TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO.	2. GOVERNMENT ACCESSION NO.	3. RECIPIENT'S CATALOG NO.
WA-RD 418.1		

4. TITLE AND SUBTITLE	5. REPORT DATE
Stormwater Runoff Cost/Benefit Project Prioritizing Stormwater Outfalls	October 1997
	6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S)	8. PERFORMING ORGANIZATION REPORT NO.
Michael E. Barber, Shari Schaftlein, and Dale Anderson	
9. PERFORMING ORGANIZATION NAME AND ADDRESS	10. WORK UNIT NO.
Washington State Transportation Center (TRAC) Civil and Environmental Engineering; Sloan Hall, Room 101 Washington State University Pullman, Washington 99164-2910	11. CONTRACT OR GRANT NO. T9902-12
12. SPONSORING AGENCY NAME AND ADDRESS	13. TYPE OF REPORT AND PERIOD COVERED
Washington State Department of Transportation Transportation Building, MS 7370 Olympia, Washington 98504-7370	Final Report
	14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

This study was conducted in cooperation with the U.S. Department of Transportation, Federal Highway Administration.

16. ABSTRACT

Environmental mitigation of storm water runoff from highways and bridges is becoming a critical part of every new project. When deciding which projects should be constructed first, it is necessary to determine which project provides the best return on investment. Determining environmental benefits has been difficult because it is hard to place a dollar value to reducing or elimination pollution. The goal of this research was to establish a scientifically justifiable approach for evaluating the benefits of environmental enhancement. The report documents the literature review and the Condition Indexing methodology adopted. A support program was developed for Windows 95 and NT operating systems that enables users to quickly evaluate and compare projects. The final result is a B/C ratio for each project. Since the costs associated with construction are well known, the gross benefit can also be determined.

17. KEY WORDS	18. DISTRIBUTION STATEMENT
Condition indexing, environmental enhancements, project evaluation, environmental mitigation	No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22616

19. SECURITY CLASSIF. (of this report)	20. SECURITY CLASSIF. (of this page)	21. NO. OF PAGES	22. PRICE
None	None	99	

Final Report
for
Research Project T9902-12
"Stormwater Runoff Cost/Benefit"

Stormwater Runoff Cost/Benefit Project

Prioritizing Stormwater Outfalls

by

Michael E. Barber
Assistant Professor
Washington State University

Shari Schaftlein
Water Quality Specialist
WSDOT

Dale Anderson
Principal
Entranceo

Washington State Transportation Center (TRAC)
Washington State University
Department of Civil & Environmental Engineering
Pullman, WA 99164-2910

Washington State Department of Transportation
Project Manager
Mark Nelson

Prepared for

Washington State Transportation Commission
Department of Transportation
and in cooperation with
U.S. Department of Transportation
Federal Highway Administration

October 1997

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Executive Summary

Municipal, state and federal construction projects are normally evaluated on the basis of total benefit versus total cost which results in a benefit/cost (B/C) ratio. In fact, the 1995 Highway Runoff Manual created by the Washington State Department of Transportation states "BMPs for existing impervious runoff will also be installed whenever the benefit derived from immediately retrofitting the roadway can be shown to outweigh the cost of installing the BMPs." Project costs include land or right of way acquisition, engineering, environmental mitigation, construction and annual operating and maintenance. Project benefits include items such as direct revenues or fees, job creation, education, reduced travel time, flood control and accident prevention. Benefits for public works projects are often difficult to quantify because, unlike private projects where benefits are narrowly defined in terms of profit, many public works benefits are intangible, nonmarket, or very subjective. This is especially true for projects involving environmental mitigation of storm water runoff since the benefits are never present as direct revenues.

The objectives of this research were to conduct a thorough review of the literature and use this information to develop a methodology for implementing a fair but simpler means of evaluating benefit/cost ratios. The literature review led to the adoption of a "Condition Indexing" approach which uses information and relational matrices to develop weighting factors. The difficulty was to provide users with an approach given the information generally available during the preliminary planning process. The results led to creation of a Visual Basic program called BEPEM (Benefit Evaluation Program for Environmental Mitigation). This decision support program uses "soft" data based on water quality, BMP selection, receiving stream information, and cost to evaluate a list of potential projects. A B/C ratio for each project is generated on a relative basis. A demonstration of the BEPEM program is presented in Chapter 4 of this report.

The conclusion drawn from this study is that the methodology works and can be implemented on a basin or state-wide basis. However, like many new technologies, the process can still be improved by input and experience from other places. An expert panel may develop improved criteria over time which will substantially improve the process. Moreover, BMP summary sheets developed during the study should be used to track projects and environmental costs as the projects are constructed. This information is critical in filling in some of the exiting gaps in the literature.

Stormwater Runoff Cost/Benefit Project
Prioritizing Stormwater Outfalls

by Michael E. Barber[1], Shari Schaftlein[2] and Dale Anderson[3]

1.0 Introduction

Municipal, state and federal construction projects are normally evaluated on the basis of gross benefit versus total cost which results in a benefit/cost (B/C) ratio. In fact, the Washington State Department of Transportation's Highway Runoff Manual (1995) clearly states "BMPs for existing impervious runoff will also be installed whenever the benefit derived from immediately retrofitting the roadway can be shown to outweigh the cost of installing the BMPs." Political considerations aside, projects which have the highest B/C ratios are the ones chosen for construction. Project costs include land or right of way acquisition, engineering, environmental mitigation, construction, and annual operating and maintenance. Project benefits include a multitude of items such as direct revenue or fees, job creation, education, reduced travel time, flood control and accident prevention. Benefits for public works projects are often hard to quantify because, unlike private projects where they are likely to be narrowly defined as profit directly generated by the facility, many public works benefits are intangible, nonmarket or very subjective. This is especially true for projects involving stormwater quality improvements since the benefits are almost never present as direct revenues.

The B/C process for stormwater retrofits of highways was made considerably more difficult with the passage of the 1987 Clean Water Act whereby Congress mandated that stormwater runoff be treated to the "maximum extent practicable" to control the discharge of pollutants (Tucker, 1990). This has led many local governments to establish highway

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[1]Assistant Professor, Department of Civil and Environmental Engineering, Washington State University, Pullman, WA 99164-2910.

[2]Water Quality Specialist, Environmental Group, Washington State Department of Transportation, Olympia, WA 98504-7300.

[3]Principal, Entranco, Bellevue, Washington, 98004.

stormwater quality criteria or goals for treating stormwater before it is discharged into local waterways. According to Huber (1989), the four general methods by which stormwater quality criteria may be addressed are: 1) best available technology (BAT), 2) best management practice (BMP), 3) water quality based standards and 4) hydrology based controls. Regardless of the method chosen, one fact remains perfectly clear, stormwater controls for environmental mitigation will cost money to construct. Since 85 percent of all money allocated to WSDOT for highways, $1.29 billion for the biennium, are specifically for roadway improvements and preservation projects, the amount of money spent on BMPs is significant (Molash, 1996).

While environmental mitigation costs should be included in project cost estimates, environmental enhancement of waterways should also be treated as benefits. Arguably, this is where the real difficulty begins because there is a considerable amount of uncertainty which goes into these calculations. The two most complex questions which must ultimately be answered to determine project benefits are: (1) How effective is the proposed treatment? and (2) How much is the improvement in stormwater quality worth? Numerous attempts to resolve this first question have been made with varying degrees of success (e.g., Nix et al., 1988; Wigmosta and Burges, 1990; Segarra-Garcia and Loganathan, 1992; Hastes and James, 1994). In addition to being overly complex for developing planning and management strategies, most of the studies have produced results indicating that the effectiveness of most control methodologies are quite variable.

To account for the variability, Driscoll et al. (1990a,b,c) developed a decision support system based on a pollutant loading and impact study conducted for the Federal Highway Administration (FHWA) and on Di Toro's (1984) probabalistic stream quality model. The result was a model capable of assessing the impacts of highway runoff on receiving streams for a specified control measure.

The latter question has been studied primarily in terms of site specific benefits and usage (e.g., recreation, commercial fishing) rather than improvement in water quality. As pointed out by Heaney (1989), however, very little information is available concerning the relationship between water quality and benefits. The United States Environmental Protection Agency (EPA) conducted a study concerning the economic benefits of urban stormwater runoff controls in which they concluded that wet ponds, constructed wetlands, and other runoff controls could raise

property values by as much as 28 percent (US EPA, 1995a). The study also concluded that commercial property owners benefitted as well by realizing lower vacancies, lower tenant turnover and higher rental prices.

The impact at the project planning stage is severe. Consider the specific case of highway construction where the roadway is either being widened or new pavement is being added to facilitate additional traffic. Because this is a common problem facing most state and local transportation departments, construction cost estimates can be obtained with a reasonable degree of certainty. Since costs are real and quantifiable and benefits are imperceptible and difficult to determine, many agencies tend to discount or exclude the environmental enhancement benefits. Traditionally, this has spelled doom for environmentally conscientious projects because quality control measures only contributed to the cost side of the equation, thus resulting in lower B/C ratios and lower priorities for these projects.

Recognizing this consequence as a deficiency in the management of stormwater resource dollars, this study attempts to provide a reasonable framework for establishing benefit/cost factors based on intrinsic interpretation of data typically available during the planning stage. A technique for evaluating projects based on "soft data" called condition indexing has been developed and implemented in other fields (Hudson, 1992). Recently, the method has been applied to the reliability of embankment dams (Andersen and Torrey, 1995). This qualitative approach to stormwater planning and management is new and the values selected for the various factors will be subject to much debate. Nevertheless, it is an important starting point for managers in need of simple evaluation tools for project selection.

Literature Review and Background Information

2.0 Background

The State of Washington Department of Transportation (WSDOT) recently recognized the positive values in environmental restorations. This realization has been converted into policy by allowing projects to assume a B/C of 1 for retrofit costs. However, while this appears to alleviate some of the excess burden, it does not succeed in eliminating the penalty for environmental enhancement. For example, two similar projects each costing $250,000 and providing $750,000 in benefits would have B/C ratios of 3:1. Using the WSDOT approach, if environmental BMPs costing $50,000 were added to Project 1, the result would be that Project 1 would cost $300,000 and produce $800,000 in benefits for an overall B/C ratio of 2.67. Since this B/C is less than the other project B/C, the decision would be to construct Project 2.

A simple solution might be to rank all projects with environmental benefits as priority projects. Unfortunately, this approach would be viewed as impractical by most people because there are real safety and strategic planning concerns which any transportation plan must adequately address. This illustrates a very crucial point concerning condition indexing. As important as comprehending what the condition indexing ranking scheme can and should do, it is equally imperative to understand what it should not do. The criteria of the index must be properly weighted so as not to overly emphasize any particular area of a project. In evaluating two projects with the same B/C ratio but where only one has environmental benefits (such as in the previous example), the index should rank the one with environmental benefits as the higher of the two projects. However, an index which eliminates what would be the highest B/C ratio ranked project simply because it doesn't have an environmental restoration component is skewed too much towards environmental benefits. With this constraint in mind, the following interaction matrix is proposed and developed into a condition indexing formula.

In summary, the remaining problems are: (1) prioritizing the overall best projects across a wide range of multi-objective goals, and (2) finding a useful common denominator to evaluate projects. In other words, the solution must first identify the list of multi-objective goals and priorities within the proposed project. The solution is further complicated by the fact that

different goals have different measures of successfulness and usefulness to society. In simple terms, once the apples and oranges in the basket have been identified, you still can't add apples and oranges together unless you can establish an equivalent basis for comparison.

The first step in solving the problem is to understand the overall transportation planning process. A conceptual example of the WSDOT approach is illustrated in Figure 2.1. As shown in the figure, the State of Washington transportation policy plan consists of four main blocks where decisions are made concerning the projects that ultimately will be constructed. At the top of the decision tree is the overall long-range view of the delivery and performance of the transportation system. This view guides the preliminary selection of projects which will be examined in the system plan. Under the system plan, ten years worth of potential projects are scoped based on service objectives, system deficiencies and their solutions. Fiscal constraints are not enforced until the end of the process. In recent years, this process has led to approximately $28 billion for proposed projects.

The first financial screening mechanism reduces the list of projects to those which fall under the ten year projected revenue forecast (currently estimated to be $18.6 billion). The revenue is projected to rise so current biennial expenditures are actually less than $18.6/5 = $3.72 billion. Under the priority programming tasks additional benefit analysis and program trade-off evaluations are conducted to further reduce the project list to coincide with currently available revenue. Figure 2.2 illustrates the priority programming structure and the competing hierarchy of the various tasks. Once complete, this results in the final highway construction program for the current two-year budget period. This information is used to update the transportation policy plan.

The second step in addressing the problem is to comprehend the full range of current solutions. The solutions can involve an in-depth review of each specific component of basin development plan or can involve looking at selected parameters as indicators of overall basin impact or plan suitability. Both types of solutions are examined in more detail below. Many different solution methodologies have been proposed. These can be represented using continuous demand systems such as traditional travel cost models, or in discrete choice models such as typical multinomial logit models, or random utility models. Because of their inherent

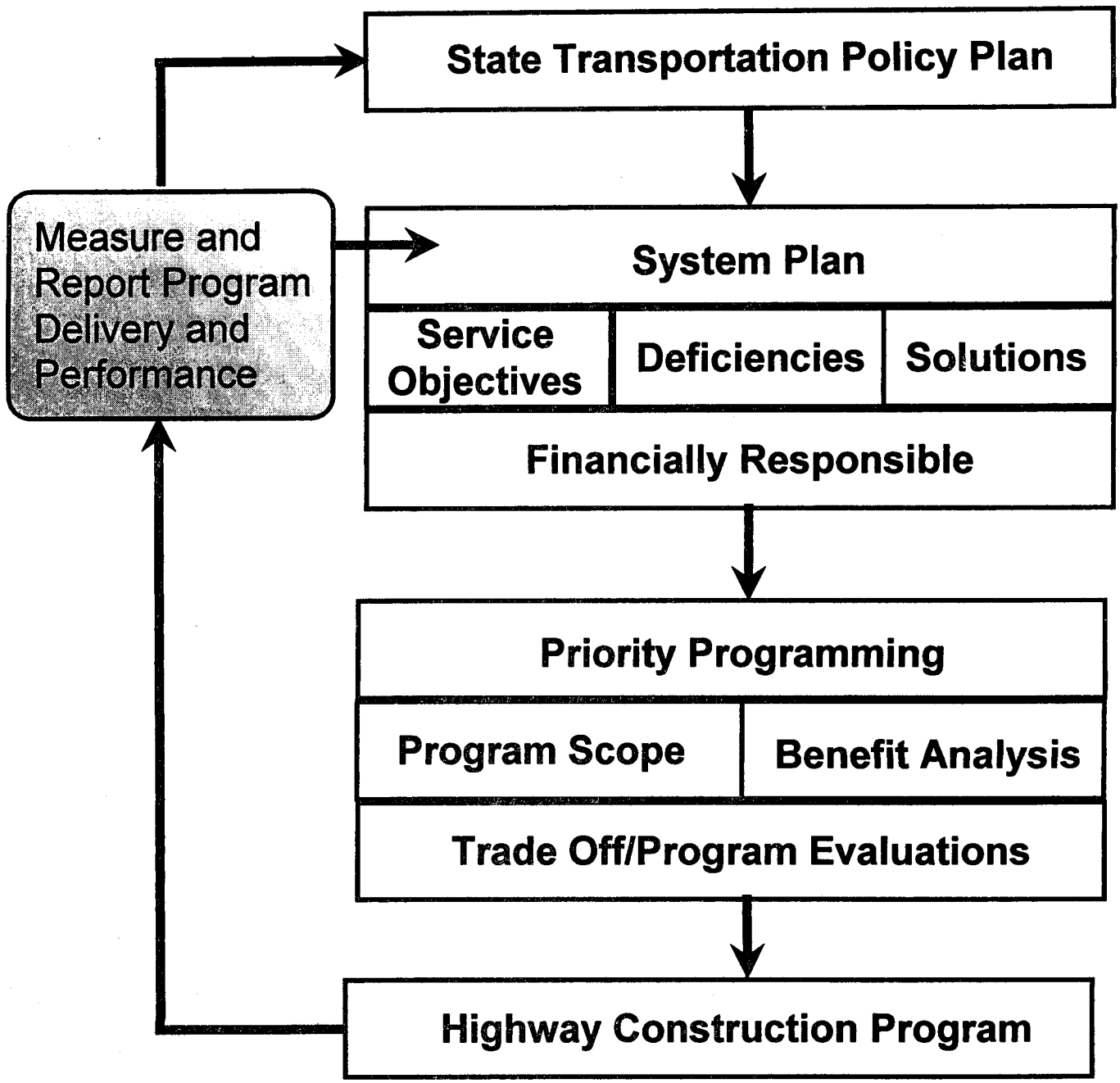


Figure 2.1 Implementing Transportation Policy Schematic

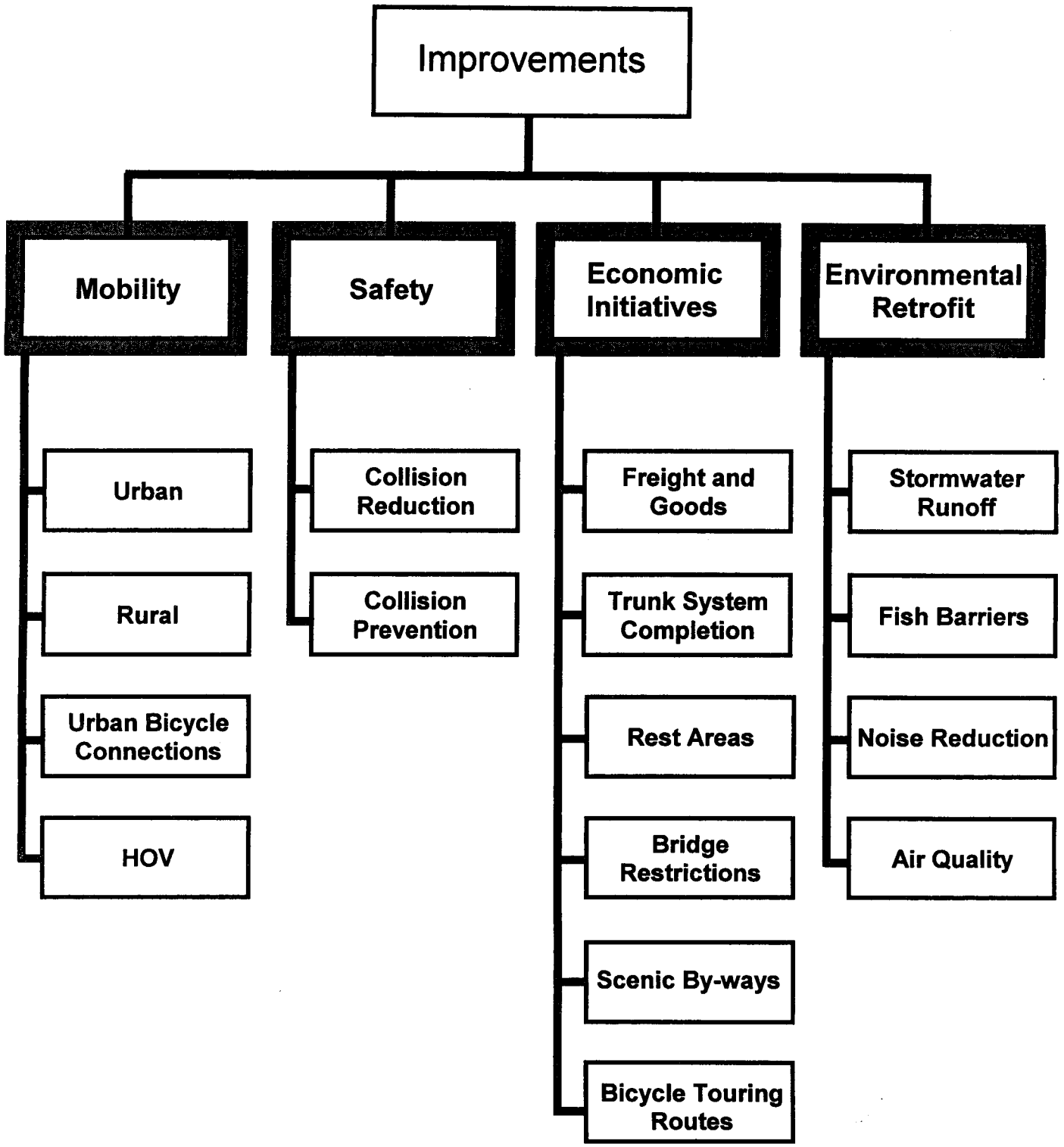


Figure 2.2 Detailed Structure of Priority Programming Block

complexity, few have been all encompassing. Instead, scientists and engineers have tended to focus on a very narrow aspect of the overall basin development plan. Brookshire and Neill (1992) concluded the volume of research that has gone into developing hedonic price, travel cost and contingent valuations methods was too voluminous to list. Instead they directed interested readers to a number of papers by Freeman (1979), Atkinson and Crocker (1987), Murdock and Thayer (1988), Mitchell and Carson (1989), and Smith and Kaoru (1990) to cite just a few. However, in spite of the amount of past investigation, their research also revealed that development of methodologies and frameworks was incomplete especially in the relatively new area of using contingent valuation data in benefit transfer applications.

Peters et al. (1995) point out that ***random utility models*** have become popular tools in assigning economic benefits from environmental quality changes. In their example, the researchers define a *utility function*, U, as the utility of selecting a particular choice or site. This can be written in equation form as:

$$U_i = V_i + \epsilon_i \tag{1}$$

where V is the systematic component, ϵ is the random component and i is a subset of the mutually exclusive choices (C_n). The systematic component is that part of the utility function that includes the site attributes and the characteristics of the decision maker. The random component accounts for uncertainties involving unexplained changes in consumer tastes, incomplete information and researcher error.

For a particular site i, the systematic component of Equation 1 can be expressed as:

$$V_i = \sum_{k=1}^{n} \beta_k X_{ki} \tag{2}$$

where β_k is the parameter to be estimated, X_{ki} is the value of each independent variable at site i, and n is the number of independent variables. Equation 2 must be repeated for C_n choices or solutions.

Assuming that the random component values are a Type 1 extreme value (Weibull) distribution, the probability, P, of selecting a choice i can be written as:

$$P(i) = \frac{e^{V_i}}{\sum_{j \in C_n} e^{V_j}} \quad (3)$$

In their example, Peters et al. (1995) used fifteen (15) independent variables to help determine the site anglers would select. A survey of 2115 respondents, out of a total of 5000 questionnaires, was used as the primary source of data. The study then used the Hanemann (1982) compensating variation measure of the change in consumer's welfare to calculate the effects of changes involving site closures.

The complexity of even a relatively simple single-objective process is demonstrated by the study conducted by Peters et al. (1995). Moreover, Horowitz and Louviere (1990) suggested that the choice set formation and models of selection from the choice set may share attributes and have correlated error processes. This would significantly increase the complexity of the model formulation and probability calculation. Many multi-objective plans would have similar correlated processes compounding difficulties in determining the value of different components.

Putting aside the difficulty in comparing different components, these types of solutions have one major drawback...cost! A complete basin evaluation and environmental impact statement may cost more than the proposed roadway improvement project. Investigation of existing water quality conditions alone may prove prohibitively expensive depending on the number of pollutants examined and the frequency of measurement. Obviously such a study is not feasible. In such instances, grouped-factored solution techniques are essential.

For large and multi-objective problems, it is necessary to group a number of individual factors together so that Equation 2 remains manageable. This may still lead to a large number of independent variables but the categories will be much broader. One major obstacle in these broader investigations is predicting the same conclusion as would have been determined using a more detailed analysis.

Loomis (1996) used the ***contingent valuation method*** (CVM) to determine the nonmarket economic value of restoring salmon and steelhead runs to the Elwha River on the Olympic Peninsula in Washington. The CVM uses a standardized survey technique for estimating the public's willingness to pay existence, recreation, and bequest (future generations)

values (Mitchell and Carson, 1989). According to Loomis (1996), CVM is recommended for performing benefit-cost analysis by Federal agencies (US Water Resources Council, 1983) and for valuing natural resource damages (US Department of the Interior, 1986) and was upheld by the Federal courts (State of Ohio versus US Department of Interior, 1989). Opponents of this method argue about the accuracy and unbiasedness of the information contained in the survey as well as the survey implementation. The precise wording of the questions can sometimes influence the answer. Biased responses can be obtained when a large percent of the individuals polled do not answer the survey or where a local community has an unduly large personal stake in the outcome. However, a blue-ribbon panel recently decided the CVM produced reliable enough estimates to be the starting point for administrative and judicial determinations (Arrow et al., 1993).

After checking for what Cummings et al. (1986) called "researching their preferences", a typical CVM survey identifies the problem, proposed solution, outcome and finally sets a random cost (within some feasible range). The respondents *vote* whether or not they would be willing to pay the cost shown on their survey. Hanemann (1984) found that the dichotomous choice coupled with varied dollar amounts permitted a statistical function having the following relationship:

$$Prob(Yes) = 1 - \frac{1}{1 + \exp[B_o - B_1 * \$Cost]} \tag{4}$$

where B_0 and B_1 are coefficients estimated using logistic regression and \$Cost is the dollar amount each respondent was asked to pay. The mean (expected) value of societies willingness to pay (average worth) is presented as (Hanemann, 1989):

$$Average\ Worth = \frac{1}{B_1} \ln[\ 1 + \exp(B_0)\ ] \tag{5}$$

Sanders et al. (1990) investigated a procedure for determining the total value of protecting rivers. Their study of the 15 most valuable rivers in Colorado found that in addition to recreational value, the sites had considerable worth in Option Value, Existence Value and

Bequest (future generation) Value. Their willingness to pay per household for increments in river protection, based on 1983 dollars, were as follows:

Recreation Value	$19.16
Option Value	$15.97
Existence Value	$27.67
Bequest Value	$36.19
TOTAL VALUE	$101.12

The results of this study indicate fundamental changes in traditional contingent valuation policy should be considered. Most federal guidelines (US Water Resources Council, 1979; 1983) value water based on national economic development (e.g., recreational, shipping) and environmental (e.g., conservation, restoration, or creation of natural and cultural resources and ecological systems) benefits rather than including the off-site value, but clearly this is not the case. Moreover, the Sanders et al. (1990) study indicated that as more stress was placed on the system, the higher the benefits could go. This conclusion matched similar studies by Fisher et al. (1972) and Smith (1972) which also demonstrated that environmental protection benefits would rise over time due to a fixed supply of natural environments.

Other researchers and economists argue that there may be an upper limit to the nonmarket benefit. In their study of the public's willingness to pay for boatable, fishable and swimmable quality water, Carson and Mitchell (1993) reported several important facts concerning both the applicability of contingent valuation studies and the economic value of pollution control efforts. For example, their study seemed to verify the concern of Hoehn and Randall (1989) and Hoehn (1991) concerning the over prediction of independently derived benefit estimates conducted for regional areas which were aggregated together to obtain national benefits. Carson and Mitchell (1993) recommend that national probabilistic sampling be conducted to predict the willingness to pay as a function of the level of water quality, income, recreational use and environmental attitudes.

As a result of their national survey, Carson and Mitchell (1993) also reported the following adjusted mean annual household values for national water quality benefits:

Boatable	$ 93
Fishable	$ 70
Swimmable	$ 78
TOTAL	$242.

The total had a standard deviation of $19 and a 95% confidence interval ranging from $205 to $279. Using these figures, the study concluded current benefits outweighed current costs but that meeting anticipated tightening of swimmable quality water regulations in all rivers would escalate total costs beyond the feasible limit. Citing a study by Lyon and Farrow (1993), the authors contended that regulations should carefully decide whether higher marginal costs offset any anticipated benefits.

The Washington Department of Fish and Wildlife (WDFW) and the Washington Department of Natural Resources (DNR) conducted a joint study on prioritizing watershed restoration and conservation on a state-wide basis (WDFW/DNR, 1995). After examining 18 methods currently used, or proposed for use, in the west coast region, the study selected a modified form of a prioritization scheme developed by the Pacific Rivers Council called the **Bradbury Process**. The WDFW/DNR approach evaluated watersheds by combining the following four priority factors:

1) Habitat Integrity and Risk of Change
2) Species Diversity and Population Abundance
3) Stocks at Risk and Species of Concern
4) Opportunities for Success.

Only 1 of the 18 prioritization schemes attempted to factor in benefit/cost analysis. That was a WDFW study involving culverts blocking fish passage. Unfortunately, this scheme was not selected so the WDFW/DNR approach does not factor in cost. The study does, however, introduce the concept of normalizing each category so the overall score is permitted to be ranked on a relative basis. For example if the high score in the water quality category was 7 out of 10, all of the scores were multiplied by 10/7. This eliminates some of the perceived notion that a project receiving 70 out of 100 is an "average" project. Instead, it can score a perfect 100 if it is

the best overall project in every category.

Limitation of Previous Studies

After President Reagan signed Executive Order 12291 requiring all new major regulations be subject to benefit-cost analysis, the US EPA developed guidelines for performing its own B/C analyses (EPA, guidelines for regulatory impact analyses, 1982). The EPA stated that "off-the-shelf methodologies and studies can serve as the basis for B/C analysis." In other words, B/C should be inferred from existing studies. Economists refer to this as "*benefit transfer*" (Desvousges et al., 1992). The location of the original study is called the "*study site*" while the location under consideration for the improvement or change is referred to as the "*policy site*." In their study of the conceptual problems of using benefit transfer, Desvousges et al. (1992) identified five "major" implementation problems. The problems mentioned in the study were: (1) determining the proper market size, (2) extrapolating willingness to pay estimates to smaller actual changes in water quality, (3) failing to consider the relationship between site characteristics, location, and value of improvements in a meaningful way, (4) computing usable estimates for substitute prices, and (5) addressing different categories of user and nonuser benefits. The study concludes that more work needs to be performed on benefit transfer models before such models can be used for deciding policy benefits.

To some extent, the approaches discussed above all include one or more of the limitations pointed out by the Desvousges et al. (1990) study. Loomis (1992), for example, concluded that cross-state benefit transfers involving Oregon-Washington ocean sport salmon fishing and Oregon-Idaho freshwater steelhead fishing or other identically defined activities are likely to be inaccurate. Not surprisingly, Loomis et al. (1995) reached the same conclusion on transferring recreational demand models for three Corps of Engineer reservoirs. However, as pointed out by Brookshire and Neill, one cannot simply ignore the problem because a dichotomy exists. What is needed is that benefit transfers be examined with the rigorous attention to detail as is benefit estimation. To accomplish this goal, advances are needed in nonmarket valuation theory and rigorous testing of hypothesis.

Criteria Determination

Exactly which criteria to use in evaluating the environmental benefits, although perhaps somewhat better defined than benefit transfer, still needs some clarification. In fact, excluding one dominant criteria from the list can dramatically bias the entire process. However, selecting the appropriate criteria must be balanced by a rational assessment of the data which is likely to be available at the time the review is being conducted. For example, is it likely that the engineer or planner will know all of the biological species downstream of the outfall or project site? If the answer is NO, then trying to assess the precise impact of small changes in different pollutant levels is probably a waste of time and money. Instead, a more indicator based general approach should be adopted. If the answer is YES, then the criteria should be adjusted accordingly. This example tends to over simplify the potential complexity of the problem. Many questions that could be asked are far more subjective. Moreover, it would be unreasonable to think that anyone would conduct a $50,000 study to see if they should add a $25,000 improvement.

The US Army Corps of Engineers presented a conceptual framework for incremental cost analysis in mitigation planning of their projects (Greeley-Polhemus, 1991). By comparing the outcomes of the "do nothing" alternative to each of the "development" scenarios, incremental cost factors can be developed. As shown in Figure 2.3, the methodology is fairly dependent on the outcomes of habitat assessment models which require a substantial amount of information and subjective interpretation that is not always available for evaluating small to medium sized projects. The approach is also heavily weighted towards aquatic species rather than improved water quality for human consumption.

Snodgrass et al. (1993) presented a framework for managing environmental quality in which the following issues were examined:

a. flooding

b. erosion

c. surface water quality

d. ground water (quality and quantity)

e. natural features (wetlands)

f. aquatic communities

g. recreation

h. aesthetics (water, valleyland)

i. terrestrial (wildlife, woodlots), and

j. receiving body.

Using these ten topics as general criteria, Snodgrass et al. (1993) developed a subbasin framework that emphasized areas similar to those shown in Table 2.1. Each of the categories could be further broken down if additional clarification in needed. For example, under habitat requirements, ecological objectives could be developed for each of the following habitat niches:

i) native cold-water fishery,

ii) self-sustaining cold-water fishery,

iii) non self-sustaining cold water fishery,

iv) cool-water fishery,

v) warm water fishery, and

vi) community composed of tolerant species.

The level to which the habitat niches can be subdivided should coincide with the amount of available data. Once again, except for identifying future deficiencies, it does not do any good to pick a criteria to which the answer is always "not sure." It should also be noted that the "Quality of Life and Land Ownership" category in the study performed by Snodgrass is not mutually exclusive to the other factors listed in Table 2.1. For example, factors such as water quality, public safety, and ecologic habitat all contribute to the quality of life.

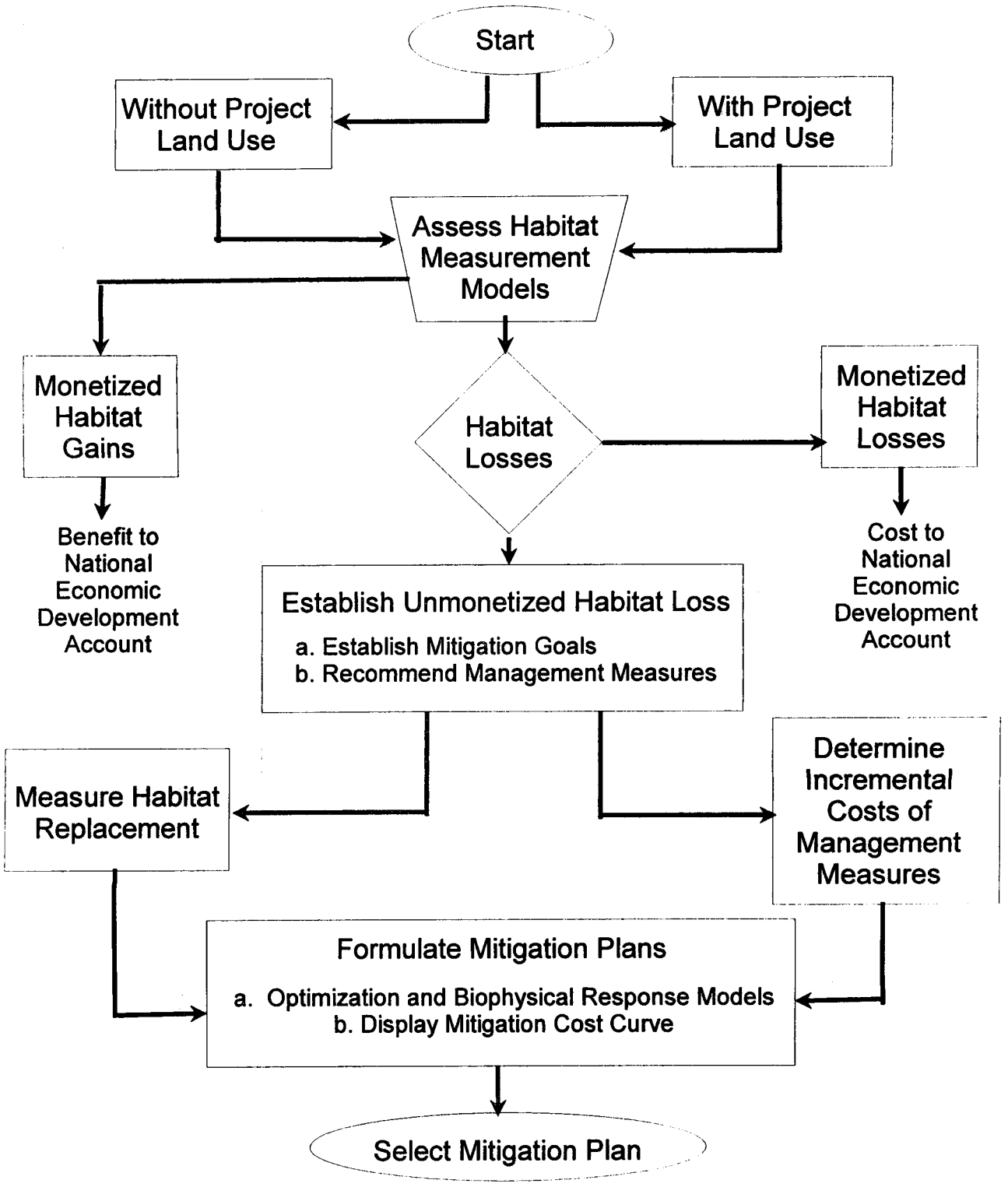


Figure 2.3 US Army Corps of Engineers Schematic for Environmental Mitigation Planning (after Greeley-Polhemus, 1991)

Table 2.1 Conceptual Ecosystem-Based Environmental Benefit Subdivisions (adapted from Snodgrass et al., 1993)
I. Quality of Life within Ecosystem
A. Linkage to Puget Sound Ecosystem
B. Pride in Local Ecosystem
C. Balance of Economic and Environmental Value
D. Quality of Life and Land Ownership
II. Water Quality and Public Health
E. Contact, Non-contact Recreation
F. Drinking Water
G. Fish Consumption
H. Aesthetics
III. Public Safety
I. Erosion and Flood Protection
J. Risk to Human Life
IV. Fisheries, Riparian and Terrestrial Habitat
K. River Beds as Fish Habitat
L. Sport Fishing
M. Enjoyment of Plants and Wildlife
N. Wildlife and Waterfowl and their Habitats

Similar attempts have been made to quantify the significance of environmental attributes. For example, a 1982 National Fisheries Survey evaluated the responses of biologists to determine the condition of receiving waters based on a mixture of biological and chemical data and subjective judgements (US EPA and USFW, 1984). The study produced the results shown in Table 2.2. When examining the factors affecting the rankings, Heaney (1989) pointed out that nearly 70 percent of the adverse impact was associated with turbidity, high water temperature, and nutrient surplus. Toxic substances (e.g., heavy metals) accounted for less than 10 percent of the impact. Except in small streams, this was the first category in which highway BMPs would be expected to make the largest contribution in terms of pollutant removal. The effect of individual BMPs at reducing turbidity and water temperature for a larger stream has not been well documented and the nutrient concentrations associated with highway runoff are typically low compared to other sources.

One of the questions raised by the Heaney (1989) study involved how to measure performance. Ultimately the cost effectiveness of any BMP will depend on what is the goal and what constitutes a success versus a failure. Heaney concluded that no single measure of performance or effectiveness existed and primary reliance was still placed on specifying a required level of treatment.

Table 2.2 Biologist Ranking of Stream Attributes

Attributes	Scale Value
Maximum ability to support sport fish and/or species of special concern	5
Medium to High ability (assumed)	4
Low to Medium ability (assumed)	3
Minimum ability to support sport fish or species of special concern	2
Ability to support non-sport fish only	1
No ability to support any fish population	0

Heaney et al. (1979) examined the cost effectiveness of promoting BOD removal from urban runoff. Based on a nationwide assessment, the study concluded that it was not very cost effective to raise the removal rate of BOD to much above 70 percent. Of course, this level will vary dramatically depending on the parameter(s) selected as the performance measure. For example, Pope and Hess (1989) computed load-detention efficiencies in a dry pond. It is important to note, however, that dry ponds are primarily flood control BMPs and are not designed for water quality purposes. Load-detention efficiency was calculated by first subtracting the load out from the load in, then dividing by the load in and finally multiplying by 100 to convert to a percent. As shown in Table 2.3, based on the results from 19 storm events the median removal efficiency ranged from -78.5 to 69.0 percent. Medina et al. (1981) proposed a cost effectiveness criteria based on the number of days the dissolved oxygen concentration fell below 4.0 mg/l. A study for the Metropolitan Washington Council of Governments by Wiegand et al. (1985) recommends BMPs be evaluated based on the amount of nutrients removed divided by the cost of the BMP. Huber (1988) discusses other examples of cost effectiveness analysis applied to urban runoff and combined sewer overflow problems.

The EPA (US EPA, 1995c) published preliminary results of their attempt to assess the effectiveness of municipal and industrial stormwater control programs. The report called for the use of environmental indicators to judge the effectiveness of stormwater management efforts. The indicators were selected from categories such as: (1) water quality, (2) physical and hydrological, (3) biological, (4) whole watershed, (5) social, (6) programmatic, and (7) site specific compliance. Their applicability matrix included lakes, streams, estuaries, land use impacts, industrial sites, municipal programs, and stormwater management programs. Unfortunately the useability of this matrix must be questioned because of the cost estimates associated with some of the indicators. For example, the EPA cites the cost of watershed imperviousness studies as $80,000 to $100,000 plus additional money for each station. BMP performance monitoring is estimated to cost $50,000 to $75,000 per BMP per year. With these costs, any attempt to verify performance would be too expensive.

Table 2.3 Statistical Summary of Load-Detention Efficiencies			
Constituent	Median	Minimum	Maximum
COD	15.5	-57	45
Dissolved Solids	-78.5	-438	-8
Suspended Solids	2.5	-152	45
Nitrate	20.0	-3	33
Ammonia	69.0	10	87
Nitrogen	-9.0	-154	60
Total Phosphorus	18.5	-10	59
Dissolved Phosphorus	0.0	-55	45
Lead	66.0	-783	98
Zinc	65.0	-99	86
Total Organic Carbon	-3.0	-62	34

In another draft report by the EPA (US EPA, 1995b), 21 broad based environmental indicators of water quality are identified. The EPA's objective is to incorporate as many of these indicators as possible into their set of 13 national environmental goals. The two national goals directly related to water use are the "Safe Drinking Water" goal and the "Clean Waters" goal. The Safe Drinking Water goal is for every public water system to consistently provide water that is safe to drink. The Clean Waters goal is for waters to support human health and uses, such as swimming, fishing, drinking, agriculture and industry. The goal also encompasses ecosystem health by sustaining healthy communities of plants, fish, and insects and by conserving and restoring wetlands. These indicators are summarized in Table 2.4. These indicators include many different areas to satisfy the requirements of both the Clean Water Act and the Safe Drinking Water Act. Many indicators are comprised of multiple parameters whose relative significance has yet to be established.

Table 2.4 EPA National Indicators for Water Quality (after US EPA, 1995b).

Comparison of National Goals, Water Subgoals and Indicators		
National Goal	Water Subgoal	Indicator
Safe Drinking Water	Conserve and Enhance Human Health	Source water protection
		Cases from waterborne disease outbreaks attributable to public water systems
		Lead levels in children
		Violations of drinking water standards
Safe Drinking Water Clean Waters	Support Uses Designated by States	Waters meeting: drinking water supply use aquatic life designated use fish and shellfish consumption use swimming and secondary contact use
Clean Waters	Conserve and Enhance Human Health	Fish and shellfish contamination
		Shellfish bed closures
		Disease outbreaks from fish/shellfish consumption
		Disease outbreaks from swimming
		Beach closures
Clean Waters	Conserve and Enhance Aquatic Ecosystems	Species at risk
		Biological integrity of the water
		Wetland acreage
		Habitat quality
		Riparian vegetation
	Conserve or Improve Ambient Conditions	Selected ground water quality constituents
		Selected surface water quality constituents
		Contaminated sediments
	Reduce or Prevent Pollutant Loadings and Other Stressors	Nonpoint source loadings to lakes and streams
		Point source loadings to surface and ground water
		Marine debris

The goals outlined by this plan are ambitious to say the least. The current plan is to have approximately 67 percent of the indicators in place by the year 2005. However, the EPA acknowledges that this plan may be somewhat difficult to implement given the problems associated with uniform data collection and reporting. In fact, some entire indicator classes, such as habitat quality and disease from fish/shellfish consumption, may not be feasible because of the difficulty in obtaining consistent, reliable data.

Given the uncertainty and expense in determining BMP performance, it seems reasonable to predict that any approach which tries to measure performance based on any single parameter is likely to fail. Furthermore, the ultimate goal of WSDOT is to improve the useable quality of the receiving stream or lake. Therefore, one possible strategy would be to develop a *water quality index* which could be used statewide to track changes in water quality. The index would not be tied to a particular BMP; the cost of this activity would be prohibitively expensive given the event variability shown in previous studies. Instead it would be tied to the receiving body of water. Consequently, the index could be used in conjunction with other State agencies and, by publishing a map of water quality indices in the paper, the index could raise public awareness of the environmental efforts supported by WSDOT. The concept of a "water quality index" is a powerful and potentially very useful tool for an organization like WSDOT. Such an index would greatly assist in setting priorities for water quality improvements funds and opportunities for off-site, out-of-kind environmental mitigation.

The water quality index would include several of the important pollutants and water quality indices identified in the EPA 1995 study. Representative factors such as DO, BOD, TSS, fecal coliforms, phosphorus, nitrogen, and lead (and other metals or compounds) could be used to develop a comparative index.

Stormwater Outfall Prioritization Scheme

Using the general model formulation implemented by Peters et al (1995), the WSDOT Olympia Region Staff developed a conceptual framework for evaluating a stormwater outfall prioritization scheme. Stormwater outfalls identified in WSDOT's Outfall Inventory and Field Screening Project were divided into three categories based on the professional judgement of the inventory crews. The high priority outfalls were then ordered according to the variables shown in Table 2.5. When used in conjunction with Equation 2, these prioritization variables produced

a ranking of outfall locations. A detailed explanation of each variable is presented in the following paragraphs.

The **type and size** of the receiving water body was determined for each outfall. General characteristics allowed for the types and sizes to be grouped into ten classifications. The ranking system was adopted from a 1992 Stormwater Runoff Management Report (Entranco, 1992) prepared for the WSDOT. The rationale behind the ranking values comes from the accepted fact that stormwater pollutants will have a greater effect on a small stream than a large stream since the dilution potential is smaller. A small stream was defined as an intermittent or unnamed tributary or creek less than five miles in length. A large stream was greater than five miles in length and a river was designated as such on topographic and county maps. Small lakes were defined as those with surface areas less than 300 acres and, conversely, water bodies having a surface area greater than 300 acres were called large lakes. Wetlands were identified using the relevant Basin Plans and National Wetland Inventory Maps. A sensitive wetland was defined as an area having a unique or rare characteristic or an area containing a rare, endangered or threatened species.

The **beneficial uses** category identified the designated use for the receiving water body. As acknowledged by the Washington State Department of Ecology (WSDOE, 1992), beneficial use categories included drinking water, public health, fisheries, flood protection and aesthetics. For water supplies not listed in this report, beneficial use information was obtained from cities, counties and basin reports. Since most water bodies had several uses, the highest ranking overall designated use was selected.

The **highway contribution to pollutant loading** variable provided a measure of the stormwater runoff from the impervious highway surfaces and related it to the probable pollutant intensity using Average Daily Traffic (ADT) as an indicator. The amount of impervious area within WSDOT's right of way (ROW) draining to an outfall was calculated by multiplying the total length of roadway drained by the width of the road. Each lane of traffic was assumed to be twelve feet wide. The shoulder was ten feet wide. Total drainage basin areas were determined from the Pierce, Thurston and King County Basin Plans or from the USGS publication: Drainage Area Data for Western Washington. Missing information was estimated using a planimeter. The

drainages were then subdivided into areas based on the prevalent types of land uses and assigned runoff coefficients ranging from 0.5 to 1.0. The potential amount of pollution from a road with an ADT of 5,000 vehicles was significantly less than one with an ADT of 50,000 cars. In fact, numerous studies have identified the fact that pollutant loading was directly proportional to the ADT. Traffic loading was broken down into low, medium, high and very high categories. The source of the ADT information was WSDOT's 1992 Annual Traffic Report.

The **off-site pollutant** source accounted for other significant sources of point or nonpoint source pollution which may enter the WSDOT stormwater system. Technically speaking, WSDOT is not responsible for other sources of pollution which may run into their stormwater system. Practically, however, WSDOT officials recognize that it is difficult to ignore the possibility of enhancing total environmental benefits by using remediation technologies in locations where they not only treat highway runoff but also pollution from other sources.

The next several categories concerned the overall cost of the BMP retrofit against its benefit to the receiving waterbody. One concern was the **right-of-way** cost. In metropolitan areas the cost of land would have to include the cost of buildings and businesses since there are few or no vacant lots. This was especial true along the corridor connecting Seattle to Tacoma and Olympia. This factor must also consider the water quality of the receiving waterbody as a measure of its sensitivity to pollution. An average multiplier of 0.5 was used for outfalls that discharge into marine waters, inter-tidal waters, a stream or river which enters marine water within 0.5 mile of the outfall, a lake with more than 300 surface acres unless the lake is nutrient limited, or a Class 3 or 4 wetland. A sensitive multiplier of 1.0 was used for outfalls discharging into all other surface waters, a Class 1 or 2 wetland, or a sensitive ground water system. Wetland classes refer to the classification system used by the WSDOE unless more stringent locally adopted sensitive ordinances are in-place. Sensitive ground water areas were the result of a designated sole source aquifer, a ground water management area or a wellhead protection area. Lake descriptions were obtained from WSDOE studies (1973a,b).

The **capital construction cost of the best management practice** was considered by grouping the BMP costs into four categories: low (<$25,000), medium ($25,000-$75,000), high ($75,000-$150,000) and very high ($150,000+). There were many factors to be considered in

the cost of a BMP such as location, size, grading and construction materials used. Low cost BMPs might include bioswales or retrofitting an existing BMP to improve its performance. The low cost category was chosen when maintenance was selected in lieu of a structural BMP. A medium cost BMP might include a wet pond with a biofiltration swale or an ecology ditch. High cost BMPs might be a large wet pond and a very high cost BMPs might be a vault or sequential BMPs. A complete list of applicable BMPs is presented in WSDOT's Stormwater Runoff Manual (1995).

The **type of conveyance structure** was factored into the ranking by identifying whether the structure was constructed of (1) an impermeable pipe or channel, (2) soil, or (3) vegetation. The rationale was that channels with vegetative surfaces were more likely to provide some treatment of the stormwater runoff prior to discharge. Conversely, an impermeable pipe would not provide any treatment, so making the BMP more valuable.

The **water quality of the receiving water body** was incorporated by identifying the correct category at the outfall.

Information from WSDOT's Project Development Division was used to incorporate **future construction plans** into the solution.

Table 2.5 Stormwater Outfall Prioritization Parameters

Independent Variable Group	β_k	X_{ki}
Type and Size of Receiving Waterbody	1.	Ground water = 10 Small stream = 8 Small lake = 6 Sensitive wetland = 6 Large stream = 5 Large lake = 3 River = 2 Wetlands = 2
Beneficial Use of Receiving Waterbody	1.	Drinking water violation = 20 Drinking water protection = 18 Public health violation = 16 Public health protection = 14 Fisheries violated = 12 Fisheries protection = 10 Aesthetics = 4
Highway Contribution to Total Runoff to Watershed	ADT Count Low = 1. Medium = 2. High = 3. Very high = 4.	% Highway Drainage > 5 % = 5 2-5 % = 4 1-2 % = 3 1/2-1% = 2 < 1/2 % = 1
Off-site Pollutant Loading Source	1.	yes = 1 no = 0

Right-of-Way Cost	WQ multiplier Average = 0.5 Sensitive = 1.0	WSDOT owned land = 4 Rural [low cost] = 3 Suburban [medium cost] = 2 Urban [high cost] = 1 Prohibitive = 0
BMP Capital Construction Cost	WQ multiplier Average = 0.5 Sensitive = 1.0	Low [$0-$25,000] = 4 Medium [$25k-$75,000] = 3 High [$75k-$150,000] = 2 Very High [>$150,000] = 1
Type of Conveyance Structure	WQ multiplier Average = 0.5 Sensitive = 1.0	Impermeable = 4 Soil = 3 Vegetation = 1
Water Quality of Receiving Body	WQ multiplier Average = 0.5 Sensitive = 1.0	303{d} listed = 5 305{b} listed = 5 Sensitive ground water = 5 Class B = 4 Class A = 3 Class AA or Marine = 2
Future Construction Plans	1.	Within boundary = 3 Stand-alone project = 1
Outfall Listed in Watershed Action Plan	1.	yes = 3 no = 0
Cost Sharing Opportunity	1.	yes = 4 no = 0
Watershed Improvement Financial Support	1.	yes = 2 no = 0
Public Relations/Educational Opportunity	1.	yes = 2 no = 0

Permit Obligation	1.	yes = 4 no = 0
Court Mandated Water Quality Standards for Watershed	1.	yes = 4 no = 0
Other Factors	1.	yes = 1 no = 0

Given the current state-of-the-art of economic benefits transfer described in Chapter 2 of this report, this attempt represents a giant leap forward by WSDOT personnel and is certainly headed in the right direction. However, the procedure does not extend to all phases of project planning nor does it encompass all the benefits identified in other benefit transfer studies (e.g., bequest and existence {vicarious} values). The net effect may be to underestimate the value of certain projects. The attempt focuses primarily on the environmental aspects of design planning. In terms satisfying a total systems approach, additional primary factors should be included. Furthermore, the rationale for selecting the point system needs further investigation in terms of correlation, value selection and magnitude. While to a large extent, the experts are likely to disagree on the exact magnitude, a general consensus should be obtainable regarding the factors considered. Moreover, great care must be maintained that selection of one variable is not overly restrictive because of the assignment of weights.

For example, consider the range of weights given to the beneficial use category. There is a 16 point difference between drinking water standard violation and flood protection although both could result in loss of life. If this is the relative importance that experts feel each use should receive then there is no problem. The problem arises when other variables are factored into the solution. The last five variable groups listed in Table 2.5 account for only thirteen points. So conceivably, a person could answer yes to all of these plus provide flood control and still not rank as high as a project providing only a benefit to drinking water standards violation without considering even if the improvement will bring the water quality into compliance. Again, there is nothing fundamentally wrong with this designation so long as the majority of experts agree to

the resulting outcome. The other problem is the breadth of the question. Currently the EPA has drinking water standards for 84 contaminants (EPA, 1995b) but many of these are not associated with typical highway runoff pollution. Barrett et al. (1993), for example, listed 37 constituents reported in the literature involving highway runoff. Farris et al. (1973) sampled only about 20 pollutants in their study for the Washington State Highway Commission and many other researchers only consider 7-15 pollutants when examining highway runoff (MWCOG, 1983; Yousef et al., 1985). As a result, construction of a BMP may not lead to a solution to the drinking water violation.

In summary, a theoretically ideal Benefit/Cost study requires precise knowledge of the following factors:

1. existing uses of water in the receiving stream,
2. planned future uses,
3. existing water quality,
4. pollutant runoff loads,
5. definitive cause-effect quality and health relationships (human and organisms),
6. effectiveness of BMPs in pollutant removal,
7. BMP construction costs,
8. a correlation matrix linking all of the above components, and
9. a monetary conversion factor reflecting the environmental benefit to dollars.

In practical terms, however, knowledge of each of these elements is generally incomplete and is thus subject to interpretation. As pointed out by Yoe (1992), between the "Cost Oblivious" decision making approach and the best case "Ideal Benefit/Cost" analysis is a range which allows for increased information to be incorporated into the decision. An environmental mitigation procedures manual conducted by the US Army Corps of Engineers' Institute of Water Resources defines this type of analysis as either *cost effectiveness analysis* or *incremental cost analysis* depending on the amount of information available (Robinson et al., 1995). The goal is to develop a reliable methodology which uses readily available information to produce the same decision as one would obtain if all the information in factors 1-9 were completely known.

Condition Indexing Approach

3.0 Introduction to Condition Indexing

A relatively new method of rationally allocating retrofit and construction funds is to use a **condition index**. A condition index is a set of rules that defines the physical state of a given problem in terms of a numerical value (Andersen and Torrey, 1995). The central task of condition indexing is to develop scientifically meaningful definitions of condition levels and methods for assessing proposed facilities among similar facilities which are consistent and reliable as relative condition indicators. The concept of condition indexing has been used in a number of engineering applications. Shahin and Knoh (1981) developed a condition index framework of pavements in roads and parking lots. The methodology was revised by Shanin and Walther (1990). Numerous other studies have developed with slight modifications in the specifics but with the same general approach, e.g., (1) divide the system into subunits, (2) rate the condition of each subunit, and (3) combine the subunit ratings into an overall facility index.

Incorporating input from a panel of experts into a developed system is an iterative process. Solving multi-objective problems can be challenging because multiple decisions must be made and conflicts between decisions must be resolved. According to Andersen and Torrey (1995), the following eight issues should be explicitly resolved in the condition indexing process: (1) purpose, (2) function or multiple functions of system facility, (3) facility description, (4) component function, (5) component importance, (6) component interaction, (7) component condition, and (8) conversion to facility condition.

Hudson (1992) utilized these issues to propose a series of seven steps for a total systems approach that efficiently represented the complex interactions between system components. The steps of Hudson's methodology are:

A. Identify specific **objectives** for evaluation, maintenance and rehabilitation activities

B. For each objective in "A", identify the **functional system(s)**

C. Code each **interaction matrix**

D. For each functional system in "B", define ranges between **ideal and failed conditions**

E. Develop **weighting functions** for the condition of each functional system

F. Repeat A-E for all objectives to form the **condition index vector** for the entire system

G. Prioritize the individual objectives to develop **multi-component weighting functions**.

Step A: Identify Objectives

The first step in the Condition Indexing methodology is to identify the specific objectives for which each of the system activities are performed. The objectives must be unique enough to create an easily measurable and unambiguous condition definition for each component of the system being rated. In other words, each component must have a clearly identifiable function per objective.

An example of an overly broad objective is "to maintain highway safety." The reason it is too broad is that some of the components can fulfill multiple safety categories. Consider a typical subunit such as highway safety slopes. For increased highway safety during dry conditions, a wide flat surface may be considered ideal. However, for the purpose of removing water quickly from a road surface this surface should be steep. These result in conflicting components. If safety slope angle is to be considered, a decision has to be made as to whether the role of the slope is more important in one category or the other. Unfortunately, if this decision is made at the component level, it could mask the overall condition index of the system with the possible result that the user will not understand how well the system really performs under the given set of conditions. Therefore, the objective should be subdivided into two or more specific objectives such as (1) provide highway shoulder and (2) remove highway runoff. Each possible objective is placed on a diagonal element in the objective matrix.

According to Andersen and Torrey (1995), the role of the expert panel in this phase of the investigation is to help define the significant objectives and verify that the objectives are specific enough to preclude ambiguous condition definitions for the functional components.

Step B: Identify Functional Systems

The second step in the procedure involved identifying the functional systems of each objective group. The user must be able to identify and determine how each individual

component interacts with the total facility. Hudson (1992) developed a rational approach for describing these cause and effect interactions. A key consideration in the process is to predict how the deterioration or loss of one component can influence the ability of other components to meet or not meet their functional roles.

A simple schematic of the function system matrix is shown below in Figure 3.1. As illustrated in the figure, the diagonal functional elements (1,1) and (2,2) are established so that the interactions can be shown in the off-diagonal boxes (1,2) and (2,1). The influence of functional component 1 on component 2 and possibly vice versa, is also shown in the figure. It is not a necessary condition of the methodology, however, to force component 2 to have an influence on component 1. The important consideration is that the weighting factor adequately address the possible co-dependence. The off-diagonal boxes at this level of abstraction are not meant to fully describe the interactions but rather to convey their general nature.

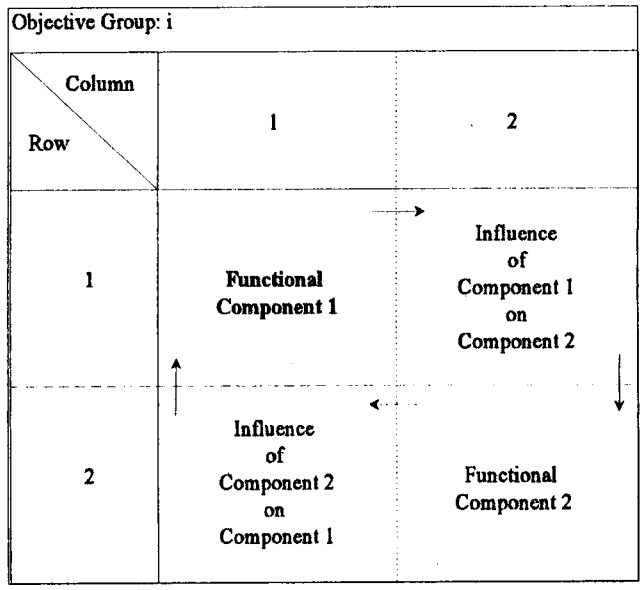


Figure 3.1 Schematic of Functional Component Matrix

The appropriate criterion to use in selecting the matrix resolution is that each component have only one clearly identifiable function. The selection must not leave open to ambiguity the potential for important matrix elements to be excluded. An expert panel would review the matrix to insure all necessary components had been considered.

Step C: Code Interaction Matrix

As discussed by Andersen and Torrey (1995), to identify the functional system components most critical for meeting the objective(s), it is necessary to describe the relative strength of the component interaction(s). Some components may affect only one specific part of the system while other components may influence several system parts. The components affecting the most system parts are the most critical or ***dominant*** components. Using three hypothetical functional components, a typical interaction matrix is coded in Table 3.1. Three functional system components were added to the diagonal objective elements. In this example, Functional Component 3 is dominant because it influences both Objective 1 and Objective 2, while the other two affect only one of the two objectives.

Table 3.1 Interaction Matrix for Functionals and Objectives

Components and Objectives					Index
Functional Component 1			Yes	No	
	Functional Component 2		No	Yes	
		Functional Component 3	Yes	Yes	
			Objective 1 Provide Shoulder		
				Objective 2 Remove Runoff	

The final column in Table 3.1 is titled "Index". This represents the sum of the normalized condition index values in each row. Instead of a simple 'yes' or 'no' response as illustrated, an expert panel assigns a ranked score of the relative impact of the 'yes' responses above each objective. Once this is normalized, the indices are summed horizontally and put in the column. This approach is discussed later in the procedure (Step 5).

It may be necessary or desirable to have more than one matrix. Ideally it would be desirable to have all of the total system interactions expressed on a numerical expression. It is easy to see that the size of the matrix can become large very quickly. Having additional matrices can help prevent the matrix from becoming too large to wield. Typically, more than 12 to 15 diagonal elements is sufficient to start causing confusion. Also, often projects have questions which have to be asked at several levels and multiple matrices are a good way of separating the ideas.

Step D: Define Ranges for Ideal and Failed Conditions

Two of the most important aspects of the proposed methodology involves defining what constitutes the ideal and the failed conditions for each functional system component and converting this into rules that determine intermediate conditions. It establishes the link between the actual physical condition and its numerical condition index.

There is little guidance in the literature with respect to defining ideal and failed states for many of the environmental components that must be rated in the condition index system. This is true even for water quality where specific concentrations are used to define the designated use of a waterway but little information on deterioration of water quality with the use bracket. For example, if the drinking water standard for a substance were 1.0 mg/l and the fisheries standard were 5.0 mg/l, does permitting the water quality to degrade from 1.1 mg/l to 4.9 mg/l represent a failure and, if so, how much of one? Obviously the water quality has deteriorated, but since it has not forced any real change in beneficial use, what is the importance placed on the deterioration? This can be made even more complicated if another water quality parameter is improving at the same time. What then is the net effect of the two changes? Perhaps the best solution would be for an expert panel to focus on deviations from the so called "ideal" conditions and reach a consensus concerning the loss of functionality.

After determining the ideal and failed conditions it is necessary to describe the method(s) by which the conditions will be evaluated. This evaluation can be made through visual observations, interpretation of instrumentation, engineering analysis, engineering judgement, or some combination of two or more methods. For example, low dissolved oxygen concentrations can be measured with a meter or someone may have reported fish "gasping for oxygen" during the latest fish-kill. Because of the potential cost of implementing a new sampling procedure, the best solution is one that involves using existing inspection or sampling procedures.

Step E: Develop Weighting Functions

Another critical aspect involves combining the functional system components into a condition index for the entire project. To complete this task, the relative importance or likelihood of each component must be determined. The condition indices can then be combined in a linear fashion with weighting functions that represent the relative importance factors. A similar method has been suggested by Greimann et al. (1990) except they used deduction values, and not functional system components.

The weighting functions can be based on the interactivity of the individual components with respect to the remainder of the total system. A component with more interactivity should have a proportionately greater affect. The weighting factors should comply with the following general criterion:

$$\sum_{k=1}^{n} \beta_k = 1 \tag{6}$$

where β_k is the weighting function of the k^{th} functional system component.

The total condition index for a particular function system can be computed as the linear combination of the condition index of each component multiplied by its corresponding weighting function in the following manner:

$$CI_i = \sum_{k=1}^{n} \beta_k \, CI_k \tag{7}$$

where CI_i is the condition index value in objective group i, CI_k is the condition index for the k^{th} functional component, and n represents the number of functional system components in objective group i.

Step F: Repeat Process for ALL Objectives to Form Condition Index Vector

For each of the remaining objective groups, repeat Steps A through E to obtain a Condition Index vector in the form of:

$$CI_{system} = (CI_1 , CI_2 , CI_3 , \ldots , CI_m) \tag{8}$$

where m is the number of objective groups. Markow et al. (1989) were the first to propose this vectorial representation of the condition index. The methodology permits the development of rankings for multiple objectives.

Step G: Develop Multi-Component Weighting Functions to Form Condition Index Scalar

By assigning probability of occurrence or severity of occupance factors to each primary objective or condition identified in Step A, a multi-component weighting function can be developed. This may be quite challenging, especially if the objectives are not related. Again the values should sum to one by obeying the following expression:

$$\sum_{j=1}^{m} \alpha_j = 1 \tag{9}$$

Once completed, the total system condition index can be computed using:

$$CI_{system} = \alpha_1 CI_1 + \alpha_2 CI_2 + \alpha_3 CI_3 + \ldots + \alpha_m CI_m \tag{10}$$

Cost comparisons and funding decisions have purposely been left out of the ranking procedure outlined here. If the budget changes, a complete re-evaluation of the projects should not be necessary. Consequently, the project(s) with the highest system condition index are considered to be the "best projects", all other things being equal. However, things are rarely

equal and at some point cost may play a deciding role. For example, a comparison between a Rolls Royce and a Yugo will undoubtedly rank the Rolls as the better car. It is not until the cost of the two automobiles is factored into the decision making process that it becomes clear why everyone is not driving a Rolls Royce. But it is also important to compare the two cars on an equal basis so cost can be readily identified as the reason more people do not drive Rolls. If additional money can be supplied to the budget, the ranking priority does not change but the decision on which car to purchase may be different.

Risk

One area of concern which is not generally factored into condition indexing schemes is the concept of risk. The weighting factors are assigned as absolute numbers which fail to take into account the variability inherent in many such decisions. If one project or solution receives a 92 and another receives a 91, the condition indexing approach clearly favors the higher ranked project regardless of the uncertainty in perhaps many of the choices. The US Department of Energy (US DOE) recognizes that risk should be incorporated into environmental restoration and management strategies. In a US DOE report (1995), a first cut at defining risk analysis, including its purposes and the principles to be followed, was presented. Based on a report jointly prepared by the National Academey of Sciences and the National Research Council (1994), the US DOE recommended four principle categories:

> 1) Risk Assessment. Use of the best available information from all sources; all judgements and assumptions should be explicitly stated.
>
> 2) Risk Management. Analyze the distribution of risk and benefit/cost of potential risk management strategies, using the best available tool and techniques.
>
> 3) Risk Communication. State risk management goals, assumptions, uncertainties and comparisons clearly, accurately, and meaningfully; provide public access in a timely manner.
>
> 4) Priority-Setting. Compare risks by grouping them into broad categories of concern and identifying the population at risk; include as broad a range of views as possible, ideally with consensus.

The document recognizes three main types of uncertainties: (1) the analytical processes, (2) the availability of information, and (3) the quality of information. At the present time, these uncertainties make incorporating risk into a condition indexing scheme extremely difficult, however, a long-term goal should be to add risk assessment. With small functional components as a basis for decision making, the process of assigning risk could be incorporated.

Framework for Outfall Evaluation

Step A above discussed the need to identify the objective(s). It should go without saying that selection of the wrong objective makes the analysis difficult if not impossible to correctly interpret. The nature of condition indexing allows for some flexibility, however, in the circular cause-and-effect qualities of the matrices. For the purpose of WSDOT outfall evaluation, the objective should be to prevent ***adverse water quality conditions***. A flowchart of the general procedure is presented in Figure 3.2. As illustrated, the first question identifies the status of the existing water quality. If the existing water quality is known, the functional system for the objective matrix can be written as shown in Table 3.2. The matrix consists of eight diagonal elements representative of some level of water quality conditions (expressed as beneficial water use) within the drainage of the proposed project. A scaled value for the "***relative severity of occurrence***" (water quality index number) is shown in the right-hand column. Notice these numbers must sum to one and a value of zero is prohibited (a zero value is representative of no consequence and therefore would eliminate that row from consideration).

The "*relative severity of occurrence*" values in Table 3.2 and the indicator values presented in Tables 3.3 through 3.9 were obtained using the original document developed by WSDOT for ranking outfalls as a basis (presented in Table 2.5). The numbers are meant to be initial values; crude estimates as a starting point for further discussion. A substantial amount of professional judgement was used in determining these values. In practice, these values must be obtained from the stakeholders through open dialogues and many iterations.

The next matrix relates the adverse water quality conditions to indicators of adverse conditions in case the existing water quality is not known. This is accomplished by creating a new matrix with the source of information and linking it to water quality indicators with both types of entries shown along the main diagonal. The weighting functions are influenced by the

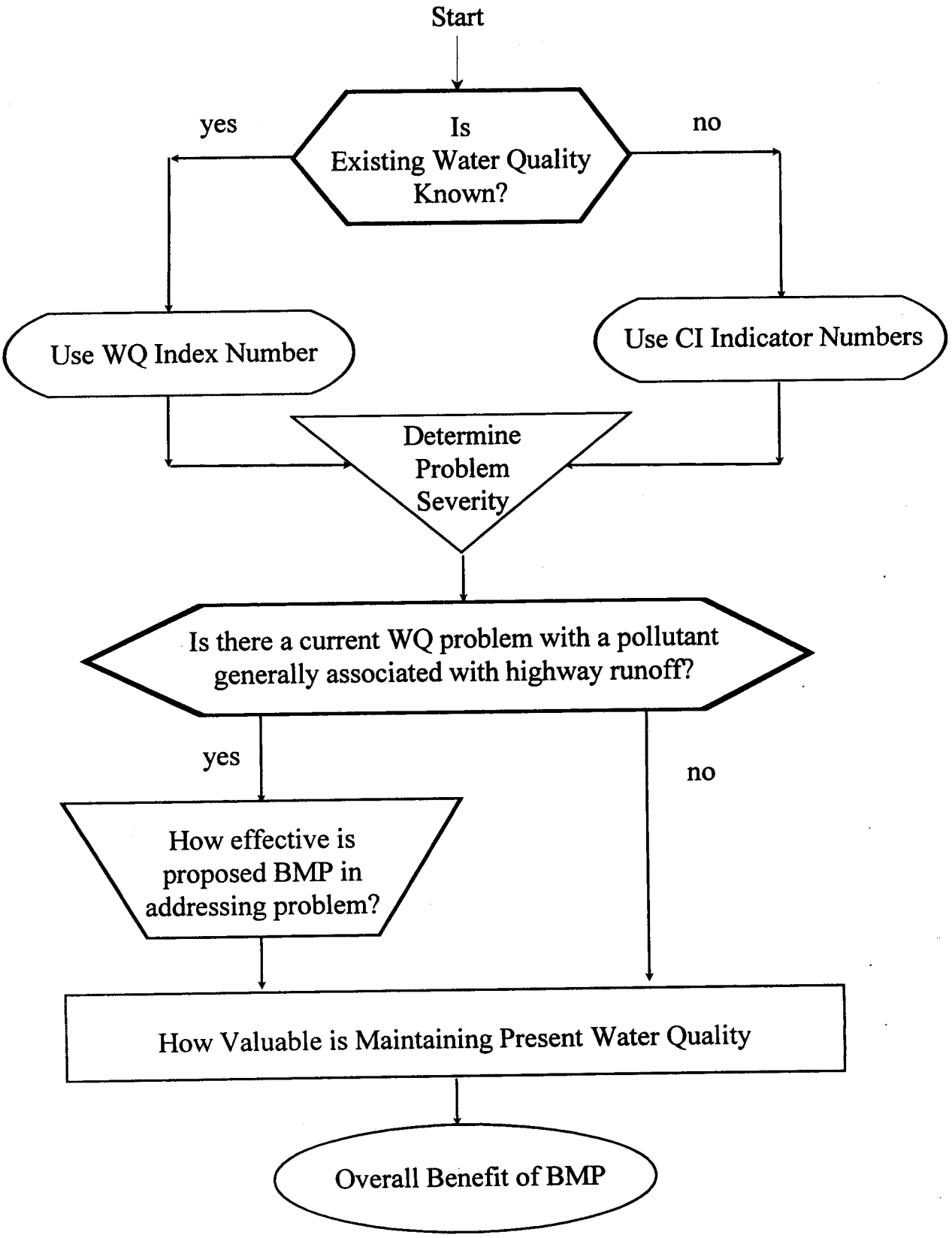


Figure 3.2 General Flowchart of Evaluation Procedure

Table 3.2 Adverse Water Quality Condition Matrix

Beneficial Use Categories								Relative Severity of occurrence
Drinking Water Standards Violated								0.21
	Drinking Water Protection							0.19
		Public Health Standards Violated						0.17
			Public Health Protection					0.15
				Fisheries Standards Violated				0.12
					Fisheries Protection			0.10
						Boating		0.04
							No Water Quality Use	0.02

source of information (reliability) and the type of indicator. For brevity and clarity, the two categories have been divided into two tables. Table 3.3 shows the sources of information and, only the new diagonal water quality indicator elements are shown in Tables 3.4a and 3.4b. The five diagonal elements from the source table (Table 3.3) would be placed along the main diagonal in the lower right hand corner of Table 3.4b. The rows above the indicator elements allow for the cause/effect relationships and the weighting factors to be included in the matrix.

The multiplication of the Source of Information categories in Table 3.3 with the Adverse Conditions elements in Table 3.4 (a and b) produces a matrix of numbers whose total sum is exactly 1.0. As an example, Table 3.5 illustrates this concept where the Source of Information relative significance indicators are placed across the top of the matrix and the Adverse Condition values are place down the left hand side of the matrix. The far right column represents the row sum, and the value in the lower right hand column is the sum of that column. This means if all of the Adverse Water Quality Conditions and all of the Water Quality Information Sources were true, then the maximum weighing factor would be 1.0. Other matrix linkages are shown later.

Table 3.3 Source of Water Quality Information

Source					Relative Significance of Indicator
Watershed Action Plan Problem					0.30
	Visual Inspection				0.25
		Newspaper/ Media Coverage			0.10
			Partial or Inconclusive Studies		0.10
				WSDOT Experience in Watershed	0.25

Table 3.4a Potential Indicators of Adverse Water Quality Conditions								
Indicator								Relative Significance of Indicator
Court Mandated Standard								0.15
	Surface Sheen on Water							0.02
		Public Relations						0.02
			Fishing Ban					0.06
				Beach Closure				0.05
					Odors & Complaints			0.06
						WQ Monitoring Data		0.08
							Fish Kills	0.10

Table 3.4b Potential Indicators of Adverse Water Quality Conditions (Continued)								
Indicator								Relative Significance of Indicator
Proximity to Population								0.05
	Single Species Indicators							0.03
		Boating Ban						0.10

			Percent of Highway Runoff to Watershed					0.07
				Very High Traffic Count (>100,000ADT)				0.09
					High Traffic Count (50,001-100,000 ADT)			0.06
						Medium Traffic Count (10,001-50,000 ADT)		0.04
							Low Traffic Count (<10,000 ADT)	0.02

Creating the matrix is a difficult step in environmental protection because there are so many potential indicators. By increasing the number of indicators, project planners can get a better understanding of the cause/effect relationships. However, while increasing the number of indicators may provide a better overall picture, it is clear that too many indicators asked at a basic level would add complication. For example, it would not be feasible to list mercury concentrations found in every kind of benthic organism as indicator elements. The list would become prohibitively long and most responses based on available information would be inconclusive. The goal, therefore, is to maintain a manageable number of elements while encompassing a majority of the important parameters or concerns. It is also important to realize that *indicator* should be viewed in a very broad sense of the word.

Almost certainly there are other indicators which should be used in addition to or in replace of the sixteen presented in Tables 3.4a and 3.4b. As previously reported, EPA (1995c) presented a list of twenty-eight potential indicators for measuring water quality impacts. Many of these were considered infeasible due to their cost. Questions were also raised about the ability of obtaining documentation concerning items, such as reported medical reports of water borne illnesses which could be an indication of water quality pollution. Consideration was also given to the expected knowledge of the planning team of the watershed in which the projects were being constructed. WSDOT personnel should critically review the performance of each of these criteria in meeting their water quality objectives.

In a similar manner, the diagonal matrix shown in Table 3.6 links the Severity of the Stormwater Discharges (e.g. what type of water body) to the indicators of Adverse Conditions listed in Tables 3.4a and 3.4b. This linkage gives an indication of the problem severity. The indicators listed in Tables 3.4a and 3.4b are moved to the lower right hand corner of Table 3.6 to link the tables. This generates an extremely large matrix of interactions.

Table 3.5 Combination of Sources and Adverse Water Quality Weighing Factors

	0.30	0.25	0.10	0.10	0.25	Row Sum
0.15	0.0450	0.0375	0.0150	0.0150	0.0375	0.15
0.02	0.0060	0.0050	0.0020	0.0020	0.0050	0.02
0.02	0.0060	0.0050	0.0020	0.0020	0.0050	0.02
0.06	0.0180	0.0150	0.0060	0.0060	0.0150	0.06
0.05	0.0150	0.0125	0.0050	0.0050	0.0125	0.05
0.06	0.0180	0.0150	0.0060	0.0060	0.0150	0.06
0.08	0.0240	0.0200	0.0080	0.0080	0.0200	0.08
0.10	0.0300	0.0250	0.0100	0.0100	0.0250	0.10
0.05	0.0150	0.0125	0.0050	0.0050	0.0125	0.05
0.03	0.0090	0.0075	0.0030	0.0030	0.0075	0.03
0.10	0.0300	0.0250	0.0100	0.0100	0.0250	0.10
0.07	0.0210	0.0175	0.0070	0.0070	0.0175	0.07
0.09	0.0270	0.0225	0.0090	0.0090	0.0225	0.09
0.06	0.0180	0.0150	0.0060	0.0060	0.0150	0.06
0.04	0.0120	0.0100	0.0040	0.0040	0.0100	0.04
0.02	0.0060	0.0050	0.0020	0.0020	0.0050	0.02
					Column Sum =	1.00

Table 3.6 Severity of Discharging to Receiving Water									
Water Body Type									Relative Order of Severity
Ground Water									0.23
	Small Stream								0.18
		Small Lake							0.14
			Sensitive Wetland						0.14
				Large Stream					0.11
					Large Lake				0.07
						River			0.05
							Wetland		0.05
								Tideland	0.03

Of course, even if the problem is quite severe, there is no guarantee that preventing highway pollution will be effective in solving the problem. For example, if perchloroethylene (an industrial solvent linked to dry cleaning activities) is the cause of the fish kill, it is highly unlikely that preventing highway runoff will provide any noticable improvement in water quality. Therefore, the question of whether the water quality problem is one generally associated with highway runoff must be addressed. Table 3.7 provides the general weighing factors used for this task.

The next matrix linkage relates the likelihood that the water quality problem is related to a pollutant normally found in high runoff (shown in Table 3.7) to the probability that the proposed BMP will be successful in treating the pollution. The likelihood of success factors (shown in Table 3.8) came from normalizing the results of comparative pollutant removal

efficiencies of various control structures conducted by Schueler (1987) and Galli (1990). Barrett et al. (1993) summarized the performance of the various design components based on field studies, laboratory investigations, modeling predictions and other theoretical considerations. The comparative pollutant removal designs were listed as high, medium and low. By tracking WSDOT's own experiences with each of these remediation technologies, better estimates of the relative probability of success values can be determined. Additional practices may also be added to the *list as long* as the relative probability values sum to one. Furthermore, the values are based on individual BMP performance and do not reflect any kind of tiered approach where two or more BMP's are installed sequentially. Insufficient data is available on multiple BMP performance to make any decisions regarding likely outcomes.

Table 3.7 Is Water Quality Problem Contributed to by Pollutant Associated with Highway Runoff?

Likelihood					Relative Significance of Indicator
Definitely Yes					0.35
	Likely				0.25
		Maybe			0.20
			Unlikely		0.15
				Definitely No	0.05

Table 3.8 Standard Remedial Practices for BMPs

Best Management Practice									Relative Probability of Success
Dry Pond									0.10
	Wet Pond								0.16
		Infiltration Trench							0.14
			Infiltration Basin						0.14
				Vegetated Filter Strip					0.08
					Grassed Swale				0.05
						Sand Filter			0.10
							Vault		0.14
								Other	0.09

Even when the current water quality problem is not caused by pollutants generally associated with highway runoff, there may be some advantage or benefit to maintaining the existing water quality in the receiving body. Several of these reasons are presented in Table 3.9 along with their relative significance factors. For example, ***location aspects*** may take into account the chance of future growth in the area, visible from major highway with high traffic counts, or near a population center. Or discharge may be going in to a known ***salmon*** or bull trout stream where any degradation of water quality is going to lead to significant delays in obtaining permits. The category "other" has been included to account for unforseen factors and omissions. To determine how valuable maintaining current water quality conditions are, Tables 3.8 to 3.9 can be linked together.

Table 3.9 Rationale for Maintaining Present Water Quality					
Reasons					Relative Significance of Indicator
Salmon Stream (or other similar situation)					0.35
	High Receiving Water Body Usage				0.25
		Location Aspects			0.25
			Other		0.10
				None	0.05

Linking Matrices

The process of linking the eight matrices identified above requires a general consensus among the expert panel regarding the relative magnitudes of the cause and effect relationships established. It will be impossible to get environmental and development experts to total agreement on this area because of some pre-conceived biases which exist as well as some very legitimate differences of opinion. However, sometimes differences occur because the indicator category is too broad and therefore subject to interpretation. In these instances, the experts should strive to divide the category into unambiguous subsets of the problem. At this point, natural biases aside, many experts tend to reach the same or similar conclusions.

Perhaps the best way to visualize the matrix combination is to examine the plan shown in Table 3.10. The Indicator Matrix diagonal presented in Tables 3.4a and 3.4b has been consolidated to a single column at the left hand side of the matrix and the Source of Information categories presented in Table 3.3 are listed along the bottom. In the column above each

beneficial use category, a scaled relative ranking coefficient, X, is determined for each indicator deemed relevant. This relative ranking is determined by the formula shown below:

$$X = \left[\frac{relative\ ranking}{normalized\ to\ 1\ for\ column}\right] \cdot relative\ severity\ index\ in\ matrix\ 1$$

Notice that the ranking coefficients are normalized to one for the COLUMN. The values of these relative ranking coefficients are summed HORIZONTALLY with the total sum of each row placed in the right hand column of the table. These values are used in the next linking process.

Table 3.10 Linking of Beneficial Use Matrix with Indicator Matrix

	Correlation Matrix					Sum of Row
Court Mandated Standard	0.0450	0.0375	0.0150	0.0150	0.0375	0.15
Surface Sheen on Water	0.0060	0.0050	0.0020	0.0020	0.0050	0.02
Public Relations	0.0060	0.0050	0.0020	0.0020	0.0050	0.02
Fishing Ban	0.0180	0.0150	0.0060	0.0060	0.0150	0.06
Beach Closure	0.0150	0.0125	0.0050	0.0050	0.0125	0.05
Odors & Complaints	0.0180	0.0150	0.0060	0.0060	0.0150	0.06
WQ Monitoring Data	0.0240	0.0200	0.0080	0.0080	0.0200	0.08
Fish Kills	0.0300	0.0250	0.0100	0.0100	0.0250	0.10

Proximity to Population	0.0150	0.0125	0.0050	0.0050	0.0125	0.05
Single Species Indicators	0.0090	0.0075	0.0030	0.0030	0.0075	0.03
Boating Ban	0.0300	0.0250	0.0100	0.0100	0.0250	0.10
Percent of Highway Runoff to Watershed	0.0210	0.0175	0.0070	0.0070	0.0175	0.07
Very High Traffic Count (>100,000ADT)	0.0270	0.0225	0.0090	0.0090	0.0225	0.09
High Traffic Count (50,001-100,000 ADT)	0.0180	0.0150	0.0060	0.0060	0.0150	0.06
Medium Traffic Count (10,001-50,000 ADT)	0.0120	0.0100	0.0040	0.0040	0.0100	0.04
Low Traffic Count (<10,000 ADT)	0.0060	0.0050	0.0020	0.0020	0.0050	0.02
	Watershed Action Plan Problem	Visual Inspection	Newspaper or Media Coverage	Partial or Inconclusive Studies	WSDOT Experience in Watershed	$\sum = 1.00$

Notice that the sum of the final column in Table 3.10 should equal one if the arithmetic has been performed correctly. Since one is the normalized total for each column before scaling for the relative severity number (itself a scaled factor of one), the total in the right hand column should equal one.

The same general procedure is now repeated to determine the problem severity, except that the Adverse Water Quality Indicators shown in Tables 3.4a and 3.4b and the Receiving Water Body Type matrix illustrated in Table 3.6 are used as the matrices. Here, the sixteen

indicator variables are placed along the x-axis and the nine Receiving Water Body Type severity parameters are positioned along the y-axis. Also, the normalized factors are multiplied by the relative significance of the indicator to get Y:

$$Y = \left[\frac{relative\ ranking}{normalized\ to\ 1\ for\ column}\right] \cdot relative\ severity\ index\ in\ matrix\ 2$$

Because of the number of indicators, the matrix is shown in two tables (Tables 3.11a and 3.11b).

Table 3.11a Linking of Indicator Matrix with Severity Matrix

	Indicator								**Subtotal** Sum of Row
Ground Water	0.0345	0.0046	0.0046	0.0138	0.0115	0.0138	0.0184	0.0230	0.1242
Small Stream	0.0270	0.0036	0.0036	0.0108	0.0090	0.0108	0.0144	0.0180	0.0972
Small Lake	0.0210	0.0028	0.0028	0.0084	0.0070	0.0084	0.0112	0.0140	0.0756
Sensitive Wetland	0.0210	0.0028	0.0028	0.0084	0.0070	0.0084	0.0112	0.0140	0.0756
Large Stream	0.0165	0.0022	0.0022	0.0066	0.0055	0.0066	0.0088	0.0110	0.0594
Large Lake	0.0105	0.0014	0.0014	0.0042	0.0035	0.0042	0.0056	0.0070	0.0378
River	0.0075	0.0010	0.0010	0.0030	0.0025	0.0030	0.0040	0.0050	0.0270
Wetland	0.0075	0.0010	0.0010	0.0030	0.0025	0.0030	0.0040	0.0050	0.0270
Tideland	0.0045	0.0006	0.0006	0.0018	0.0015	0.0018	0.0024	0.0030	0.0162
	Court Mandated Standard	Surface Sheen	P.R.	Fishing Ban	Beach Closure	Odors	WQ Data	Fish Kills	

Table 3.11b Linking of Indicator Matrix with Severity Matrix (Continued)									
	Indicator								**Total** Sum of Row
Ground Water	0.0115	0.0069	0.0230	0.0161	0.0207	0.0138	0.0092	0.0046	0.23
Small Stream	0.0090	0.0054	0.0180	0.0126	0.0162	0.0108	0.0072	0.0036	0.18
Small Lake	0.0070	0.0042	0.0140	0.0098	0.0126	0.0084	0.0056	0.0028	0.14
Sensitive Wetland	0.0070	0.0042	0.0140	0.0098	0.0126	0.0084	0.0056	0.0028	0.14
Large Stream	0.0055	0.0033	0.0110	0.0077	0.0099	0.0066	0.0044	0.0022	0.11
Large Lake	0.0035	0.0021	0.0070	0.0049	0.0063	0.0042	0.0028	0.0014	0.07
River	0.0025	0.0015	0.0050	0.0035	0.0045	0.0030	0.0020	0.0010	0.05
Wetland	0.0025	0.0015	0.0050	0.0035	0.0045	0.0030	0.0020	0.0010	0.05
Tideland	0.0015	0.0009	0.0030	0.0021	0.0027	0.0018	0.0012	0.0006	0.03
	Proximity to Population	Single Species Indicator	Boating Ban	Percent of Highway Runoff to Watershed	Very High Traffic	High Traffic	Medium Traffic	Low Traffic	$\sum = 1.00^*$

* Row Totals and Total Sum include values from previous table.

In examining the flowchart illustrated in Figure 3.2, it is evident that once the question of problem severity has been solved, it must be determined whether the water quality problem is one that is typically associated with highway runoff and if the selected BMP will be effective in solving the problem. Table 3.12 shows the results of linking the matrices introduced in Tables 3.7 and 3.8. Rather than ask specific questions concerning individual pollutants, this weighting factor addresses more qualitative aspects by phrasing the question in a yes-no-maybe format. This type of information is generally more readily available than precise water quality concentration data.

Table 3.12 Linking of Highway Runoff Problem Matrix with BMP Matrix										
	Best Management Practice									Sum of Row
Definitely Yes	0.0350	0.0560	0.0490	0.0490	0.0280	0.0175	0.0350	0.0490	0.0315	0.35
Likely	0.0250	0.0400	0.0350	0.0350	0.0200	0.0125	0.0250	0.0350	0.0225	0.25
Maybe	0.0200	0.0320	0.0280	0.0280	0.0160	0.0100	0.0200	0.0280	0.0180	0.20
Unlikely	0.0150	0.0240	0.0210	0.0210	0.0120	0.0075	0.0150	0.0210	0.0135	0.15
Definitely No	0.0050	0.0080	0.0070	0.0070	0.0040	0.0025	0.0050	0.0070	0.0045	0.05
	Dry Pond	Wet Pond	Infiltration Trench	Infiltration Basin	Vegetated Filter Strip	Grassed Swale	Sand Filter	Vault	Other	$\Sigma = 1.00$

It should again be pointed out that even if the water quality problem(s) in the receiving stream is not (are not) directly attributable to highway runoff, there may be some intrinsic value in maintaining the existing water quality. The selection of "None" means nothing can be readily identified, so very little additional weight is given to that selection.

Weighted functions from the four matrix convolutions are added together for each project, divided by the highest ranked project value, and multiplied by 100% to obtain a percent relative level of significance. Then, to obtain the appropriately weighted condition index value, the projects are scaled relative to the average project. The result is a number generally between 1.0 and 2.0, although values can be somewhat higher if the choice is between only a few projects having a large discrepance between the top project and all of the other selections. For example, to be above 2.0, the average project score would have to be below 50 percent.

Table 3.13 Value of Maintaining Present Water Quality						
	Pollution Control Device					Sum of Row
Dry Pond	0.0350	0.0250	0.0250	0.0100	0.0050	0.10
Wet Pond	0.0560	0.0400	0.0400	0.0160	0.0080	0.16
Infiltration Trench	0.0490	0.0350	0.0350	0.0140	0.0070	0.14
Infiltration Basin	0.0490	0.0350	0.0350	0.0140	0.0070	0.14
Vegetated Filter Strip	0.0280	0.0200	0.0200	0.0080	0.0040	0.08
Grassed Swale	0.0175	0.0125	0.0125	0.0050	0.0025	0.05
Sand Filter	0.0350	0.0250	0.0250	0.0100	0.0050	0.10
Vault	0.0490	0.0350	0.0350	0.0140	0.0070	0.14
Other	0.0315	0.0225	0.0225	0.0090	0.0045	0.09
	Salmon Stream (or other similar situation)	High Receiving Water Body Usage	Location Aspects	Other	None	$\sum = 1.00$

Converting Condition Index Rank to Benefit/Cost

In any ranking scheme, the ultimate goal will be to convert the score into a meaningful number which individuals can use. In the simplest example possible, consider five hypothetical project evaluations based on the condition index ranking scheme here which produced ranking scores of 1.67, 1.33, 1.00, 0.67 and 0.33, as shown in Table 3.14. Based solely on the ranking, the decision would be to build the project receiving the highest score (1.67). However, this is where the costs of the projects should be included. Therefore, the next step is to factor the Project Cost Ratio (PCR) into the index. To accomplish this task, the average project cost ($70K for this example) must be determined. The total environmental project cost is divided by the average project cost to produce the Project Cost Ratio (PCR) shown in Column 4. The condition index in Column 2 is divided by the PCR as shown in Column 5. These values are then changed

using the lowest rated project as a baseline measure (assuming WSDOT wishes to maintain its current procedure of assigning a B/C ratio of at least one). The difference between 1.0 and the lowest rated project in Column 5 (1.0 - 0.385 = 0.615) is added (note difference may be negative if lowest rated project is above 1.0) to each value in Column 5 to produce the B/C ratio shown in Column 6.

Table 3.14 Cost Inclusion Factor in CI Ranking

Project #	Condition Index	Project Cost	PCR	CI/PCR Ratio	B/C Ratio
1	1.67	$125k	1.7857	1.67/1.7857 = 0.935	1.550
2	1.33	$50k	0.7143	1.33/0.7143 = 1.862	2.477
3	1.00	$75k	1.0714	1.00/1.0714 = 0.933	1.548
4	0.67	$40k	0.5714	0.67/0.5714 = 1.173	1.788
5	0.33	$60k	0.8571	0.33/0.8571 = 0.385	1.000

Under this scenario, if WSDOT had $215,000 (approximately 3 times the average project cost) to spend in the environmental retrofit/restoration category, the decision would be to construct Projects 2, 4, and 1. This would result in the largest net benefit to the environment for the amount of money available.

Notice the effect that cost has on the project selection. In this hypothetical example, this procedure eliminates the third highest rated project from the list because of cost. The decision to build Project 1 over Project 3 is made by only a slight difference in B/C ratio. Some persons are likely to argue that this procedure gives cost too large a role in the decision making process.

However, this is where the maximum certainty lies in the overall process. By completing the BMP Cost Summary sheets provided in Appendix A and maintaining a good database on the cost of environmental construction facilities, WSDOT will have current, reliable information concerning the cost side at all times. In the future, it may be possible to understand all the subtle links that tie the watershed together, but for now uncertainty is something we must all live with. It appears to make sense to separate the subjective benefits from the "known" costs until this step.

The values shown above are not the final B/C values. As previously discussed, Sanders et al. *(1990)* investigated a procedure for determining the total value of protecting rivers in Colorado and found that in addition to recreational value, the sites had considerable worth in Option Value, Existence Value and Bequest (future generation) Value. Short of conducting a contingency market valuation survey, the following rough estimates can be made from Sanders et al. (1990) numbers:

Option Value Multiplier = 1 + 15.97/101.12 = 1.16
Existence Value Multiplier = 1 + 27.67/101.12 = 1.27
Bequest Value Multiplier = 1 + 36.19/101.12 = 1.36

As a result, the final benefit/cost ratio for the three hypothetical projects are:

Table 3.15 Final Summary of B/C Ratios

Project #	Normalized B/C	OVM	EVM	BVM	B/C Ratio
1	1.550	1.16	1.27	1.36	3.11
2	2.477	1.16	1.27	1.36	4.96
3	1.548	1.16	1.27	1.36	3.10
4	1.788	1.16	1.27	1.36	3.58
5	1.000	1.16	1.27	1.36	2.00

One additional point should be made about the B/C ratios presented in Table 3.15. The average B/C ratio of the fictitious projects is 3.35 which, at first glance, may seem somewhat high. However, this value is fairly consistent with the environmental mitigation ratio found by the Washington State Department of Fish and Wildlife (WDFW). In a memo by Sax (1995), it was reported that a WDFW study concluded that for every dollar spent on treating storm water, it returns three dollars in economic benefits (B/C = 3.0).

Example of Proposed Procedure

Since the cost are known, the benefits (in dollars) can now be estimated for all projects. Since the benefits no longer hurt the overall project, additional enthusiasm should help promote the widespread use of environmental measures in highway projects. An example, in terms of a case study of WSDOT outfalls, is presented below to help facilitate the understanding of the overall process.

4.0 Case Study Analysis

A decision support system called **B**enefit-cost **E**valuation **P**rogram for **E**nvironmental **M**itigation (**BEPEM**) was developed to assist in determining the benefit/cost ratios using Microsoft's Visual Basic 4.0. This platform allows for a convenient graphical interface which belies the complexity of programmed behind several of the buttons. The program screens are shown in Appendix C. The complexity of the programming is masked by the object oriented buttons and prompts shown in Appendix C. Behind many continue buttons, or seemingly simple yes/no prompts lies a considerable amount of program code. Figure 4.1 illustrates this example by presenting the subroutine which is executed when the "Calculate Projects B/C" button shown in Screen #14 is clicked. Fortunately, since the user has supplied all of the necessary information using prior data prompts, the calculation of the overall B/C ratio becomes a relatively simple series of executing mathematical operations. The user is spared the process of developing a cumbersome structured input file.

The utility of this program is demonstrated by examining the twenty potential outfall projects presented in Table 4.1. This list comes from the Stormwater Outfall Prioritization Scheme section of an interim report prepared for the WSDOT's Olympic Region in February, 1995. Four major assumptions were made in completing this example which could significantly effect the program outcome. In no particular order of significance, the assumptions were:

1) the existing water quality was known and assumed to be equal to the beneficial use,
2) the problem severities were all based on court, water quality data, proximity and ADT,
3) the costs were ESTIMATED within a range provided in the original analysis, and
4) BMP types were all assumed to be combinations of dry ponds and grassed swales.

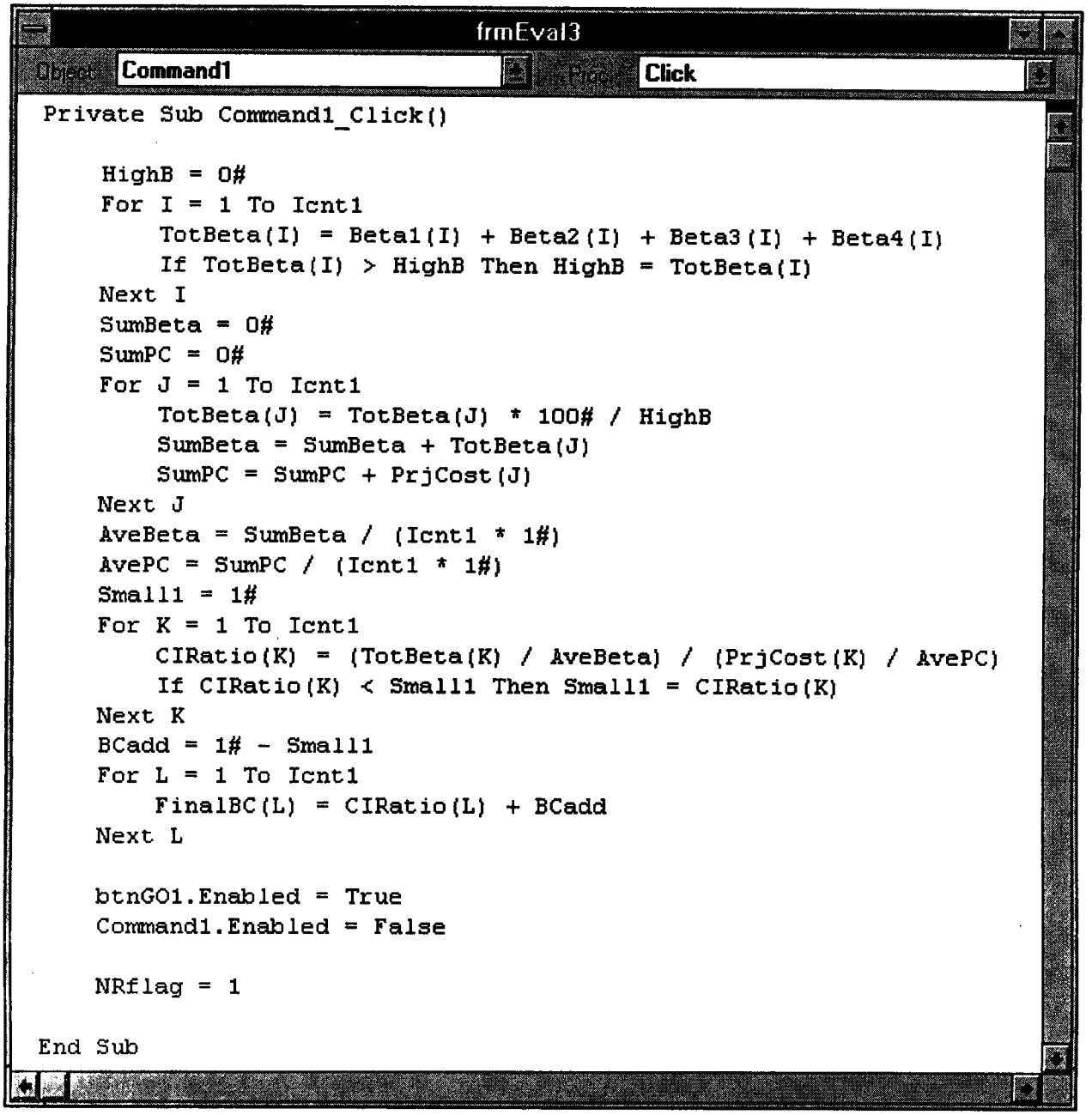


Figure 4.1 Example of Programming using Visual Basic

Item 3 (cost estimates) should be further explained. The original analysis of WSDOT projects listed project costs in ranges of (1) less than $25,000, (2) between $25,000 and $75,000, (3) between $75,000 and $150,000 and (4) over $150,000. As a means of illustration, the costs shown in Table 4.1 all abide by the initial ranges, but were arbitrarily varied within each bracket.

As a consequence of these assumptions, it must be emphatically stated that the B/C ratios generated and presented in the results are done so only as a demonstration of the program. No attempts should be made to base or criticize future WSDOT project prioritization plans using these values as the support argument.

At the end of the analysis the results were saved in an ASCII file as requested in the Exit form of the program. The output file contains a header, the number of projects, and a list of general project information, betas, cost and b/c ratio. The benefit/cost ratio is the value presented in the far right column of the output file. These results are shown below in Table 4.2. The B/C ratios in the output file are printed out to three decimals so several of the projects appear to be tied are actually ranked in numerical order. Given the uncertainty involving these values, one decimal place is probably sufficient.

Table 4.1 List of Twenty Potential Outfall Projects							
Project Name	Outfall Identifier	Receiving Waterbody	Water Body Type	Beneficial Use	ADT	BMP	Cost
1	SR5 118.90 L 18	Central Pierce County Sole Source Aquifer	GW	DWP	HT	GS + DP	20,000
2	SR5 121.05 L 150	Central Pierce County Sole Source Aquifer	GW	DWP	HT	GS + DP	40,000
3	SR5 120.91 R 670	Central Pierce County Sole Source Aquifer	GW	DWP	HT	GS + DP	60,000
4	SR5 141.38 R 85	East Branch of Hylebos Creek	SS	NWQU	VT	GS + DP	22,500
5	SR5 138.43 R42	Tributary of Hylebos Creek	SS	FSV	VT	GS + DP	17,500
6	SR5 125.63 L 0 M	Clover Creek to Steilacoom Lake	LS/SL	FSV	HT	GS + DP	112,500
7	SR5 139.15 R 10 M	West Branch of Hylebos Creek	LS	FSV	VT	GS + DP	200,000
8	SR5 122.46 R 65	Murray Creek to American Lake	SS/SL	FSV	HT	GS + DP	125,000
9	SR5 135.94 L 25	Fife Ditch to Wetland to Puyallup River	W/R	NWQU	VT	GS + DP	50,000
10	SR7 48.54 R 4	Central Pierce County Sole Source Aquifer	GW	DWP	MT	GS + DP	250,000
11	SR7 50.49 L 10	Central Pierce County Sole Source Aquifer	GW	DWP	MT	GS + DP	15,000

12	SR7 51.08 R 15	Clover Creek	LS	FSV	MT	GS + DP	90,000
13	SR18 0.32 L 20	East Branch of Hylebos Creek	SS	FSV	HT	GS + DP	110,000
14	SR18 0.30 R 175	East Branch of Hylebos Creek	SS	FSV	HT	GS + DP	300,000
15	SR161 20.06 R 47	Central Pierce County Sole Source Aquifer	GW	DWP	MT	GS + DP	200,000
16	SR512 9.34-9.61 R 125	Tributary to Clark Creek	SS	FSV	HT	GS + DP	250,000
17	SR512 3.31 R 20 M	Tributary to North Fork of Clover Creek	SS	FSV	HT	GS + DP	125,000
18	SR512 11.34 R 0 M	Puyallup River	R	FSV	HT	GS + DP	125,000
19	SR512 11.40 L 127	Puyallup River	R	FSV	HT	GS + DP	300,000
20	SR512 1.02 R 55	Tributary to North Fork of Clover Creek	SS	NWQU	HT	GS + DP	350,000

GW - ground water
LS - large stream
SS - small stream
R - river
W - wetland
HT - high average daily traffic
LT - low average daily traffic
MT - medium average daily traffic
VT - very high average daily traffic

DP - dry pond
GS - grass swale
IB - infiltration basin
WP - wet pond

DWSV - drinking water standards violated
DWP - drinking water protection
PHSV - public health standards violated
PHS - public health protection
PHP- public health protection
FSV- fisheries Standards Violated
FP- Fisheries Protection
B - Boating
NWQU - No Water Quality Usage

Table 4.2 Modified Output Listing of Outfall Project B/C Ratios					
Project Name	Outfall Identifier	Current Rank	Beneficial Use	B/C Ratio	Previous Ranking and Score
1	SR5 - 118.90 L 18	2	DWP	11.5	1/71
2	SR5 - 121.05 L 150	4	DWP	6.2	2/70
3	SR5 - 120.91 R 670	6	DWP	4.4	3/70
4	SR5 - 141.38 R 85	7	NWQU	3.5	7/55
5	SR5 - 138.43 R42	3	FSV	7.0	9/54
6	SR5 - 125.63 L 0 M	9-10 tie	FSV	1.9	14/44
7	SR5 - 139.15 R 10 M	16	FSV	1.4	16/43
8	SR5 - 122.46 R 65	12	FSV	1.8	17/43
9	SR5 - 135.94 L 25	5	NWQU	5.1	20/32
10	SR7 - 48.54 R 4	13	DWP	1.7	4/69
11	**SR7 - 50.49 L 10**	**1**	**DWP**	**14.9**	**6/67**
12	SR7 - 51.08 R 15	8	FSV	1.9	12/48
13	SR18 - 0.32 L 20	11	FSV	1.8	8/55
14	SR18 - 0.30 R 175	18	FSV	1.2	11/50
15	SR161 - 20.06 R 47	9-10 tie	DWP	1.9	5/68
16	SR512 - 9.34-9.61 R 125	17	FSV	1.3	10/51
17	SR512 - 3.31 R 20 M	14	FSV	1.7	13/48
18	SR512 - 11.34 R 0 M	15	FSV	1.6	15/44
19	SR512 - 11.40 L 127	19	FSV	1.2	18/40
20	SR512 - 1.02 R 55	20	NWQU	1.0	19/33

To reiterate a critical point, the four assumptions discussed previously have a substantial impact of the B/C ratios by design. For example, assuming the BMP's were all the same removes any significance of one of the beta functions. Furthermore, since all of the project outfalls were located in the Seattle/Tacoma region, the relative significance of maintaining water quality for each project were basically identical. This excluded yet another beta function. With impacts due to the variations in 2 out of 4 functions eliminated, the cost of the projects took on additional significance. Consequently, lower priced projects faired much better higher priced projects and skewed the B/C ratios to abnormally high levels. For example, the highest ranked project (Project 11 in Table 4.2) has a predicted B/C ratio of 14.9. The second ranked project (Project 1 in Table 4.2) has a B/C ratio of 11.5. This occurs even though Project 1 has a higher overall beta function. The difference is cost. Project 1 costs 20,000 and Project 11 costs 15,000. This small difference results in a larger than normal increase in B/C ratio due to the lack of other differences between the projects.

Planning and Implementation Procedures

Since BEPEM allows the user to save an ASCII file with all of the project information included, the file can easily be updated as projects are completed and additional projects are added. Using any text editor, completed files can be deleted from the list. By specifying an existing file name, a user may append projects to the file (or to a different file name). This program can be implemented into the decision making process WSDOT uses to rank projects. However, projects should also be tracked in terms of the information required to see if the weighting factors need to be modified in the future. Additionally, before these values are used to assist in making final decisions a panel of experts should review the values carefully to see what changes in weights would be appropriate.

Finally, as with any decision support system, the program's ability to anticipate and account for all consequences is limited. As such, users should closely examine any projects that contain unique features that are not typically addressed in transportation planning. These projects may be unduly rewarded or penalized by the current DSS.

Conclusions and Recommendations

5.0 Conclusions

Environmental enhancement due to implementation of stormwater BMPs has been documented by numerous agencies and researchers. The planning and construction of such BMPs are often hard to justify based on traditional benefit/cost analysis because, while construction and operation & maintenance costs are relatively easy to quantify, assigning meaningful benefit dollars to BMPs is difficult to do without some degree of uncertainly.

An interaction matrix for condition indexing of highway outfall retrofit projects has been developed for ranking projects in the System Planning and Priority Programming phases of an overall transportation plan. The matrix provides a rational basis of comparing projects with preliminary data typically available during the early phases of project selection. The matrix results in an index number for each project permitting transportation planners to rank the overall merit of each project including safety, need and environmental benefit.

The procedure was applied to WSDOT projects in the Puget Sound region of western Washington and compared to a B/C ranking conducted previously. The method succeeded in rearranging the project rankings only slightly at either end of the spectrum but clearly affecting the projects near the funding cut-off the most.

Considerable debate may still be necessary to determine the exact magnitude of each of the weighting factors in the condition index. This will involve significant advances in evaluation of environmental benefits of cleaner water. Moreover, it is not expected that all groups involved in the planning process will ever agree on an exact formula, especially when one of their favorite projects is cut from the list. However, the condition indexing methodology does provide a reasonable approach to recognizing the need to incorporate environmental benefits into the planning process and not to penalize projects that have the greatest potential positive impact on receiving water quality.

5.1 Recommendations

WSDOT has already begun to incorporate environmental mitigation measures into their designs in accordance to regulatory constraints. This work is further evidence to their commitment to environmental mitigation and restoration, however, it should not be viewed as the end of the road. Additional research, investigation and education will help improve the cost effectiveness of planning and construction of highway projects while insuring an environment safe for future Washington generations. Several topics should be considered as potential avenues for improving the quality of decisions and the rational for project selection. These topics include the following:

A. Improve and Expand Condition Indexing Matrix

The Condition Indexing Matrix proposed is based on an extremely small sample of "expert" opinion. As such, it most certainly has areas in which additional information and decisions should be included in the ranking process. Because the interaction matrix is incomplete, the ranking score might not produce the true solution which would adversely lead to improper project selection. This problem is most acute when trying to compare two or more equally priced remediation or mitigation projects. A raw score of 74 may not be superior to another project ranked as 73. This problem could be easily corrected by assembling a task committee with environmental representatives from WSDOT, DOE, WDFW, DNR, US Army Corps of Engineers, US EPA, University of Washington, and Washington State University. The task committee could hold a workshop where each component of the condition indexing matrix was examined. Additional categories could be added as recommended by the committee.

Another way to evaluate the final matrix is to conduct a detailed study of the environmental benefits of a single drainage basin. This could be done in cooperation with the Watershed Coordinating Council's efforts. Using the results of the study, the task committee could determine what management decisions should be made. These decisions could then be compared to the remedial actions suggested by the Condition Indexing scheme to see if, and where, discrepancies occur and determine what relationship changes would be necessary to correct the problem(s).

B. Improve Weighing Factors

Similar constraints exist for the Weighing Factors. As pointed out by Loucks et al. (1981), it is not always easy for the weights to be determined. The values used were selected based on the original WSDOT project scoping study and the information found in the literature. There will certainly be discussion regarding the relative magnitudes of the weights. The process would be significantly improved with additional input and perspectives. Both the weighing factors and the condition indexing matrix are meant to be starting positions in the discussion and NOT the final definitive result.

C. Look at Feasibility of Adopting Condition Indexing Procedure for Every Phase of Project Planning, Scheduling and Construction

The Condition Indexing scheme proposed does not eliminate all of the subjectivity of project evaluation because at some point it is necessary to compare and convert "apples to oranges", i.e., the index number must be converted into a dollar value. Given the lack of detailed information sometimes available, especially in the system planning phase, it might be feasible to adopt a condition indexing procedure for each phase of the project. This would permit direct comparison of all projects being proposed on an equal basis. Ultimately, other State agencies could adopt similar guidelines to help legislators decide on the priority for the increased demand for tax dollars. The last step is an extremely ambitious step which could only be attempted after the procedure was proven effective at a smaller scale.

D. Examine Ramifications of Designating a Higher Percentage of Construction Budget to Environmental Mitigation Efforts

One way of getting more environmental benefits designed into existing construction plans is to increase the funding of the Environmental Retrofit category (I-4). This effort could be integrated with the Watershed Coordinating Council's efforts described in the Washington State Department of Ecology (1994) report so as to maximize benefits in a particular watershed. A strong push should also be made to NCHRP to fund a national survey on the nonmarket benefits of environmental mitigation projects. The study should involve a team of economists, scientists and engineers to establish the correct format of the survey. The results would help

justify environmental expenditures in this category.

E. Continue to Educate Personnel and Public Regarding the Benefits of Environmental Mitigation for Highway Runoff Projects

In every study conducted on the subject, it appeared that education was the best way of getting the general public and agency personnel to agree on the value of environmental protection and management issues. This includes taking visible credit for accomplishments and improvements made to the environment as well as promoting the ideas of preserving the environment for future generations. The South Florida Water Management District, for example, posts permanent signs along the highway when it creates a drainage canal or constructed wetland pond notifying the passing motorists of their project. The Environmental Cost Savings Study conducted for the Washington State Legislative Transportation Committee (1994) recommended cross-training between WSDOT, DOE, WDFW, and WDNR as a way of reducing costs. Cross-training of WSDOT highway planners and designers within the Department's Environmental Division may succeed in raising the level of consciousness towards nonmarket environmental benefits.

References

Andersen, G.R. and V.H. Torrey III. (1995). "Function Based Condition Indexing for Embankment Dams," ASCE in press.

Arrow, K., R. Solow, P. Portney, E. Leamer, R. Radner and H. Schuman. (1993). "Report of the NOAA Panel on Contingent Valuation," Federal Register, 58(10), 4602-4614.

Atkinson, S.E. and T.D. Crocker. (1987). "A bayesian Approach to Assessing the Robustness of Hedonic Property Value Studies," Journal of Applied Econometrics, Vol 2, pp 27-45.

Barrett, M.E., R.D. Zuber, E.R. Collins III, J.F. Malina Jr, R.J Charbeneau, and G.H. Ward. (1993). "A review and Evaluation of Literature Pertaining to the Quantity and Control of Pollution from Highway Runoff and Construction," Center for Research in Water Resources, University of Texas at Austin, Austin, Texas.

Brookshire, D.S. and H.R. Neill. (1992). "Benefit Transfers: Conceptual and Empirical Issues," Water Resources Research, Vol 28, No 3, pp 651-655.

Carson, R.T. and R.C. Mitchell. (1993). "The Value of Clean Water: The Public's Willingness to Pay for Boatable, Fishable and Swimmable Quality Water," Water Resources Research, Vol 29, No 7, pp 2445-2454.

Cummings, R., D. Brookshire and W. Schulze. (1986). "Valuing Environmental Goods," Rowman and Allenheld, Totowa, N.J.

Desvousges, W.H., M.C. Naughton and G.R. Parsons. (1992). "Benefit Transfer: Conceptual Problems in Estimating Water Quality Benefits using Existing Studies," Water Resources Research, Vol 28, No 3, pp 675-683.

Di Toro, D. (1984). "Probability Model of Stream Quality Due to Runoff," ASCE, Journal of Environmental Engineering, Vol. 110, No. 3, pp 607-627.

Driscoll, E.D., P.E. Shelly and E.W. Strecker. (1990a). "Pollutant Loadings and Impacts from Highway Runoff - Volume I: Design Procedures," FHWA/RD/88-006, Washington, D.C.

Driscoll, E.D., P.E. Shelly and E.W. Strecker. (1990b). "Pollutant Loadings and Impacts from Highway Runoff - Volume II: Users Guide for Interactive Computer Implementation of Design Procedure," FHWA/RD/88-007, Washington, D.C.

Driscoll, E.D., P.E. Shelly and E.W. Strecker. (1990c). "Pollutant Loadings and Impacts from Highway Runoff - Volume III: Analytical Investigation and Research Report," FHWA/RD/88-008, Washington, D.C.

Farris, G., R. Dalseg, and P. Machno. (1973). "Freeway Runoff from the I-90 Corridor," A study prepared for the Washington State Highway Commission Department of Highways by the Municipality of Metropolitan Seattle.

Fisher, A.C., J.V. Krutilla, and C.J. Cicchetti. (1972). "The Economics of Environmental Preservation: A Theoretical and Empirical Analysis," American Economic Review, Vol 62, pp 605-619.

Freeman, A.M. (1979). "The Hedonic Price Approach to Measuring Environmental Benefits: Survey of the Issues," Scandinavian Journal of Economics, Vol 81, pp 154-173.

Galli, J. (1990). "Peat-Sand Filters: A Proposed Stormwater management Practice for Urbanized Areas," Department of Environmental Programs, Metropolitan Washington Council of Governments, Washington, D.C.

Greeley-Polhemus Group. (1991). "Economic and Environmental Considerations for Incremental Cost Analysis in Mitigation Planning," IWR Report 91-R-1, US Army Corps of Engineers, Institute for Water Resources, Washington, D.C.

Greimann, L., J. Strecker and K. Rens. (1990). "Inspection and Rating of Miter Lock Gates," Technical Report REMR-OM-7, US Army Construction Engineering Research Laboratory, Champaign, Illinois.

Hanemann, W.M. (1982). "Applied Welfare Analysis with Qualitative Response Models," Working Paper 241, California Agricultural Experiment Station, University of California, Berkeley, California.

Hanemann, W.M. (1984). "Welfare Evaluations in Contingent Valuation Experiments with Discrete Responses," American Journal of Agricultural Economics, Vol 66, No 3, pp 332-341.

Hanemann, W.M. (1989). "Welfare Evaluations in Contingent Valuation Experiments with Discrete Response Data: Reply," American journal of Agricultural Economics, Vol 71, No 4, pp 1057-1061.

Hastes, T.W. and W.P. James. (1994). "Predicting Sediment Yield in Storm-Water Runoff from Urban Areas," Journal of Water Resources Planning and Management, ASCE, Vol 120, No 5, pp 630.

Heaney, J.P., W..C. Huber, R. Field and RH. Sullivan. (1979). "Nationwide Cost of Wet-Weather Pollution Control," Journal of the Water Pollution Control Federation (formerly WPCF now WEF), Vol 51, No 8, pp 2043-2053.

Heaney, J.P. (1989). "Cost Effectiveness and Urban Storm-Water Quality Criteria," in Design of

Urban Runoff Quality Controls, Edited by L. Roesner, B. Urbonas and M. Sonnen, ASCE, New York, NY.

Hoehn, J.P. (1991). "Valuating the Multidimensional Impacts of Environmental Policy: Theory and Methods, American Journal of Agricultural Economics, Vol 73, pp289-299.

Hoehn, J.P. and A. Randall. (1989). "Too Many Proposals Pass the Benefit Cost Test," American Economic Review, Vol 79, pp 544-551.

Horowitz, J. and J.J. Louviere. (1990). "The External Validity of Choice Models Based on Laboratory Choice Experiments," in Spatial Choice and Processes, edited by M.M. Fischer, P. Nijkamp and Y.Y. Papageorgiou, North-Holland, Amsterdam.

Huber, W.C. (1988). "Technological, Hydrological and BMP Basis for Water Quality Criteria and Goals," Proceedings ASCE Conference on Current Practice and Design Criteria for Urban Runoff Water Quality Control, NY.

Huber, W.C. (1989). "Technological, Hydrological and BMP Basis for Water Quality Criteria and Goals" in Design of Urban Runoff Quality Controls, Edited by L. Roesner, B. Urbonas and M. Sonnen, ASCE, New York, NY.

Hudson, JA (1992). "Rock Engineering Systems: Theory and Practice," Ellis Horwood, New York, NY.

Loomis, J.B., B. Roach, F. Ward and R. Ready. (1995). "Testing Transferability of Recreation Demand Models Across Regions: A Study of Corps of Engineer Reservoirs," Water Resources Research, Vol 31, No 3., pp 721-730.

Loomis, J.B. (1992). "The Evolution of a More Rigorous Approach to Benefit Transfer: Benefit Function Transfer," Water Resources Research, Vol 28, No 3, pp 701-705.

Loomis, J.B. (1996). "Measuring the Economic Benefits of Removing Dams and Restoring the Elwha River: Results of a Contingent Valuation Survey," Water Resources Research, Vol 32, No 2, pp 441-447.

Loucks, D.P., J.R. Stedinger, D.A. Haith. (1981). "Water Resource Systems Planning and Analysis," Prentice-Hall, Englewood Cliffs, NJ.

Lyon, R.M. and S. Farrow. (1993). "An Analysis of Clean Water Act Issues," proceedings Association of Environmental and Resource Economists, January 1993, Anaheim, CA.

Markow, M.J., S. McNeil, D. Acharya and M. Brown. (1989). "Network Level REMR Management System for Civil Works Structures: Concept Demonstration onInland Waterways Locks," Technical Report REMR-OM-, US Army Construction Engineering

Research Laboratory, Champaign, Illinois.

Medina, M.A., W.C. Huber, J.P. Heaney and R. Field. (1981). "River Quality Model for Urban Stormwater Impacts," Journal of the Water Resources Planning and Management Division, ASCE, Vol 107, WR 1, pp 263-280.

Metropolitan Washington Council of Governments (MWCOG). (1983). "Nationwide Urban Runoff Program: Pollutant Removal Capability of Urban Best Management Practices in the Washington Metropolitan Area - Final Report," Water Resources Planning Board, Washington, D.C.

Mitchell, R.C. and R.T. Carson. (1989). "Using Surveys to Value Public Goods: The Contingent Valuation Method," Resources for the Future, Washington, D.C.

Molash, E. (1996). Personal Communications via Email, March 21, 1996.

Murdock, J.C. and M.A. Thayer. (1988). "Hedonic Price Estimation of Variable Urban Air Quality," Journal of Environmental Economic Management, Vol 15, pp 143-146.

NAS/NRC (National Academy of Sciences/National Research Council). (1994). "Building Consensus Through Risk Assessment and Management of the Department of Energy's Environmental Remediation Program," Committee to Review Risk Management in the DOE's Environmental Remediation Program, National Academy Press, Washington, D.C.

Nix, S.J., J.P. Heaney and W.C. Huber. (1988). "Suspended Solids Removal is Detention Basins," Journal of Environmental Engineering, ASCE, Vol 114, No 6, pp 1331.

Peters, T., W.L. Adamowicz, and P.C. Boxall, "Influence of Choice Set Considerations in Modeling the Benefits from Improved Water Quality," Water Resource Research, Vol 31, No 7, pp 1781-1787.

Pope, L.M. and L. G. Hess. (1989). "Load-Detention Efficiencies in a Dry-Pond Basin," in Design of Urban Runoff Quality Controls, Edited by L. Roesner, B. Urbonas and M. Sonnen, ASCE, New York, NY.

Robinson, R, W. Hansen, K. Orth and S. Franco. (1995). "Evaluation of Environmental Investments Procedures Manual - Interim:Cost Effectiveness and Incremental Cost Analyses," US Army Corps of Engineers, IWR Report 95-R-1, Washington, D.C.

Sanders, L.D., R.G. Walsh and J.B. Loomis. (1990). "Toward Empirical Estimation of the Total Value of Protecting Rivers," Water Resources Research, Vol 26, No 7 pp 1345-1357.

Sax, S. (1995). Cost Benefit Minutes. February 28, 1995 meeting at WSDOT NW Region.

Schueler, R.R. (1987). "Controlling Urban Runoff: A Practical Manual for Planning and Designing Urban BMPs," Department of Environmental Programs, Metropolitan Council of Governments, Washington, D.C.

Segarra-Garcia, R. And G.V. Loganathan. (1992). "Storm-Water Detention Storage Design Under Random Pollutant Loading," Journal of Water Resources Planning and Management, ASCE, Vol 118, No 5, pp 475.

Smith, V.K. (1972). "The Effect of Technological Change of Different Uses of Environmental Resources," in Natural Environments: Studies in Theoretical and Applied Analysis, edited by J.V. Krutilla, Johns Hopkins University Press, Baltimore, MD.

Smith, V.K. and Y. Kaoru. (1990). "Signals or Noise? Explaining the Variation in Recreation Benefit Estimates," American Journal of Agricultural Economics, Vol 72, No 2, pp 419-433.

Snodgrass, W., D.E. Maunder, K. Schiefer, and K.C. Whistler. (1993). "Tools for Evaluating Environmental Quality, Water Quality and Water Quantity Issues," in New Techniques for Modeling the Management of Stormwater Quality Impacts, Edited by W. James, Lewis Publishers, Baco Raton, Florida.

State of Ohio versus US Department of the Interior. (1989). US District Court of Appeals (for the District of Columbia), No. 86-1575, July 14, 1989.

Tucker, L.S. (1990). "Stormwater Regulations from Local Governments' View," in Urban Stormwater Quality Enhancement, Edited by H. Torno, ASCE, New York, NY.

US Department of Energy. (1995). "Risks and the Risk Debate: Searching for Common Ground - The First Step," Volume 1, Office of Environmental Management, Washington, D.C.

US Department of the Interior. (1986). "Natural Resource Damage Assessments, Final Rule," Federal Register, 51(148), 27,614-27,753.

US EPA and US Fish and Wildlife. (1984). "1982 National Fisheries Survey," Three Volumes, Washington, D.C.

US EPA. (1995a). "Economic Benefits of Runoff Controls," EPA Office of Wetlands, Oceans and Watersheds, EPA 841-S-95-002, September 1995.

US EPA. (1995b). "National Indicators for Water," Draft Report from EPA Office of Water, dated June 16, 1995, Washington, D.C.

US EPA. (1995c). "Environmental Indicators to Assess the Effectiveness of Municipal and Industrial Stormwater control Programs," Draft Report from EPA Office of Wastewater

Management, dated March, 1995, Washington, D.C.

US Water Resources Council. (1979). "Procedures for Evaluation of National Economic Development (NED) Benefits and Costs in Water Resources Planning," Federal Register, 44(242), 72,950-72,965.

US Water Resources Council. (1983). "Economic and Environmental Principles for Water and Related Land Resources Implementation Studies," US Government Printing Office, Washington, D.C.

Washington State Department of Ecology. (1973a). "Lakes of Washington: Volume I Western Washington," 3rd edition, Department of Ecology, Olympia, Washington.

Washington State Department of Ecology. (1973b). "Lakes of Washington: Volume II Eastern Washington," 2nd edition, Department of Ecology, Olympia, Washington.

Washington State Department of Ecology. (1994). "Report to the Governor and the Legislature of Washington State by the Watershed Coordinating Council - Summary Report," Department of Ecology, Olympia, Washington.

Washington State Department of Fish and Wildlife. (1995). "Preliminary Priority Watersheds for Restoration and Conservation of Fish and Wildlife - Technical Supplement," Department of Fish and Wildlife and Department of Natural Resources, Olympia, Washington.

Washington State Legislative Transportation Committee. (1994). "Environmental Cost Savings and Permit Coordination Study - Final Report," prepared by Ficklin Environmental Services, Berk & Associates, David Evans & Associates, and Preston Gates & Ellis, Olympia, Washington.

Wiegand, C., T. Schueler, W. Chittenden and D. Jellick. (1985). "Cost of Urban Runoff Quality Controls," in Urban Runoff Quality, Washington, D.C.

Wigmosta, M.S. and S.J. Burges. (1990). "Proposed Model for Evaluating Urban Hydrologic Change," Journal of Water Resources Planning and Management, ASCE, Vol 116, No 6, pp 742.

Yoe, C. (1992). "Incremental Cost Analysis Primer for Environmental Resources Planning," (draft) Prepared by the Greely-Polhemus Group for the US Army Corps of Engineers, Institute for Water Resources, Alexandria, V.A.

Yousef, Y.A., M.P. Wanielista, and H.H. Harper. (1985). "Removal of Highway Contaminants by Roadside Swales," Transportation Research Record, 1017, pp 62-68.

Appendix A

Key Instructions to BMP Summaries

Although every attempt was made to make the BMP Summary information sheets understandable and easy to complete, several issues need further explanation to insure that all respondents are answering the questions in a similar manner. Below are several points of clarification which should assist in this endeavor. If you still have questions, please contact Ms. Shari Schaftlein at WSDOT in Olympia.

- Costs identified in BMP should only include items specific to BMP construction NOT the overall project. For example, the cost of a grass swale constructed on the right-of-way of an existing project should include grading and seeding but not the cost of the land since it had to be acquired for the project. However, if additional acreage must be purchased, then the cost should be included in the BMP Summary.

- If applicable, please identify specific types of equipment or controls in the comments section. For example, if the project included a specific type of oil/water separator or if a pipe diameter was required, please provide that information.

Appendix B

BMP Summary Sheets

EROSION CONTROL BMP SUMMARY

Complete one form for each project

Project title: _____

Project description: _____

SR: _____ Milepost #: _____ Project length (mi): _____

Contract #: _____ Topo Map #: _____

Total cleared area (ac.): _____ Times maint. required: _____

BMP	QUANTITY	UNIT COST	TOTAL COST
Sediment Retention			
Filter fence	_____ (lin. ft.)	$_____	$_____
Straw bale barrier	_____ (lin. ft.)	$_____	$_____
Brush barrier	_____ (lin. ft.)	$_____	$_____
Gravel filter berm	_____ (cu. ft.)	$_____	$_____
Storm Drain inlet prot.	_____ (ea.)	$_____	$_____
Sediment trap	_____ (cu. ft.)	$_____	$_____
Temporary sediment pond	_____ (cu. ft.)	$_____	$_____
Other (specify)	_____	$_____	$_____
Temporary Cover Practices			
Seeding, fertilizer, & mulch	_____ (sq. ft.)	$_____	$_____
Matting Type	_____ (sq. ft.)	$_____	$_____
Plastic covering	_____ (sq. ft.)	$_____	$_____
Other (specify)	_____	$_____	$_____
Structural Erosion Control			
Stabilized construction entrance/tire wash	_____ (ea.)	$_____	$_____
Const. road stabilization	_____ (lin. ft.)	$_____	$_____
Dust control	_____ (ac.)	$_____	$_____
Pipe slope drains	_____ (lin. ft.)	$_____	$_____
Level spreaders	_____ (ea.)	$_____	$_____
Interceptor dike and swale	_____ (ea.)	$_____	$_____
Check dams	_____ (ea.)	$_____	$_____
Other (specify)	_____	$_____	$_____
	Total BMP Cost		$_____

Person completing form: _____ Date: _____

(Comments on other side of page)

Project challenges/comments: _____

Please include in your comments any extenuating site conditions which made the specific costs greater than (or less than) they would be for most other similar projects. Please also comment on the need for maintenance for each BMP over the construction period of the project and how many storm events this entailed.

WATER QUALITY BMP SUMMARY

Complete one form for each BMP constructed

Project title: _____

Project description: _____

SR: _____ Milepost #: _____ Project length (mi): _____

Contract #: _____ Topo Map #: _____

New impervious area tributary to BMP (ac.): _____ Total impervious area tributary to BMP (ac.): _____

Total offsite area tributary to BMP (ac): _____ Total area tributary to BMP (ac.): _____

Design storm and rainfall (if available): _____

Design method/manual (date) : _____

Circle BMP used: filter strip, biofiltration swale, wet pond, infiltration, presettling pond, wet vault, o/w separator, other (experimental or other_____)

BMP length or volume: _____ BMP surface area (sq. ft.): _____

ITEM	QUANTITY (for BMP)	UNIT COST	TOTAL COST
Excavation	_____ (cu. ft.)	$_____	$_____
Fill/compact	_____ (cu. ft.)	$_____	$_____
Seeding and maint.	_____ (sq. ft.)	$_____	$_____
Storm drain pipe (with trench and backfill)	_____ (lin. ft.)	$_____	$_____
Catch basins	_____ (ea.)	$_____	$_____
Access roads	_____ (lin. ft.)	$_____	$_____
Control structures	_____ (ea.)	$_____	$_____
Vaults	_____ (ea.)	$_____	$_____
Lining	_____ (sq. ft.)	$_____	$_____
Right-of-way	_____ (sq. ft.)	$_____	$_____
Other (specify)	_____	$_____	$_____
Design/permitting			$_____
Miscellaneous			$_____
	Total BMP Cost		$_____

Note: Include only the additional quantities which were required to install this BMP. When water quality and quantity BMPs are combined, indicate this in notes and estimate quantities for each function (e.g. no excavation for wet pond dead storage in water quantity).

Person completing form: _____ Date: _____

(Comments on other side of page)

Project challenges/comments: _____

Please include in your comments any extenuating site conditions which made the specific costs greater than (or less than) they would be for most other similar projects.

WATER QUANTITY BMP SUMMARY

Complete one form for each BMP constructed

Project title: _____

Project description: _____

SR: _____ Milepost #: _____ Project length (mi): _____

Contract #: _____ Topo Map #: _____

New impervious area tributary to BMP (ac.): _____ Total impervious area tributary to BMP (ac.): _____

Total offsite area tributary to BMP (ac): _____ Total area tributary to BMP (ac.): _____

Design storm and rainfall (if available): _____

Design method/manual (date): _____

Circle BMP(s) used: infiltration pond, dry pond, dry vault, other

(experimental or other_____)

BMP volume (cu. ft.): _____ BMP surface area (sq. ft.): _____

ITEM	QUANTITY (for BMP)	UNIT COST	TOTAL COST
Excavation	_____(cu. ft.)	$_____	$_____
Fill/compact	_____(cu. ft.)	$_____	$_____
Seeding and maint.	_____(sq. ft.)	$_____	$_____
Storm drain pipe (with trench and backfill)	_____(lin. ft.)	$_____	$_____
Catch basins	_____(ea.)	$_____	$_____
Vaults	_____(ea.)	$_____	$_____
Access roads	_____(lin. ft.)	$_____	$_____
Control structures	_____(ea.)	$_____	$_____
Lining	_____(sq. ft.)	$_____	$_____
Right-of-way	_____(sq. ft.)	$_____	$_____
Other (specify)	_____	$_____	$_____
Design/permitting			$_____
Miscellaneous			$_____
	Total BMP Cost		$_____

Note: Include only the additional quantities which were required to install this BMP. When water quality and quantity BMPs are combined, indicate this in notes and estimate quantities for each function (e.g. no excavation for wet pond dead storage in water quantity).

Person completing form: _____ Date: _____

(Comments on other side of page)

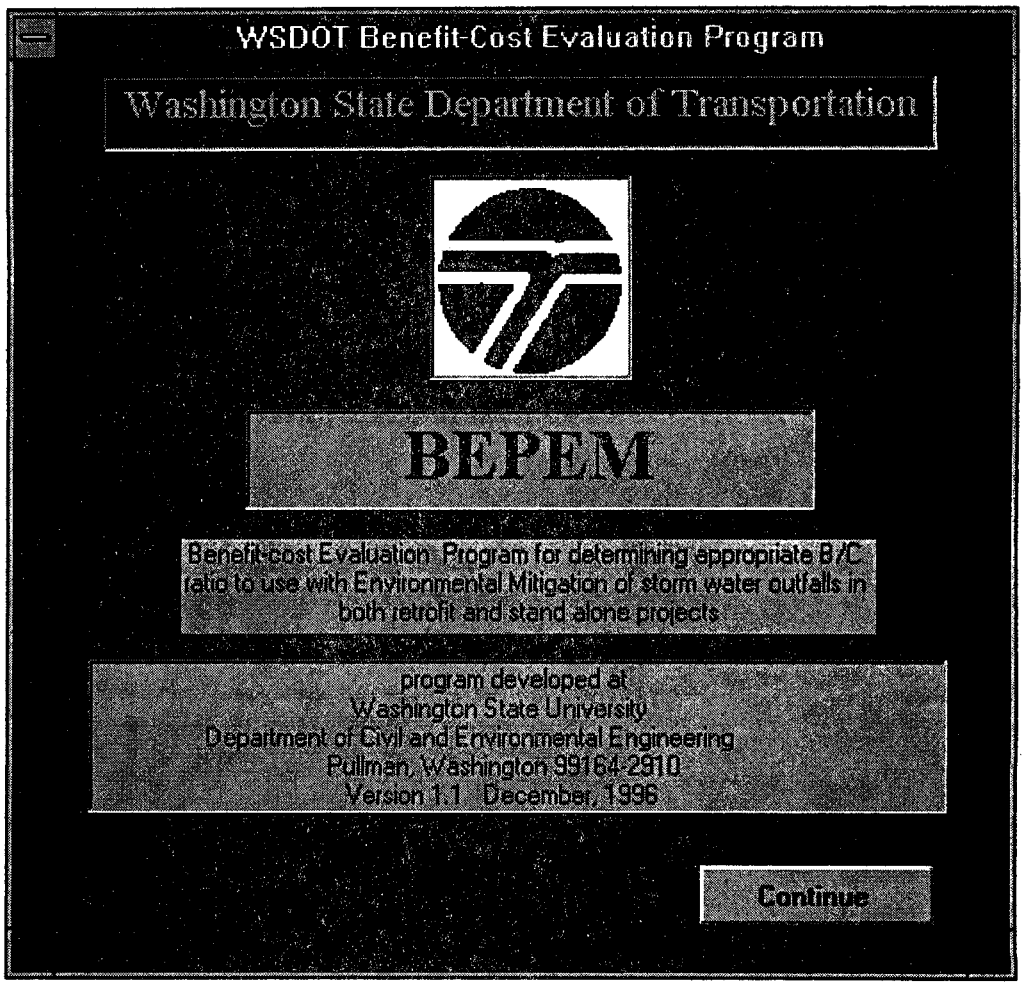
Project challenges/comments: _____

Please include in your comments any extenuating site conditions which made the specific costs greater than (or less than) they would be for most other similar projects.

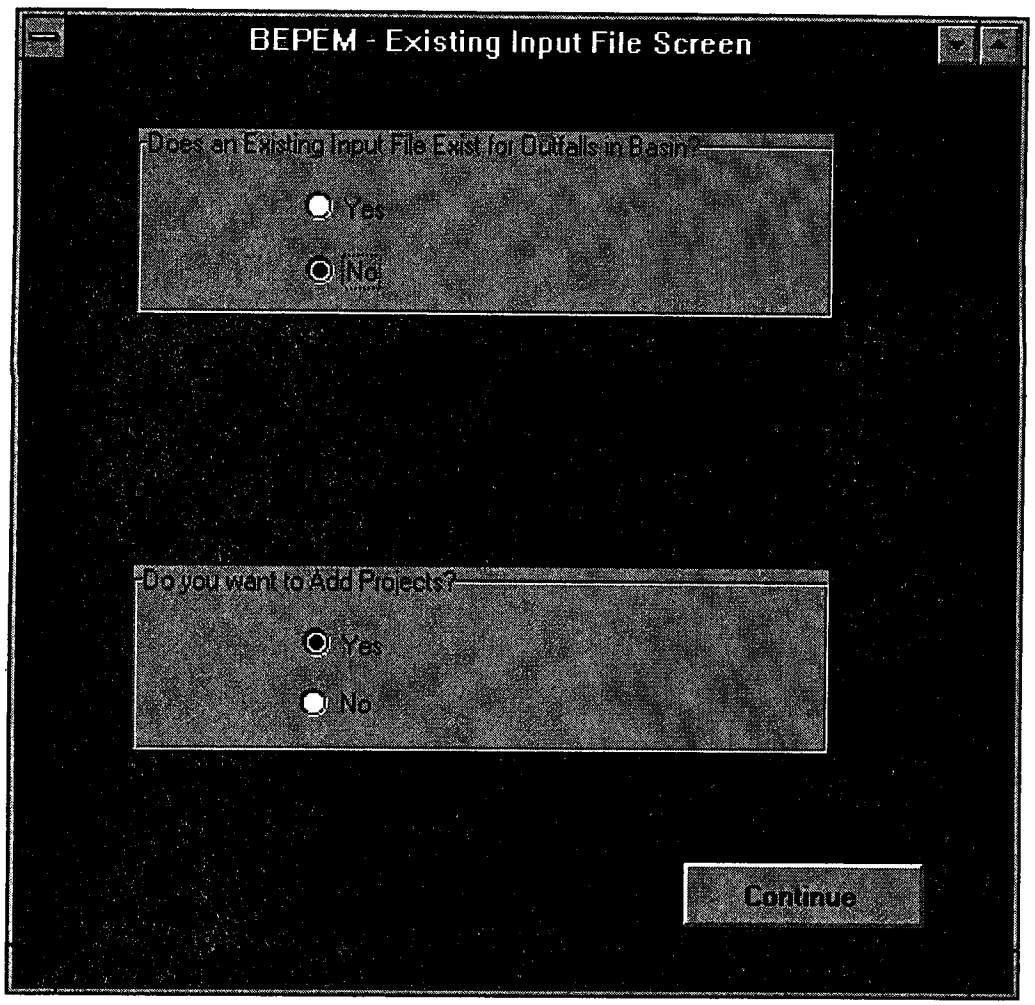
Appendix C

Screen Captures of BMP Evaluation Program

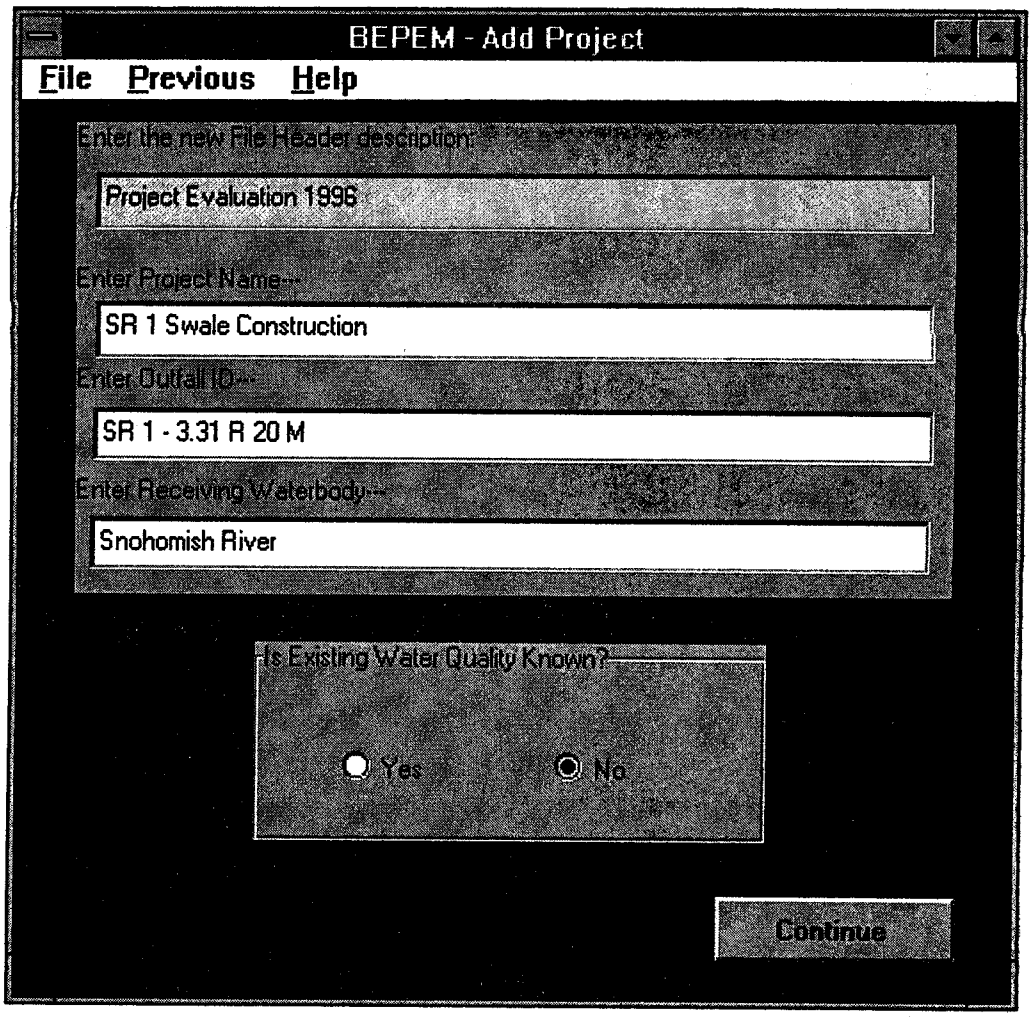
C-1 Screen #1: Introduction Form to BEPEM



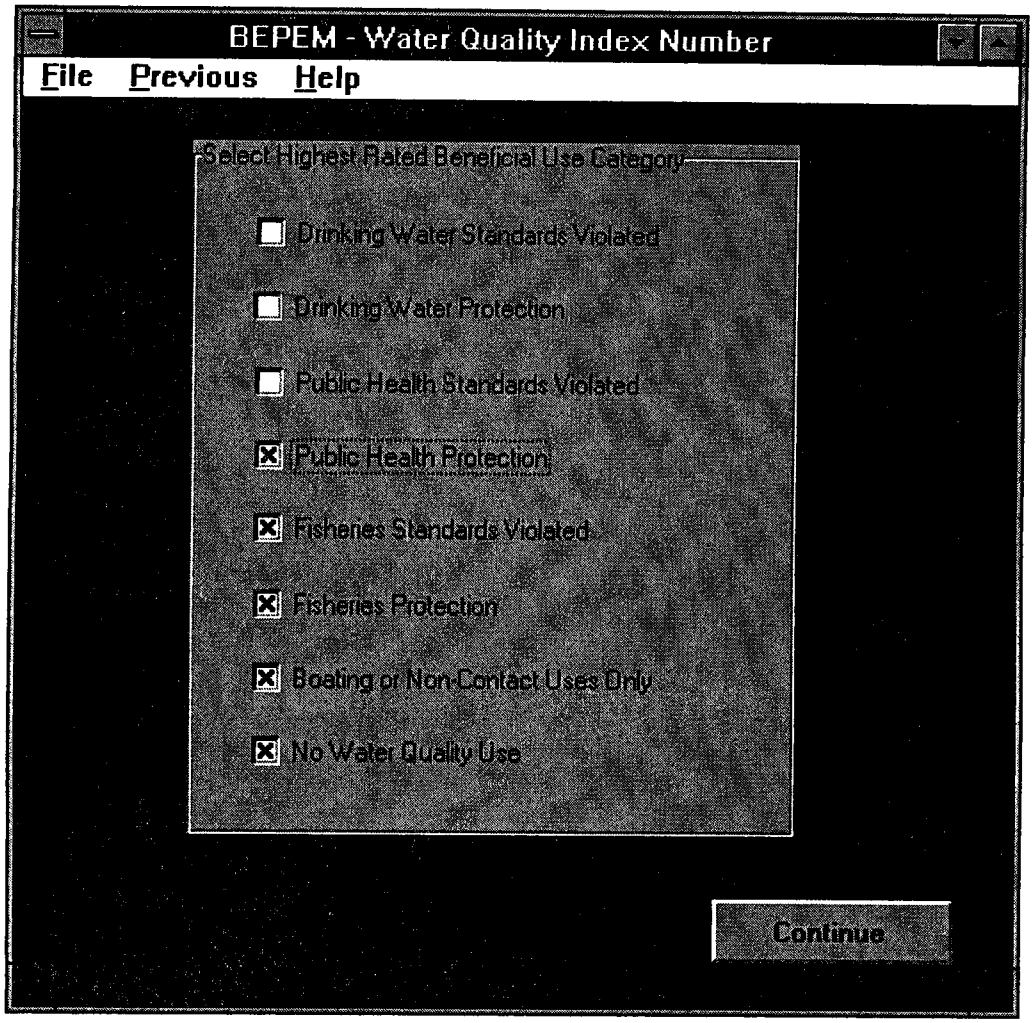
C-2 Screen #2: Prompts for whether an Input File Exists and whether New Projects will be added



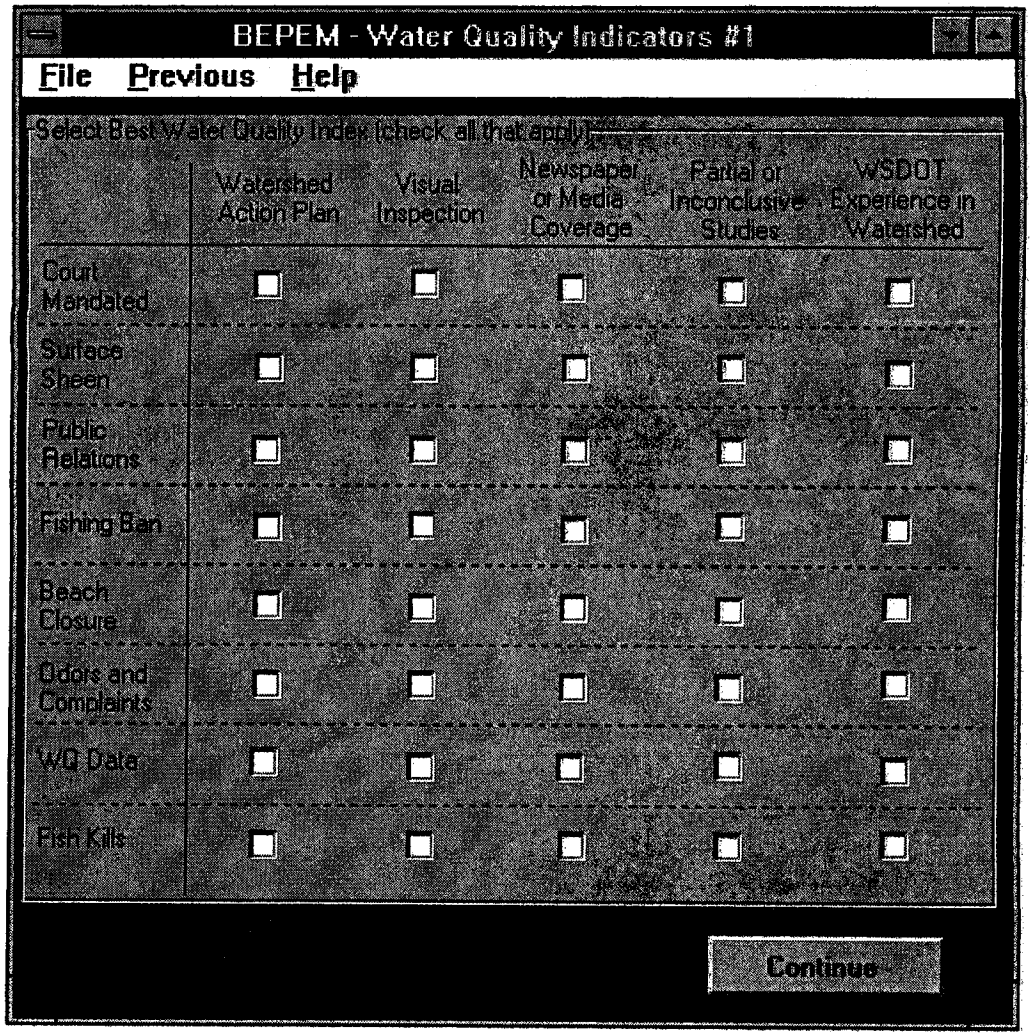
C-3 Screen #3: If Add Projects response on Screen #2 is yes, then this form requests information concerning New Project



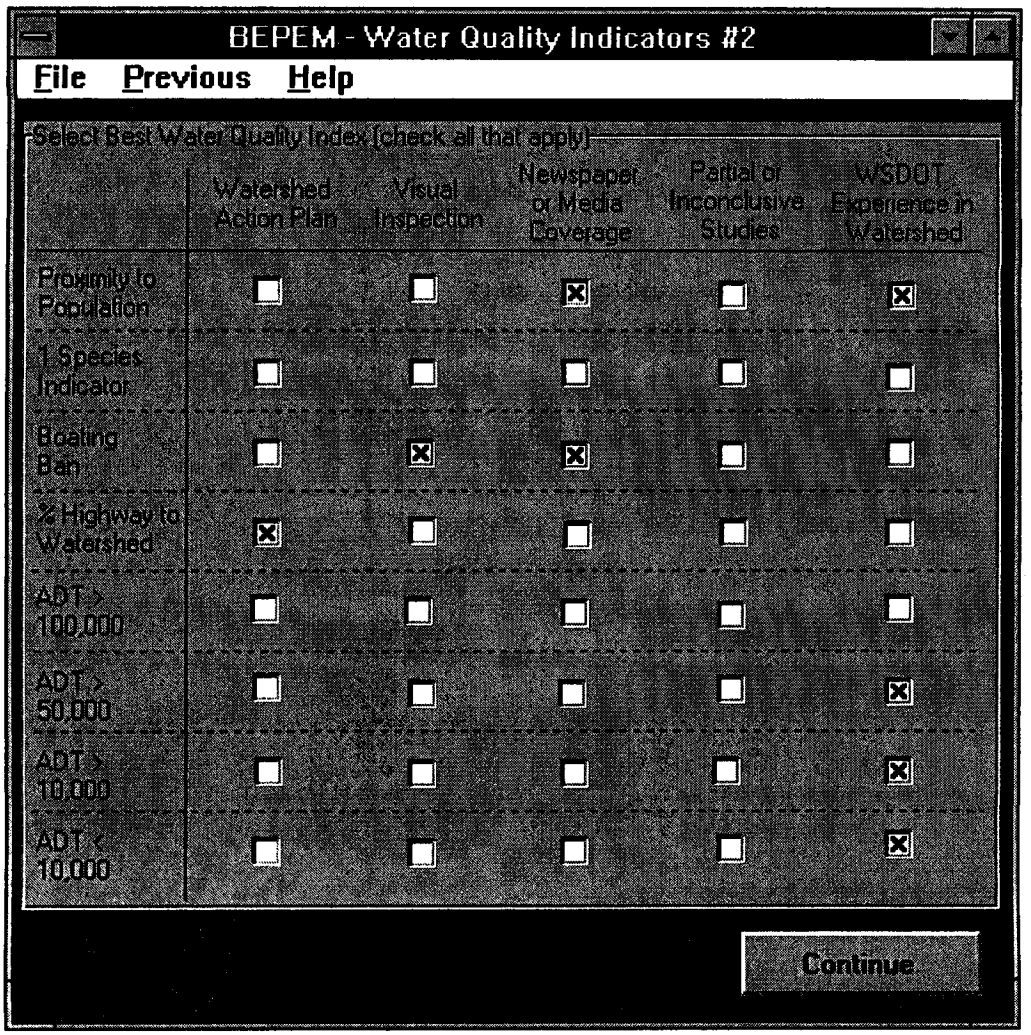
C-4 Screen #4: Selection of Water Quality Index when receiving water quality is known



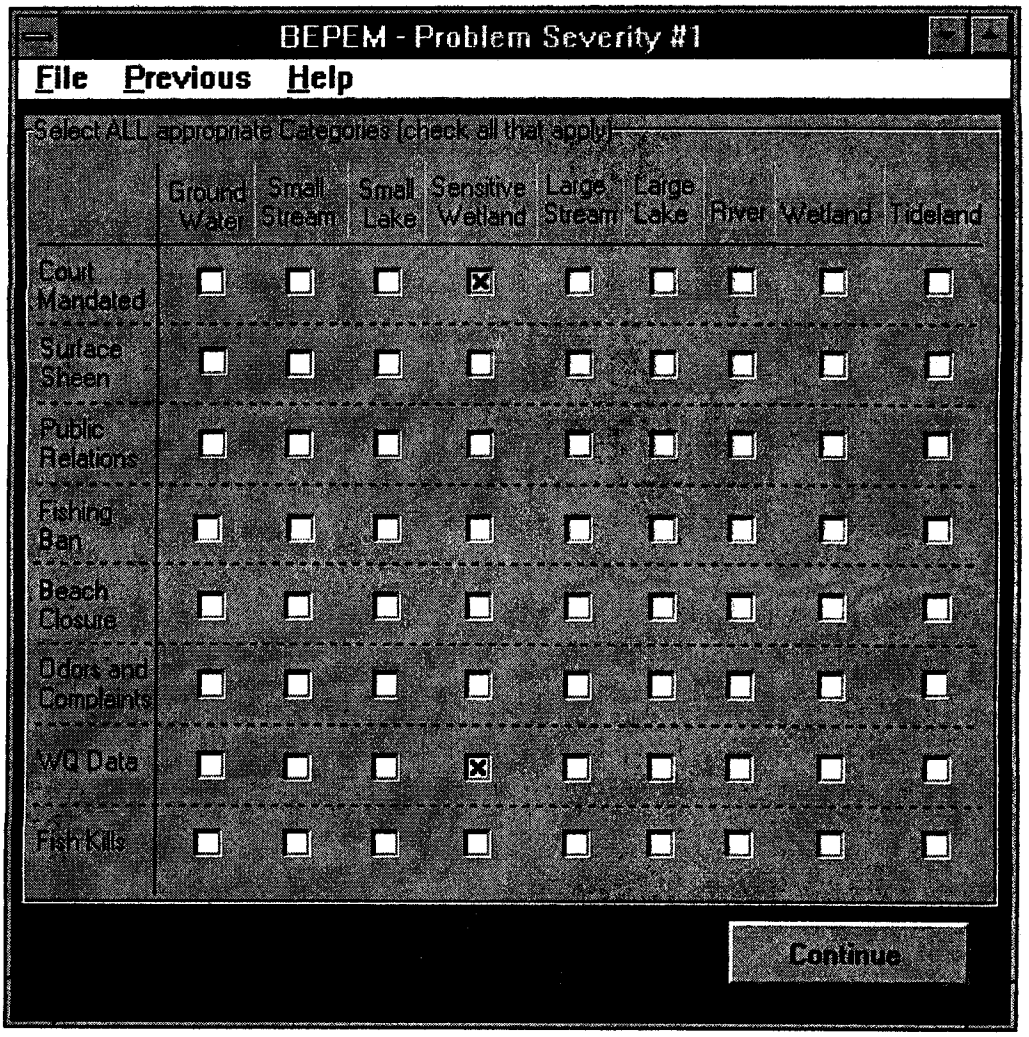
C-5 Screen #5: Development of Water Quality Index when Receiving Water Quality is not known (Screen 1 of 2)



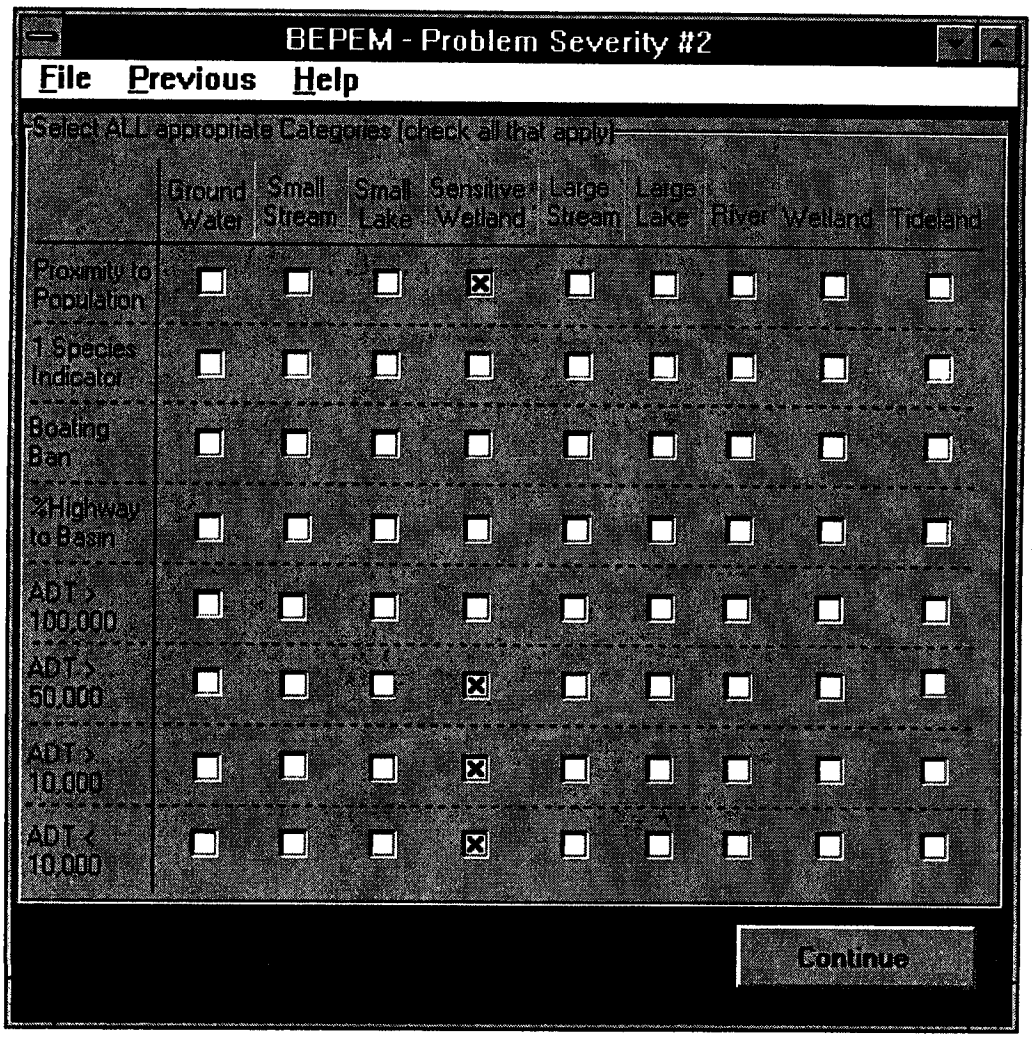
C-6 Screen #6: Development of Water Quality Index when Receiving Water Quality is not known (Screen 2 of 2)



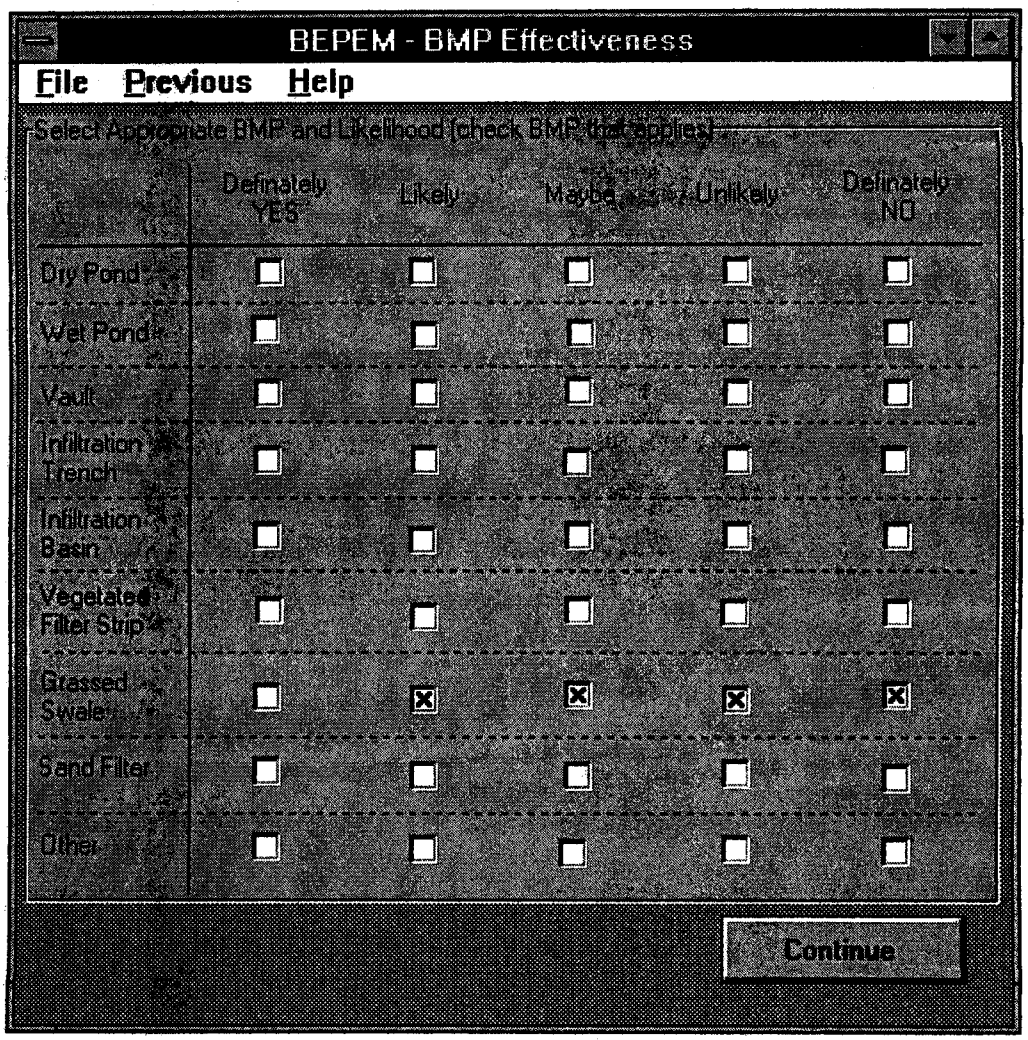
C-7 Screen #7: Determine Problem Severity by Linking Receiving Water Bodies to Pollution Indicator (Screen 1 of 2)



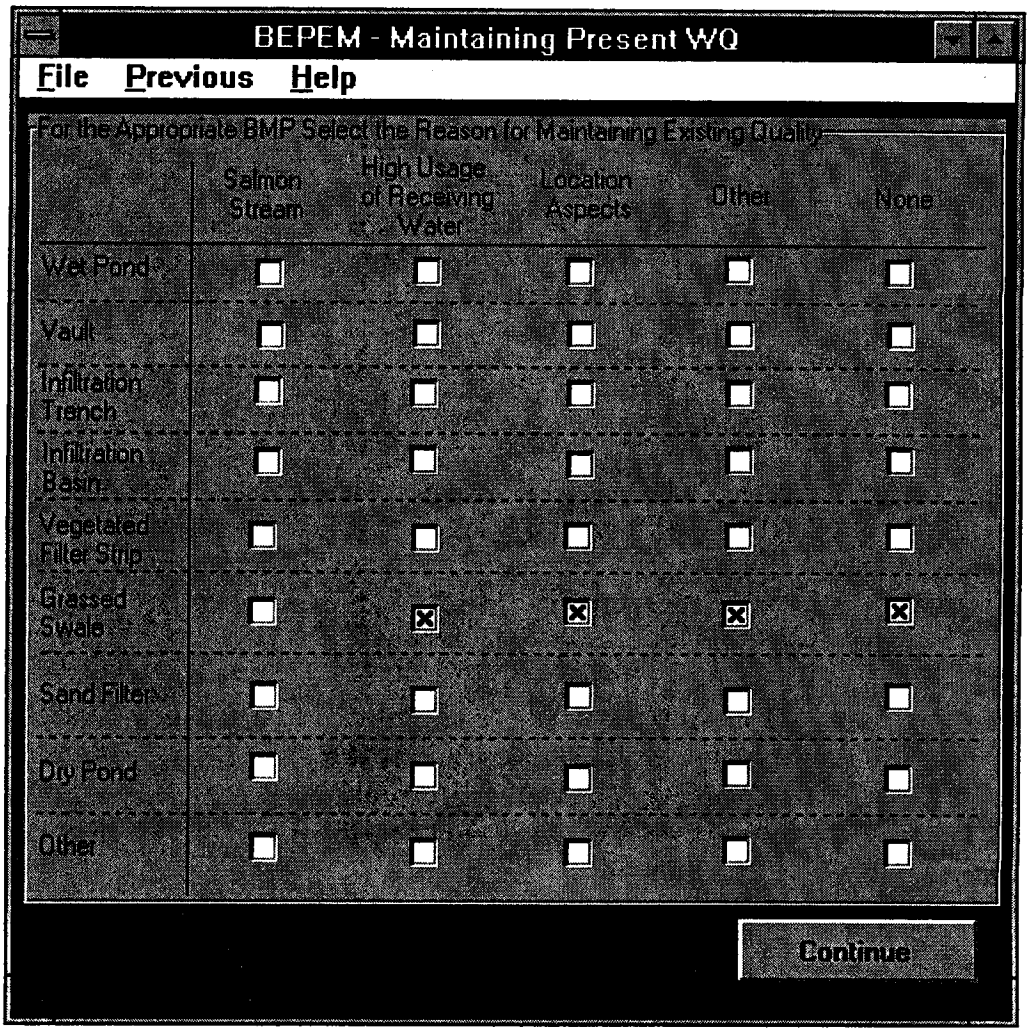
C-8 Screen #8:Determine Problem Severity by Linking Receiving Water Bodies to Pollution Indicator (Screen 2 of 2)



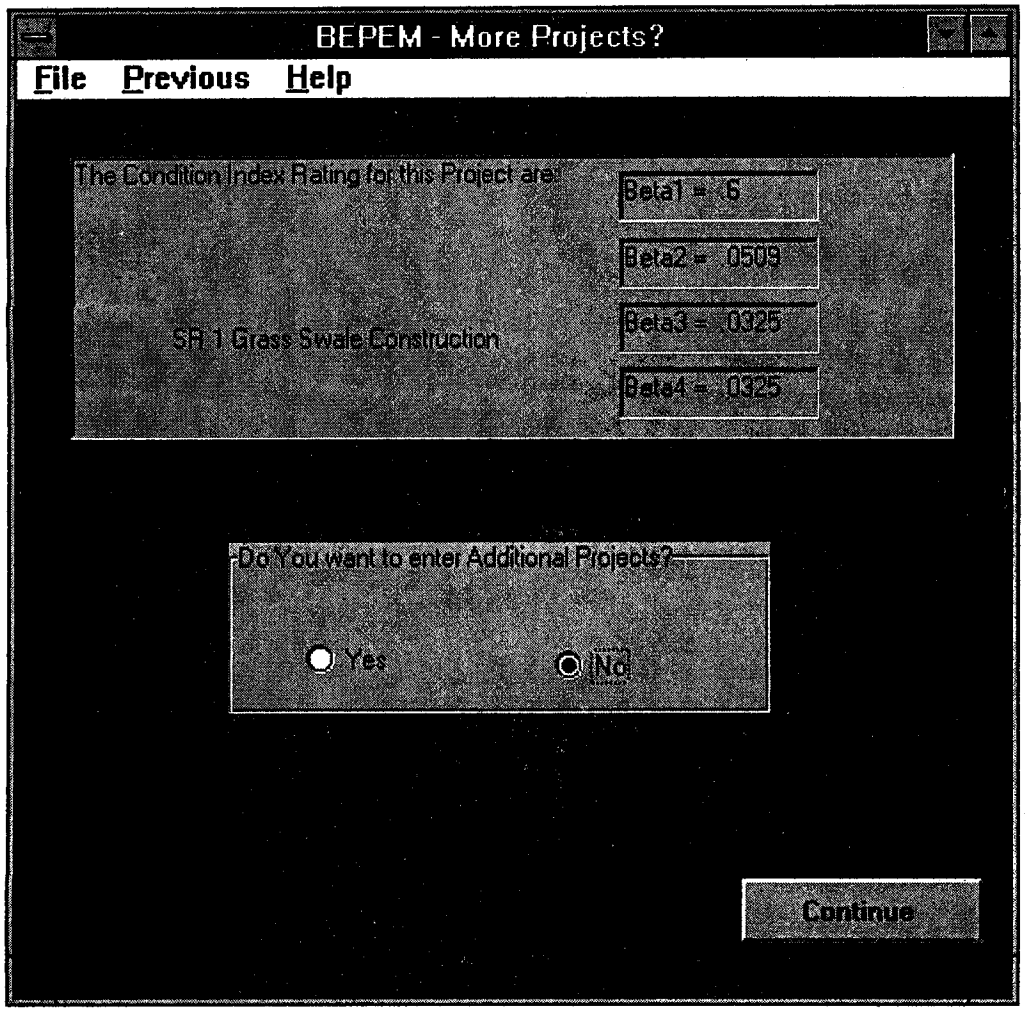
C-9 Screen #9: Parameter Selection relating BMP to likelyhood that Water Quality Problem is related to Highway Pollution



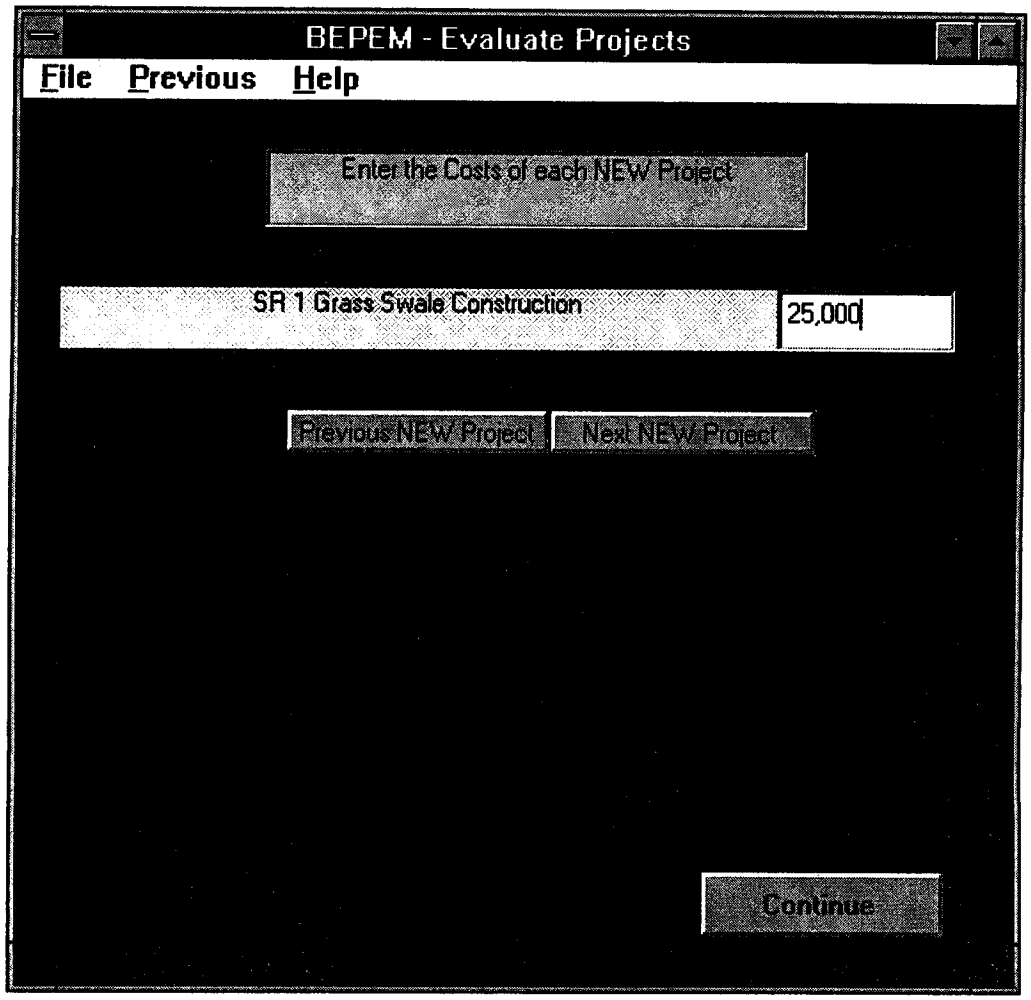
C-10 Screen #10: Index creation for protecting current Water Quality from Highway Runoff



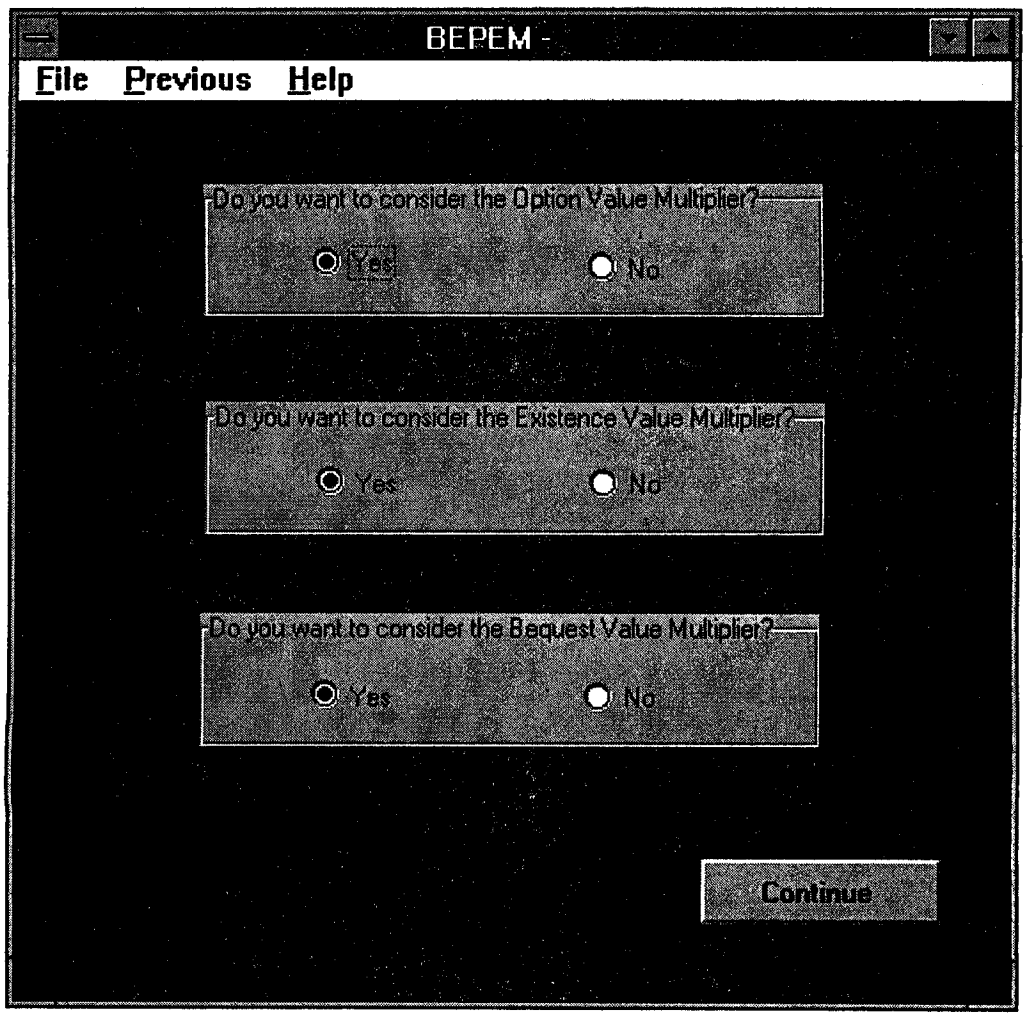
C-11 Screen #11: Summary of Project Indicies



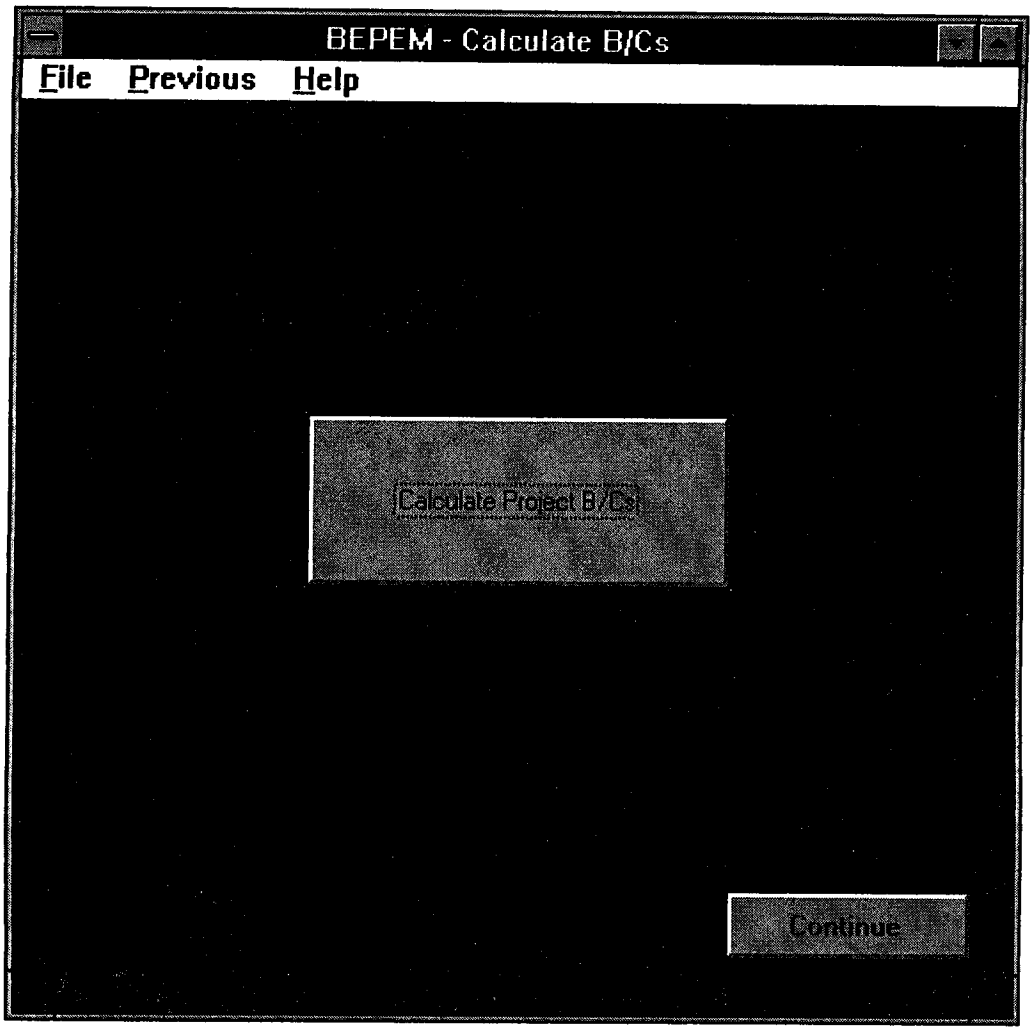
C-12 Screen #12: BMP Cost Inclusion or Update Screen



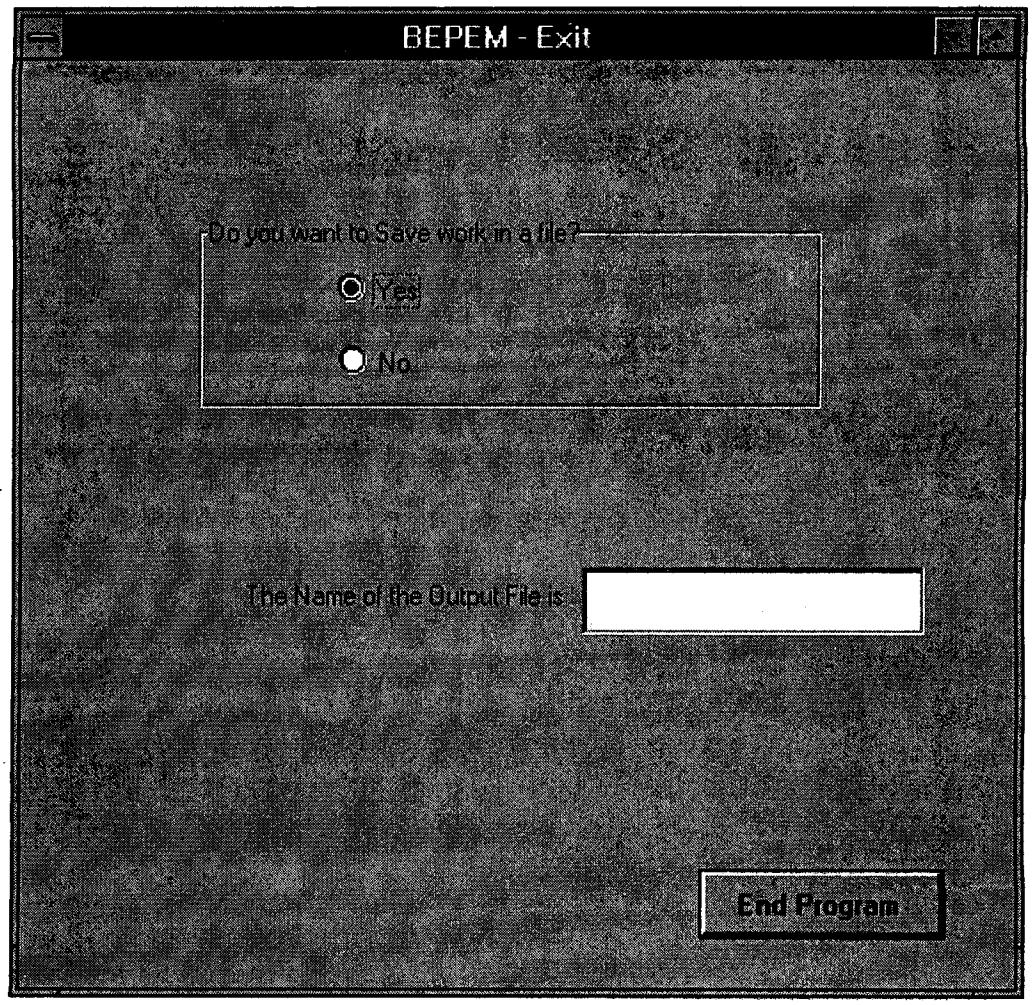
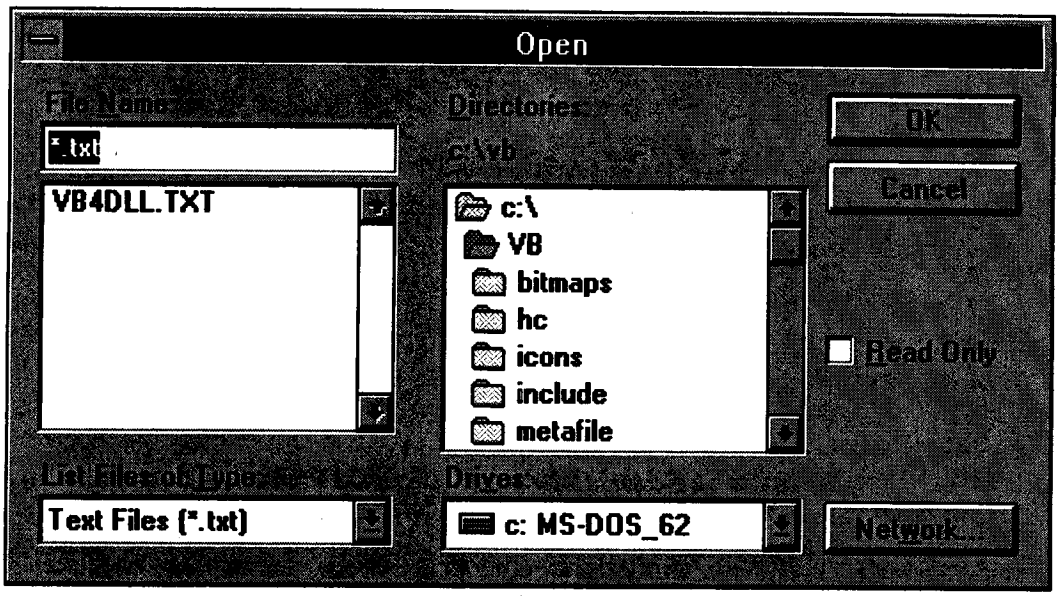
C-13 Screen #13: Alternative to include Option, Existence and Bequest Values Multipliers



C-14 Screen #14: Form which Computes Benefit/Cost Ratio for Each Project



C-15 Screen #15(a): Form to Permit User to select Output File to Save Results (Only output)



C-15 Screen #15(b): If Yes is selected, then windows-like menu to Specify Output File