each year in the analysis period. These aggregate benefits (in units of $ per unit volume) can then be exported back to the AC model. From there, the results from the two models can be included in an overall benefit-cost analysis for a given BMP or set of BMP's.

Chapter 2

Methodology

In this chapter we present an overview of the EB methodology in general terms, with a focus on explaining the logic behind the model. We identify the quantitative relationships that need to be represented, and describe the information flow from the input water savings, through the intermediate calculations, to the output environmental benefit value. We also discuss the limitations imposed on the actual spreadsheet implementation by the specific requirements for this project, and summarize a list of important issues that have arisen over the course of this work.

2.1 Summary of Economic Theory

This section provides an overview of issues described in more detail in the Appendix. For some environmental services such as wetland and riparian habitat, a value estimate exists in the form of the price paid to acquire land for restoration projects. For services with no actual market, the economic values used here involve an application of what is generally known as non-market valuation. The object of non-market valuation is to measure, in monetary terms, the value that people place on an item, regardless of whether the item is a conventional marketed commodity such as a loaf of bread or a new car, or something that cannot be purchased in a market such as a pristine wilderness or a healthy body.

Generally the value of an environmental service will derive from a diversity of human activities or considerations. Valuation of a service can take several forms, and more than one may apply in a given situation. Valuable aspects of environmental amenities can be divided into *use* and *non-use* values. Non-use values are sometimes defined as option or existence values, and are intended to capture the value people place on knowing that an environmental resource exists, irrespective of whether they are active users of that resource. As non-use values reflect attitudes rather than specific activities, they should in principle be applied to the general population that is aware of, or potentially has access to, the resource. In practice it can be very difficult to determine to what extent a survey of non-use values genuinely reflects the values of this more general population.

Use values are more straighforward and are associated directly with use of an environmental service by a specific set of users, but may include qualitative aspects related to aesthetic and other concerns. For example, for some recreational users a environment with dramatic views such as the Grand Canyon may be more valuable than a less spectacular but more pristine wilderness. For others, just the opposite is true.

Conceptually, the use value of non-market items can be measured by the change in income that would be equivalent to them in terms of the impact on the individual's well-being. Roughly, the idea is to calculate the *consumer surplus* associated with use of the service. Thus, while the items themselves are not monetary in nature and cannot be obtained by the individual through the expenditure of his or her own funds, the monetary value of those items to the individual can be represented in terms of a standardized measure of the value of individual economic well-being. There are two ways in which this value is commonly defined. In one, the monetary amount represents the most that the individual would be willing to pay to obtain the item rather than go without it. This is known as the willingness to pay (WTP) measure of monetary value. In the other, the monetary value corresponds to the minimum amount that the individual would be willing to accept as compensation to forego the item. This is known as the willingness to accept (WTA) measure of monetary value. Measures of WTP and WTA are based primarily on surveys in which people either are asked to indicate amounts directly, or in which survey questions are designed in such a way that the preferences of individuals can be deduced and relative economic values inferred. The Appendix contains a detailed discussion of the theory and applications of non-market valuation.

Non-market valuation is a rapidly evolving field, and although many issues remain to be resolved, the approach is sound and has been used in a variety of applications to quantify the value of benefits, amenities or services provided by the environment. This deals with one half of the problem being addressed in this study. The other half consists of determining how water savings from a particular source, and with a given seasonal pattern, lead to a change in the availability of a particular environmental amenity or service. This is an extremely complex problem at the intersection of physics, hydrology, biology and environmental science. It is possible to infer a chain of events that lead, for example, from reservoir operating rules, to changes in water temperature downstream of the reservoir, to changes in the survival rate for fish that spawn in the streams. Given the complexity of the subject and the relatively small number of quantitative studies that exist, the number of effects that can be included in the EB model must be driven by the available data. Here, we will ignore for the moment the problem of obtaining data, and proceed to a discussion of the functional relationships to be modeled in the environmental benefits calculation. The advantage of this approach is that first, it provides a framework which will help organize the discussion of the biological and physical details, and second, by taking a slightly more abstract view, we can develop a methodology that is flexible enough to incorporate new sources of data as they become available in the future.

2.2 Environmental Benefits

The method for calculating environmental benefits identifies three basic functional relationships:

- Environmental values depend upon the magnitude of the impact of the utility's proposed change in water use on a given environmental service. The affected environmental services are determined by the type of raw water source the utility draws from. We refer to the impact of a change in water use on an environmental service as an environmental impact.
- The size of the environmental impact depends the sensitivity of the service to the availability of water, and may depend on the seasonal pattern of both the environmental water demand and the conservation savings.
- The economic value of the environmental service is based on market values where they exist, or alternatively on estimates of WTP or WTA obtained from a review of the existing literature.

To avoid problems related to transferring ecological and economic data between locations, only data from California are used in the current study. Economic values are adjusted to account for the passage of time, and where appropriate, changes in population and average income levels.

Equations expressing these relationships form the basis of the spreadsheet environmental valuation calculation. These equations are presented below in section 2.6. Here we describe the logical flow of the calculation by working backward from the desired result to the data inputs.

The final output of the spreadsheet calculation is the total value per unit volume, in 2005 dollars, of the environmental benefits associated with the water savings input by the spreadsheet user. For a given service provided by a water source, we take the product of the estimated impact on that service times the value of the service in whatever units are appropriate. These values are then summed over all water supply sources, and environmental services, in the base year and in each year of the analysis period. This is an approximation, as it is quite possible that the value (in constant dollars) of a particular environmental service will change in the future, but it is beyond the scope of this study to try to project these changes. This step of the process is shown in the flow chart in figure 2.1.

As an illustrative example, suppose a BMP results in a reduction in demand of 10,000 acre-feet per year (afy) from a stream that will result in an increase of trout population in the stream of 100 trout. The annual environmental impact of this BMP is 100 trout/1000 afy or 0.1 trout/afy. Suppose there is a credible environmental valuation study that determines that the value of the trout in such a stream is \$30/trout. Then the value of the *trout habitat* environmental service in the base year is (30 \$/trout) $\times$ (0.1 trout/afy) or \$3/afy.

2.3 Determination of Environmental Impacts

For the purpose of the EB calculation, water that is not diverted from primary sources because of conservation is assumed to remain at the source. From there, it is equivalent to any other unit

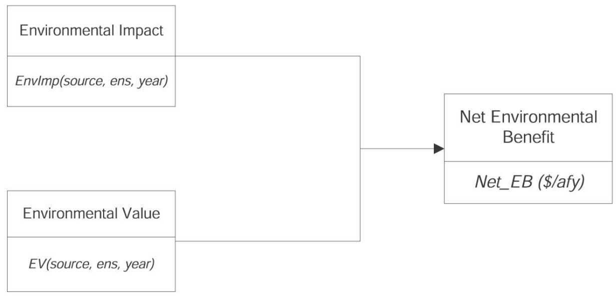

Figure 2.1: Final step of the environmental benefits calculation. The variable names in the figures are those used in the equations presented in section 2.6

of water originating at that source. The environmental impact of a given amount of saved water therefore depends on the raw water supply source affected by the demand reduction. These are the *marginal* sources, *i.e.* those that would provide The utility with its next unit of supply for some fraction of the year. the EB spreadsheet model covers a period of years which we refer to as the *analysis period*. The user inputs estimated annual water savings, and definitions to the set of sources on the margin, for each year of the analysis period.[1] Water savings and marginal sources are defined separately for peak and off-peak periods. In the EB calculation, because the environmental demand for water can vary significantly over the course of the year, the annual calculation is resolved into months. This allows specification of seasonal changes in both environmental benefits and conservation savings. The user input water savings are distributed over months by defining the specific months corresponding to the peak and off-peak periods. If monthly data on water savings are available, the user can input these directly.

The water saved by conservation is allocated to particular months of the year by specifying the fraction of the annual total saved in each month. For example, suppose a program saves 1000 afy, 600 in the peak season, and 400 in the off-peak season. Suppose further that, for this utility, the peak season are the four months May through August, and off-peak is the rest of the year. The savings are then 600/4=150 acre-feet per month (afm) for each peak month, and 400/8= 50 afm for each off-peak month. The raw water supply source attribution for the peak and off-peak seasons is taken from the AC model, and converted to a monthly attribution using the definition of the months comprising each season. Utility staff make these attributions by filling in the appropriate tables in the AC model, and importing the data to the EB model. This step of the process is represented in figure 2.2.

If water conservation is not implemented there are environmental impacts from both the diversion of the water supply and the disposition of the water once it leaves the utility service area.

[1]This information is also required for the avoided cost calculation, and is in fact imported from the AC to the EB model.

Ecological impacts occurring upstream of the user are accounted for by treating conservation as an addition to raw water availability. To fully account for the downstream impacts, some consideration of the actual physical paths taken by water from source to environmental sink would be needed. This level of detail is not practical to implement in a model that is intended to be used by all member agencies, with no requirements for users to input environmental data. For this reason, the current version of the EB model only looks at the downstream impacts associated with urban landscape irrigation. In this case, conservation is associated with reduced runoff, which in turn reduces the volume of water that must be treated before being released to the receiving watershed.

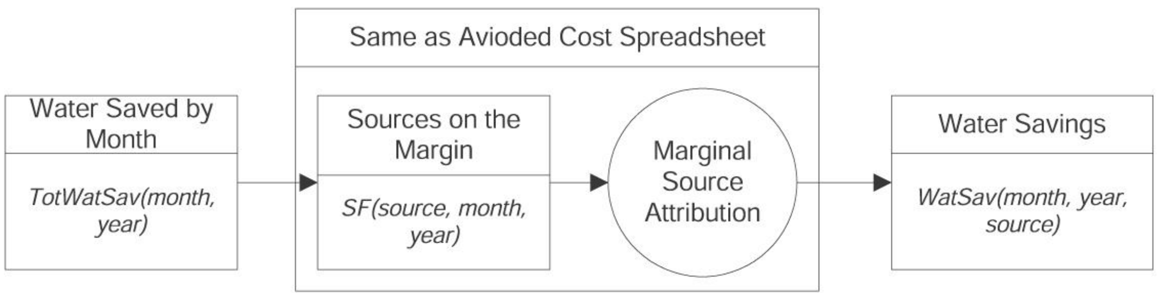

Figure 2.2: Representation of the water savings input data.

The next step of the environmental impact calculation is to estimate the gain with respect to environmental services for each of the affected water supply sources. These include such things as the number of additional fish supported per acre-foot of water not diverted from a stream, the amount of wetlands created or maintained by reducing diversions or the recreation benefits associated with higher reservoir levels. Environmental impacts also include the air quality impacts of reducing the amount of energy used to treat water and move it through the conveyance system. Consistent with the guidelines specified in chapter 1, the spreadsheet provides default values for a set of environmental services that can be described quantitatively, based on studies in the available literature. The spreadsheet also allows users to modify these values.

For many of the sources and impact types, there may not be a specific study available to provide an estimate of the magnitude of the environmental impact per unit of flow or diversion. In these cases, average estimates are developed here, based on the available information. For example, it is known that overall, the building of reservoirs and related changes in stream flow have resulted in significant reduction to fish stocks. Physically, it is obvious that the volume of habitat available to fish is defined by the amount of water flowing through the system. On an average basis, existing data can be used to correlate the level of fish populations to the total flow of water in the river system. While this method is very approximate, it at least acknowledges that every water diversion has some impact, and the net impact of all diversions is significant and must be accounted for somehow. This method also distributes the cost of environmental degradation in proportion to the amount of water taken from the environment by each agency.

Within the EB spreadsheet, the relationship between water sources and environmental services is represented as a set of linked data tables. A list of water sources is provided, from which the user can choose those that apply to their utility. Water sources are characterized by type and by some location information. For this version of the model, users are asked to assign each source to one of the ten Hydrologic Regions (HR) defined by the California Department of Water Resources [14]. Each water source type has an associated set of services. The list of services is confined to those that can currently be quantified. Services associated with a source may also be conditioned on location. For each service, a relation between quantity of service and changes in either stream-flow or total annual diversions is specified.

The flow chart shown in figure 2.3 provides a summary of the steps in this part of the calculation. Given the water savings attributed to each water supply source, and a relation between quantity of service provided and water available at the source, the environmental impact of the water savings is defined as the product of the two, summed over each month of the year. At this stage of the calculation it is possible that some of the impacts will be negative, *i.e.* , water savings may induce a reduction in the quantity of service offered. This will lead to a negative value for the economic benefit, which we interpret as a cost. The environmental impacts that result from this step of the calculation are indexed by source and by service type. To project the environmental impacts out over the analysis period, the same process is repeated for the set of marginal water supply sources defined in each of the future years. For practical reasons, in this study the relation between environmental service and water supply is assumed to be constant, *i.e.* the default values defining the sensitivity of the environmental service to the availability of water do not change over time.

2.4 Economic Value of Environmental Services

Once the environmental impact per source and service type is calculated, the next step is to attach monetary values to each of the environmental services. Computationally, this is done by looking up values in a table. The creation of this table is described in this section. Preparation of the environmental values table comprises three steps: (1) Extracting environmental values from the literature, (2) applying a benefits transfer factor, [2] and (3) constructing a weighted average of different values when appropriate. For each value considered, in addition to defining a default value, a value range can be defined by estimating upper and lower bounds for the uncertainty or variability of the value. The conditions for using a value from a study are: the study deals with a relevant environmental service, the methodology is well-described, and the data sources are thoroughly documented and statistically significant.

The benefits transfer factor is intended to account for the differences between the conditions in which the study was done and the water source represented in the EB spreadsheet. It should include the effect of inflation, and demographic differences such as activity levels and average income. When

[2] See the Appendix for definition and explanation of benefits transfer.

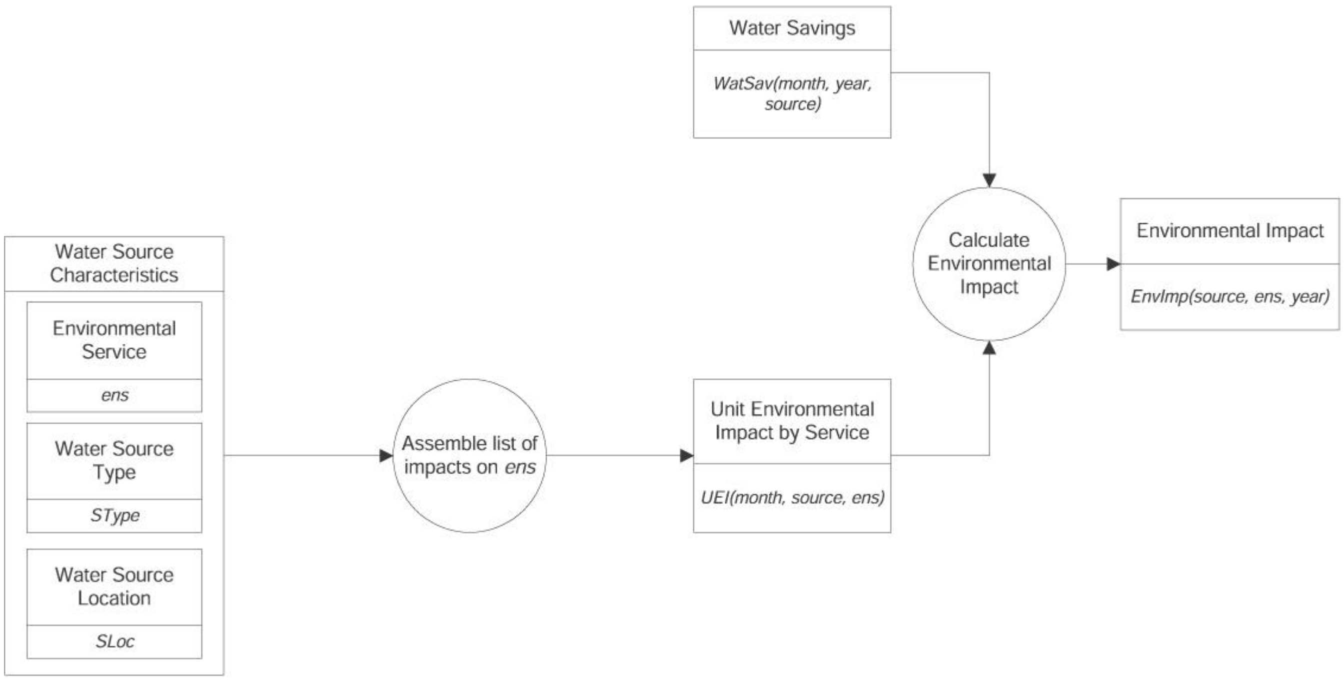

Figure 2.3: Overview of the calculation of the environmental impact of input water savings.

enough data are available, benefits transfer factors can also account for such things as differences in the range or quality of the environmental service provided. When different values are available from multiple studies for the same environmental impact or environmentally related activity, weighting factors can in principle be applied to each depending on the relevance and quality of the study. In the absence of any distinguishing features between multiple studies, a simple average of the study values will be used. The steps relevant to this section of the analysis are depicted in figure 2.4.

The monetized value of a particular environmental service may be constructed from several component steps, and is not always represented in the literature in units that are appropriate to the needs of the EB model. For example, the value people place on recreational fishing may be measured in units of $ per user-day Clearly, the number and species of fish in a particular stream will affect the value users place on fishing there. For the EB model, the environmental impact of additional water for fish habitat is measured in units of fish per afy, so the environmental value needs to be expressed in $ per fish. If the number of fish caught per trip is known, the required value can be calculated. The need to have the economic values available in appropriate units unfortunately limits the number of studies that can be used for this analysis.

The availability of water affects the economic value of associated human activities in diverse ways. For example, degradation of fish habitat may reduce the quality of fishing as measured by the

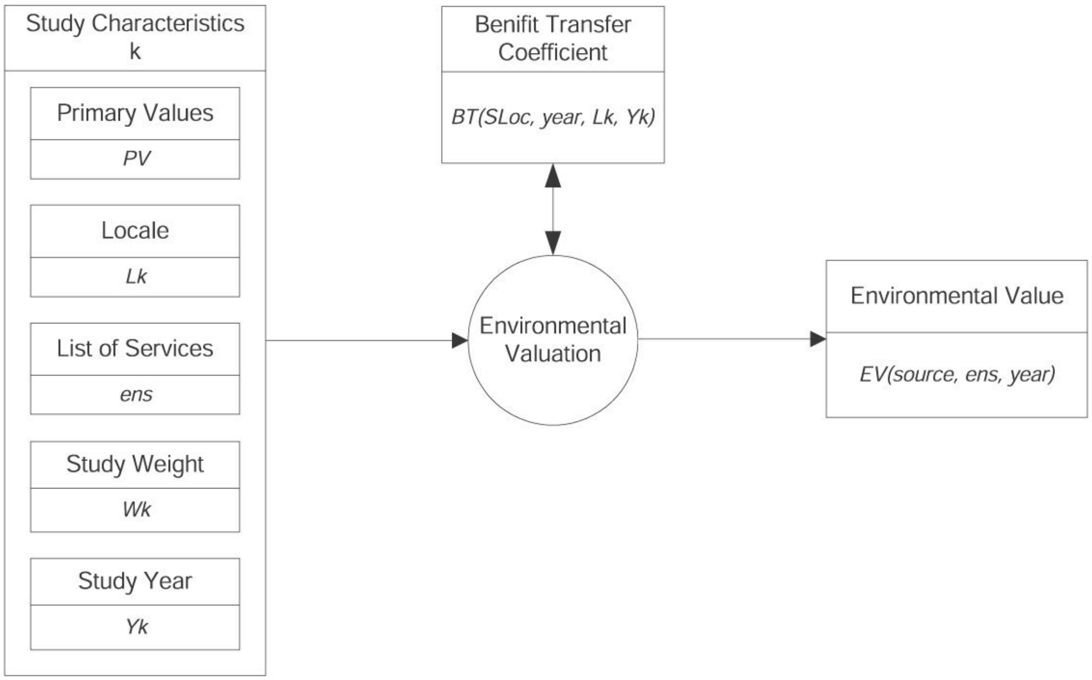

Figure 2.4: Assignment of an environmental value for environmental services provided by a water supply source.

number of fish caught per trip, or reduce the consumer surplus associated with fishing by forcing users to travel farther to obtain the same level of fishing quality. Our ability to quantify changes to the level of service the environment can sustain, and how these are affected by water withdrawals, is limited by the data currently available. The economic data is not sufficient to assign a marginal value to changes in the quality of a service, so only quantitative changes are included in the EB spreadsheet. Existence and other non-use values are not included. It seems reasonable to assume that they would not be affected in a meaningful way by the marginal water savings arising due to the BMPs.

While market values are not generally defined for individual environmental services, there is a market for repurchase of land for environmental restoration projects. In particular, a number of organizations have been active in purchasing acreage in wetlands and riparian zones for restoration and public use. These purchases provide a direct estimate of the actual societal WTP for maintenance of these water-dependent habitats. This estimate is a lower bound, as it does not include the additional costs associated with restoration and maintenance. This type of data can be used without having to itemize each service provided, and represents the valuation of a bundle of services provided by a particular type of habitat. They are included in the current EB model by simply defining wetland or riparian zones as a service in itself.

Figure 2.5 presents the entire flow of the calculation on one page. Section 2.6 at the end of this chapter summarizes the calculations in equation form, using the same notation as the figures.

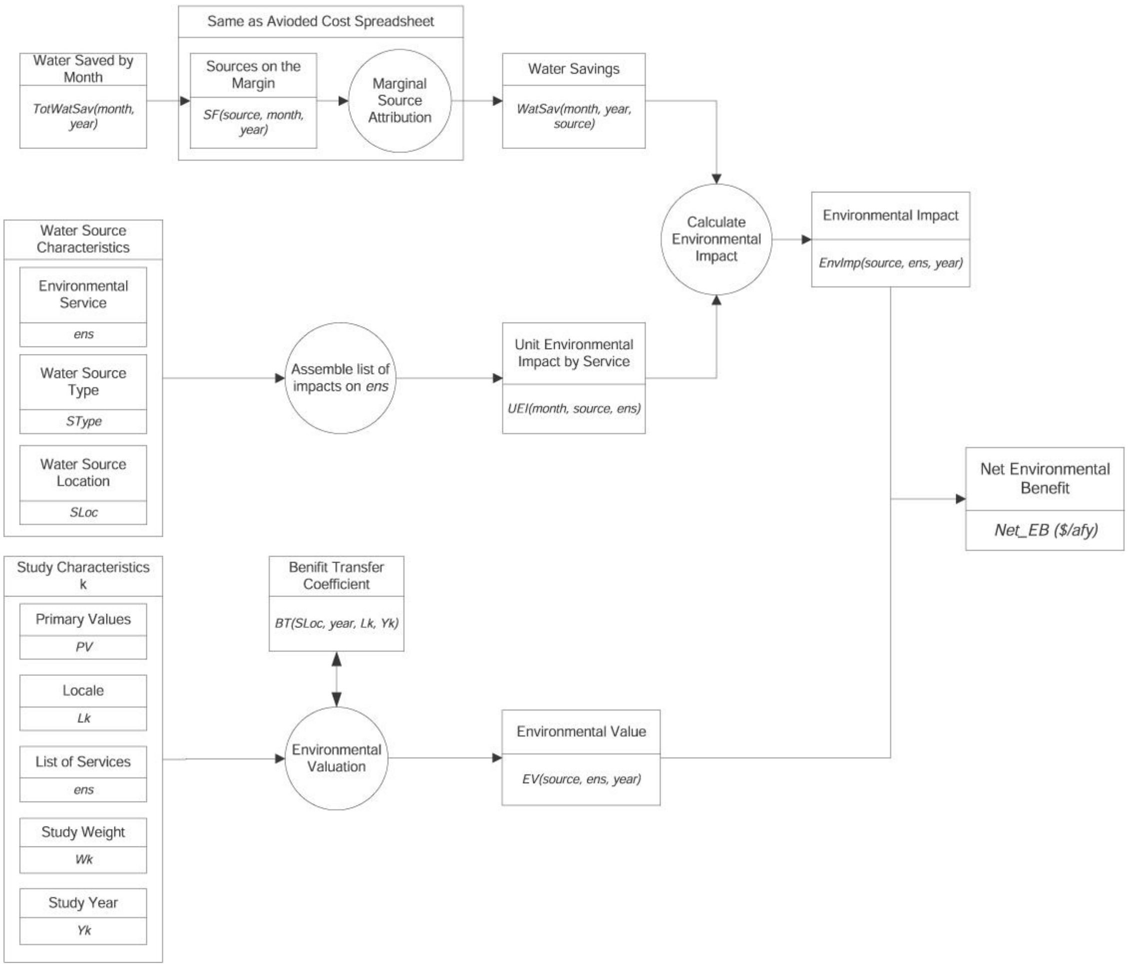

Figure 2.5: Flow chart of all steps in the calculation of environmental benefits.

2.5 Issues for Discussion

In this section we provide a list of policy and technical issues that have arisen over the course of the project in discussion with the Council Project Advisory Committee. Not all of these issues can be decided purely on scientific or quantitative grounds. Some arise because resource limitations of this project, and the relatively small amount of data currently available, force the EB model to make some rather drastic simplifications. Other issues may be more philosophical in nature. For all issues, when there is an element of policy choice, it is important that the influence of such choices be clearly delineated.

In the list below, issues are categorized as technical or policy, and the solution decided on for this project is presented.

The environment cannot be monetized (Policy) *Description* Some people feel that monetizing the environment misrepresents its real importance, and that the natural environment is intrinsically valuable even if human beings do not all place a dollar value on it. *Solution* By engaging in this environmental valuation effort, the Council has decided as a policy matter to attempt to monetize environmental benefits. The goal is to provide stakeholders with additional information that can help to characterize the relative benefits of different policy choices. This information is in no sense conclusive and does not preclude other approaches to dealing with environmental concerns.

Lack of a standard environmental benefits typology (Policy) *Description* People benefit from many different aspects of the natural environment, and in many different ways. Hence, there is no single typology that is useful in all circumstances for classifying the benefits of environmental protection or the damages from environmental degradation. *Solution* As stated in the Council's MOU, the Council is to provide guidelines to be used by all water suppliers in computing BMP benefits and costs, including "the benefits of water made available to other entities as a result of conservation efforts." In order to identify a reasonable scope for this project, the project team has compiled a list of the most significant environmental impacts in accordance with the CalFed Record of Decision [4], specifically the Mitigation Measures adopted in the ROD (Appendix A). The impacts listed there that are directly linked to water withdrawals include:

- restoration and maintenance of riparian and aquatic vegetation
- reduction of ground-water pumping
- support of aquifer recharge
- erosion and sediment control
- air quality improvements due to reduced emissions
- restoration and maintenance of native fish species
- creation or maintenance of fish habit, including increased aquatic area
- restoration of critical in-stream and channel-forming flows
- minimization of water transfers that harm fish and wildlife and their habitats

- enhancement of wetland and riparian habitat acreage and value
- reduced disturbance to areas occupied by special status species
- protection and enhancement of recreation resources
- improved flood control
- water quality enhancement
- quantity or quality of constituents discharged by treatment facilities

The above list forms the basis for the set of environmental services that are included in the spreadsheet. The EB model is designed to estimate the marginal impacts due to continuous, relatively small changes in demand for water, and is therefore not appropriate to use in evaluating the impacts of new, large-scale projects such as new reservoirs. The impacts of building *vs.* deferring new facilities are dealt with through existing environmental review processes. Reduced water demand also leads to reduced energy use for conveyance and treatment. The associated benefits come under the catgory of air quality above, and are included as an optional additional calculation in the spreadsheet. Land-use impacts are not covered in the current model, as they are not directly impacted by marginal water demand reduction.

Double counting of environmental impact costs (Technical) *Description* In calculating the avoided costs and environmental benefits of conserved water, there is a risk of double counting. The possibility of double counting occurs when the cost of environmental impact mitigation is included in the avoided cost of new water supply infrastructure. Therefore, it must be clearly defined which costs and environmental impacts are included in the avoided cost analysis and which are included in the environmental benefits analysis. *Solution* After internal discussion, the Avoided Cost and Environmental Benefits teams have agreed to the following provisional solution to the double counting issue:

1. Avoided costs are defined such that they correspond to actual incremental costs in the actual regulatory environment in which new supply infrastructure is built.
2. Environmental benefits shall consist of only those impacts over and above the mitigation activities that may be required by the current regulatory environment.
3. The EB model does not count conservation affecting water obtained through purchases or transfers. Water leaves the primary raw source only once, and it is only then that the environmental impacts considered by the EB model are counted.

Amount of water conserved *vs.* amount of water to the environment (Technical) *Description* The EB model needs to clarify the relationship between water saved by a utility and water materializing somewhere to provide a benefit to the environment. It is also not clear that water saved in one service area will not just be sold elsewhere in the state. *Solution* The EB model does not assume that the entire amount of conserved water goes to the environment.

It treats conserved water as an accrual to the total amount of water that *could be* available to meet environmental needs. The probability that a unit of raw water will go to a given environmental use is calculated from estimates of total water use for these needs, as published in the DWR Waterplan [9]. These probabilities are calculated independently for each hydrologic region. In some cases they not needed: for example, water that is not withdrawn from a river increases directly the volume of available fish habitat; water not withdrawn from a reservoir increases directly the surface area available to recreational use. As for whether water conserved by one utility could be sold by another, this issue is outside the scope of the model, which does not attempt to predict the future behavior of water users. It is always the case that a benefit made available through one action could be undone by another action. This does not change the fact that a value can be associated with the benefit.

When water is saved *vs.* when water accrues to the environment (Technical) *Description* There may be a timing issue regarding when water is saved and when the benefit is received. Therefore, there should be a temporal element in the model. *Solution* Mathematically, the temporal resolution of the EB model is determined by the temporal resolution of the input data, *i.e.* the input water savings. This input is available only on an annual or seasonal basis. Consistent with this fact, and in accordance with standard practice, the model evaluates environmental benefits on the basis of annual average values, accounting only for seasonal variations when they are significant. Hence, the delay between conservation and potential benefit is averaged out. Clearly this is an approximation, however a more detailed model would require both higher temporal *and* spatial resolution, which exceeds the scope of the current project.

Environmental impact dependencies and interactions (Technical) *Description* Different environmental impacts can have interdependencies. Ecological systems are highly interconnected, and in reality environmental services are not available in isolation. Complex environmental interactions may lead to a nonlinear relationship between water availability and service impacts. *Solution* For practical reasons, this version of the EB model is based on long-time and large-scale spatial averages, and is therefore limited to capturing first-order effects. Consistent with this approach, only relatively independent ecological service impacts are included. Budgets of millions are spent trying to characterize the nonlinear relationships between different ecosystem components, and as these relationships become clearer the information may be used to refine the definitions and values used in the model.

Other aspects of water system operations also affect the environment (Technical) *Description* Many aspects of water system operations, for example pumping across the Delta, dam operations, or release of chemicals from treatment plants, affect the environment. Quantitatively, the effects may be more significant than those modeled in the current EB spreadsheet. *Solution* As the EB model is designed to be used by any and all Council member agencies, it is not appropriate to use it to model the effects of micro-level system components such as dam reoperation. Many of these other impacts are at least partially mitigated through existing regulatory and management programs. For example, the Environmental Water Account is used to limit environmental damage due to pumping in the Delta. The EB project has been directed to focus on environmental impacts that are currently not accounted for in any other program. Given limits on the available resources and data, the focus is on environmental services for which there is a direct physical link to water withdrawals. The spreadsheet is designed to make it easy for environmental impacts related to other system components to be added in the future.

Data uncertainty (Technical) *Description* All data have some uncertainty. How will this be handled in the model? *Solution* It's important to distinguish here between uncertainty and variability. While it is true that data values are uncertain, even if they were not the existence of real, irreducible variability in the quantities being measured would lead to a range of estimates for the EB calculations. Given limited resources for this project, point values are used for all the default data values. However, the spreadsheet contains two features to facilitate the calculation of sensitivities by the user. All data values include low, medium and high estimates, with the medium being the default. A data-entry form allows users to easily choose the low or high value instead. High and low values are defined from existing data when it is available. Otherwise, the low value is defined as half the medium, and the high value as twice the medium. The spreadsheet also provides a detailed breakdown of intermediate results. This allows the user to see how much each environmental service and water source contributes to the net environmental value, and therefore to focus their attention on the most significant services.

Natural hydrological variability is not represented in the model (Technical) *Description* Water availability in the natural environment is highly variable, and the value of conserved water to the environment may depend significantly on whether conservation occurs in a wet or a dry year. The EB model deals only with an average year. *Solution* It is true that the ecosystem impacts vary in wet *vs.* dry years, but there are also good reasons why this is not represented in the current model. Ecosystems in their natural state are adapted to hydrologic variability, and in fact many processes (such as regeneration of riparian vegetation) are *dependent* on a succession of wet and dry years for normal functioning. The overall health of an ecosystem must be defined over a period of time that is long enough to smooth out these fluctuations. For this reason, the ecological literature does not provide any basis for defining environmental sensitivities as a function of wet or dry years. The next order of complexity would have to include some representation of the population dynamics for different species, and how they are affected by water year type. This goes significantly beyond the scope of the current project, and would only be practical in a model that is much more limited in geographic scope. If the classification of the water year is an important determinant of a utility's estimated water savings, this can be handled by defining different sets of inputs to use in EB model runs. If a utility has the expertise to refine the ecosystem impact values to represent non-average conditions, they are free to enter their own values into the spreadsheet.

Property rights assignment (Technical) *Description* The valuation of an environmental good depends on whether or not a person has a right to enjoy the particular good. If a person has a right to the good then WTA good is the proper measure of its value. If the person does not have a right to the good, then WTP is the correct measure of the good's value. For example, clean breathable air may be considered by many to be a fundamental right, and therefore best measured by WTA, while recreation on a particular lake would be considered by many to not be a right but a service that would best be measured by WTP. There is no strict empirical sense in which one measure can be considered more correct than the other. *Solution* Valuations depend on many variables that are not controlled, so different studies generally arrive at different values. WTP and WTA can be considered as both representing reasonable estimates under different assumptions, and can therefore both be included in the range of values for a service.

2.6 Equations for Environmental Values Estimation

This section reviews the spreadsheet calculations and presents them in equation form. Each set of equations corresponds to a stage of the calculation as outlined in the flowchart.

The spreadsheet estimates the environmental value of a given pattern water of water savings. It is not necessary to know which BMP programs are responsible for the savings, but it is necessary to provide information about where and when the savings occur. For the environmental benefits model, because environmental water needs vary seasonally, with different definitions of seasons for different services, the data are assumed to have a monthly time resolution. The analysis covers an extended period of time defined by the user, so the input water savings also have a year dependence.

We define $TotWatSav(month, year)$ to be the quantity of water saved, by month, for each year in the analysis period. Water savings then need to be attributed to a source. This is done by specifying a factor $SF(source, month, year)$, which indicates the fraction of water savings that come from a particular source in that year. These two quantities are also required for the avoided cost spreadsheet. The water savings by month, year and source is written:

$$WatSav(month, year, source) = TotWatSav(month, year) * SF(source, month, year) \tag{2.1}$$

This equation corresponds to the piece of the flow chart depicted in figure 2.2. The next input we need is the estimate of the environmental impact at the source resulting from reduced demand for water. We do this as follows: For each source included in the spreadsheet, several properties are defined, in particular a categorical variable $SType$ describing the type of water source, and a source location descriptor $SLoc$. For each type and location of source, we compile a set of environmental services provided by that source. For each service, a unit environmental impact measure is provided, which estimates the change in quantity of service per unit change in flow or diversion. We denote this environmental impact variable as $UEI(month, source, ens)$, where ens is the index indicating which type of environmental service is being considered. UEI is expressed in units of service quantity per afy, where the service quantity must be defined in context. The construction of this dataset is complicated, and we defer further discussion of it to chapters 4 and 5. The total environmental impact associated with $WatSav$ is then calculated as:

$$EnvImp(source, ens, year) = \Sigma_{month} WatSav(month, year, source) * UEI(month, source, ens) \tag{2.2}$$

where the sum is taken over months. This step of the calculation is represented in figure 2.3.

The next step is to assemble the data on environmental values that is appropriate to this set of water sources and associated environmental services. The data source for these values is a set of studies, where each study is given an index k. The study is assumed to specify a set of values which may also depend on the locale L_k where the study was done, and the year Y_k of the study[3]. The primary study values are denoted $PV(ens, k, L_k, Y_k)$. The primary study value needs to be transferred to the water source location $SLoc$, a procedure that generally requires a rescaling of the primary study value by a benefits transfer factor BT. This factor is assumed here to depend only on the initial study location, the source location, the study year and the year being considered in the calculation. We denote this coefficient as $BT(SLoc, year, Lk, Yk)$. Finally, if multiple studies are used, each is assigned a weight W_k. This weight is defined relative to other studies that treat sufficiently similar topics. If all studies are considered equivalent, each is given a weight of unity.

The environmental value associated with the variable $UEI(source, ens, year)$ is then:

$$EV(source, ens, year) = \Sigma_k [PV(ens, k, L_k, Y_k) * BT(SLoc, year, L_k, Y_k) * W_k], \tag{2.3}$$

where the sum is taken over all the studies with relevant values for the service ens. This equation corresponds to figure 2.4.

The last step of the calculation is to assemble the quantities defined above into a single net dollar value of environmental benefits per unit of water saved for each year of the analysis. The values in future years are not discounted in the EB model (the annual EB values can be imported into the AC model where they will be discounted and summed along with all other avoided costs). The total annual value of the environmental benefits associated with TotWatSav is then:

$$Net\_EB(year) = \Sigma_{source,ens} EnvImp(source, ens, year) * EV(source, ens, year). \tag{2.4}$$

Here the sum is taken over all sources and services, and the units are 2005 dollars. A net benefit per unit of water saved in each year is defined as

$$Unit\_EB(year) = Net\_EB(year)/(\Sigma_{month} TotWatSav(month, year)). \tag{2.5}$$

[3]We include these dependencies to be completely general, but in this study we use only data from California, so there is no location dependence.

Intermediate quantities, such as the value of environmental benefits by service in each year, are also presented in tables in the spreadsheet. The whole calculation is represented as a flow chart in figure 2.5.

Chapter 3

Data Sources

In this chapter we outline a framework for the organization of data needed by the EB spreadsheet model, provide more detail on how the data are characterized, and provide a brief, illustrative literature review. The focus is on the logical structure of the model and we ingore, for the moment, problems arising from actual limitations of the available data. The use of real data to calculate the default values used in the EB model is discussed in Chapter 4.

3.1 Introduction

To summarize, the EB methodology outlined in the previous chapter consists of four steps: (1) characterize the input water savings; (2) estimate the physical and biological environmental impacts associated with the water savings; (3) determine the economic values appropriate to the set of environmental impacts and calculate the associated cost or benefit; and (4) calculate the annual net environmental benefit.

The data needed for the EB calculation can be grouped into three categories, which correspond roughly to the first three steps in the methodology: (1) user inputs, which are provided by the water utilities as inputs to the spreadsheet; (2) biological and physical characterization of environmental impacts; and (3) economic values assigned to environmental resources. In sections 3.2, 3.3 and 3.4 of this chapter we discuss in detail each of these three datasets and their spatial and temporal characteristics. Two schematic database tables that organize the environmental and economic data are shown in figures 3.1 and 3.2. These are useful for summarizing the data inputs and illustrating how different types of data are linked, but are not reproduced exactly in the spreadsheet model. To give the reader a sense of what kind of information is currently available, the last section presents a short list of some of the data sources that have been reviewed for this study, particularly public databases and review articles. A complete bibliography of data sources and references is found at the end of this report.

3.2 Input Water Savings

The water savings are assumed to be available as an input. The savings represent a decrease in demand relative to the base case with no BMP implementation. Demand reductions translate into less water taken from a particular source or set of sources, which may vary seasonally. The sources from which the next unit of water would be taken are referred to as marginal. In both the EB and AC models, the list of marginal sources and the fraction of water taken from each during the summer and winter seasons are user inputs. As BMP programs typically impact water use over an extended time, the spreadsheet covers a period of years which we refer to as the analysis period. The user defines the analysis period, and specifies how the inputs vary over this time. Finally, the user provides a list of the months to be allocated to each season. These data are input through the AC model, and imported into the EB model.

As noted in section 1.5, the AC model deals with water system components, while the EB model currently concerns itself only with raw water sources. For these water sources, some additional information is needed by the EB model. The environmental impacts associated with water savings often vary over the course of the year. To model this variation, the EB model assumes that water savings and ecological variables depend on the month of the year. For the water savings, input annual or seasonal values are converted to the appropriate monthly values using the user-defined set of months corresponding to each seasonal period.

The water demand savings are thus defined as a function of three variables:

source the physical water source,

month the month of the year, and

year the year of the analysis period.

The system component must also be associated with one of the water source types represented in the spreadsheet. The water source type is used as a key to relate the user input water savings to the other data in the EB spreadsheet. For practical purposes, the list of water source types used is finite, and spreadsheet users select those appropriate to their service area from this list. Finally, for each water source, the user is asked to indicate the hydrologic region (HR) where the source is found. The EB model uses the Calwater 2.2 [14] definitions of ten hydrologic regions in California, which are listed in table 4.1. A figure illustrating the region boundaries can be found in the EB model User Guide. The model assumes that all ecological data varies with HR, and variation with HR is included in the model wherever the data allows. If regional data is not available, statewide average values are used in each HR.

3.3 Environmental Impacts by Water Source

The EB calculation uses the concept of environmental services to describe the relationship between human activities or attitudes and the physical environment. This notion is equivalent to environmental amenities or beneficial uses [51]. Some examples of environmental services are: recreation such fishing, boating and swimming; water quality enhancement; flood control; species habitat and maintenance of genetic diversity *etc.* In the EB model, the data on environmental services are limited to the information needed to characterize the relationship between the service and the availability of water. These can be organized into the set of tables shown in figure 3.1. In this figure, the Water Source List and Environmental Service List itemize the sources and services for which impacts and benefits are calculated explicitly. In practice these lists are determined by the available data. Additional items can be added to these lists, to enhance future versions of the model as more data becomes available.

Specific environmental services are associated with particular types of water source. For example, only some rivers provide habitat to listed anadromous fish species. To represent this association, we use the Water Source Characteristics table, which provides a link between the list of water sources and the list of environmental services. The source variable is thus characterized by a name, a location and a type description. The location variable here is the HR. The type variable can be used to aggregate sources that provide similar environmental services. For example, recreation surveys often do not distinguish between reservoirs and lakes, so the same type could be assigned to them if the data requires it.

In determining the environmental impact of reduced water use, we should in principle account for the fact that water typically remains at the source for a finite time before continuing downstream, for example to a wetland or into the Bay-Delta. Environmental costs and benefits downstream may result from conservation upstream. This is acknowledged here by including a downstream type characteristic in the table, which could allow a limited set of network relations to be represented in the model. An environmental service can be linked directly to a source, or indirectly through the downstream type field. As previously noted, full consideration of downstream effects could not be implemented in the current version of the model, so this feature is not actually used in the spreadsheet.

The Environmental Services List also links to a table labelled Environmental Services Characteristic, which is used to provide more detail on each of the services. In principle this table can itemize any characteristic deemed relevant. Based on current data we have included: water source type, which provides a link back to the water source information; a flag indicating whether the service provides use values and/or existence values; seasonal dependence; and participation level, which relates to the benefits transfer exercise (see section 3.4).

These tables show only source-related environmental impacts. Two other categories of environmental impact are included in the EB spreadsheet model but not in these tables. These are reduction of the load on the wastewater system, and reduced energy use and associated pollution. These are fairly straightforward to model and are described in section 4.2.6.

3.4 Environmental Values

Literature on the economic valuation of environmental services has been collected into a number of resources in the form of databases and review articles. This makes the task of collecting and classifying economic information quite a bit easier than for the environmental data. The challenge is to select the appropriate set of studies from the existing literature, and make the necessary adjustments to convert values from the study to values appropriate to the context of Council member agencies. The most extensively studied service is recreation, particularly sport fishing.

Figure 3.2 shows the organization of data from environmental valuation studies for use in this project into four tables: Bibliography of Studies, Primary Study Values, Site Characteristics, and Benefits Transfer Data. The Bibliography table includes the study name, author and reference information, an indicator of the study site, and a global weight that indicates whether the study data can be directly used in the EB model. The bibliographic database of studies is more extensive than the set of studies used to construct final spreadsheet values.

The Site Characteristics table is used to record information about the study site that is useful in understanding the degree of similarity between the study site and a particular water supply source. This table can include as many characteristics as desired. The source type variable provides a link to the Water Source Characteristics table of figure 3.1. For this work, to avoid complications associated with the benefits tranfer excercise, we use only studies which provide data for California or regions including California.

For each study the Primary Study Values table is used to store the values taken directly from the study with no adjustment. The service_name labels the environmental service discussed in the study, and acts as a link to the environmental impacts data tables. The primary values are coded as either use values or existence values, although as noted previously only use values are included in the EB model. Additional data needed to characterize the study values are the methodology used, the units, and the year of the study. The year is used when converting to constant dollars, and the units are needed to convert the study values to the units used in the EB calculations. This structure is very similar to the organization used in existing databases such as the Environmental Valuation Resource Inventory [19], or the Sportfishing database [21].

Finally, a table is included for the data that are needed to compute benefits transfer coefficients. There is a row in this table for each service included in the given study. The participation level indicates the degree of use of the service at the study site, and can be compared to the similar field in the Environmental Service Characteristics table of figure 3.1. These two fields allow us to adjust for different levels of use between the study site and the water supply source. The data_year defines the year in which study values were collected, and allows data values to be adjusted for the passage of time. The BT_index is used to capture other considerations that may require the study data to be adjusted before being applied in the EB model. For example, a recreational study site may contain more facilities, such as picnic areas and boating docks, than the average. The BT_index can be used to adjust this value down to reflect the more typical case.

3.5 Illustrative Short List of Data Sources

This section describes data sources consisting of collections of reports that have been organized by other authors either as review articles or as publicly available databases. The goal of this section is to give the reader an overview of the kind of information that is publicly available. A much longer list of reports has been reviewed and archived as part of this work.

The Beneficial Use Values Database (BUVD) [51] This database and associated report compiles economic values for beneficial uses of water in California, as identified by the State Water Resources Control Board (SWRCB). It was intended to be a companion to the Water Quality Standards Inventory Database. The BUVD project is no longer active. It contains information from 131 studies of various types, with the most recent being 1994. Separate tables contain information about (1) documents; (2) author; (3) geographic areas the study is applicable to; (4) beneficial uses maintained by the SWRCB; (5) a modified list of beneficial uses that are more convenient for analyzing the literature and are linked to SWRCB beneficial uses; (6) valuation methods used; and (7) value estimates and their characteristics. Data from the BUVD has not been used directly in the EB model, but could be useful as an overview of the range of values obtained by different methodologies and in different contexts. LBNL has extracted a summary report of the information included in the BUVD that is relevant to this project, based on location and service type, which is available on request.

Benefit Transfer of Outdoor Recreation Use Values (2000), *Randall Rosenberger and John Loomis* [43]. This study includes an annotated bibliography with information on the literature on valuation of outdoor recreation use. The information is presented by study source, benefit measures, recreation activity, valuation methodology, and USDA Forest Service region. The literature review spans 1967 to 1998, covers 21 recreation activities and reviews 163 individual studies. This data has not been used directly in the EB model. A very useful component of this report is a discussion and evaluation of different techniques for doing benefit transfer.

Calfish Database [6] This is an active database maintained as a joint project among a large number of state, federal and other agencies. It reviews all significant studies of fish populations within California. The data are organized both through a relational database that can generate tables of numbers, and through a GIS interface that allows the users to easily call up study information on a particular area. This database has been reviewed extensively and used to help estimate fish population counts for the EB model. The most recent numbers on fish counts have been extracted and used to supplement anadromous fish population estimates from other sources.

Economic Valuation of Changes in the Quality of Life (1995), *W. Michael Hanemann, G. Helfand, G. Green and F. Larrivee*. This paper provides an overview of the application of non-market valuation in environmental economics. It includes a thorough literature review, case studies dealing with water and air pollution, data tables, and an extensive bibliography of environmental valuation studies in California up to 1995. A slightly edited version is attached as an Appendix to this report.

Environmental Valuation Reference Inventory (EVRI) [19] This ongoing project maintains a searchable database of empirical studies on the economic value of environmental benefits and human health effects. The site also includes information on benefits transfer studies. The database provides users with a summary of the study, including survey mode, analysis methodology, and reproduction of data tables. It covers all environmental amenities, and contains a number studies for California. The EVRI summary data page is structured similarly to the tables of figure 3.2, but is more complete.

Sport Fishing Values Database [21] This project is active and maintained for the U.S. Fish and Wildlife Service, and focuses on use values for recreational fishing. It summarizes a subset of the available literature on the economic valuation of sport fishing across the country. The data are summarized in tables structured along the lines of those illustrated in figure 3.2. It includes information on the type of method used to estimate use values, and some information on values per fish caught as well as per user-day. This database has been used to compile data on anadromous fish for the California region, which are incorporated into the value estimates described in section 5.2.4.

Environmental Impacts Data Tables

Water Source List (source_name)
Sacramento River
San Joaquin River
Bay Delta
CVP - NOD
CVP - SOD
SWP - NOD
SWP - SOD
local surface water
local groundwater
other major rivers
major reservoirs

Water Source Characteristics
source_name
region_name
source_type
downstream_type

Water Source Types (source_type)
lake
reservoir
stream
major river
groundwater
wetland
delta

HSA Regions (region_name)
region_name
region_boundary

Environmental Service List (service_name)
fish habitat
bird habitat
air quality
water quality
wetland
riparian vegetation
flood control
boating
sport fishing
hunting
other recreation

Environmental Service Characterisitcs
service_name
source_type
participation_level1
season_dependence
use_value1
existence_value1

Figure 3.1: Schematic of environmental service data tables.

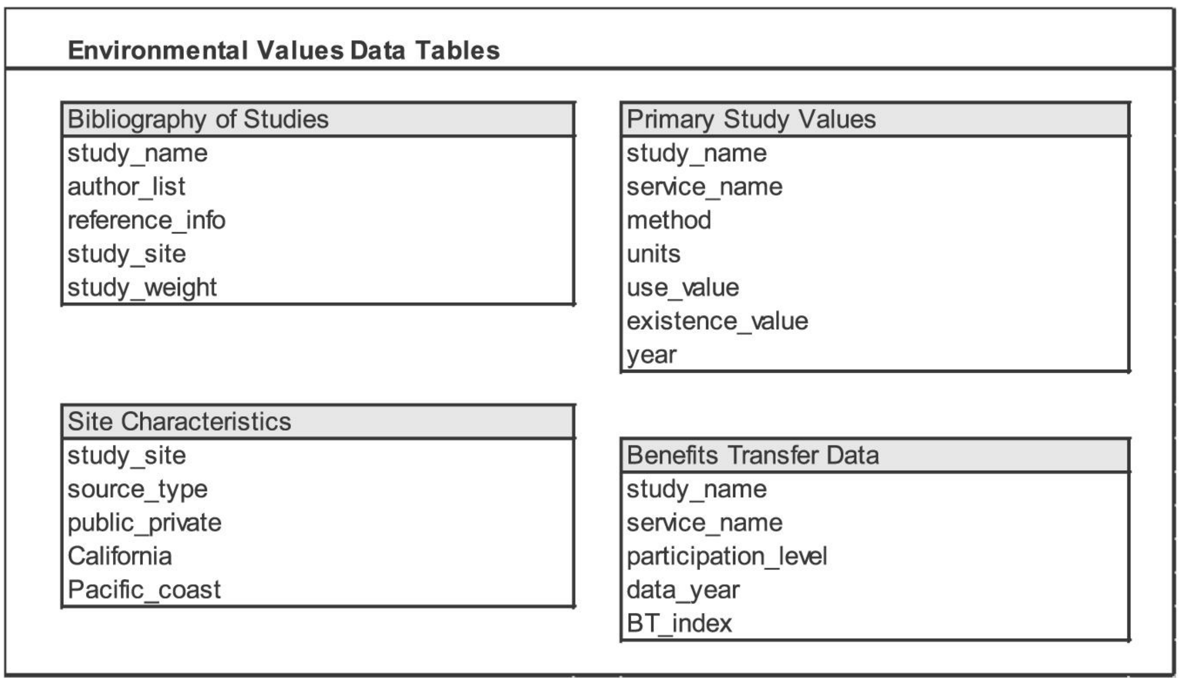

Figure 3.2: Schematic of environmental value data tables.

Chapter 4

Data Values for the Environmental Benefits of Conserved Water

4.1 Introduction

This chapter provides background information and detailed calculations for the data value inputs that have been developed for the current version of the Environmental Benefits (EB) spreadsheet tool. Data has been collected only from publicly available sources. Preference is given to recent data that are specific to California. Given the highly specialized nature of some of the data needs, it is not always possible to find recent information.

The calculation of environmental benefits starts with a determination of the ecological and recreation-related consequences of reducing the amount of water taken directly from natural sources (or *raw water*). Depending on the situation, an environmental service may be affected by the volume of water present (as for lake and reservoir recreation), or by the flow (as for fish populations). The reduced withdrawals are inputs to the EB spreadsheet model and are expressed as a volume (acre-feet) per month. These numbers are converted to flow values or summed to get seasonal or annual withdrawal volumes as needed.

After some general introductory remarks, we present a detailed discussion of the development of the ecological impact and economic valuation numbers for each environmental service currently included in the spreadsheet. These are: reservoir and lake recreation, riparian habitat, wetlands, anadromous fish riverine habitat, and San Francisco Bay water quality. We are not aware of any additional sources of quantitative information that could be used to increase the number of services represented in the EB model. The spreadsheet has been designed to make it relatively easy to add other services if more information becomes available at a later date.

A full list of references is given in the bibliography at the end of this report. The list of citations relevant to a particular service is included at the end of each subsection.

HR	Region Name
NC	North Coast
SF	San Francisco Bay
CC	Central Coast
SC	South Coast
NL	North Lohontan
SL	South Lahontan
SR	Sacramento River
SJ	San Joaquin River
TL	Tulare Lake
CR	Colorado River
CA	State Average

Table 4.1: Definition of hydrologic region codes. Note the Central Coast region includes the Los Angeles, Santa Ana and San Diego planning areas.

4.1.1 Temporal Adjustment

Most of the economic data are not current and therefore needs to be adjusted for changes over time. Two effects are modeled here. The first is inflation, which reflects the changing purchasing power of the dollar. Inflation adjustments are made using the Consumer Price Index for all urban residents as provided by the Bureau of Labor Statistics [2] (an online CPI calculator can be used to get the appropriate ratio between any two years). A second modification is necessary for economic use-values that scale with population levels, in this case recreation. It is quite reasonable to assume that total recreation use in the state increases with population. While it's also possible that relative levels of participation in different activities may change with time, there is insufficient data available at this time to verify this.

4.1.2 Regional variation

Given the widely varying climate, geography and demographics within California, it's important to have some level of regional disaggregation in the data values. In this model the spatial unit of analysis is the Calwater 2.2 Hydrologic Region (HR) [14], which divides the state into ten major watersheds. Table 4.1 lists the region names and corresponding two-letter codes. The HR dependence enters the calculation through the list of environmental services. The relative quantity of water needed to sustain these services (which is zero if the service doesn't exist in a region) is used to scale the overall ecological impact values.

The allocation of water and flows to different environmental uses is taken from the the California Department of Water Resources (DWR) Draft 2005 California Water Plan Update [9]. We use the year 2000 data from this report, representing a typical or near-normal water year. Unfortunately, this data are not complete enough to provide an annual value for natural flow or total runoff by HR, however it can be used to roughly determine the fraction of total annual water supply that goes to consumptive use for different environmental services. These fractions are calculated for each HR, and used to represent the probability that any given unit of conserved raw water will end up being supplied to that service. This approach allows us to avoid attempting to track a unit of water from its source to its final consumptive end, which is an enormously difficult task in general and cannot be implemented practically in a simple spreadsheet model. We note that water *flows* are not a form of consumptive use, and are able to provide multiple environmental services, for example simultaneously sustaining fish populations and riparian vegetation.

4.2 Estimating marginal impacts

Urban water conservation results in relatively small reductions to raw water withdrawals at the margin, which occur more or less randomly in space and time relative to streamflow patterns, but are repeated month after month. The programs leading to savings persist for times on the order of a decade or two. Under these conditions, it is appropriate to use average values to represent both ecological impacts and their valuations. We focus only on those features of the environment that are directly linked to the volume or flow of water available, as these capture the first-order impacts of a change in water use. For example, while stream channel morphology and water temperature are both strong determinants of the quality of fish habitat in rivers [46], neither is directly modified by small marginal flow changes. Conversely, the volume of flow in the river defines directly the size of the available habitat, so on the average, over a long time period, changes to this volume will impact fish populations. Even with a high level of natural variability in the system, marginal changes that occur consistently over the long term can have a significant effect on the average state.

4.2.1 Reservoir or Lake recreation

Reservoirs and lakes are used for a variety of recreation activities, including swimming, boating and picnicking. In a series of studies of reservoir recreation use [31, 37, 54, 55], the freshwater recreation benefits of reservoirs were estimated from visitation data using a variant of a travel cost model. The models include a parameter that measures the elasticity of rates of visitation with respect to changes in reservoir surface area, which was found to be approximately equal to one. This is reasonable, as the number of users the water body can support will scale with the available area. Even for activities taking place on shore, higher water levels are generally preferable, as lowering the water level can decrease the attractiveness of the site. A change in storage level can thus be related to a change in area, then to a change in visitation rates. Given a value per user-day for the recreation benefits at each reservoir, we can calculate the dollar value of the recreation benefit associated with a change in storage.

In practice the time between when water savings and reservoir releases occur will vary, but to be consistent with our annual average calculation we assume that the average residence time of water in the reservoir is one year (some water is released sooner, some later, and some evaporates). In a normal year, the beginning year and end of year reservoir storage in California are approximately equal [8].

To estimate the fraction of water returned to reservoirs that is eventually released to streams and rivers, we calculate the average percentage of storage lost to evaporation by HR and assume that water not lost to evaporation in a year eventually continues downstream, thus potentially producing environmental benefits to fisheries, riparian habitat and downstream wetlands. Evaporation rates per unit area can be extracted from the CALSIM II data [10].

Equations

The relationship between reservoir area and reservoir volume can be approximated by a power law of the form:

$$A = c\, S^p \tag{4.1}$$

where A is the area, S the storage, and c and p are constants that depend on the reservoir. This type of function is used in the CALSIM II model of the CVP-SWP system [10]. From this equation, a change in storage ΔS induces a change in area ΔA with

$$\Delta A = p\frac{A}{S}\Delta S. \tag{4.2}$$

Let $U_{res}(A)$ be the annual rate of visitation when the reservoir has surface area A. We define the coefficient of elasticity between visitation and surface area as e_A, such that a change in surface area ΔA induces a change in visitation ΔU_{res} with

$$\Delta U_{res} = e_A \frac{U_{res}}{A}\Delta A. \tag{4.3}$$

The units of ΔU_{res} are user-days per year. The value V_{res} of the consumer surplus associated with reservoir recreation, in units of dollars per user-day per year, was also estimated in the travel cost studies [31]. Combining equations (4.2) and (4.3), and multiplying by V_{res} gives the annual marginal benefit (in units of dollars per acre-foot per year) of a change in the reservoir storage level:

$$mb_{res} = V_{res}\, e_A\, p\, \frac{U_{res}}{S}\, \Delta S. \tag{4.4}$$

Data values

Data on the relationship between reservoir size and area is available from the CALSIM II model [10] The file *res_info.table*, included with the model, provides a series of values of A and S, which we fit to a power law to obtain the coefficients c and p. The results of this calculation are presented in

Table 4.2.1. Note that only the exponent p, not the actual reservoir area, is needed in equation (4.4). There are many more reservoirs in the state than are included in the CALSIM II model. To approximate the parameter p for the other reservoirs, we use the simple average of the values in the table, which is equal to 0.61. Historical data on reservoir storage levels is available from the California Data Exchange Center [8]. The site posts average monthly values, calculated from approximately 20 to 40 years of data, depending on the reservoir.

Wade *et al.* [54] estimated the coefficient of elasticity between visitation and surface area as 1.0. More recent work [37] indicates a slightly lower value of 0.9. In these calculations we set $e_A = 0.9$. Mitchell & Wade [31] also provide tables of estimated annual visitation rates for 2000, and daily per capita benefits (*i.e.* dollars per user-day per year), for about eighty reservoirs in California (see their Table 15). These values are used here to estimate U_{res} and V_{res} for each reservoir. The benefits are converted from 1985 to 2005 dollars using a CPI inflation ratio of 1.8 [2]. In cases where we have visitation data but no storage data, the reservoir is not included in the calculation. The average for the state across 67 reservoirs is \$36.86 per user day

Wade *et al.* [54] provide a disaggregation of annual visitation over months for several major reservoirs. From their data, on average about 70% of recreation use occurs in the months May through September. Although there is some variation by month within seasons, it is not included here as the disaggregation of water savings by month is very approximate. To include the dependence on month m, equation 4.4 is modified to:

$$mb_{res}(m) = f_m \; V_{res} \; e_A \; p \; \frac{U_{res}}{S} \; \Delta S(m). \tag{4.5}$$

Here f_m is a factor that distributes total annual visitor-days over months. It is equal to $0.7/5 = 0.14$ in each of the months May through September, and $0.3/7{=}0.043$ in all the other months.

The factors U_{res}, V_{res}, p, S in equation 4.5 are defined for each reservoir, but to be consistent with the level of resolution in the spreadsheet model, we compute average values for each HR. For each reservoir the benefit factor $f_m V_{res} e_A p \frac{U_{res}}{S}$ is calculated, and then the storage-weighted average is calculated over all reservoirs in the region. (We use storage weighting to account properly for the likelihood that a withdrawal comes from a given reservoir). The results of this calculation are presented in Table 4.2.1. The change in storage ΔS is just the savings for this water source type input by the user, defined for each month m. To calculate the annual recreation benefit, the monthly water savings are multiplied by the monthly benefit factors and summed for the year.

References

[2], [8], [10], [31], [37], [54], [55].

4.2.2 Riparian Habitat

Riparian habitat provides multiple ecological benefits which may be difficult to value individually. In general, adequate water supply is a necessary but not sufficient condition for maintaining riparian

Calsim Node	Reservoir Name	Constant c	Exponent p	Average Storage TAF
1	Trinity	-0.31	0.68	1,866
3	Whiskeytown	0.14	0.64	222
4	Shasta	-0.08	0.68	3,289
5	Keswick	-1.50	0.81	22
6	Oroville	-0.68	0.69	2,584
7	Thermalito	0.66	0.63	55
8	Folsom	-1.04	0.76	621
9	Natoma	-0.07	0.69	8
10	New Melones	-0.36	0.67	1,383
11	San Luis CVP	3.39	0.39	620
12	San Luis SWP	3.45	0.39	796
15	Del Valle	-0.06	0.62	34
16	Tulloch	-1.84	0.81	60
18	Millerton	0.03	0.65	301
20	McClure	-1.07	0.72	577
25	Silverwood	0.33	0.58	65
27	Perris	2.19	0.47	111
28	Pyramid	-0.74	0.66	161
29	Castaic	-0.31	0.64	255
52	Hensley	1.21	0.54	33
53	Eastman	1.73	0.48	75
81	New Don Pedro	-0.31	0.67	1,413
90	Pardee	3.73	0.40	182
91	Camanche	1.95	0.46	258
92	New Hogan	1.03	0.58	144

Table 4.2: Constant c and exponent p of equation 4.1 for the reservoirs in the CALSIM II model of the California central valley [10]. Average reservoir storage values are taken from CDEC data [8].

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	N
NC	0.034	0.034	0.034	0.034	0.104	0.104	0.104	0.104	0.104	0.034	0.034	0.034	6
SF	0.273	0.273	0.273	0.273	0.787	0.787	0.787	0.787	0.787	0.273	0.273	0.273	2
CC	0.012	0.012	0.012	0.012	0.035	0.035	0.035	0.035	0.035	0.012	0.012	0.012	1
SC	0.186	0.186	0.186	0.186	0.600	0.600	0.600	0.600	0.600	0.186	0.186	0.186	7
NL	0.143	0.143	0.143	0.143	0.376	0.376	0.376	0.376	0.376	0.143	0.143	0.143	5
SL	0.126	0.126	0.126	0.126	0.399	0.399	0.399	0.399	0.399	0.126	0.126	0.126	2
SR	0.037	0.037	0.037	0.037	0.109	0.109	0.109	0.109	0.109	0.037	0.037	0.037	24
SJ	0.024	0.024	0.024	0.024	0.076	0.076	0.076	0.076	0.076	0.024	0.024	0.024	15
TL	0.115	0.115	0.115	0.115	0.244	0.244	0.244	0.244	0.244	0.115	0.115	0.115	4
CR	0.086	0.086	0.086	0.086	0.268	0.268	0.268	0.268	0.268	0.086	0.086	0.086	1
CA	0.048	0.048	0.048	0.048	0.140	0.140	0.140	0.140	0.140	0.048	0.048	0.048	67

Table 4.3: Monthly reservoir recreation environmental impact factors by month and by HR (units are user days/acre-foot).

vegetation. Numerous studies have demonstrated that alteration of the natural flow regime has significant impacts on the health of riparian vegetation [1, 33, 35, 41]. In a comparative study between stream reaches which differ primarily in the level of riparian forest cover, it was shown that the loss of forest can lead to channel narrowing and deepening, with numerous other impacts following from these [47]. Riparian cover has a large impact on local water temperatures and consequently on fish habitat [46], while riparian vegetation helps maintain stream water quality by filtering runoff [47]. Woody debris is an important food source and helps maintain a diversity of micro-habitats, and so is an important component in preserving local species richness [39, 44, 47, 48].

In California, native cottonwood and willow are the dominant riparian forest species in arid and semi-arid regions [12, 33]. Detailed studies of cottonwood community dynamics as a function of flow regime [29, 41] have confirmed that this species is well-adapted to natural annual flow variation, and that mature cottonwood forest should be most abundant for the natural flow regime [29]. The analysis also suggests that stable flow regimes result in highly variable population sizes prone to local extinction. Restoration projects have demonstrated that under the right conditions (which include water availability) riparian cottonwood forest can be re-established within a couple of years [42].

Riparian water use

The ecological effect that needs to be modeled here is the relationship between water availability and acreage of riparian habitat. Because so many factors impact the presence or absence of ecologically functional riparian zones, we use here a *potential* analysis based on the consumptive water needs of dominant riparian species. First we calculate the riparian area that would exist under natural conditions, based on the length of river miles in each region and an average buffer zone width.

We then compute the consumptive use of this forest based on evapotranspiration data for various native plants.

The California Rivers Assessment (CARA) [13, 52] is a comprehensive database containing information on large-size to medium-size rivers in the state, including the total length of flowing river miles per watershed. This data was used to calculate a total length of rivers for each hydrological region. Assuming an average buffer zone width of 50 feet, which is a rough lower bound to the width that is adequate to preserve ecosystem function, we can calculate the total potential acreage by region. The results are presented in column three of Table 4.4.

To calculate the water use, we follow guidelines developed for irrigation water needs for native plants in California [50]. The calculation requires two steps. In the first, the *evapo-transpiration of applied water* or ET is determined as a function of month and climate region for a grass reference species. This data are available from the California Irrigation Management Information System web site [11], for climate-based ET regions. These were overlapped with the HR boundaries to determine reference ET values by HR. In the second step, a multiplier is applied to the reference data to account for different species characteristics, density of ground cover and other variable factors. The California Natural Diversity Database [12] was used to determine which plant species are found in riparian zones for each HR. Reference [50] was used to determine the multipliers for each plant type. A simple average over all the plants present in a given region was then used to calculate a single water use value by month and HR. Summing over months gives an annual consumptive water use which is shown in column two of Table 4.4. This represents the amount of water (in feet) required, over the course of one year, to sustain one acre of vegetation. The inverse represents the number of acres sustained by one acre-foot of water per year.

Monthly water needs vary due to climatic factors (temperature, humidity and precipitation), and also due to seasonal variation in the plant growth cycle. Obviously, to maintain riparian vegetation the appropriate amount of water must be supplied each month. The conserved raw water savings also vary on a monthly basis, and may be more or less effective in sustaining riparian habitat. To account for this variation, we use the percentage of total annual consumptive use that occurs in each month as a weighting factor that indicates when during the year the riparian vegetation water needs are highest. We calculate a riparian habitat impact factor by multiplying this percentage times the acres sustained per acre-foot of water on an annual basis. These numbers are presented in Table 4.5. Multiplying these numbers by the input water savings provides an estimate of the number of acres that can be sustained on average given the varying water needs of the habitat. This method will produce different answers for the same total annual supply if it is distributed differently over the months of the year. In particular, if water savings are lower when water needs are higher, the calculated net impact will be reduced.

To complete the calculation we need to know the probability that any given unit of conserved water will end up being used to sustain riparian vegetation. The calculation proceeds as follows: Multiplying the total potential acreage by water needs per acre per year provides an estimate of total potential riparian water use per year, as shown in column four of Table 4.4. In column five of this table we provide estimates, based on DWR data [9] of the total river flow in each HR. The ratio

HR	Water Use (ft/yr)	Potential Area (1000 acres)	Potential ETAW (TAF/ year)	HR Flow (TAF/year)	Attribution Factor
NC	1.49	241	357.6	19,649	0.018
SF	1.51	43	64.7	272	0.238
CC	1.40	186	314.6	146	1.000
SC	1.69	142	238.8	240	0.957
NL	2.14	55	117.5	627	0.187
SL	3.25	285	923.6	126	1.000
SR	2.03	297	603.6	25,594	0.024
SJ	2.32	175	406.8	3,848	0.106
TL	2.01	136	274.4	2,317	0.118
CR	3.01	193	581.1	37	1.000
CA	2.08	1752	3704.6	51,500	0.072

Table 4.4: Riparian habitat potential consumptive water requirement estimates by HR. ETAW stands for evapo-transpiration of applied water, and gives the total potential consumptive water use. Actual water use will of course depend on water availability.

of these two numbers provides an estimate of the fraction of conserved water that can contribute to riparian consumptive use. If the factor computed here is greater than one, the value one is used. This corresponds to cases where the quantity of riparian vegetation is limited by water supply.

Economic data

For this analysis, the most readily available economic data are per-acre purchase prices for different habitat acquisition projects, which can be considered a proxy for the value placed on this service. The data available for California are shown in Table 4.5. These prices cover a large range, as is often the case for economic data. Many economic events (such as the purchase of land) are the outcome of a succession of steps, each of which is necessary and subject to various random influences. Processes of this type are generally described using log-normal distributions, where the log of the random variable is assumed to follow a normal or Gaussian distribution. Assuming this type of distribution for the purchase prices in Table 4.5, and converting prices to 2005 dollars, the log-normal mean value is $2950/acre. The simple average and area-weighted average are included in the table for comparison. This estimate should be considered conservative for two reasons. First, the purchases listed in the table generally also include acreage that is of lower value in terms of ecological productivity. Secondly, these prices do not include the costs of restoration and maintenance which are also borne by the purchaser, and which indicate additional willingness to pay for the service.

For the spreadsheet model, we need to convert the purchase price to an annualized value. This value again neglects operation and maintenance costs of the habitat. In a naturally functioning

HR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
NC	0.022	0.029	0.047	0.065	0.079	0.089	0.094	0.085	0.066	0.049	0.029	0.019	0.673
SF	0.017	0.025	0.046	0.064	0.082	0.092	0.095	0.085	0.068	0.046	0.025	0.015	0.66
CC	0.019	0.029	0.048	0.068	0.084	0.098	0.105	0.095	0.071	0.050	0.027	0.018	0.712
SC	0.021	0.027	0.042	0.057	0.068	0.075	0.079	0.074	0.058	0.043	0.028	0.02	0.592
NL	0.011	0.018	0.027	0.041	0.054	0.066	0.075	0.067	0.005	0.032	0.016	0.01	0.467
SL	0.009	0.013	0.022	0.028	0.037	0.042	0.045	0.004	0.003	0.021	0.012	0.009	0.308
SR	0.011	0.018	0.030	0.045	0.060	0.070	0.078	0.069	0.051	0.034	0.016	0.01	0.492
SJ	0.011	0.017	0.027	0.040	0.052	0.060	0.065	0.059	0.044	0.030	0.016	0.01	0.431
TL	0.011	0.019	0.032	0.048	0.063	0.071	0.074	0.066	0.050	0.035	0.017	0.01	0.496
CR	0.010	0.014	0.023	0.031	0.040	0.045	0.048	0.043	0.033	0.023	0.013	0.009	0.332
CA	0.014	0.021	0.034	0.049	0.062	0.071	0.076	0.068	0.052	0.036	0.020	0.013	0.516

Table 4.5: Riparian habitat consumptive water use factors by month and HR. These numbers are multiplied by the input water savings to determine the number of acres maintained on average over the course of a year. Monthly variation occurs because of seasonal changes in temperature and atmospheric humidity, which affect total evapotranspiration.

ecosystem these costs are zero by definition, but acreage used for public reserves parks always requires some maintenance. To do so we use a standard amortization formula based on 6% interest and a thirty year payment plan. This leads to an annual capital recovery factor of 0.0723, or equivalently an annualized economic value of $0.0723 \cdot 2950$ or \$215/acre/year. Applying this average price to the water-use per acre calculated from Table 4.4 leads to a dollar value per unit volume of water for this service.

References

[1], [13], [8], [12], [11], [29], [33], [35], [39], [41], [42], [44], [46], [47], [48], [50], [52], [9].

4.2.3 Wetlands

Wetland water use

Like riparian vegetation, wetlands provide a wide variety of services including habitat for fish and birds, water quality improvements, flood control and recreational opportunities. Without sufficient water wetlands cease to exist as functioning ecosystems, and are therefore one of the more environmentally sensitive services. The annual water deliveries to particular wetlands supported by the State Water Project or Central Valley project can be extracted from the CALSIM II data [10]. Depending on whether the wetland is seasonal or year-round, water may be pumped in or drained out over the course of the year. Operational decisions for managed wetlands are not likely to be impacted by the marginal conservation of raw water by urban agencies. As for riparian habitat,

Name	Area (acres)	Price ($/acre)	Date	County
Stornetta Ranch	1,132	$6,796	2004	Mendocino
Garcia River Forest	24,000	$750	2004	Mendocino
Monte Vista Ranch	4,056	$3,920	2005	San Diego
Santa Clara River	377	$1,525	2005	Ventura
Homer Ranch	1,837	$817	2004	Tulare
Gilroy Hot Springs	242	$9,917	2003	Santa Clara
Arroyo Seco	1,675	$1,731	2002	Monterey
Mount Hamilton	61,000	$311	1998	Santa Clara
Howard Ranch	12,360	$1,100	1999	Sacramento
San Pasqual Valley	75	$21,218	2004	San Diego
Santa Ysabel West	1,512	$1,984	1999	San Diego
Joughin Ranch	1,733	$4,155	2003	Los Angeles
Ahmanson Ranch	2,983	$50,285	2003	Los Angeles
Palo Corona Ranch	9,898	$3,738	2002	Carmel
Garcia River Watershed	23,780	$1,409	2004	Mendocino
Simple Average		$7,310		
Area-weighted Average		$2,140		
Log-based Average		$2,960		

Table 4.6: Riparian habitat purchase price data.

HR	Wetland CU (TAF/year)	HR Flow (TAF/year)	Attribution Factor
NC	194.4	19,649	0.0049
SF	6.2	272	0.0057
CC	0.1	146	0.0003
SC	38.1	250	0.0763
NL	25.9	627	0.0158
SL	0	126	0
SR	169.7	25,594	0.0033
SJ	149.7	3,848	0.0194
TL	73.8	2,317	0.0089
CR	30.2	37	0.4137
CA	600	51,500	0.0058

Table 4.7: Wetlands consumptive use (CU) data and attribution factor by HR. In the SL (South Lahontan) region, the very small wetland acreage has been added to the riparian habitat. For the CR (Colorado River) region, wetlands are supported by imports and so the attribution factor is set to zero in the spreadsheet.

Name	Area acres	Price $/acre	Date	County
Cargill Salt Flats	16,000	$8,181	2002	Alameda/Santa Clara
Ormond Beach	276	$46,739	2005	Oxnard / San Diego
San Elijo Lagoon	8	$125,000	2004	San Diego
Highway 37 Marsh	2,327	$8,637	2004	Marin/Sonoma
Rancho Santa Fe	15	$24,500	2004	San Diego
Bolsa Chica	880	$28,400	2004	Orange
Ormond Beach	500	$46,000	2004	Ventura
Santa Ana River	83	$69,500	2004	Los Angeles
San Dieguito River	132	$37,200	2004	San Diego
Huntington Beach	17	$44,000	2004	Orange
Simple Average		$43,645		
Area-weighted Average		$9,575		
Log-based Average		$34,500		

Table 4.8: Wetlands habitat purchase data.

our analysis is based on the consumptive water use by wetlands. In the normal course of events this water would be replaced by natural inflows; equivalently, any additional inflows that are sustained over a long enough period of time could allow a larger acreage to be sustained. Evaporation losses are estimated to be about six inches per acre of wetland per year, or half an acre-foot per year per acre of wetland.

An estimate of the total (managed) wetland consumptive use is available from the DWR waterplan update [9], and is shown in column two of Table 4.7. To calculate the attribution factor (the probability that a unit of conserved water will end up in a wetland), we take the ratio of the CU number to the total estimated local flow in that region, defined as the local diversions plus environmental water requirements. The ratio of these two numbers defines the attribution factor, presented in Table 4.7.

Economic data

Again following the riparian habitat analysis, we use purchase prices for wetland restoration projects to approximate the social willingness to pay for functional wetland habitat. We note that this underestimates the value placed on wetlands, as the purchase price of the land does not represent the full cost incurred by the restoration project.

Data on wetland purchases has been gathered from various sources on the web, and is summarized in Table 4.8. As expected, they show a wide range of variation. Using the values in Table 4.8 and assuming a log normal distribution, the mean purchase price is about is $34,500/acre. To convert the purchase value to an annualized value we assume an amortization at 6% interest over thirty years, leading to an annual capital recovery factor 0.0723, and an annualized value of

$2,500/acre/year.

In 2003, 557 acres of the Ballona wetlands in Los Angeles county were purchased at a price of just under $250,000 per acre. This is a restoration project that combines a number of extreme factors: it is a highly ecologically sensitive area, with very high population density and relatively high income. Hence, in such a small sample it could be considered an outlier, in the sense that it over-represents this set of conditions. It is therefore not included in the sample compiled in table 4.8.

References

[9], [30], [40], [56].

4.2.4 Fish habitat: Salmonids

While hundreds of fish species are known in California, with many of them threatened or endangered [12], management of the state water supply has focused on the needs of salmonids that are listed through the federal Endangered Species Act. The health of these populations has been extensively reviewed in a recent report by the West Coast Salmon Biological Review Team (BRT) [36], which is used here as the primary source of information on fish populations. A secondary source, useful to fill in some of the gaps left by the BRT report, is the Calfish on-line database [6], which provides a compilation of data from a large number of population studies conducted over the last thirty years. While it is safe to assume that the BRT reviewed the most recent population data, they only cover regions defined as Ecologically Significant Units (ESU's), which do not cover the entire state.[1] Here we consider only natural populations, as hatchery fish are strictly speaking not part of the natural environment. Hatchery populations are restocked each year, so it is not clear how they would be affected by marginal water conservation.

The EB spreadsheet model requires quantitative data both on fish populations and their economic valuation, which is only available at this time for salmon and steelhead. While striped bass is an important recreational fishing species in the Bay, actual population counts are not currently available (only relative abundance indices [22]), so we have not been able to include it in the model. Anadromous salmonids are in many ways the ideal species to use as an overall indicator of ecosystem health, as their range stretches from the Bay to the mountains, and their life cycle makes them very sensitive to many environmental factors. As usual, we focus here only on those factors directly physically impacted by water withdrawals. The key point is that the volume of flow in the system determines the total available habitat at any time, which in turn should scale on average with population. While many variables influence the details, flow defines the basic condition for existence of the fish habitat, and is one of the few variables for which we expect to see correlations at large spatial scales and long time scales.

[1] Given limited species mobility, genetically specific populations come to occupy particular regions. An Ecologically Significant Unit is a region within which a local species variant is defined.

Fish-flow relationship

A somewhat standardized procedure for evaluating the ecological impact of flow alterations, known as the Instream Flow Incremental Methodology or IFIM [46], was pioneered by the US Fish and Wildlife Service and has been in use for over twenty years. Numerous species-specific studies have been carried out using the IFIM [3]. The method is valid at the reach scale (on the order of a few stream widths) but requires a large amount of input data for calibration. While it is unclear just how well models and data developed at the reach scale generalize to larger spatial scales, a number of recent studies have shown that these models do display reliable correlations between large-scale hydrologic variables and habitat quality. Hatfield & Bruce [20] reviewed 127 habitat simulation studies to determine which variables predict the optimum flow for several salmonid species at different life stages. They found that the mean annual discharge (for the river as a whole) is the best predictor of habitat quality. There was some dependence on latitude/longitude in some cases, while flow variability, elevation, watershed area, and distance to the coast were not found to be significant. A series of studies were undertaken by Lamouroux and coworkers [26, 27, 28, 38] to evaluate how well habitat-flow models do at predicting fish community assemblages in different regions. An assemblage is a collection of populations that are found together consistently. Comparing data across different regions of France and the US, they were able to show that variation in two relatively simple flow-dependent physical measures[2] can account for a significant portion of the variance seen in fish populations. The significance of this work is that it demonstrates clearly that there is a straightforward correlation between basic physical flow properties and the composition and abundance of fish populations.

As the EB spreadsheet model is concerned with average properties over a fairly long time period, we base our evaluation of the fish-flow relationship on large scale measures—specifically, total flow numbers for major rivers by HR, and average population counts (over the last ten to twenty years) which we have extracted from the BRT report [36] and Calfish [6]. As a conceptual exercise, it is useful to establish three points on a hypothetical fish-flow curve: the zero point, historical conditions and current conditions. These three points are shown in figure 4.1 While the numbers are rough, we only need the order of magnitude to make our point. At the zero point, zero flow means zero fish. Reviewing the BRT report for salmon and steelhead, a rough total estimate of historical (pre-industrial) populations of adult spawners is about three million, while the current levels are more on the order of 100,000 (including only ESU's). State average total flow is about 52000 TAF/year, and would not have differed by more than 10-20% historically (flow timing would have differed greatly, but not total average volume). Populations have been reduced drastically and are currently in a precarious state.

The question being asked in this model is, given a change in available flow, what is the average long-term impact on fish; mathematically the question is what is the average slope of the fish-flow curve? Between the historical and current conditions, we see that a relatively small decrease in flow

[2] The measures used were the Froude number, which distinguishes roughly between pool and riffle habitat, and Reynolds number which is an estimate of the intensity of the mean flow.

leads to a drop in population by one to two orders of magnitude. What this actually illustrates is the importance of other factors, such as dam construction and water quality, in reducing fish populations. For this reason, the slop of the line between the historical and current data points is a serious over-estimate of the sensitivity of fish to flow, and would at the most provide a maximum upper bound. The line between the current conditions point and the zero point illustrates a relationship where the number of fish decreases smoothly to zero as flow is decreased. It is very likely that fish populations would crash long before the zero flow point was reached, so the slope of this line represents a lower bound of the sensitivity of fish to flow. These two lines bracket the fish-flow sensitivity as lying between about 0.02 fish/afy and 0.1 fish/afy.

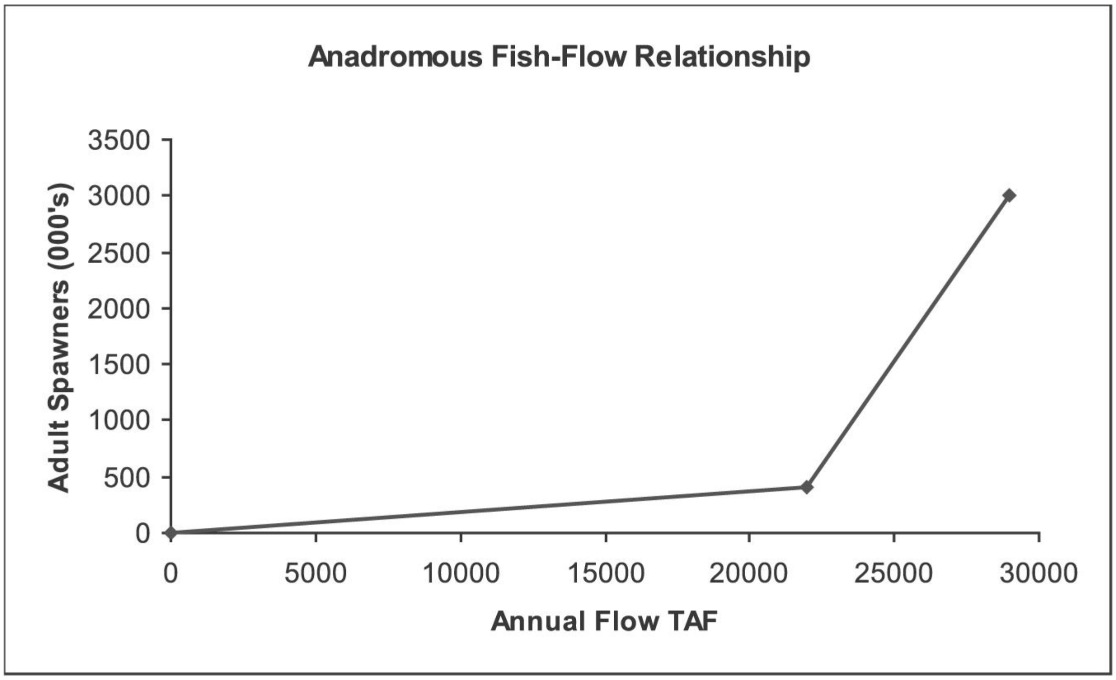

Figure 4.1: Rough fish and flow counts for all of California for three system states.

Another way to estimate the fish-flow relationship is to use fish and flow data compiled for different hydrologic regions under current conditons. For population estimates, we begin with the BRT report. For the North Coast, San Joaquin and Sacramento River regions, we add observations from the Calfish data as these can be higher than the numbers reported in the BRT (this is likely due to the ESU focus of the latter). The Calfish data used here are the adult-return spawner estimates. In all cases we use a median value over the range of years for which data are available, which is typically from the early 1980's to the present. As before, for flow numbers by HR we refer to the DWR waterplan [9]. These numbers are included in Table 4.9, and plotted in figure

4.2. The figure uses a log scale to provide better visual resolution for the smaller values. A linear regression model fit to the fish *vs.* flow data by HR shows that the curve does indeed follow a linear relationship, with an R^2 of 0.9. The fish-flow sensitivity computed from this graph is about 14 spawners per 1000 afy, or 0.014 fish/afy. This estimate is consistent with the lower bound described above, obtained by simply dividing the number of fish by the annual flow. We use this simple approximate method to define data at the HR level.

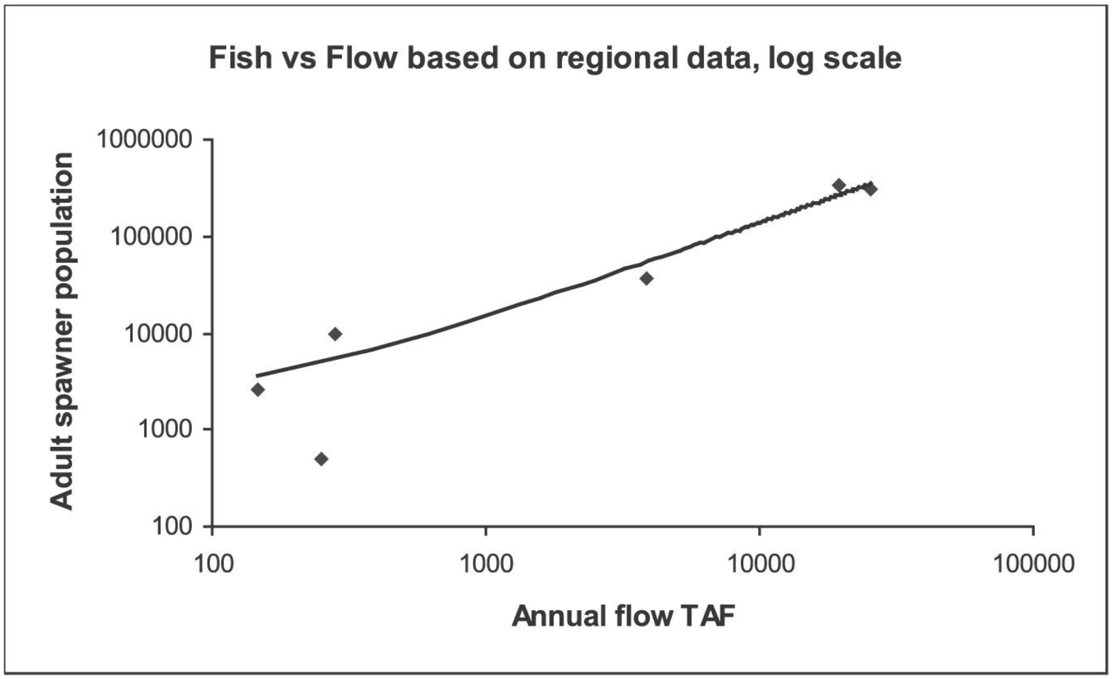

Figure 4.2: Anadromous fish and flow estimates by hydrologic region (HR), current data.

Economic data

The most detailed study on the economic value of sport fishing for salmonids in California is the Bay Area Sportfish Economic Study (BASES) [49], conducted by the National Marine Fisheries Service over seven two-month survey waves in 1985-1986. A total of 33,678 households were contacted throughout Central and Northern California [3]. A summary of the study is available on-line through the Sportfishing Values Database [21].

[3]The 19 counties surveyed are Alameda, Contra Costa, Del Norte, Humbolt, Marin, Mendocino, Monterey, Napa, Sacramento, San Benito, San Francisco, San Joaquin, San Mateo, Santa Clara, Santa Cruz, Solano, Sonoma, Trinity, and Yolo.

HR	Est. Adult Spawners	Flow (TAFy)	Impact Factor (afy/fish)	Comments
NC	340,000	19,649	0.017	
SF	10,000	272	0.036	
CC	2,600	146	0.018	
SC	500	250	0.002	Natural runs nearly extinct
NL	0	627	0.0	No listed salmonids
SL	0	126	0.0	No listed salmonids
SR	300,000	25,594	0.012	Bay/Delta system
SJ	3,600	3,848	0.009	Bay/Delta system
TL	0	2,317	0.0	No listed salmonids
CR	0	37	0.0	No listed salmonids
CA	689,100	51,500	0.013	

Table 4.9: Salmonid/Striped Bass stream/river environmental impact factors by HR.

We have chosen to base our analysis on this one study because it is by far the most extensive for California, and it allows us to calculate the economic value (defined here as consumer surplus) *per-fish* and not just per-household or per-trip. A few other studies in the Sportfishing database examine the value to anglers of fishing trips, but the results are presented on a per-trip or per-household basis. To convert these to per-fish, we would have to make assumptions about the number of trips per household, and the number of fish caught per trip. The lack of good data on which to base these assumptions does not justify the additional effort.

Using the BASES study does require a few assumptions, in particular:

- We're implicitly assuming that the value of the existence of fish populations is dominated by their recreational use-value for anglers. This leads to an under-estimate, as other social and economic values are not counted.
- While the survey was conducted specifically for fishing in the San Francisco Bay-Delta, we assume the values are comparable for other locations where salmonids can be caught.
- As for other recreation, we assume that the overall level of fishing activity scales with population, and we convert the values to current year dollars using the CPI [2].
- Because we're considering increases to flows, which in general lead to increases in fish habitat, the WTP for an increase in the resource is an appropriate measure.
- As is standard, we assume that catch rates scale with the size of the fish population, which in turn scales with the number of adult spawners (the latter are what is usually counted in biological studies [6]).

To adjust for population change, we use data from the Demographic Research Unit of the California Department of Finance, which shows that the population in the survey counties has increased by 30% since 1986. During this time, the consumer price index rose by 70%.

We use the data from Thomson *et al.* [49], as summarized in the Sportfishing database [21], in two ways. First, we take the reported average marginal consumer surplus per fish caught per year, and compute the log-normal average over all non-zero values. This leads to a value of $37 per fish in 1986, which is converted using only CPI to $63 per fish in 2005.

A second approach is based on the reported WTP for a 100% increase in catch for all anglers in the survey. If this is normalized by population, we arrive at a value of $3.40/capita in 1986. Using the CPI to convert to 2005 dollars, and multiplying by current population levels, we arrive at a total annual value for 2005 of $21,493,500/year. Again, this is the marginal economic value of increasing fishing yields 100%. To get a per-fish value, we need to normalize by some population estimate. Our rough count of the salmonid population in Table 4.9 is about 690,000 which represents an average over the last twenty years. Dividing the total value by this number, we arrive at a value estimate of about $31/fish in 2005 dollars.

We consider that the range $30 - $60 per fish represents a reasonable estimate of the economic use-value assigned to fish by anglers. Given a value per fish, and the fish-flow impact factors of Table 4.9, we can compute an economic value for the environmental service of sustaining fish populations. As noted above, this is undoubtedly an underestimate, as it only counts the value of fish to anglers.

References

[3], [6], [9], [12], [20], [22], [26], [27], [28], [36], [38], [21], [46], [49].

4.2.5 San Francisco Bay Salinity

We present here a brief description of flow impacts on salinity in the San Francisco Bay-Delta, based on an analysis of data generated by the Dayflow model [23]. This model is used to predict the so-called X2 position, defined as the distance in km along the main channel of the Bay-Delta from the Golden Gate Bridge, at which the value of the salinity on the bottom of the Bay is 2 psu. It is used as a measure of water quality. High values of X2 indicate that salty water is penetrating more deeply into the Bay-Delta, which generally lowers habitat quality for native species (although some non-native species may prefer this state). The Dayflow model predicts the location of X2 as a function of a number of variables measured in the Bay-Delta. As we are concerned with long-term averages, we are only interested in how X2 varies with net inflow.

The Dayflow data archive provides daily values for total inflow Q and X2 position x from 1996 to 2004. We sort this data into bins based on month, and use linear regression to compute an approximate relationship between Q and x. The slope of the x *vs.* Q curve provides an estimate of the sensitivity of the X2 position to inflow for each month. We define the change in X2 per flow

Month	N	dX (km/afm)
JAN	248	-0.023
FEB	226	-0.016
MAR	248	-0.019
APR	240	-0.033
MAY	248	-0.042
JUN	240	-0.044
JUL	248	-0.037
AUG	248	-0.045
SEP	240	-0.054
OCT	248	-0.073
NOV	240	-0.061
DEC	248	-0.034

Table 4.10: Change in X2 position per unit change in flow (dX) in the San Francisco Bay-Delta, by month. N is the number of observations used to calculate the change dX. Flow units are acre-feet per month.

unit as dX. The numbers are presented in Table 4.10.

Kimmerer [24, 25] has looked extensively at how salinity in the Bay-Delta impacts the abundance of a variety of species. There is good evidence of long-term average correlation between the X2 position and population levels, for example for shrimp, flounder, smelt and striped bass [24]. This data could be used to calculate population impacts of changes to inflows, although for now only relative abundances and not absolute fish counts are known. Moreover, we have not been able to find any economic data that would allow us to assign a dollar value to these populations. For this reason, this set of calculations has not been pursued in the current version of the model. The SF Bay salinity impacts have been included in the spreadsheet as a place-holder, so that when such data does become available the impacts can be included in the EB calculations.

References

[23], [24], [25].

4.2.6 Other impacts

At the request of the Council, two environmental impacts that are not directly related to withdrawals have been included in the spreadsheet. These are energy and urban runoff, discussed briefly in this section. The determination of these values depends only on the volume of water saved, and so this part of the calculation is not represented in figure 2.5.

Energy impacts

Reducing the amount of water delivered to consumers reduces, for some utilities, the amount of energy needed to maintain their operations. This will have an environmental impact, primarily in the form of reductions to harmful emissions. To estimate the dollar value of these impacts, we need to estimate:

- The energy use by fuel type (electricity or natural gas) per unit volume of water. This number is an input to the EB spreadsheet, along with the price per unit of energy paid by the utility. A default value for energy prices is included. It is calculated using data from the most recent Annual Energy Outlook [18], based on the estimated industrial sector fuel price for 2005 for the Pacific region. In current dollars, the prices are $5.90/MBtu for natural gas, and $0.077/kWh for electricity.
- The emissions intensity, or mass emitted per unit of fuel consumed. These numbers are available for those emissions that are currently regulated, particularly NOx. For natural gas, we assume that it is burned primarily to generate electricity, and use the same number for both gas and electricity. The AEO provides total NOX emissions for electricity generation, from which we get at an average emissions factor of 0.004 lbs/kilowatt-hour [18].
- The cost of emissions abatement in dollars per unit mass. This is estimated here as the average cost of an emissions permit traded within California, which is about $6000/ton NOx [7] in 2001 dollars. Since these are not consumer costs, we use the GDP to convert to 2005 dollars rather than the CPI. The factor for 2001 to 2005 is 1.06 [34], so the NOx price in current dollars is $6360/ton.

The total dollar value of emissions reduction per unit volume of conserved water is equal to the product of the three items listed above.

Urban runoff

BMP's that target landscape irrigation in urban areas can lead to significant reductions in polluted urban runoff [32] and reduce the volume of wastewater that needs to be treated. The associated environmental benefits are represented in a simple way in the spreadsheet. The user inputs the relative fraction of conserved water that ends up as urban runoff by month. The environmental value is assumed to be equal to the savings associated with not having to treat this amount as wastewater. The cost of wastewater treatment per unit volume varies between hundreds to about a thousand dollars per acre-foot. The user inputs this cost to the EB spreadsheet.

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[7], [18], [34], [32].

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Appendix A

Estimating the Economic Value of Environmental Goods: Overview of non-market valuation

This chapter is an edited version of the paper *Economic Valuation of Changes in the Quality of Life* 1995, by W. Michael Hanemann, G. Helfand, G. Green and F. Larrivee.

What does economic valuation mean? Previously, people thought that economic value relates to markets, involves businesses, and consists essentially of revenues or profits. They naturally think of value as being like a price. If something sells for $6 in a market, then this must be its value. Thus, economic valuation is the science of market prices. An implication of this line of thinking is that, when something does not sell in a market and, therefore, does not have a price, there is no economic value.

The modern view is that economics is not about markets *per se* but about people, their preferences, and their behavior in relation to scarce resources. Markets offer one arena in which choices are made and from which preferences can be deduced, but by no means the only arena. But, economists also recognize that people gain pleasure and satisfaction from many other things that do not pass through the market. The modern economic theory of value encompasses both sources of satisfaction - market and non-market.

This methodology economists use to measure monetary value generally is known as non-market valuation. The object of non-market valuation is to measure, in monetary terms, the value that people place on an item, regardless of whether the item is a conventional marketed commodity.

A.1 Meaning of economic value

The modern economic concept of monetary value is defined in terms of a tradeoff that an individual would be willing to make between some item of value to the individual and money. When an economist says that a person values some particular item at $45, this means no more, and no less, than that the individual would be willing to exchange the item for $45. The item in question need not be a market good. If it is a non-market item, it is being valued by the change in income that the individual sees as equivalent to it, in terms of the impact on his well-being. While the item itself is not monetary in nature, its monetary value is represented in terms of the amount of money that the individual would be willing to exchange it for.

There are two ways in which the exchange could be conceptualized. One is that $45 is the most that the individual would be willing to pay to obtain the item rather than go without it. This is known as the willingness to pay (WTP) measure of monetary value. The other possible conceptualization is that $45 is the minimum amount that the individual would be willing to accept as compensation to forego the item. This is known as the willingness to accept (WTA) measure of monetary value.

WTP and WTA are the modern definitions of economic value. It should be noted that WTP and WTA do not necessarily have the same value. Whether they are the same depends in part on the individual's preferences, and in part on what is being valued. If the item being valued is a purely monetary change - a pure change in income or wealth - it turns out that WTP and WTA always have the same value. For example, a person's WTP to gain a windfall increase in income of $10 must be the same as their WTA to forego this increase - namely, $10. However, if the change is non-monetary, for example, an improvement in boating opportunities in the Delta or better protection for an endangered species of native fish, then the WTP and WTA values are not necessarily the same. Specifically, it is possible for the WTA value to be larger than the WTP value. It turns out that a key factor determining whether WTP and WTA are the same or not is the extent to which the individual sees the item being valued as substitutable for his money income: if money is a perfect substitute for the item being valued, the WTP and WTA values for the item must coincide, but otherwise not. In this chapter, we focus on WTP values both because this is likely more conservative and more reliable than measurement of WTA values.

Consumer's surplus is another term that is sometimes used to refer generically to both WTP and WTA as a measure of monetary value. The term originated specifically in the context of valuing market items. The term *surplus* captures the important notion that the expenditure on a market item is not an accurate measure of the item's value - it is typically a portion of that value. If a person spends $500 a year to go boating in the Delta, and makes 3 trips a year, the ability to go boating in the Delta must be worth at least what is being spent - otherwise why would the person make those trips? But, it could be substantially more than what is being spent. For example, the person might actually be willing to pay as much as $800 a year to be able to go boating in the Delta. Since he only does spend $500, he enjoys a surplus of $300 from the opportunity to go boating. This surplus is analogous to the profit for a firm - it represents the net value of the activity to the individual. This net value is the relevant measure of value for economic purposes. It is what is being measured by the WTP or WTA measures.

For consumption activities such as boating, the consumer's surplus is often expressed on a per unit (per trip) basis - in the above example, this is $100 per trip ($300 consumer's surplus over 3 trips). In the present context this might be used in one of two ways. One possibility is that the primary impact of the environmental change scenario involves a change in the number of trips. For example, because of a deterioration in water quality conditions, there is a reduction in boating in the Delta, and the typical boater cuts back from 3 to 2 trips per year, the loss being valued at the estimated consumer's surplus ($100) per trip. An alternative scenario is that the primary impact of the change involves a change in the quality of the trip experience, rather than the number of trips per se. For example, a boater still makes 3 trips per year, but they are now less satisfying than previously. Or the individual switches to an alternative but more costly site, so that while he still makes 3 boating trips per year, his consumer's surplus is reduced by the higher cost per trip. In these cases, the primary loss may be a reduction in the consumer's surplus per trip (*e.g.* , from $100 to $75) rather than a change in the number of trips.

A.2 Public goods and use versus non-use values

Two important conceptual points in this context are the distinction between public and private goods, and the distinction between use and non-use value.

Public goods are defined as those that are nonrivalrous (use by one person does not affect the use of another) and nonexcludable (that no one can be excluded from using the public good without excluding a whole class of individuals). Private goods on the other hand generally are rivalrous (they can be consumed by only one individual at a time) and excludable (the owner of the good can exclude others from using it). Of course, there are many goods that fall within the range between these two types of definitions, including many environmental benefits. For example, whitewater kayaking may be nonrivalrous and nonexcludable if you are alone on the river and have your own equipment, but it exhibits more characteristics of private goods when the river is well traveled and you use a guide service.

The significance of the distinction between public and private goods is that the valuation of public goods is fundamentally different than that for private goods because a public good can be enjoyed simultaneously by many while a private good can be consumed by only one party at a time. Thus, the value placed on a given unit of a private good is that of a single user. In an efficient market, this will be the user with the highest and best use for the item. By contrast, the value placed on a public good is that of many people, namely all those for whom the item has some value

Another important distinction arises from the notion that some people's motives for valuing the natural environment may differ from those motives for valuing a typical market good. People may value the natural environment out of considerations unrelated to their own immediate and direct use of it. One example is what became known as *option value.* For example some people, who do not now visit a national park, may still be willing to pay money to protect it from destruction or irreversible damage because they want to preserve their option of visiting it in the future. Other examples involve what became known as "bequest value" and *existence value*. With bequest value, the notion is that some people would be willing to pay because they want to preserve the park for future generations. With nonuse value, the notion is that some people would be willing to pay even if they knew that neither they nor their children would ever visit it.

The distinction between use and nonuse value intersects with that between public and private goods. The use value of an item is quintessentially a private good; the nonuse value, to the extent that this exists, is quintessentially a public good, since it can be enjoyed simultaneously by multiple individuals.

Although the concept of nonuse value has been recognized in the economics literature for forty years, it still is sometimes an object of controversy. For this reason, the application of these values in the present analysis will be done conservatively. The two primary criteria for use of non-use values are that (1) a major change may occur, *e.g.* , a threat to the existence of a species, or (2) a highly significant resource may change a sufficiently to undermine its fundamental value, *e.g.* , obscuring a visual resource.

A.3 Methods of estimating values

Environmental benefits can be measured in several ways, and these can be separated into two categories, of revealed preferences and direct inference. Travel cost modeling is an example of the former, while contingent valuation is the best known of the latter.

A.3.1 Revealed preferences and travel cost methods

The insight behind the travel cost method is that, while people can't buy environmental resources such as clean air, clean water, or a pristine lake in the same way they can buy cans of soup or chocolate truffles, nevertheless there sometimes is a sense in which environmental quality can be bought through the market. This is because there sometimes are private market goods that are complementary to the natural environment, *i.e.* , the enjoyment of the private good is enhanced by, or somehow depends on, the presence of the environmental public good. Thus, recreation at a site (the private good) depends on clean water or abundant fish (the public good), and the demand for the former reflects, in part, a demand for the latter. The hallmark of the travel cost method is not the specific application to recreation but rather the general approach of seeking out a private market good whose demand can serve, at least partly, as a surrogate for the demand for the environmental public good.

A similar principle underlies another approach to environmental valuation, the hedonic pricing method. Here, the private good is houses or real estate more generally. The price of a house reflects not only its physical attributes (*e.g.* , the number of bedrooms, the size of the lot) but also neighborhood amenities (*e.g.* , whether it is in a safe area, whether it is close to transportation) and, sometimes, environmental amenities (*e.g.* whether it is close to the beach or located in a part of the town with less air pollution).

These approaches are all based on the concept of revealed preference that holds that, since people's preferences motivate their behavior, it should be possible to infer their preferences from their behavior through some appropriate analysis. While it clearly contains a core of truth, it may oversimplify or mislead in various ways. In addition, for the purpose of valuing non-market commodities such as the natural environment, the problem arises that the market commodities being used as a surrogate for the demand for environmental quality may not completely capture people's preferences for the environment - people care for the environment partly because of their interest in these commodities (*e.g.* , recreation) and partly for other reasons unconnected with the interest in these commodities. The latter is what is referred to earlier as existence or nonuse value. This value cannot be measured by revealed preference approaches such as the travel cost, averting expenditures or hedonic pricing methods, yet it may be an important part of the total value that people place on the natural environmental.

A.3.2 Stated preference and the contingent valuation method

Because they infer preference from externally observed behavior rather than measuring it directly, these revealed preference approaches are sometimes called indirect valuation. The alternative, direct valuation, is to interview people and elicit their WTP or WTA directly. This can be done in various ways. One is to interview people, describe the environmental change in question, and then simply ask respondents how much they would be willing to pay to bring it about. A variant of this approach uses a closed-ended question format. Typically a program that would bring the change about is presented to respondents, and then they are asked: If this program cost a household like yours $x per year, would you vote for it? These are both examples of what is known in economics as the contingent valuation (CV) method. In the latter approach, one varies the amount $x across different subjects, and their responses (the percentage who say yes at different dollar amounts) traces out a type of demand curve for the item from which a measure of value such as mean WTP, or median WTP, can be estimated.

Another version of this general approach is to present subjects with multiple programs, each bringing some package of benefits and each having some distinct cost. Subjects might then be asked to select the single program that they prefer best; or they might be asked to rank all the programs, from best to worst; or they might be asked to provide a numerical rating of each program. Each subject might be asked to repeat this exercise for several sets of programs. Using a statistical analysis of the responses, it is possible to derive an estimate of the mean or median WTP underlying the pattern of responses observed in the sample. These approaches are known as conjoint analysis or, more generally, as stated preference.

A.4 Use of nonmarket valuation

The first application of the revealed preference approach occurred in 1956 when the State of California wished to assess the recreational benefits that might arise from the proposed State Water Project. A visitors' survey was conducted at several lakes in the Sierras and data were collected on how far they had traveled and how much they had spent. Using these data, a rough demand curve was traced out, and an estimate of consumer's surplus was constructed. This analysis appeared in Trice and Wood (1958) Around the same time, Marion Clawson (1959) at Resources for the Future had begun collecting data on visits to Yosemite and other major national parks in order to apply the travel cost method to them By 1964, there were at least five more applications in various parts of the US, and the approach had become an established procedure.

Probably the first application of contingent valuation is by Davis (1963), which dealt with the economic value of outdoor recreation in the Maine woods. To measure this Davis interviewed a sample of hunters and recreationists and asked how much more they would have been willing to pay to visit the area. The next application was by Ridker (1967). To measure the damages from air pollution, Ridker included some questions in a survey about people's WTP to avoid soiling from air pollution. In 1969, a steady stream of CV studies began to appear in the economics literature. Official recognition was given to CV in 1979, when the US Water Resources Council included it along, with travel cost, as the recommended methods of non-market valuation. The same recommendation was contained in Army Corps of Engineers Principles and Guidelines (1983).

There continued to be some controversy about CV during the 1980s, especially in connection with its use by the federal and state governments to measure non-use values associated with natural resource damages from toxic releases, which could be claimed by the governments acting as trustees for the public under the CERCLA law enacted in 1980. The controversy about the validity of CV to measure nonuse value reached a fever pitch following the Exxon Valdez oil spill in 1989, and the subsequent passage of the Oil Pollution Act in 1990. As part of the process of developing regulations for the assessment of damages from oil spills, NOAA convened a Blue Ribbon Panel headed by two Nobel laureates in economics. In its report, issued in 1993, the NOAA Panel endorsed the use of the closed-ended form of CV as starting point for the assessment of natural resources damages, provided the study was carried out following some specific guidelines intended to achieve the level of reliability required in litigation

A.5 Problems that arise in estimation of non-market value

The valuation exercise cannot be carried out in a vacuum: how one should go about measurement depends on what is to be measured and where it is geographically located. Different measurement goals will call for different measurement strategies. Moreover, a failure to identify the goal clearly may limit what can be accomplished through the measurement exercise.

For example, if one succeeds in measuring the total value associated with a set of environmental goods, this may shed little light on the benefit associate with policies that prevent some degree of deterioration in the good. Conversely, measuring the value associated with an incremental change may not shed much light on the total value of the entire set of environmental goods. Moreover, measuring the value of one incremental change - say, cleaning up a highly polluted resource - may not shed much light on the value of a quite different incremental change - cleaning up a relatively unpolluted resource.

One way to address measurement challenges it to distinguish between average and marginal value. The average value is simply the total value divided by the number of units of the environmental good. The marginal value is the value associated with an incremental change in the number of units of the good. The distinction would be of no consequence if the marginal value were constant. Then, average and marginal would be the same, and total value could be obtained simply by scaling up the value associated with any incremental change in the environmental good.

While it is an empirical question, there is much evidence that the marginal value of an environmental commodity is generally not constant but rather varies with the scope and scale of the commodity. For example in a region with 75 freshwater lakes the loss associated with the destruction of one lake ecosystem may be smaller than l/75th of the loss associated with the simultaneous destruction of all the lakes. Similarly, the loss associated with the destruction of the first lake will probably be substantially less than the loss associated with the destruction of the last lake, assuming that the other 74 lakes had already been destroyed.

A.6 Benefits transfer

To the extent that the value of an environmental good varies as a function of the composition and abundance from other environmental goods of the natural environment and the socio-economic context of the people that value the good, it is problematic to engage in what is called *benefits transfer*, extrapolating from preexisting studies to determine the value of an environmental good in another time and context. While it is true that values from other studies may shed light on how an environmental good is valued, those values were defined for specific incremental changes in specific geographic locations. Even if the study had valued the same good in the same geographic region, it may not be valid to use values from other studies unless the same incremental change is being considered. That said, because of the paucity of economic data on environmental commodities in California, there is often no alternative but to rely on benefits transfer for environmental values estimates.

Benefits transfer serves two purposes. Firstly, and this is the most important reason, benefits transfer can be used to get an indication of the order of magnitude of an environmental impact. This helps determine whether an impact is significant, *i.e.* when estimates have a high monetary value, and worthy of further investigation by an original study. Secondly, benefits transfer may be suitable for direct use in decision making. It should be recognized, however, that benefits transfer is only a second-best option after original research.

Certain conditions have to be met for a valid transfer of value to take place (Boyle and Bergstrom, 1992; Desvousges *et al.*, 1992; EFTEC, 2000). These are widely recognized to be:

- studies included in the analysis must themselves be sound;
- studies should contain WTP regressions, *i.e.* regressions showing how WTP varies with explanatory variables;
- study and policy sites must be similar in terms of population characteristics, or differences in characteristics must be adjusted for;
- the environmental change being valued at the two sites should be similar, and WTP measures cannot be changed into WTA measures and vice versa;
- site characteristics should be the same, or differences should be accounted for; and
- property rights should be the same across the sites.

Even if all the above criteria are met, benefits transfers are only as accurate as the original valuation study or studies. Thus, the quality of the data and the methodology of the original study or studies need to be examined.

The three most common benefits transfer procedures are; (i) transfer an average WTP estimate from one primary study, (ii) transfer a WTP function, and (iii) transfer WTP estimates from meta-analyses. These are discussed in turn below. Examples of (ii) are Kirchoff *et al.* (1997) and Smith *et al.* (2002); examples of (iii) are Rosenberger and Loomis (2001) and Shrestha and Loomis (2003). The vast majority of benefit transfers in the literature use (i); a recent example is Ready *et al.* (2004).

A.6.1 Transferring average WTP from a single study to another site which has no study

The simplest and most common procedure is to borrow an estimate of WTP in context i (the study site) and apply it to context j (the new site). This may be done by taking a single value or by averaging a set of values from the literature. These may be left unadjusted, or they may be adjusted in some way. An adjustment that is always performed is to correct for inflation by adjusting the monetary value using the change in the consumer price index between the date of the study being transferred and the date of the present study. In principle, it possible to make other types of adjustment for factors that could create a differences in average WTP, such as:

- socio-economic characteristics of the relevant populations;
- differences in preferences, habits, life-style between the populations

- physical characteristics of the study and policy site;
- proposed change in provision between the sites of the good to be valued; and
- market conditions applying to the sites (for example differences in the choice set of consumption opportunities and the availability of substitutes) (Bateman *et al.* 1999).

A commonly used formula for adjusted transfer, which assumes that income is the only important source of difference between the two populations, is that the WTP at the new site is equal to the WTP at the study site when adjusted by two factors (1) a ratio of income per capita in the new site over the income per capita at the study site and (2) an estimate of how the WTP for the environmental attribute in question varies with changes in income. Put in equation form:

$$WTP_j = WTP_i(Y_j/Y_i)e, \tag{A.1}$$

Where:

- Y_j is income per capita in the new site,
- Y_i is the income per capita in the study site,
- WTP is willingness to pay, and
- e is the income elasticity of WTP.

This has been used mainly in benefits transfer between countries. An alternative approach when the transfer is between different countries is to use the ratio of income between the two countries, as income (measured as purchasing power parity) is known to be one of the most important factors resulting in changes in WTP. However, it is also possible to make a similar adjustment for, say, changes in age structure between the two sites, changes in population density, and so on. Making multiple changes of this kind amounts to transferring benefit functions (see below).

A.6.2 Transferring benefit functions

A more sophisticated approach is to transfer the benefit function from site i and apply it to context j. Thus if it is known that factors affecting WTP at the two different sites are equal, then WTP can be estimated. Given that the characteristics of the population to which the estimate will be transferred is likely to differ from those of the study population it is hoped that benefits estimates can be improved by using the transfer equation to modify the estimate of average WTP to account for these differences. This approach relies on the availability of an appropriate valuation function in the original study which may be used for benefits transfer purposes, and it assumes that the variables in the estimated benefit function account for all the sources of difference between the two populations.

A.6.3 Transferring benefit functions: meta analysis

An alternative procedure is to use meta-analysis to take the results from a number of studies and analyze them in such a way that the variations in WTP found in those studies can be explained. In principle, this should improve the transfer since it corrects for factors that influence the estimated of WTP, at least to the extent that these are included as explanatory variables in the meta-analytic regression.

In recent years, several studies have appeared that compare the results of various types of benefits transfer with results obtained by doing a specific analysis for the item to which the benefit is being transferred. Examples of such validation studies include the following: Ready *et al.* (2004) examine the transfer of values for health impacts related to air and water quality among several European countries. Barton and Mourato (2003) examine the transfer of values for health effects from bathing water contamination between Portugal and Costa Rica. Barton (2002) examines the transfer of a value for improved bathing water quality from one town in Costa Rica to another. Kirchhoff *et al.* (1997) examine the transfer of values for outdoor recreation by non-residents visitors at four sites in Arizona and New Mexico. All of these studies find that there can be quite substantial errors in the use of benefits transfer. While in some cases it appears that transferring benefit functions can be more accurate than transferring average values, this is not confirmed in other cases. Meta-analysis of contingent valuation studies can explain a reasonable proportion of the variation in the original studies, but the original studies do not include sufficient information to test whether more information would have increased the explanatory power of the meta-analysis. The missing information may well be of the motivational type, *i.e.* why people have their values. It is clear that people's attitudes are often important determinants of WTP, yet most benefits transfers makes little effort to test for variability in attitudes across sites.

In summary, the use of benefit transfer by any method is not problem-free and is likely to generate a substantial, though not well measured, margin of error. Given the limitations of time and resources, however, it is not possible to conduct an environmental costing analysis without some use of benefit transfer.

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