Title

Valuing the Environmental Benefits of Urban Water Conservation

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1 Introduction

This report documents a project undertaken for the California Urban Water Conservation Council (the Council) to create a new method of accounting for the diverse environmental benefits of raw water savings. The environmental benefits (EB) model was designed to provide water utilities with a practical tool that they can use to assign a monetary value to the benefits[1] that may accrue from implementing any of the Council-recommended Best Management Practices (BMPs). The model treats only environmental services associated directly with water, and is intended to cover miscellaneous impacts that are not currently accounted for in any other cost-benefit analysis.

It is assumed here that the water savings associated with implementation of BMPs can be quantified, and represented as a reduction in the demand for water from a particular set of water supply sources. Our interest is in reductions to withdrawals from *raw* water sources, such as streams, reservoirs or groundwater resources, which also provide water directly to the natural environment. The reduction in demand from a raw water source may result in a change to the availability of an environmental service provided by that source. For example, reservoirs provide recreational services, and the number of users the reservoir can support will scale with its surface area. These environmental services have economic value 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.

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 resulting from the water savings. 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 impact is used to refer to a change to the service or beneficial use provided by the environment.

The model developed for this project will be used by all water agencies that are members of the Council. For many of these agencies, the amount of water conserved annually is small, and the associated environmental impacts may also be small and subject to relatively large uncertainty. It is often argued that such small effects are negligible and can safely be ignored. This argument is incorrect, as it ignores the fact that even if each individual contribution is small, there can be many of them, so that the overall impact is significant. A major innovation of this project is to develop a framework within which the small contributions of many different actions can be accounted for and summed up in a reasonable manner.

Environmental valuation is still relatively new, and there are numerous complications,

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[1] For simplicity we refer in this discussion only to benefits, with the understanding that these can take on negative values to represent costs.

ambiguities, data gaps and differences of opinion that make the construction of a definitive methodology problematic. Hence, the value of this study is more in bringing the required elements together in a coherent framework, rather than coming up with definitive value estimates for conserved water. 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 this reason, the numbers coming out of this work should be taken as first draft, typically lower bound estimates. They provide information on the relative utility of additional water under current conditions for some services, but do not in any way constitute an exhaustive list of all valuable environmental benefits. The valuations provided by the EB model may be of use to water agencies in developing cost-sharing programs with other agencies or organizations concerned about environmental preservation and restoration.

This report describes the technical work performed at LBNL to design the model and calculate default ecological impact and environmental value estimates. The final report submitted to the Council for this project [21] provides additional information on the project background, policy issues considered by the Council, and discussion of how the model should be used in practice. A User Guide [22], also provided by LBNL to the Council, describes in detail how to use the model.

The EB model was developed to be used along with another Council-sponsored model which calculates direct avoided infrastructure costs arising from water demand reductions, known as the *AC (Avoided Cost) model* [20]. The two models use a consistent water system definition and take the same input data. The EB model calculates all benefits in 2005 dollars, and assumes that environmental values remain constant in real terms over the time horizon of the analysis. In an actual cost-benefit application, accounting adjustments to these numbers would be made outside the EB model and will not be discussed here.

This document is organized as follows: The Background section reviews the California Urban Water Conservation Council Memorandum of Understanding and outlines the Council guidelines for the analysis. The Methodology section presents an overview of the environmental benefits calculation in general terms, with a focus on explaining the logic behind the model. We identify the quantitative relationships used to represent the system, 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 model by the specific requirements for this project.

In the Data Sources section we provide an overview of the relevant information available in the literature and through public on-line databases, and outline how the numbers needed in the calculation can be defined. This section is again written in general terms, so as to clarify how the environmental and economic data needed for a complete analysis would be used in this particular model. As is generally the case, limitations on the available data mean that the analysis must use a number of approximations and interpolations. These are described in detail in the Data Values section. Here we describe the actual calculations used to convert raw data into the numbers that are found in the default tables in the EB model spreadsheet. For the economic data, we use both market values and non-market values, depending on the service. This paper will not discuss in any detail the derivation of non-market values. The Appendix to the final report [21] contains a reprint of a paper by Hanemann *et al.* [25] which provides a detailed introduction to the subject.

2 Background

The Council was created by the Memorandum of Understanding Regarding Urban Water Conservation in California (MOU), 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 described in the MOU, a copy of which is available through the Council's website [18]. There are currently 14 BMPs addressing residential, commercial, industrial, landscape, system loss and leak detection, education, public information, and pricing conservation practices. Signatory water suppliers are expected to implement a BMP 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 suggested methodology for computing BMP benefits and costs is outlined in the the Council *Guidelines for Preparing Cost-Effectiveness Analyses of Urban Water Conservation Best Management Practices* [19].

2.1 Environmental Benefits and BMP Evaluation

BMP benefits in principle include water and wastewater utility avoided costs and environmental benefits. The existing 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 version of the EB model. A short list of other Council requirements for the model is given below.

1. Provide a common set of definitions and terminology.
2. Make data input easy.
3. Enforce consistency with the Avoided Cost model.
4. Provide a set of default values for all environmental and economic data.
5. Make the underlying analytical assumptions transparent to the degree possible.
6. Focus on what can be quantified, and provide a range of values that account for variability and uncertainty.
7. Design the spreadsheet tool to be easy to use for scenario and sensitivity analyses.

2.2 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, those sources are linked to a particular set of environmental services, and the currently defined values associated with those services are calculated. The model does not attempt to track a unit of water as it follows a particular path through the system. Instead, we use hydrologic data and estimates of the total consumptive use of water for different environmental services to calculate the probability that a given unit of water will contribute to maintaining a service. All raw water sources, including those that may lie outside the utility's service area, should be included in the input data. Many services, for example recreation opportunities and species habitat, are not confined to local populations. 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. Only water sources within the state of California should be counted, and only data relevant to California are used here in calculating the benefits estimates. To avoid double-counting, water transfers should not be included in the input water savings.

2.3 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) [20]. These 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. The EB and AC models describe BMP impacts of the *same* programs for the *same* system, so a number of steps have been taken to ensure consistency in the system description, the time frame for the analysis, energy costs, discount rates *etc.* To facilitate their use, the models are also able to exchange data inputs and outputs.

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. Within the AC model the user specifies a set of *on-margin probabilities*, which represent the fraction of time a given water system component is operating on the margin, and would therefore be directly impacted by small reductions in water demand. The full 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. The raw water system component must be associated with a *water source type*, and it must be assigned to a *hydrologic region* [22], [17]. 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, season definition, seasonal water savings in the base year, and the projection of water savings over the analysis period from the AC model. While the avoided cost calculation only requires water savings on a seasonal basis, for the EB model higher time resolution is needed, as many environmental impacts vary with the time of year. By default the EB model calculates the benefits for each raw water system component on a per-unit-volume basis. The on-margin probabilities are used to compute the annual aggregate environmental benefits over all raw water system components for each year in the analysis period. Within the EB model, a lack of data prevents us from projecting any changes to future environmental values over the analysis period. These are therefore assumed to be constant in real terms, hence the benefits are expressed as constant (2005) dollars per unit volume in each year. These values can be exported back to the AC model, where any discounting or other accounting adjustments may be applied in a manner consistent with the method used for other avoided costs. The results of both models can then be incorporated into an overall benefit-cost analysis for a given BMP or set of BMPs.

3 Methodology

In this section 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 used to represent the system, 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 Council requirements for this project.

The approach taken here separates the problem into two independent components: calculation of the impact of water availability on an environmental service, and estimation of the value associated with that service. The first is determined by the physical and biological properties of the system. The second is dependent on the social value placed on a service by humans, which is assumed here to be expressed as a price for the service[2].

The primary original contribution of this work is the development of an accounting scheme for estimating the impact on various ecological sub-systems of small changes in the availability of water. We refer to these as ecological or environmental sensitivities. For determination of a price associated with an environmental service, we rely primarily on reviews of the existing literature. In some cases, a value estimate can be developed from the price paid to acquire land for restoration projects. In other cases, where there is no actual market for the service, the economic data are taken from studies using various forms of non-market valuation. The basic ideas behind non-market valuation are summarized in the next section.

3.1 Summary of Economic Theory

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 straightforward and are associated directly with use of an environ-

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[2] This report does not endorse any particular position on the value of the environment. The use of prices to express value is a practical approach adopted by the Council for this project.

mental service by a specific set of users, which may include qualitative aspects related to aesthetic and other concerns. For example, for some recreational users an 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 a non-market item can be measured by the change in income that would be equivalent to it in terms of the impact on the individual's well-being. 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. 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.

3.2 Environmental Benefits

Economic valuation 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.

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

- Environmental values depend upon the magnitude of the impact of a reduction in water use on a given environmental service. The affected environmental services are determined by the type of raw water source, for example, whether it is a lake, a stream or a groundwater resource. 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 on 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 model environmental valuation calculation. These equations are presented below in section 3.6. 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 calculation is the total value per unit volume, in 2005 dollars, of the environmental benefits associated with the water savings input by the 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 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) × (0.1 trout/afy) or \$3/afy.

3.3 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 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 user inputs estimated annual water savings, and defines the set of marginal sources for each year of the analysis period, for the peak and off-peak seasons. 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. This step of the process is represented in Figure 2.

In reality, 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. 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 Council 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.

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.

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 allows the net impact of a large number of small diversions to be properly accounted for. 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 [17]. 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 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.

3.4 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, and (3) constructing a weighted average of different values when appropriate. 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 model. It should include the effect of inflation, and demographic differences such as activity levels and average income. When 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 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 dollars 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 dollars 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, including qualitative aspects which are difficult to account for. Currently, the economic data is not sufficient to assign a marginal value to changes in the quality of a service, so only quantitative changes (for example, the number of fish caught per trip) are included in the EB model. 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 lower-bound estimate of the societal WTP for preservation of these water-dependent habitats (this estimate is a lower bound because it doesn't include any 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 for wetland and riparian zones by defining each of them as a service in itself.

Figure 5 presents the entire flow of the calculation on one page. Section 3.6 at the end of this section summarizes the calculations in equation form, using the same notation as the figures.

3.5 Simplifications in the model

In this section we explain the reasoning behind some of the simplifications and approximations used in the EB model. In some cases these are forced on us by resource limitations for the project, or the lack of sufficient data. In other cases, the simplifications are appropriate given the intended application of the model to *annual* water savings potentially distributed over a very broad physical area. Not all of these issues can be decided purely on scientific or quantitative grounds. When there is an element of policy choice, it is important that the influence of such choices be clearly delineated.

One of the most basic philosophical issues that arises is whether or not the value of the environment in a general sense can or should be monetized. Some people feel that to do so misrepresents its real importance, and that intrinsic value exists independent of whether one has developed a scheme for calculating an associated dollar value. This discussion is moot here, as the Council has already taken the decision to use monetized environmental benefits in its cost-benefit framework. The purpose of the analysis is to provide quantitative information on the impacts of following one course of action over another. This does not preclude the use of other approaches to dealing with environmental concerns.

The Council MOU instructs water suppliers to include "the benefits of water made available to other entities as a result of conservation efforts", but does not provide additional guidance on the types of benefits to consider. In order to identify a reasonable scope for this project, we used the CalFed Record of Decision (Appendix A: Mitigation Measures) [5], to compile a comprehensive list of significant environmental impacts directly linked to reduced raw water demand. These 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 model. 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. Impacts from new projects are dealt with through existing environmental review processes, and should not be included in the EB model[3]. Reduced water demand also leads to reduced energy use for conveyance and treatment, with the associated benefits coming under the category of

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[3] They may appear in the AC model as part of the project capital costs.

air quality above. Land-use impacts are not covered in the current model, as they are not directly impacted by marginal water demand reduction. To avoid double-counting, water obtained through purchases or transfers should not be included in the calculation of input water savings. Water leaves the primary raw source only once, and it is only at that point that an environmental impact is counted in the EB model.

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, compared to estimates of total current flows, as published in the DWR Waterplan [12]. These probabilities are calculated independently for each hydrologic region. In some cases they are 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.

In reality, there is a time lag between when water is saved and when the benefit is received, and many environmental processes involve complex interactions between events occurring at different times and in different places. Practically, the temporal resolution of the EB model is determined by the resolution of the input water savings. This is currently 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. Any 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. The spatial resolution of the model is at the scale of the largest watersheds in California. Large-scale spatial averaging is consistent with the long-time averaging used in the model, and allows us to estimate what are basically first-order effects. Only relatively independent ecological service impacts are considered. A great deal of research is directed at improving the characterization of relationships between different ecosystem components, and as these become clearer the information may be used to refine the definitions and values used in the model.

Given limits on the available resources and data, the focus here is on environmental services for which there is a direct physical link to water withdrawals. The EB model does not consider other aspects of water system operations, such as pumping across the Delta, dam operations, or the release of chemicals from treatment plants. As the model is designed to be used by any and all Council member agencies, it is not appropriate to try to incorporate impacts associated with highly localized system operations. Some of these other impacts are at least partially mitigated through existing regulatory and management programs. For example, the Environmental Water Account [6] is used to limit environmental damage due to pumping in the Delta.

Water availability in the natural environment fluctuates strongly from year to year, and the sensitivity of ecosystems to the availability of water may depend in unpredictable ways on whether it is a wet or a dry water year. The EB model deals only with an average year. 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.

The data values approximated here are both uncertain and highly variable. The standard method for dealing with uncertain or variable data is to conduct sensitivity analyses. The spreadsheet has been designed to facilitate the calculation of sensitivities by the user. All data values include low, medium and high estimates, with the medium being the default. The low value is defined as half the medium, and the high value as twice the medium. A data-entry form allows users to easily choose the low or high value instead, or to input their own data if it is available.

3.6 Equations for Environmental Value Estimation

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

The model 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 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 $TotWatSav(mon, yr)$ 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 $SF(source, mon, yr)$, which indicates the fraction of water savings that come from a particular source in that year. The water savings by month, year and source is written:

$$WatSav(mon, yr, source) = TotWatSav(mon, yr) * SF(source, mon, yr) \tag{1}$$

This equation corresponds to the piece of the flow chart depicted in Figure 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 model, 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 $UEI(mon, source, ens)$, 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 section 4 and 5. The total environmental impact associated with $WatSav$ is then calculated as:

$$EnvImp(source, ens, yr) = \Sigma_{mon} WatSav(mon, yr, source) * UEI(mon, source, ens) \quad (2)$$

where the sum is taken over months. This step of the calculation is represented in Figure 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[4]. 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 $BT(SLoc, yr, L_k, Y_k)$. 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.

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

$$EV(source, ens, yr) = \Sigma_k [PV(ens, k, L_k, Y_k) * BT(SLoc, yr, L_k, Y_k) * W_k], \quad (3)$$

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

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

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:

$$Net\_EB(yr) = \Sigma_{source,ens} EnvImp(source, ens, yr) * EV(source, ens, yr). \tag{4}$$

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

$$Unit\_EB(yr) = Net\_EB(yr)/(\Sigma_{mon} TotWatSav(mon, yr)). \tag{5}$$

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 5.

4 Data Sources

In this section we present the framework used to organize the data in the EB model, and discuss in some detail how the data are characterized. The focus is on the logical structure of the model and we ignore, for the moment, problems arising from the limitations of the available data. The use of real data to calculate default values for the EB model spreadsheet is discussed in Section 5. To give the reader a sense of the kind of information that is currently available, Appendix A contains a brief description of the (mostly web-based) data and document archives that have been used in this study. A complete list of references to data sources and other documents is given in the bibliography of this report.

4.1 Introduction

To summarize, the EB methodology outlined in the previous section 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 typically provided by water utility staff; (2) biological and physical characterization of environmental impacts; and (3) economic values assigned to environmental services. Here we discuss in detail each of these three datasets and their spatial and temporal characteristics. The data we use in this work are drawn from a wide range of research subjects, and studies undertaken with very different purposes in mind. Before we can use this information in the EB model calculation, we first need to define the specific set of variables we will extract, and how they relate to one another. This organizational problem is dealt with here by defining a database schema, or set of linked tables, that can be used to store the needed data. Our schematic tables for ecological and economic data are shown in figures 6 and 7. Note that these are *not* the data tables that appear in the spreadsheet model. The spreadsheet tables result from additional calculations on the input data, as described in Section 5.

4.2 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. 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 model 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. 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 associations between a raw water source, a water source type and a location are also user inputs. The water source type and location are used as keys to relate the water savings to the other data in the EB model. For practical purposes, the EB model provides a list of possible water source types, and the user selects one for each source included in their system representation. Each of the water sources is also assigned to a hydrologic region (HR). The EB model uses the Calwater 2.2 [17] definitions of ten hydrologic regions in California, which are listed in table 1. A figure illustrating the region boundaries can be found in the EB model User Guide [22]. These regions are physically determined and correspond to the largest watersheds in the state, which are roughly independent of one another for the purposes of water balance accounting. Some, for example the Sacramento and San Joaquin hydrologic regions, also correspond to large river systems. The model assumes that all ecological data vary with HR. If regional data are not available, statewide average values are used in each HR.

4.3 Environmental Impacts by Water Source

The EB calculation uses the concept of environmental service to describe the relationship between human activities or attitudes and the physical environment. This notion is equivalent to environmental amenities or beneficial uses [59]. Some examples of environmental services are: 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 6. 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. Within the model, additional items can be added to these lists as more data become available in the future.

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 water source 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 do not distinguish between reservoirs and lakes, so they are assigned the same type for this service. For completeness, this table also includes a *downstream type* characteristic. Such a feature allows a limited set of network relations to be represented in the model, for example to track the flow of a unit of water across successive source types, or to represent the disposition of a unit of water after it leaves a utility service area. Given the resource limitations of this project, this feature is not used in the current implementation of the model spreadsheet.

The Environmental Services List also links to a table labeled *Environmental Services Characteristics*, 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.

These tables only include data for environmental impacts related to raw water availability. Two other categories of environmental impact are included in the EB spreadsheet model but not in these tables: reduction of the load on the wastewater system, and reduced energy use and associated air quality impacts. Both of these depend only on the quantity of saved water, not where it comes from. They are fairly straightforward to model and are described in section 5.10.

4.4 Environmental Values

Literature on the economic valuation of environmental services has been compiled in a number of databases and review articles, in particular for recreation. This makes the task of collecting and classifying economic information quite a bit easier than for the environmental data. For this study, our task is to select from appropriate sources and make the necessary adjustments to transfer the published values to the context of Council member agencies.

Figure 7 shows the organization of data from environmental valuation studies 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 6. For this work, to avoid complications associated with the benefits transfer exercise, 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 current 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 [24], or the Sportfishing database [27].

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 6. 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.

5 Calculation of Default Data Values

5.1 Introduction

This section describes in detail the calculations behind the default data tables included in the current version of the EB spreadsheet model. All data used in this work is collected from public sources. Preference is given to the most 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 raw water sources. Depending on the situation, an environmental service may be affected by the volume of water present or by the average flow rate. The water savings input are expressed as a volume in acre-feet per month (afm). In the intermediate calculations, these numbers are converted to flow values or summed to get seasonal or annual withdrawal volumes as appropriate.

This section is organized as follows: the rest of the introduction consists of some general remarks on temporal and spatial variation in the data, and the difference between marginal and average impact estimates. We then present a detailed discussion of how the ecological impact and economic valuation numbers were estimated, 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. The set of references relevant to a particular service is included at the end of each subsection. A full list of references is given in the bibliography at the end of this report. While we are not aware of any additional quantitative information that could be used to increase the number of services represented in the EB model, the spreadsheet design makes it relatively easy to add services as more information becomes available.

It's important to clarify that this methodology doesn't lead to a fixed dollar benefit value of water returned to the environment. The dollar value calculations depend on the input water savings pattern and the particular configuration of sources used by a water utility. Each utility will thus calculate a different value. The tables do record fixed dollar values per unit of service, but the ecological sensitivity factors needed to relate the service level to the water available are dependent on utility input data. Theoretically, the model could be used to compute regional average values, either at the state level or by hydrologic region, but this would require a definition of the correct on-margin probabilities for each source, as well as specification of the seasonal pattern of water savings. This in turn would require an overview of all utility operations within the region.

5.1.1 Temporal Adjustment

Most of the economic data are not current and therefore need 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 [3] (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 seems 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.

5.1.2 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) [17], which divides the state into ten major watersheds. Table 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 is used to scale the overall ecological impact values. If a service doesn't exist in a given region, the associated water need is set equal to zero.

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 [12]. These documents include a set of tables entitled *Water Use and Distribution of*

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

Dedicated Supplies, one for each HR. These tables provide annual estimates for total inflow, outflow, and applied and net water use for a variety of end uses, for three historical years representing typical wet, dry and normal years. We use the year 2000 data from this report, which corresponds to a normal water year. The data are used to determine the approximate fraction of total annual water supply (observed inflows) 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. Our approach does not attempt to track a unit of water from its source to its final consumptive end, as that problem is not well-defined physically. In some cases the water provides a service with no consumptive use and a given unit of water can provide multiple environmental services.

5.1.3 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, year after year. 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 [54], 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. As noted previously, our goal here is to have a robust accounting of first order effects which may be small for any given water utility but which add up over space and time to a significant total.

5.2 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 [39, 45, 62, 63], 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-of-year and end-of-year reservoir storage in California are approximately equal [10].

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 [13].

5.2.1 Equations

The relationship between reservoir area and reservoir volume can be approximated by a power law of the form $A \propto S^p$, or equivalently

$$\log A = c \ + p \log S \tag{6}$$

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 [13]. From this equation, a change in storage ΔS induces a change in area ΔA with

$$\frac{\Delta A}{A} = p\,\frac{\Delta S}{S}. \tag{7}$$

Let $U(A)$ 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 with

$$\frac{\Delta U}{U} = e_A\,\frac{\Delta A}{A}. \tag{8}$$

The units of ΔU are user-days per year. The value V 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 [39]. Combining equations (7) and (8), and multiplying by V gives the annual marginal benefit B_{marg} (in units of dollars per acre-foot per year) of a change in the reservoir storage level:

$$B_{marg} = V\ U\ e_A\ p\,\frac{\Delta S}{S}. \tag{9}$$

5.2.2 Data values

Data on the relationship between reservoir size and area is available from the CALSIM II model [13] 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 5.2.3. Note that only the exponent p, not the actual reservoir area, is needed in equation (9). 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 [10]. The site posts average monthly values, calculated from approximately 20 to 40 years of data, depending on the reservoir.

Wade *et al.* [62] estimated the coefficient of elasticity between visitation and surface area as 1.0. More recent work [45] indicates a slightly lower value of 0.9. In these calculations we set $e_A = 0.9$. Mitchell & Wade [39] 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 and V for each reservoir. The benefits are converted from 1985 to 2005 dollars using a CPI inflation ratio of 1.8 [3]. 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.* [62] 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 9 is modified to:

$$B_{marg}(m) = f(m)\ V\ e_A\ p\ \frac{U}{S}\ \Delta S(m). \tag{10}$$

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, V, p, S in equation 10 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 $f(m)Ve_Ap\frac{U}{S}$ 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 5.2.3. 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.

5.2.3 References

[3], [10], [13], [39], [45], [62], [63].

5.3 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

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 2: Constant c and exponent p of equation 6 for the reservoirs in the CALSIM II model of the California central valley [13]. Average reservoir storage values are taken from CDEC data [10].

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

maintaining riparian vegetation. Numerous studies have demonstrated that alteration of the natural flow regime has significant impacts on the health of riparian vegetation [1, 41, 43, 49]. 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 [55]. Riparian cover has a large impact on local water temperatures and consequently on fish habitat [54], while riparian vegetation helps maintain stream water quality by filtering runoff [55]. The woody debris produced by riparian trees and shrubs is an important in-stream food source, and helps maintain a diversity of micro-habitats, which in turn is a key factor in the preservation of local species richness [47, 52, 55, 56].

In California, native cottonwood and willow are the dominant riparian forest species in arid and semi-arid regions [15, 41]. Detailed studies of cottonwood community dynamics as a function of flow regime have confirmed that this species is well-adapted to natural annual flow variation [36, 49]. Mature cottonwood forest should be most abundant for the natural flow regime, while stable flow regimes can result in highly variable population sizes prone to local extinction [36]. 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 [50].

5.3.1 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 water use by this potential forest, based on evapotranspiration data for various native plants, assuming historically typical levels of annual inflow. This gives us a baseline value for the amount of water that could be used to maintain riparian vegetation in each HR.

The California Rivers Assessment (CARA) [16, 60] 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 [32, 37], we can calculate the total potential acreage by region. The results are presented in column three of Table 4.

To calculate the water use, we follow guidelines developed for irrigation water needs for native plants in California [58]. The calculation requires two steps. In the first, the *evapotranspiration 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 [14], 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 [15] was used to determine which plant species are found in riparian zones for each HR. Reference [58] 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. 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 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,

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: 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.

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. In column five of this table we provide estimates, based on DWR data [12] of the total river flow in each HR. The ratio 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.

5.3.2 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 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

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 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.

or Gaussian distribution. Assuming this type of distribution for the purchase prices in Table 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 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 leads to a dollar value per unit volume of water for this service.

5.3.3 References

[1], [16], [10], [15], [14], [32], [36], [37], [41], [43], [47], [49], [50], [52], [54], [55], [56], [58], [60], [12].

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 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 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 8: Wetlands habitat purchase data.

5.4 Wetlands

5.4.1 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 [13]. 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, 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 [48], 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 [12], and is shown in column two of Table 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 7.

5.4.2 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 8. As expected, they show a wide range of variation. Using the values in Table 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 8.

5.4.3 References

[12], [38], [48], [64].

5.5 Fish habitat: Salmonids

While hundreds of fish species are known in California, with many of them threatened or endangered [11, 15], management of the state water supply has focused on the needs of salmonids that are listed through the federal Endangered Species Act. Anadromous salmonids are in many ways the ideal species to use as an 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 only on those factors that are directly impacted by water withdrawals. The health of salmonid populations has been extensively reviewed in a recent report by the West Coast Salmon Biological Review Team (BRT) [44], which is used here as the primary source of information on fish populations. 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.[5] To fill in some of the gaps left by the BRT report, we also make use of the Calfish on-line database [8], which contains a compilation of data from most of the fish population studies conducted in California over the last thirty years. In this analysis we consider only wild populations, as hatchery fish are strictly speaking not part of the natural environment. Hatchery populations are restocked each year, and so are unlikely to be directly affected by marginal water conservation in any case.

The EB spreadsheet model requires quantitative data both on fish populations and their economic valuation. In our review of existing studies, we found sufficient data only for a few species of salmon and steelhead. Striped bass is an important recreational fishing species in the Bay, and is included in some economic surveys, but population counts are not currently available. Relative abundance indices have been developed by the Interagency Ecological Program [28], but these indicate only whether the populations are rising or falling over time, and don't provide all the information needed for the model calculations.

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[5] 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.

In our analysis, the key relationship is between the level of flow in the river system and the population level, represented by the number of adult spawners. Physically, the volume of flow in the system determines the total available habitat. All other things being equal, the temporally averaged population should scale directly with habitat size. This is a basic finding of mathematical population modeling, which defines two population regimes based on the density of organisms [2]. On the low density side, population growth is habitat- (or resource-) limited and an increase in the available resources will produce a corresponding increase in population. On the high density side, populations are limited by competition, parasites and other density-dependent effects. As all species considered here are under stress in California, they are all in the low density regime. Clearly the level of population supported by a given level of flow will depend on other variables in the system, but in general an increase in flow (*i.e.* habitat size) will support an increase in population. The flow of water defines the basic condition of existence of the habitat, and is also one of the few variables which will correlate with population over large spatial scales and long time scales [54]. This hypothesis is checked below by comparing population and total flow across different regions within the state.

5.5.1 Fish-flow relationship

A somewhat standardized procedure for evaluating the ecological impact of flow alterations, known as the Instream Flow Incremental Methodology or IFIM [54], 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 [4]. The method is valid at the reach[6] scale but requires a large amount of input data for calibration. Physical habitat models are typically calibrated at the reach scale, and it is difficult to generalize a single model to larger spatial scales. However, a number of recent studies have shown that these models do display reliable correlations between large-scale hydrologic variables and habitat quality. Hatfield & Bruce [26] reviewed 127 habitat simulation studies to determine which variables predict the optimum flow for a variety of salmonid species at different life stages. They found that the mean annual discharge (*i.e.* average annual flow through the river) is the best predictor of habitat quality. There is some dependence on latitude/longitude in some cases, while flow variability, elevation, watershed area, and distance to the coast do not appear to be significant. A series of studies were undertaken by Lamouroux and coworkers [33, 34, 35, 46] to evaluate how well habitat-flow models predict fish community assemblages under widely different conditions. An assemblage is a collection of different species that are found together consistently. Comparing data across different regions of France and the US, they were able

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[6] A reach is a stream segment with a length of a few times the stream width.

to show that variation in two simple flow-dependent physical measures[7] can account for a significant portion of the variance seen in fish populations. The significance of this work is that it confirms 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 an analysis period of 10-30 years, we base our evaluation of the fish-flow relationship on large scale measures—specifically, average annual discharge for major rivers by HR, and average salmonid population counts over the last ten to twenty years extracted from the BRT report [44] and Calfish [8]. Note in this model the issue of whether and how the river is managed does not arise - we're only concerned with the quantity of water in the system. Assuming that the fish population level depends on annual flow is mathematically equivalent to describing the fish-flow relationship as a curve. The question we need to answer for the model is, given a change in flow, what is the change in fish population; *i.e.* what is the average slope of the fish-flow curve? This slope is the *fish-flow sensitivity* in units of fish per afy. The data we have don't allow us to answer this question directly. Instead, we develop three rough estimates based on some very simple principles. These estimates are all consistent with one another, and while they are not very precise, we expect them to be robust.

The first estimate of the fish-flow relationship is based on population and flow data compiled for different hydrologic regions under current conditions. The count is of adult spawners and includes chinook and coho salmon, and steelhead trout. Population estimates were initially developed by reviewing the BRT report. For the North Coast, San Joaquin and Sacramento River regions, we have also added 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). 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 [12]. These numbers are included in Table 9, and plotted in Figure 8. Each point on the curve represents data for one HR. This approach glosses over the other physical differences between regions (such as climate and demographics), and assumes that the primary determinant of the number of fish left in the region is the amount of water flowing in its rivers. 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 a good fit 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 can be interpreted as an average value for the whole state.

A second estimate can be obtained from the same data simply by dividing the number

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[7] The measures used were the Froude number and the Reynolds number, which depend only on the flow rate and the physical dimensions of the channel.

HR	Est. Adult Spawners	Flow (Tafy)	Sensitivity (fish/afy)	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	—	No listed salmonids
SL	0	126	—	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	—	No listed salmonids
CR	0	37	—	No listed salmonids
CA	689,100	51,500	0.013	

Table 9: Salmonid stream/river environmental sensitivities by HR.

of fish by the annual flow in each HR. This is equivalent to assuming that the fish-flow relationship within each HR is a straight line that passes through zero. In this case the fish-flow curve has a constant slope that is estimated by the ratio of total fish to total flow at one point on the line. These numbers are included in the third column of table 9. Note the value of 0.013 for California as a whole is very close the value of 0.014 computed above, reflecting the fact that the data used in figure 8 is well-fit by a straight line. These numbers are used as the default, HR dependent sensitivities in the spreadsheet.

Our third approach doesn't provide a direct estimate of the fish-flow sensitivity, but does provide some insight into the importance of factors other than flow. The BRT provides rough estimates both of current and historical (*i.e.* pre-industrial) population levels for listed species in the state. The estimated total of salmon and steelhead historical populations is about three million, while current levels are on the order of 3-400,000 [8]. Currently, the average total river flow is about 50,000 TAF/year. Historically, the flow *timing* would have differed greatly, but the total average volume would not have been significantly different. Based on a comparison of total inflows to total outflow to the Delta taken from the CALSIM II data [13], we estimate that the historical average discharge to the delta might have been about 10-20% higher without diversions. Between the historical and current conditions, we see that a relatively small decrease in flow leads to an order of magnitude drop in population. Clearly, this drastic reduction is due to stress factors other than reduced flow volume, of which

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[8] This is less than table 9 as it includes only the ESU's.

there are many (dam construction, water quality, channel modifications *etc.* [44, 61]). The current and historical points, along with the zero point, are shown in Figure 9. Based on these two points, we can again draw lines through the zero point and estimate the fish-flow sensitivity as the slope of these lines. This method gives the values of about 0.01 fish/afy for current conditions and 0.05 fish/afy for historical conditions. The historical value can be considered a rough upper bound on the fish-flow sensitivity. The current value is comparable to the values obtained above. Note that drawing a line through the zero point is equivalent to assuming that 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 is a lower bound (*i.e.* likely an underestimate) of the sensitivity of fish to flow.

5.5.2 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) [57], 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 [9]. A summary of the study is available on-line through the Sportfishing Values Database [27].

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.

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[9] 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.

- 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 [3].
- 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 [8]).

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.* [57], as summarized in the Sportfishing database [27], 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 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 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.

5.5.3 References

[2], [4], [8], [12], [15], [26], [28], [33], [34], [35], [44], [46], [27], [54], [57], [61].

5.6 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 [29]. This model is used

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 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.

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. A psu is a *practical salinity unit*, and is equal to about 0.1% by weight. The X2 position is used as a measure of water quality, with high values of X2 indicating that salty water is penetrating more deeply into the Bay-Delta. This generally lowers habitat quality for native species, and may promote the growth of invasive species. 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 unit as dX. The numbers are presented in Table 10.

Kimmerer [30, 31] 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 [30]. 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.

However, we are not aware of any economic data that would allow us to assign a dollar value to these populations. For this reason, there are no monetized environmental benefits for Bay-Delta water quality in the current spreadsheet version of the model. The physical salinity impacts have been included as a place-holder, so that if and when economic data does become available the impacts can be included in the EB calculations.

5.6.1 References

[29], [30], [31].

5.7 Other impacts

At the request of the Council, two environmental impacts that are not directly related to water withdrawals have been included in the spreadsheet: energy-related qir quality impacts and urban runoff. These are discussed briefly in this section. The determination of these values depends only on the volume of water saved, with no connection to any water source characteristics, so this part of the calculation is not represented in Figure 5.

5.7.1 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 [23], 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 of pollutants emitted per unit of fuel consumed. These numbers are available only for pollutants that are currently regulated, specifically 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 [23].

- 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 [9] 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 [42], 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 factors listed above.

5.7.2 Urban runoff

BMP's that target landscape irrigation in urban areas can lead to significant reductions in polluted urban runoff [40] 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 percentage of each unit of conserved water that ends up as urban runoff, by month. Presumably, landscape irrigation savings will vary strongly with weather, so monthly resolution is needed for the input data. 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. The product of the total volume of run-off reduction times the treatment cost gives the monetized environmental benefit.

5.7.3 References

[9], [23], [42], [40].

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A Appendix A: Quantitative Data Sources

This appendix lists a set of publicly available databases or review articles that have been used to generate the default ecological and economic values. It is included to give the reader an overview of the information at the time of this study.

The Beneficial Use Values Database (BUVD) [59]. 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.

Benefit Transfer of Outdoor Recreation Use Values [51]. 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.

Calfish Database [8]. 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.

California Data Exchange Center [10]. This web site provides an extensive archive of historical and current data on California water systems, included river flow and stage measurements, reservoir levels, precipitation *etc.*

California Natural Diversity Data Base [15]. This database is developed and maintained by the Wildlife & Habitat Data Analysis Branch of the California Department of Fish and Game. It provides a compilation of observations of a large number of plant, insect and animal species throughout California, as well as information on preferred species habitats and the federal and state status for listed species.

California Rivers Assessment [16]. This web-based GIS tool and database is maintained at the University of California at Davis. It contains data on all the large-size to medium-size rivers in the state, organized by watershed. Data include the length of flowing river miles, precipitation averages, and watershed areas.

Environmental Valuation Reference Inventory (EVRI) [24]. 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 7, but is more complete.

Sport Fishing Values Database [27]. 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 7. 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.

A Appendix B: Figures

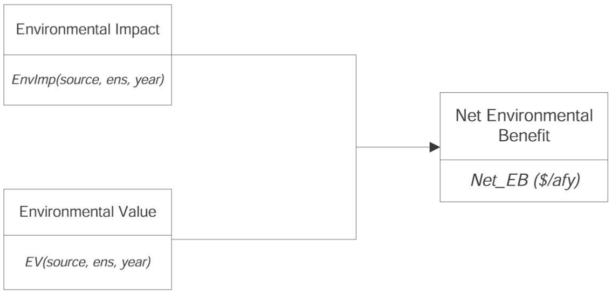


Figure 1: Final step of the environmental benefits calculation. The variable names in the figures are those used in the equations presented in section 3.6

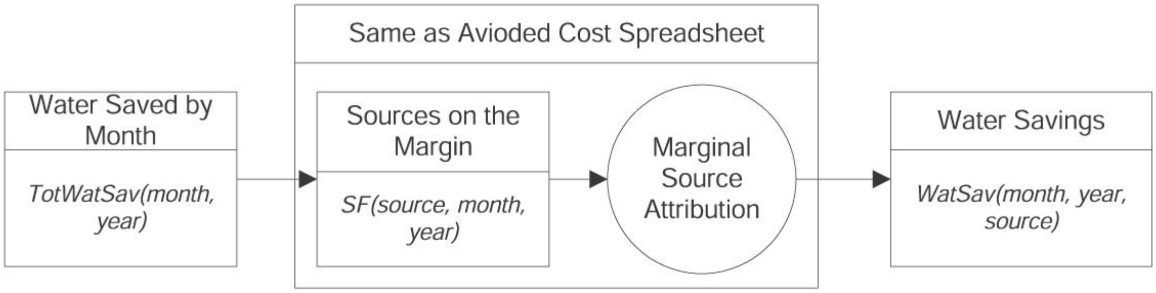


Figure 2: Representation of the water savings input data.

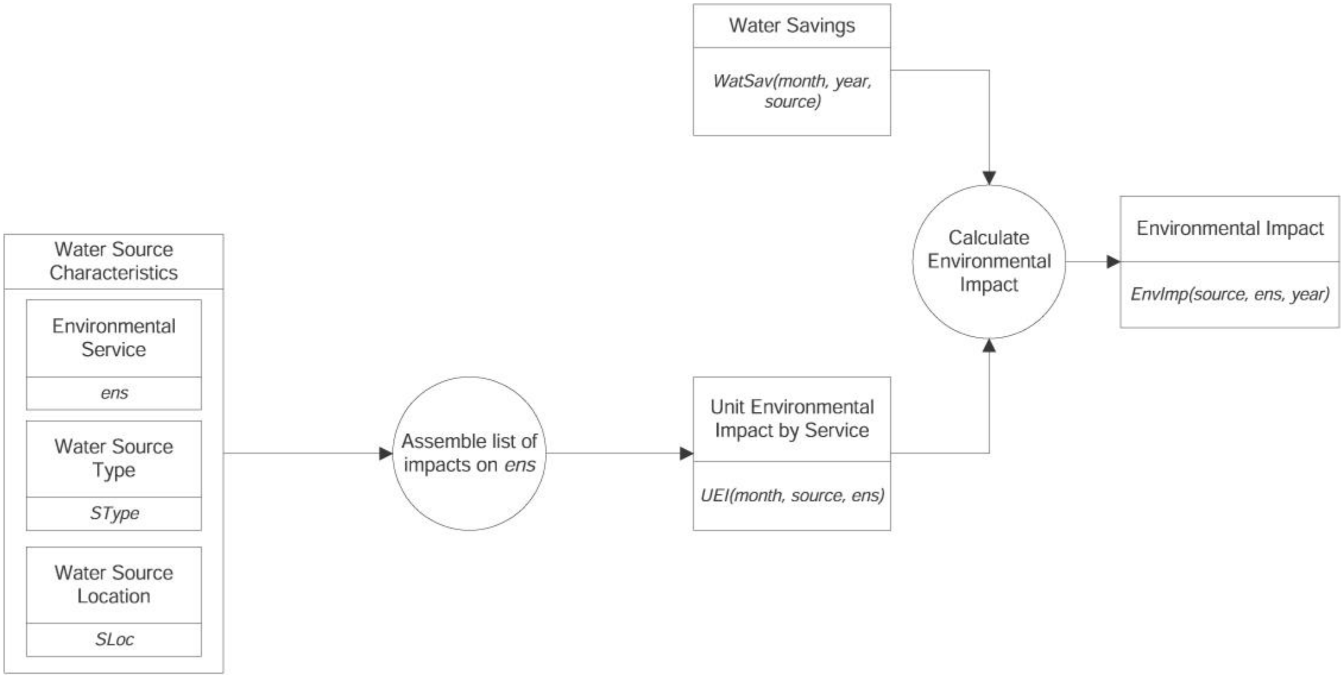


Figure 3: Overview of the calculation of the environmental impact of input water savings.

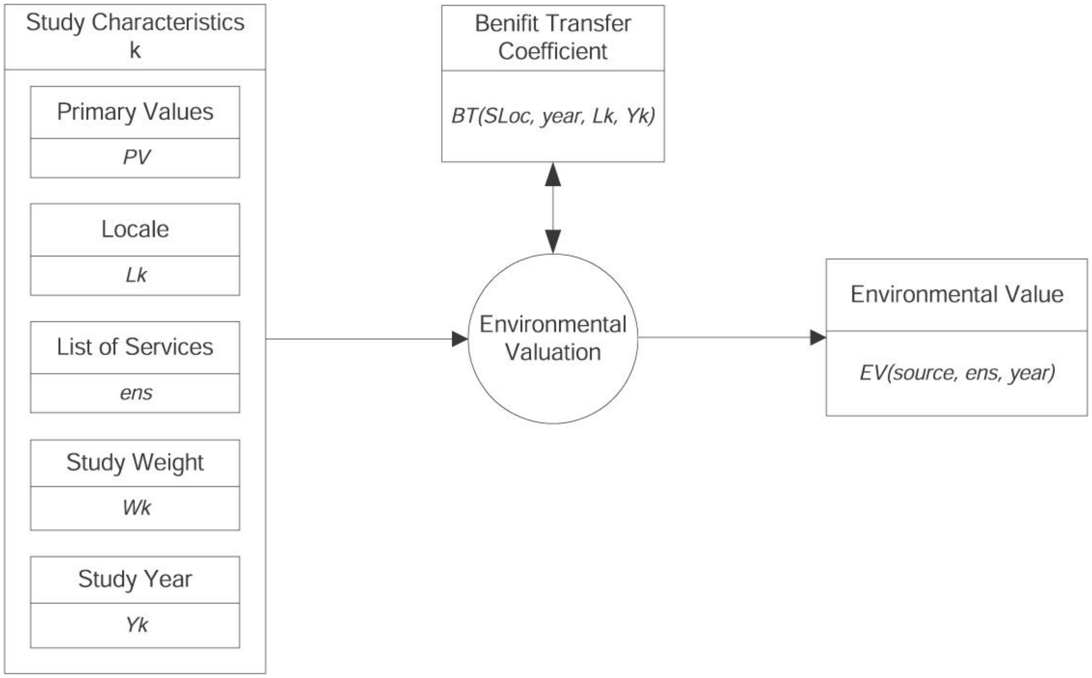


Figure 4: Assignment of an environmental value for environmental services provided by a water supply source.

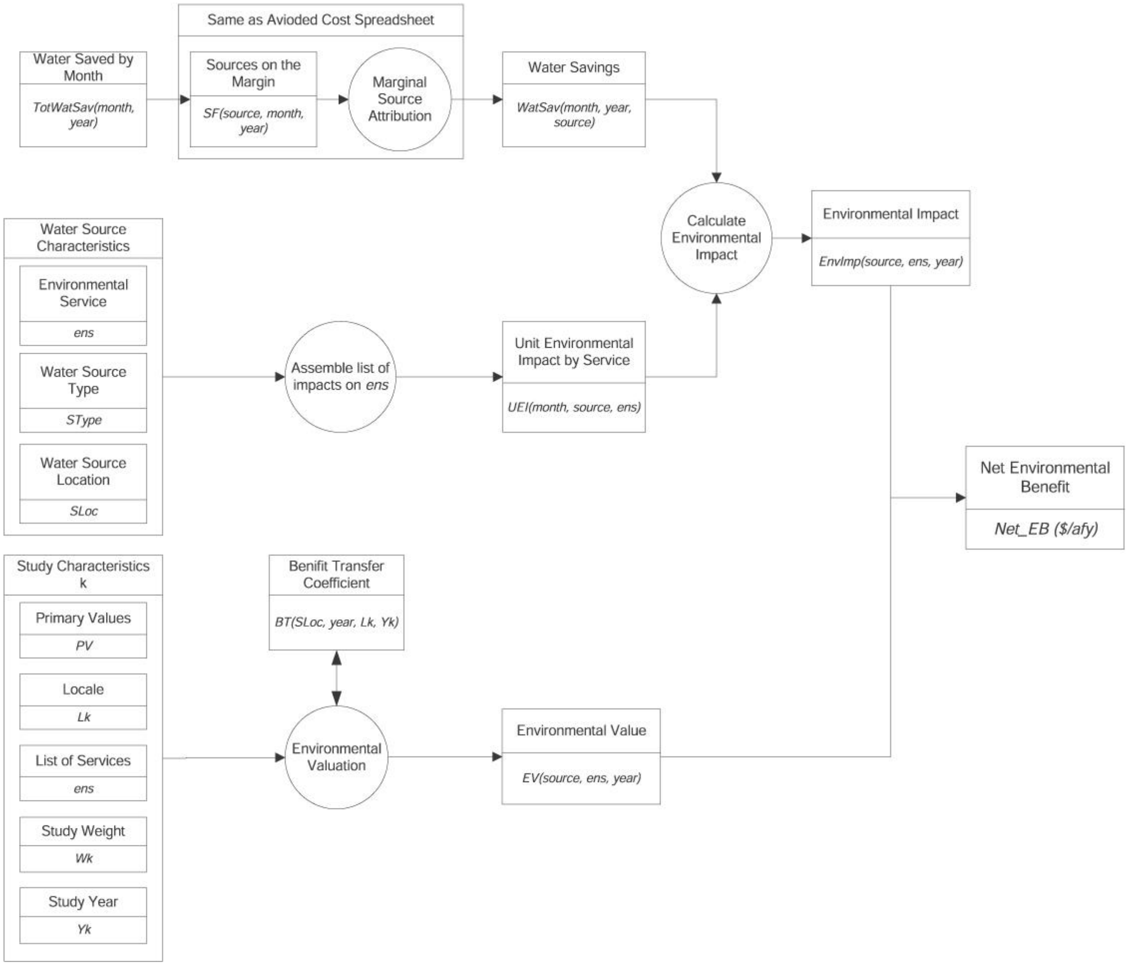
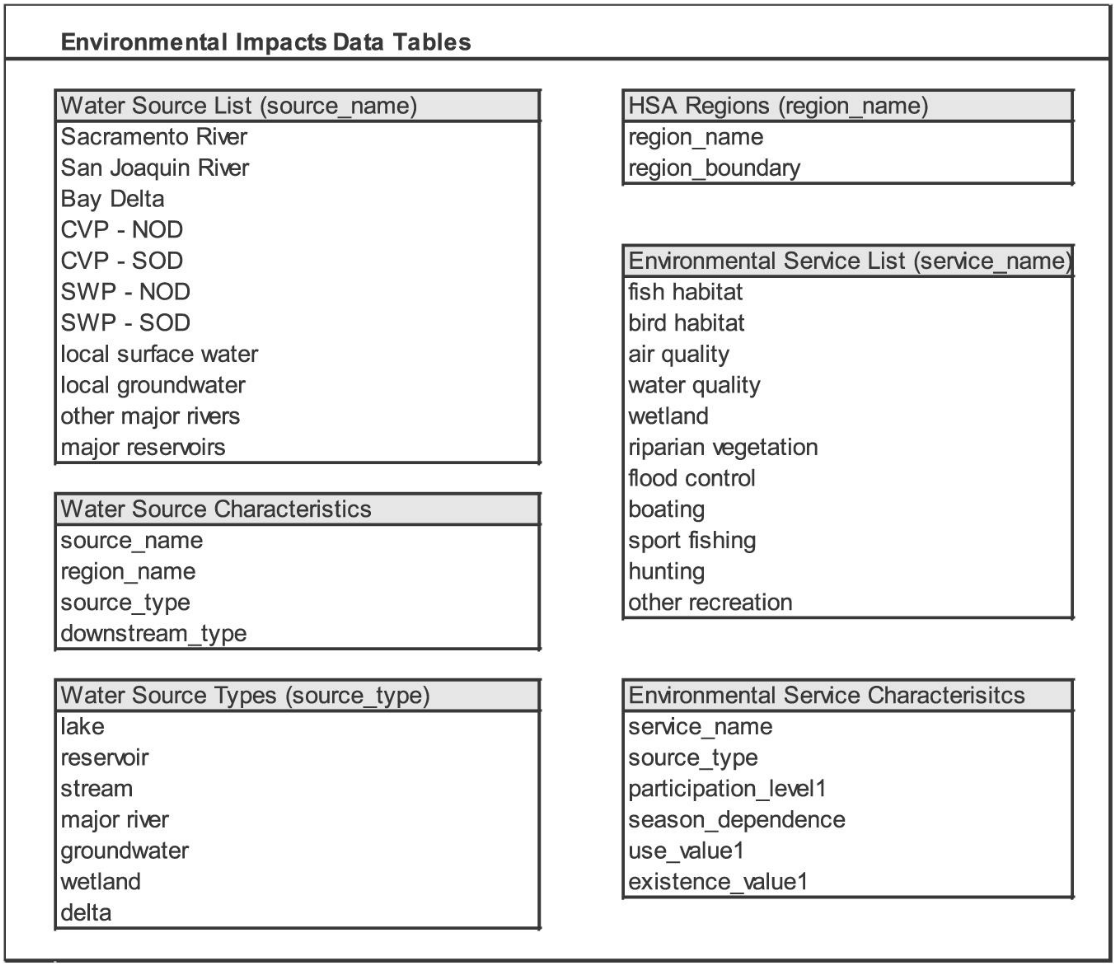


Figure 5: Flow chart of all steps in the calculation of environmental benefits.



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

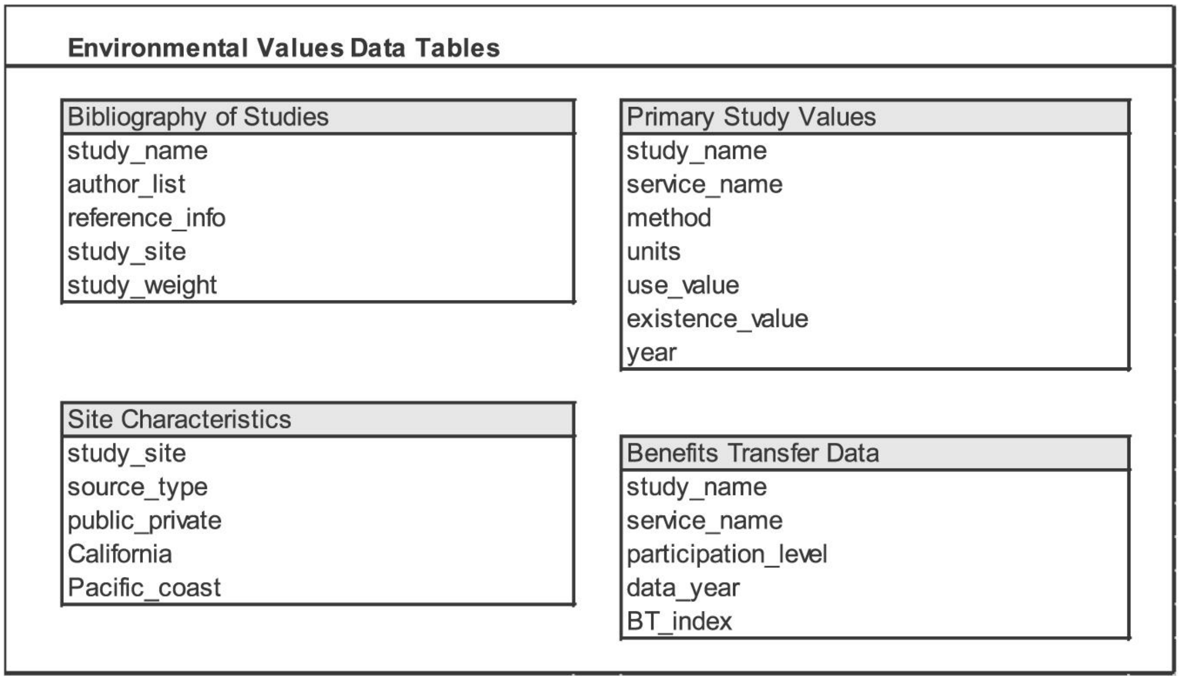
Water Source Types (source_type)
lake
reservoir
stream
major river
groundwater
wetland
delta

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 6: Schematic of environmental service data tables.



Environmental Values Data Tables

Bibliography of Studies
study_name
author_list
reference_info
study_site
study_weight

Primary Study Values
study_name
service_name
method
units
use_value
existence_value
year

Site Characteristics
study_site
source_type
public_private
California
Pacific_coast

Benefits Transfer Data
study_name
service_name
participation_level
data_year
BT_index

Figure 7: Schematic of environmental value data tables.

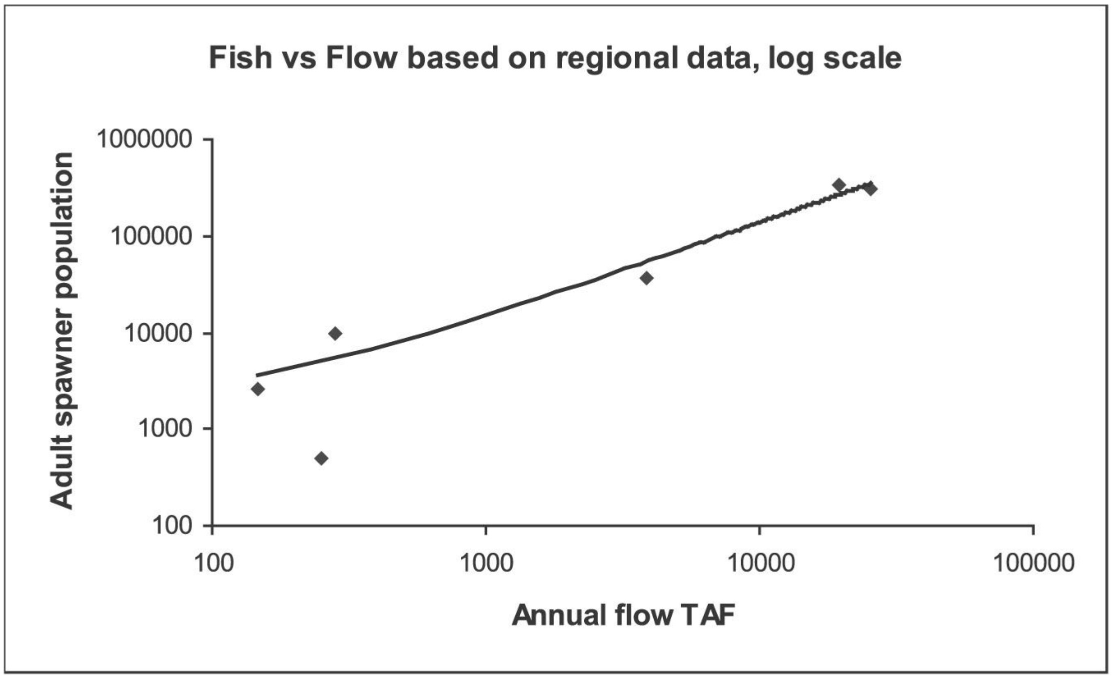


Figure 8: Salmonid fish and flow estimates by hydrologic region (HR), based on current data.

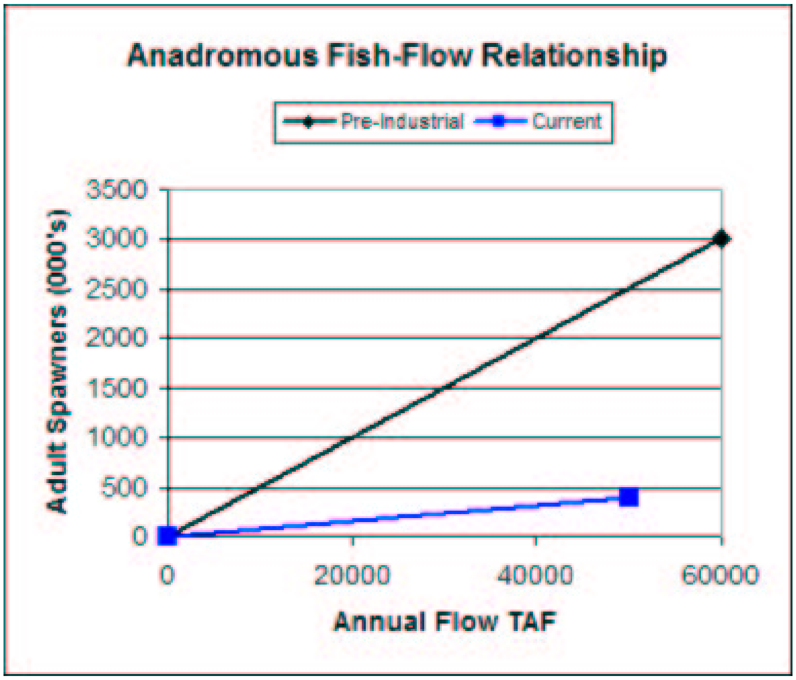


Figure 9: Rough fish and flow counts under historical and current conditions.