

Developed by the Integrated Decision Support Group (IDS)
for
The United States Bureau of Reclamation



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About the Red Bluff Software

As part of the Red Bluff Diversion Dam Fish Passage Program (Red Bluff Program) the United States Bureau of Reclamation (Reclamation) and the Integrated Decision Support Group (IDS) are developing software for an IBM compatible Personal Computer for performing multi-criteria analysis. This software will be used to develop and evaluate possible management alternatives for the Red Bluff Diversion Dam (RBDD) along the Sacramento River in Northern California. This software is general enough to eventually analyze management alternatives for other sites and purposes.

Currently, the Red Bluff Software helps users formulate management alternatives to address fish passage problems associated with the Red Bluff Diversion Dam and to compare their alternatives with previously considered alternatives. This project is designed to evaluate, solicit, and track public input into the management alternatives and decisions.

Hardware Requirements

The Red Bluff Software requires a IBM compatible Personal Computer with a 486 processor. Windows 3.1 and DOS 6.0 or higher needs to be installed with 8 megabytes of available Random Access Memory (RAM). The monitor should be able to display 1024 x 768 pixels (super VGA).

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1.0 Introduction

With conflicting interests between different groups for determining management strategies for public resources (companies, agencies, etc.) becoming more common, multi-criteria analysis has become an essential technique in business, industry, and government. Multi-criteria analysis is a methodology for ranking management alternatives based on defined evaluation criteria that are weighted by the user. Multi-criteria analysis provides a rational methodology for decision making in the face of uncertainty. It enables the decision maker to choose among alternatives.

The Red Bluff Software presented here is a tool to be used in gaining a greater understanding of the issues surrounding the Red Bluff Diversion Dam Fish Passage Program. This software uses the concept of Multi-Criteria Analysis to compare alternatives.

1.1 About This Document

At the current stage of development, a variety of additional features are planned which would be beneficial in helping and informing users. Plans call for comprehensive on-line help and background information. This documentation covers the design and use of the software. Technical information on the issues and problems of fish passage at Red Bluff Diversion Dam can be found in Reclamation (1992) and Reclamation (1993).

1.2 The Intent

The intent of this software is to create a system with the flexibility to change individual or combinations of variables and quickly display the impacts on management alternatives. By providing this flexibility, the user can gain a greater understanding of important issues surrounding the fish passage problem at Red Bluff Diversion Dam. Reclamation will solicit feedback on development alternatives for the Red Bluff Diversion Dam from within Reclamation and eventually from the public using this software.

As with any software, new users may not be familiar with behind the scene workings and calculations from which the visual comparisons are generated. As a result, it is important for Reclamation to gain input on this prototype system to make it an acceptable means of communicating the technical issues. Section 4.0 provides a technical overview of multi-criteria analysis. In this prototype testing phase of the project, Reclamation seeks assistance in testing the assumptions and sensitivity of the models we have chosen. Reclamation seeks input on all aspects of the Software, from the layout of the various screens to types and ways in which users would like information displayed.

1.3 The Software

There are three different modules within the software. The first module allows users to

define new alternatives. The second module allows the user to compare different alternatives, and the third module allows users to evaluate alternatives using the multi-criteria analysis program. A wide variety of both technical and layman users have been and continue to be considered while developing the software. Different user levels can be set depending on the familiarity with the software. At the software's most advanced level, the technical team has the ability to adjust nearly all the various assumptions made in determining the ranking of alternatives.

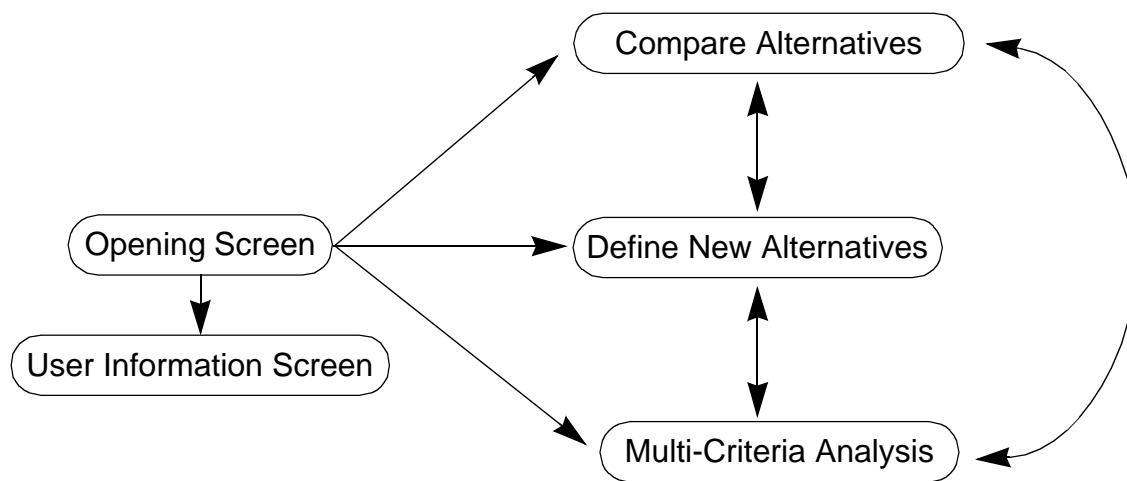


Figure 1: Navigational Schematic of the Red Bluff Software

1.4 The Use

Eventually, the Red Bluff Software will allow the public to use the new capabilities of multi-criteria analysis within the framework of a friendly interface. Information on the individual users of the system will be tracked and the scenarios developed by the user will be stored. The user will have the ability to view pre-defined management alternatives alongside their own alternatives using the same global variables, such as salmon mortality rates. These same global variables can be changed by the user and used to compare all the alternatives. For example, if the price-per-pound of ocean commercial salmon is changed, the new price-per-pound rate will be used for comparing all the alternatives. (i.e. comparing apples with apples, instead of apples with oranges).

2.0 Current Alternatives

2.1 Introduction

Alternatives are a combination of assumptions and managements decisions that can be expected to yield certain results, including construction costs and fish mortality rates. The Red Bluff Software allows the user to create new alternatives, but it also contains current Reclamation alternatives developed through the overall Red Bluff Project. Most of the current alternatives revolve around fish ladders, gate scheduling and pumping plant, bypasses, and combinations of these three elements. Applications and combinations of these concepts vary among the alternatives.

2.2 What are Current Alternatives?

Current alternatives are a shortened list of alternatives that have been considered for RBDD in the past and are included for a starting point in developing and evaluating new alternatives. The Red Bluff Software will also consider alternatives generated through additional ideas and comments provided by the public, the interagency team, Federal, State, and local agencies, and others. All alternatives assume pre-1987 conditions.

2.3 Fish Ladder Concepts

- 3A3.....Increase left and right fish ladders' flow to 800 cfs (cfs = cubic feet per second) and build new center fish ladder with 1,000 cfs flow
- 3B3.....Replace left fish ladder to increase flow to 2,100 cfs, increase right fish ladder to 800 cfs, and build new center fish ladder with 1,000 cfs.
- 3C3.....Replace left fish ladder to increase flow to 3,000 cfs, increase right fish ladder to 800 cfs, and build new center fish ladder with 1,000 cfs.

2.4 Gate and Fish Ladder Concepts

- 3A4.....Increase left and right fish ladders' flow to 800 cfs and build new center fish ladder with 1,000 cfs. RBDD gates would be open from Dec. 1 to April 1
- 3B4.....Same as Alternative 3A4 but replace left fish ladder to improve flow capacity to 2,100 cfs.
- 3C4.....Same as Alternative 3A4 but replace left fish ladder to improve flow capacity to 3,000 cfs.

2.5 Gate Scheduling Pumping Plant Concepts

When agricultural users require irrigation water and the gates are open the only way to

supply irrigation water to the T-C Canal is to install a pumping plant at the base of the dam to pump water into the canal for distribution. Therefore, when the gates are open and there is an irrigation demand the pumping plant is assumed to be operational.

- 4A.....Build a pumping plant with a capacity of 2,720 cfs, the full amount of diversions to the T-C Canal. Keep RBDD gates permanently open.
- 4B.....Build a pumping plant with a capacity of 2,480 cfs. Lower RBDD gates during the peak demand summer months (mid-May to mid-July) to supplement diversions to the T-C Canal, creating Lake Red Bluff for those months.
- 4C.....Build a pumping plant with a capacity of 1,360 cfs. Lower RBDD gates from April 15 to October 1, creating Lake Red Bluff for those months.

2.6 Combination Fish Ladder and Pumping Plant Concepts

- 4C1.....Increase left and right fish ladders' flow to 800 cfs. Build a new center fish ladder with 1,000 cfs flow. Build a pumping plant with a capacity of 1,360 cfs to divert water from October 1 to April 15. Lower RBDD gates from April 15 to October 1, creating Lake Red Bluff for those months.
- 4C2.....Same as 4C1 but new center fish ladder would have a flow capacity of 2,100 cfs.

2.7 Comparing Alternatives

Reclamation considers four planing criteria when evaluation alternatives: acceptability (politically and publicly acceptable and compatible with existing regulations), effectiveness (how well it solves the salmon mortality problem), efficiency (solves the salmon mortality problem cost-effectively), and completeness (how much of the salmon mortality problem is solved).

- Acceptability is a measure of public opinion.
- Effectiveness is a measure of salmon survival.
- Efficiency is a measure of economic factors.

This software considers acceptability, effectiveness, and efficiency. The overall RBDD Program will address completeness.

3.0 Software Description

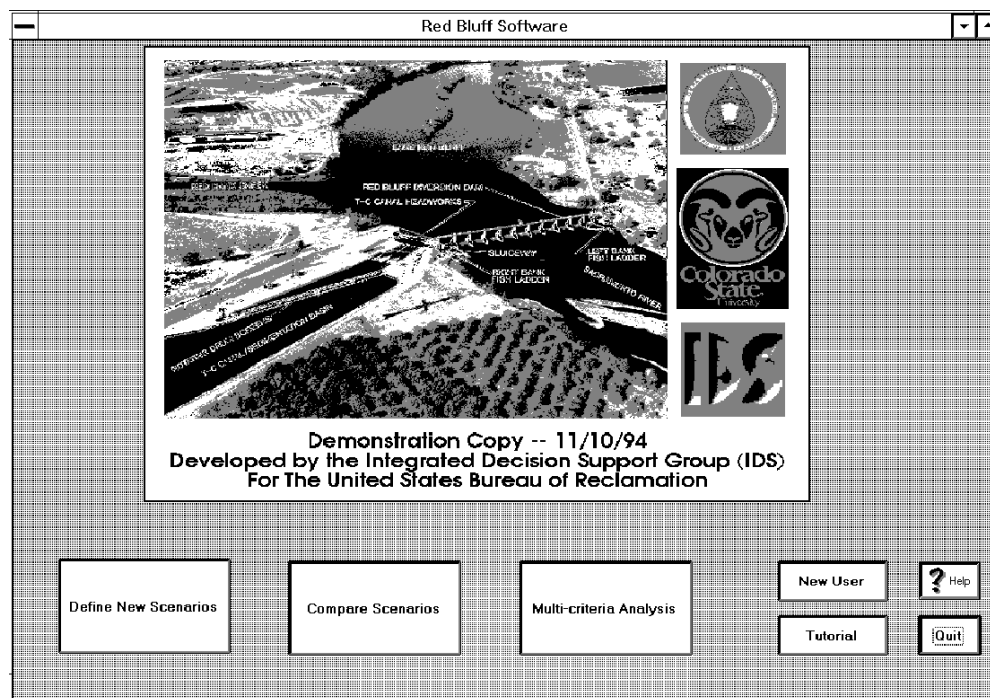


Figure 2: Opening Screen

3.1 Opening Screen

1. Define New Alternatives -

The **Define New Alternatives Screen** allows the user to formulate new management alternatives.

2. Compare Alternatives -

The **Compare Alternatives Screen** is used to evaluate all alternatives including alternatives created by the user. Four alternative can be displayed at on time at the technical user level, two at the intermediate level and one at the basic level.

3. Multi-Criteria Analysis -

The **Multi-Criteria Analysis Screen** allows the user to run a multi-criteria model that weighs and analyzes alternatives to rank them based on the various criteria and the methodology presented in section 3.0.

4. New User -

Allows the user to register as a new user and to enter information such as name, address, interest group, user level, etc.

5. Tutorial -

Still under construction. Currently demonstrates sound capabilities.

6. Help

Help displays text designed to introduce the user to the software.

7. Quit

The *Quit* option will exit the interface.

3.2 New User

Welcome to the Red Bluff Project!

What is your name?

Of the following groups, choose one to which you would most likely belong:

- > Agricultural Water User
- > Commercial Fisherman
- > Environmental Group Member
- ◀ Government Agency Representative
- > Citizen of Red Bluff
- > Other

How would you rate your skill level as a user of this program?

- > Basic
- > Intermediate
- ◀ Technical

Contact Information (OPTIONAL)

Street Address

City, State, Zip

Phone Number

Figure 3: New User Screen

1. What is your name?

The information for this question will be used as the base name for the scenarios the user creates. (e.g. **Figure 3** would be alternative Joe). As the user creates additional new alternatives they can be saved as a name chosen by the user using the *File Save* option in the **Define New Alternatives Screen**. If the user enters a first and last name only the first name will be used as the base name for the alternatives.

2. Interest Groups -

This information will be valuable to Reclamation for understanding some of the motivations for alternative variable choices and weights set for evaluation criteria.

3. Skill level of the user -

The basic level displays only one graph at a time and has less flexibility setting parameters. Technical is for the most sophisticated users of the system and offers more choices for variable settings and graphs that are displayed. The intermediate level is a balance between the two. All the figures in this document are from the intermediate user level.

4. Contact Information -

This information is optional. In the future, entering this information would add the user to the Red Bluff Project mailing list and the user would receive progress updates and meeting notices.

3.3 Define New Alternatives

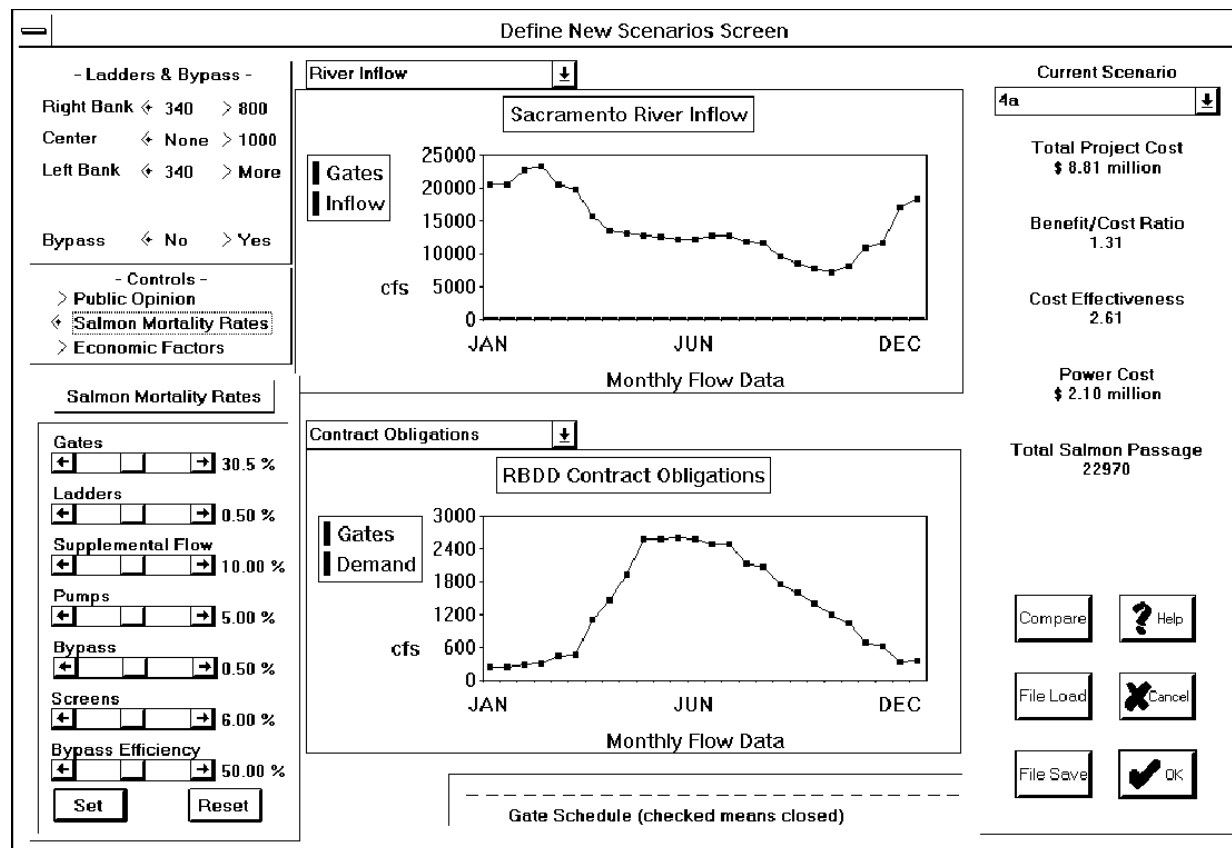


Figure 4: Define New Alternatives Screen with Fish Mortality Rates.

1. Ladders & Bypass -

There are three positions where fish ladders can be constructed or already exist on the diversion dam (left, center, and right). The left fish ladders are along the north bank of the Sacramento River and the right ladders are along the south bank. Currently, there are fish ladders on both the left and the right bank of the river. Some alternatives propose enlarging these ladders and possibly installing a center ladder. A bypass would be an alternate route for salmon past the dam. Currently no bypass exists, but some proposals suggest installing one.

2. Controls -

There are three types of controls (Public Opinion, Salmon Mortality Rates, and Economic Factors). These are the same controls as in previous screens. Public Opinion and Salmon Mortality Rates controls will be displayed within the **Define New Alternatives Screen** and the Economic Factors control will bring up the screen in 2.1a (Figure 2). The Public Opinion Control is displayed in Figure 4.

3. Graphs -

These line graphs are mainly for setting the gate schedule. Selecting one of the boxes under the graphs closes the dam for a two week period (two boxes represent one month).

4. Total Salmon Passage -

Total salmon passage is the amount of salmon fry that successfully make it past the Red Bluff Diversion Dam.

5. Total Salmon Mortality -

Total salmon mortality is a summation of all the mortality rates for salmon fry migrating to the ocean and salmon

3.0 Software Description

runs back up the river to spawn.

6. Current Alternative.

When one of the alternatives is selected the data for that particular alternative will be reflected along the right side of the window under the current alternative scroll list. The user can modify this alternative and save with the *File Save* option.

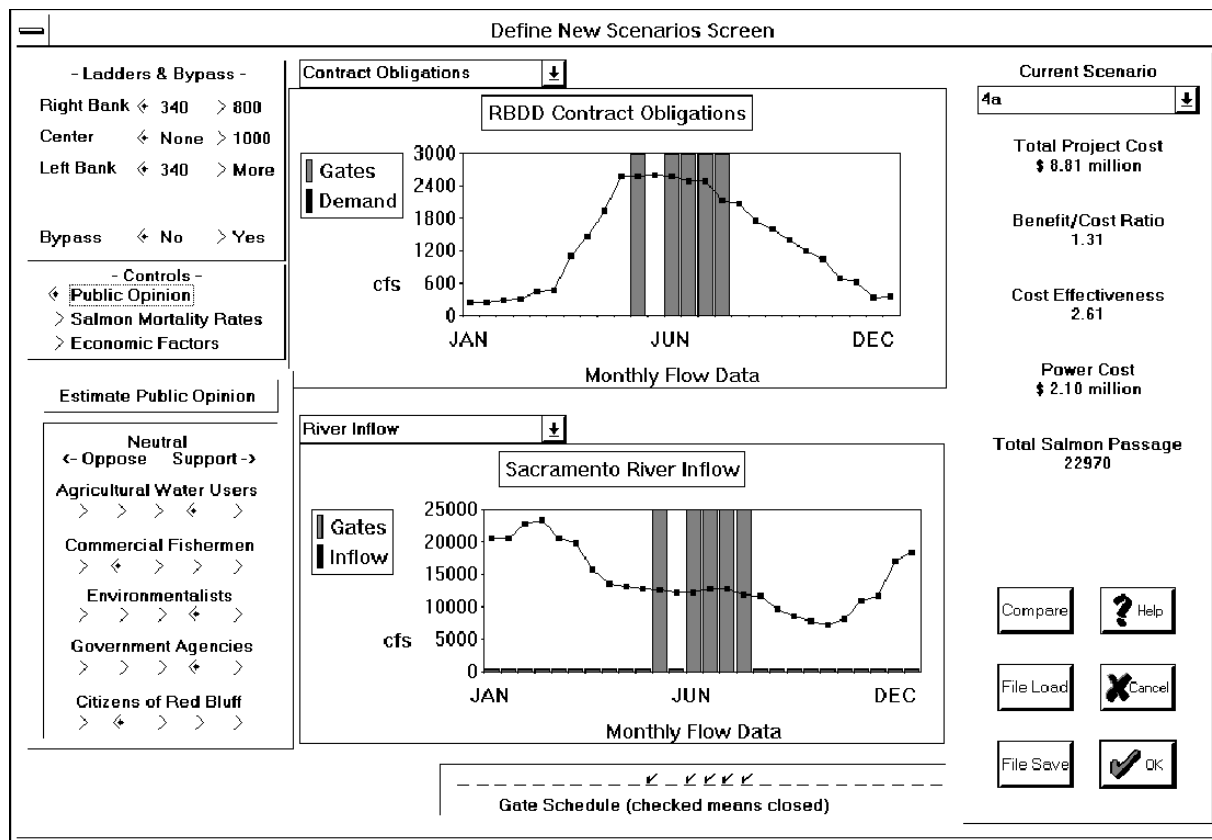


Figure 5: Define New Alternatives Screen with Public Information Input

7. Total Projected Cost -

The total projected cost of each alternative is the cost of all the new construction that would be expected for that alternative.

8. Benefit/Cost Ratio -

The benefits include recreational and commercial economic viability for salmon runs. The cost is the annual equivalent cost.

9. Cost Effectiveness -

Cost effectiveness is the amount of fish that will survive based on the annual equivalent cost of construction. Cost effectiveness is the expected time period for the construction over the total projected cost.

10. Power Cost -

Power cost is the electricity cost for operating the pumps when the gates are open to deliver the amount of water required by contract obligations for the irrigation canal.

11. Compare -

The *Compare* button will bring up the **Compare Alternatives Screen**.

12. File Load -

The *File Load* button will bring up a dialog box that allows the user to select an alternative from a file. The alternatives listed will include all the user created alternatives. The user can currently load 14 new alternatives in addition to the 11 current alternatives.

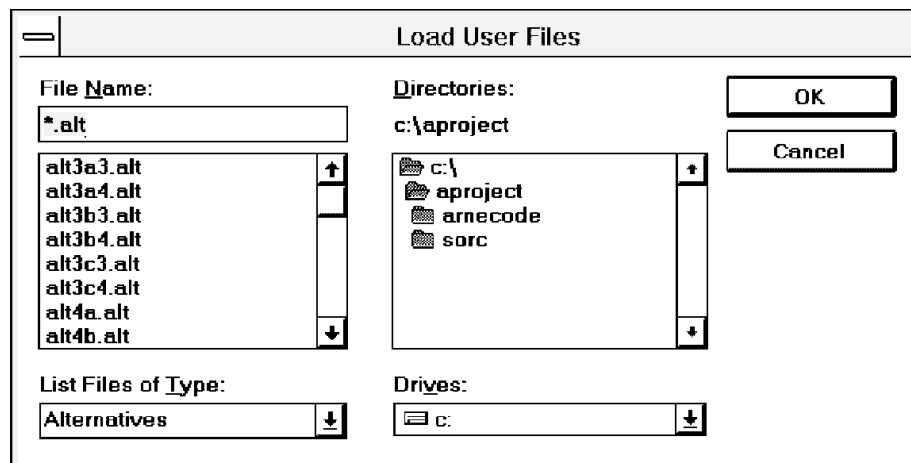


Figure 6: File Load Option from the Define Alternatives Window

13. File Save -

The *File Save* button will bring up a dialog box that allows the user to save an alternative in a file.

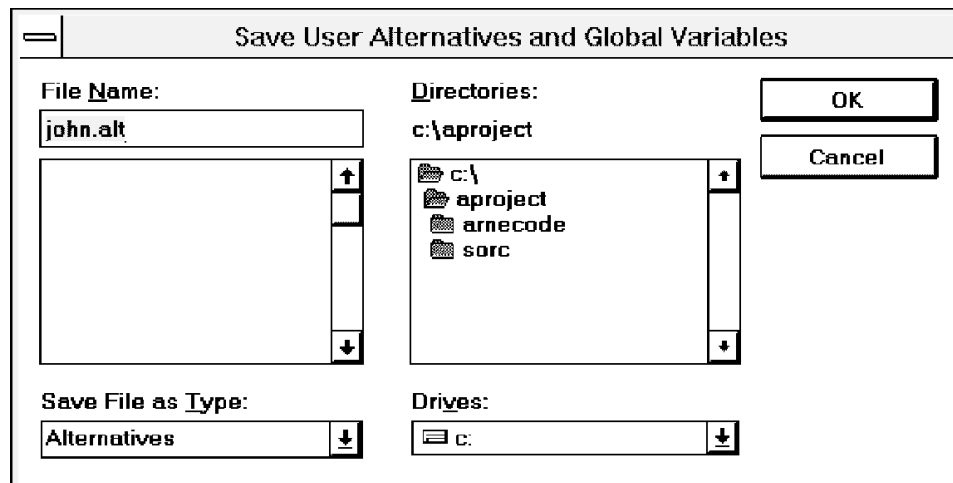


Figure 7: File Save Option from the Define Alternatives Window

14. Help, Cancel, and OK -

The *Help* option will display text designed to help the user. *Cancel* will return to the original screen without saving any changes. *OK* will save any values changed in the economic factors or the salmon mortality rate controls and return to the original screen.

3.4 Compare Alternatives

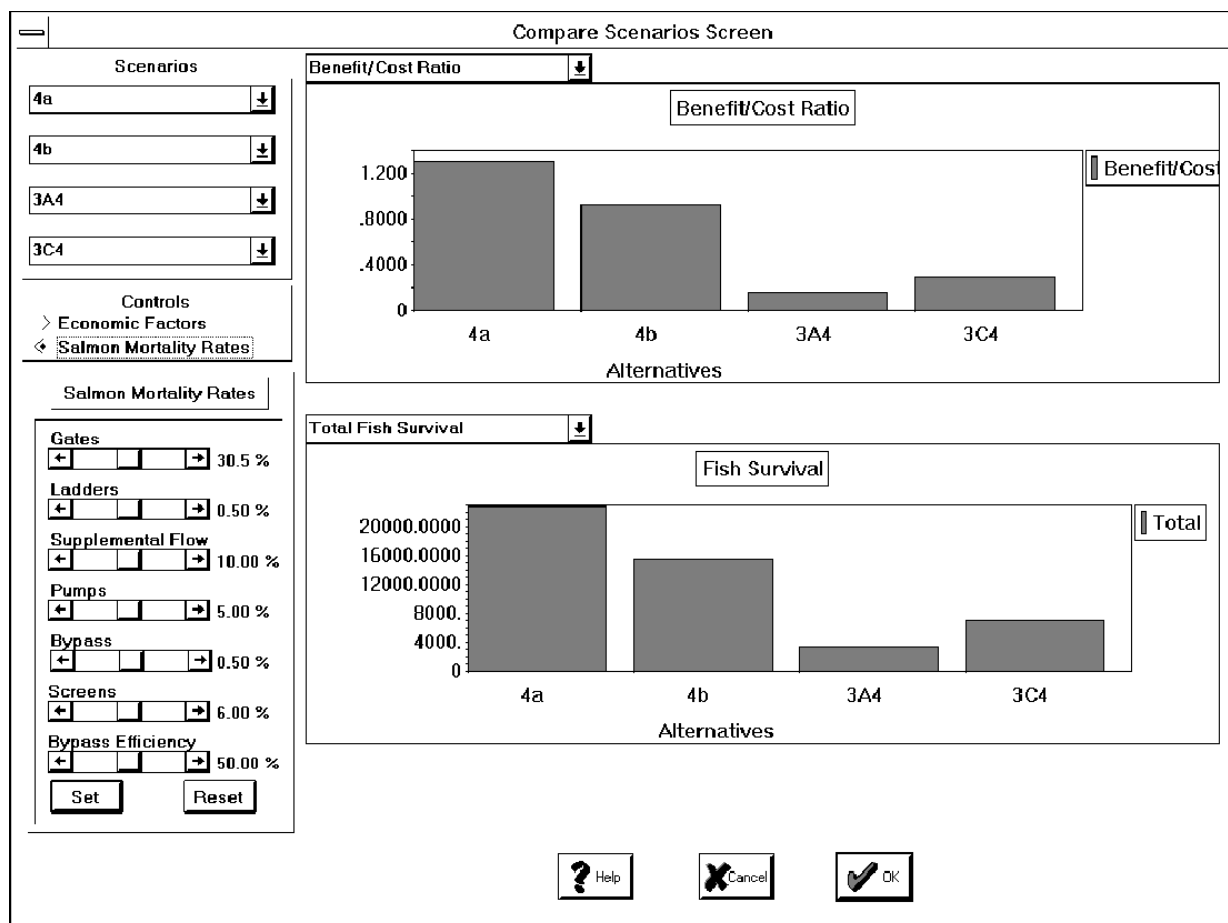


Figure 8: Compare Alternatives Screen

1. Alternatives -

Four different alternatives can be selected for comparison. Selecting the arrow on the right hand side of alternative title box will display a scrollable list with different alternatives.

2. Controls -

Two types of controls can be set (economic factors and salmon mortality rates). The economic factors control setting will bring-up a new screen at the technical user level with economic and other miscellaneous factors and will bring up a small scroll window for the intermediate user level with just the economic factors. Similarly, the *Salmon Mortality Rates* option will bring up a small scroll window with salmon mortality rate settings for both levels. At the basic level these controls are not displayed.

3. Graphs

The graphs that can be displayed in this screen have to do with legal or physical limitations on the system that all alternatives must adhere to.

4. Help, Cancel, and OK

The *Help* option will display text designed to help the user. *Cancel* will return to the original screen without saving any changes. *OK* will save any values changed in the economic factors or the salmon mortality rate controls and return to the original screen.

3.4a Economic and Other Factors

Economic And Other Factors

Section	Parameter	Value
Cost Factors	Total Construction Costs	100 %
	Construction Period	10 years
	Operations, Maintenance, and Repair	100 %
	Power Cost	100 %
Economics Factors	Interest Rate	8.75 %
	Trips per Salmon for River Sport	5.56
	Trips per Salmon for Ocean Sport	1.19
	Value per Trip for River Sport	51.00
	Value per Trip for Ocean Sport	60.00
	Price per Pound of Salmon	2.57
Fisheries Data	Salmon Base Population - Fall	94000.00
	Salmon Base Population - Spring	13000.00
	Salmon Base Population - Winter	2000.00
	Salmon Base Population - Late Fall	11000.00
	River Carrying Capacity - Fall	400000.0
	River Carrying Capacity - Spring	150000.0
	River Carrying Capacity - Winter	200000.0
	River Carrying Capacity - Late Fall	150000.0
	Catch to Escapement Ratios Winter Commercial	154.00
	River Sport	0.00
	Ocean Sport	533.00
	Non-Winter Commercial	1420.00
River Sport	60.00	
Ocean Sport	580.00	

Buttons:

Figure 9: Economic and Other Factors Screen

1. **Cost Factors -**

The cost factors include annual equivalent cost; the period of construction; the operations, maintenance, and repair costs that can be expected over the life of the system; and finally the power costs that can be expected for the pumps when the gates are closed.

2. **Economic Factors -**

The economic factors include the interest rate that can be expected on the loan for construction costs; trips per salmon for river sport and ocean sport fishing; value per trip for river and ocean sport fishing; and price per pound for salmon.

3. **Fisheries Data -**

The fisheries data include the salmon base population rate for fall, spring, winter, and late fall; river carrying capacity for fall, spring, winter, and late fall; and catch-escapement ratios for winter and non-winter (rates are for commercial, river, and ocean sport fishing).

4. **Help, Cancel, and OK**

The *Help* option will display text designed to help the user. *Cancel* will return to the original screen without saving any changes. *OK* will save any values changed in the economic factors or the salmon mortality rate controls and return to the original screen.

5. **Note**

The percentages and numerical values were given a realistic range of values to fluctuate. For example the maximum interest rate that is currently allowed is 8.75%. These ranges can be changed by the system manager, if needed. These ranges are currently set with as much latitude as can be expected to realistically occur.

3.4b Salmon Mortality Rates

Category	Value (%)
Gates	30.5 %
Ladders	0.50 %
Supplemental Flow	10.00 %
Pumps	5.00 %
Bypass	0.50 %
Screens	6.00 %
Bypass Efficiency	50.00 %

Buttons: Set, Reset

Figure 10: Salmon Mortality Rates

1. Gates -
The salmon mortality rates for gates reflect the loss of fry to predation when the gates are closed.
2. Ladders -
The salmon mortality rates for ladders reflect the loss of salmon on the upstream run and the efficiency of the ladders in increasing the number of salmon that make it past the diversion dam to reproduce.
3. Supplemental Flow -
Supplemental flow is a flow of water near the base of the fish ladders to lure the fish up the ladder.
4. Pumps -
The pump mortality rates reflect the loss of fish caught in the pump inlet.
5. Bypass -
There may be some dangers from predators in the bypass.
6. Screens -
The screens are on the inlet to the irrigation canal to keep the fish out of the canal where they are lost to the river and vulnerable to predation.
7. Bypass Efficiency -
The bypass is proposed as an alternative route for fish around the diversion dam, there will be a certain efficiency associated with this bypass for the mortality rate. The efficiency is the number of fish that would use the bypass if it was constructed.

3.5 Criteria Weights

Assign Weights for Criteria

Effectiveness - How important is improving the salmon run? 30 % Set Subcriteria

Efficiency - How Important is the cost? 40 % Set Subcriteria

Acceptability - How important is interest group support? 30 % Set Subcriteria

Percent Allocated 100 %

? Help X Cancel RUN

Figure 11: Assign Weights for Criteria Screen.

1. Help and Cancel

The *Help* option will display text designed to help the user. *Cancel* will return to the original screen without saving any changes.

2. Run -

This will run the multi-criteria analysis software and the alternatives will be ranked according to the criteria in this screen and other screens.

3. Effectiveness - How important is improving the salmon run?

Effectiveness measures how well the alternative solves the problem. The values for these criteria reflect a weight of how important each criteria is in the overall decision making process for ranking the alternatives. One hundred percent means that it is very important to improve the salmon run. This value will be used for all the alternatives that are evaluated with the multi-criteria analysis.

4. Efficiency - How important is the cost?

Efficiency is a measure of how cost effective the alternative is. One hundred percent means that the cost is a very important concern. This value will be used for all the alternatives that are evaluated with the multi-criteria analysis.

5. Acceptability - How important is interest group support?

Acceptability is a measure of how politically and publicly acceptable and compatible with existing regulations the alternative is for various interest groups. Interest groups consist of many different citizen groups. For example, citizens of Red Bluff who have an annual boat race, commercial fisherman who want to maintain the salmon runs, environmental groups, and others.

Effectiveness

- How important is improving the salmon run?

Acceptability

- How important is interest group support

Efficiency - How Important is the cost?

Note - The percentages of effectiveness, efficiency and acceptability sub-criteria must add up to 100 percent.

Figure 12: Sub-Criteria for Effectiveness, Efficiency, and Acceptability

3.6 The Multi-Criteria Analysis Screen

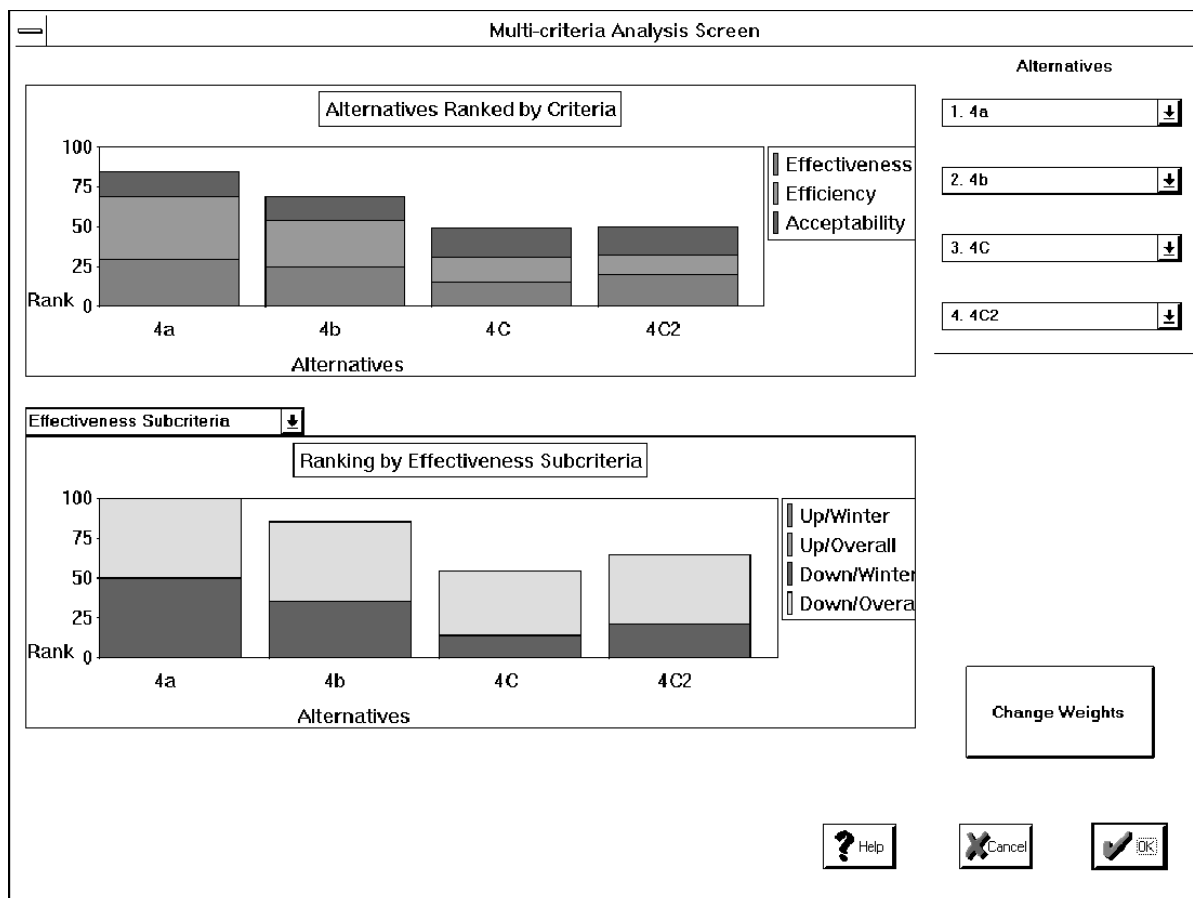


Figure 13: Multi-criteria Analysis Screen.

6. Graphs -

The graphs in the **Multi-criteria Analysis Screen** at the intermediate user level represent how the various alternatives are ranked (Figure 13). The different bar colors represent the three criteria. At the basic user level, only the first graph is displayed and at the technical level the criteria and the sub-criteria are displayed.

7. Alternatives -

Four different alternatives can be selected for comparison. Selecting the arrow on the right hand side of the alternative title box will display a scrollable list with different alternatives. This scrollable list orders the ranked alternatives in relation to the user defined criteria. The best ranked alternative is displayed first.

8. Change Weights -

The *Change Weights* button will return the user to the **Assign Weights Screen**.

9. Help, Cancel, and OK -

The *Help* option will display text designed to help the user. *Cancel* will return to the original screen without saving any changes. *OK* will save any values changed in the economic factors or the salmon mortality rate controls and return to the original screen.

4.0 Technical Overview for Multi-Criteria Analysis

In the past decade much attention has been paid to multi-criteria evaluation approaches to determine management alternatives for complex public resource systems. As the decision making task increases, researchers have observed systematic discrepancies between rational theory and actual behavior. In other words, given the choice between management alternatives people will not consistently select the “best” alternative based on evaluation criteria. Evidence exists that even experts in public resource management have great difficulty in intuitively combining information in appropriate ways (Goicoechea et al, 1982). Because of the severe limitation on the intuitive decision making process, analytical methods can be used to help determine the worth of multi-attributed alternatives. One technique that has been used successfully is multi-criteria analysis. This method can rank existing alternatives quantitatively according to weighted criteria.

In the area of water resources allocation the operation of a multi-purpose reservoir like the Red Bluff Diversion Dam may call for delivering irrigation water while still trying to maintain minimum water levels in the reservoir and downstream to accommodate environmental, commercial, and recreational goals. These goals, can often be conflicting in nature. By trying to satisfy these goals simultaneously, it may no longer be clear what is the best management alternative. his software allows the user to define alternatives and set the relative weights of evaluation criteria. In this software the evaluation criteria are effectiveness, efficiency, and acceptability.

4.1 Theory

Multi-criteria evaluation methods deal with a finite number of feasible choice possibilities (courses of action, strategies, solutions, alternative plans or projects), while continuous methods, multi-objective evaluation methods, may encompass an infinite number of possible choices. The main aim of multi-criteria evaluation methods is to provide a basis for classifying a number of possible choices on the basis of multiple criteria.

In general, the analysis of all discrete problems can be represented in four components:

- 1 - $\{D\}$, the set of decision or action variables (alternatives).
- 2 - $\{\theta\}$, the set of uncontrollable variables or states of nature, or events.
- 3 - $f(\theta)$, the probability distribution for the states of nature or the importance of the objective.
- 4 - The payoff function, $R(D, \theta)$, the loss function $L(D, \theta)$, or the utility function $U(D, \theta)$.

An evaluation matrix or the payoff matrix is shown below. The rating of the i th criterion on the j th alternative ($i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$) is represented by r_{ij} .

4.0 Technical Overview for Multi-Criteria Analysis

$$\begin{bmatrix} r_{11} & r_{12} & \cdot & \cdot & \cdot & r_{1n} \\ r_{21} & r_{22} & \cdot & \cdot & \cdot & r_{2n} \\ \cdot & & & & & \\ \cdot & & & & & \\ \cdot & & & & & \\ r_{m1} & r_{m2} & \cdot & \cdot & \cdot & r_{mn} \end{bmatrix} \quad (1)$$

This is the evaluation matrix (sometimes also called impact matrix or project effect matrix). This matrix has elements which represent a measure of the quality of alternative i for criteria j , i.e. the effect of alternative i on the judgement criteria j . In traditional evaluation methods it is assumed that r_{ij} is measured on a cardinal matrix. In the case of a qualitative evaluation problem, r_{ij} may be measured on an ordinal, binary or nominal scale.

For example, in the Red Bluff software the predefined alternatives will be 4A, 4B, 3A4, 3C4, etc. and the evaluation criteria will be effectiveness, efficiency, and acceptability. The efficiency criteria are subdivided into three sub-criteria which are net annual benefits, benefit-cost ratio, and a cost effectiveness index. The evaluation matrix can be represent for three sub-criteria and the four alternative as:

$$\begin{bmatrix} 3771 & 516 & -979 & -1101 \\ 1.50 & 1.08 & 0.52 & 0.69 \\ 2.97 & 2.11 & 1.44 & 1.72 \end{bmatrix} \quad (2)$$

There are different methods to solve the multi-criteria evaluation problem represented by the utility matrix like Exclusionary screening (Goicoechea et al, 1982), conjunctive Ranking (Goicoechea et al, 1982), PROMETHEE method (Brans and Mareschal, 1989), Copeland's Reasonable Social Welfare (Goicoechea et al, 1982), Compromising Programming (Zeleny, 1973), Weighing Average Method (Carver, 1991), Electre Method (Nijkamp and van Delft, 1977), Goal Programming method (Budnick et al, 1988) and Analytical Hierarchal Procedure method "AHP" (Harker, 1988).

The method choice depends on the characteristic of the problem faced. Hobbs (1979) identified four criteria which can be used to compare and evaluate multiple objective or criteria methods:

- 1 - Theoretical validity.
- 2 - Flexibility.
- 3 - Results compared to other methods.
- 4 - Ease of use.

In the Red Bluff Software, the Weight Average Method (Carver, 1991) satisfies the four criteria represented by Hobbs.

The Weighted Average Method is probably the most commonly employed comparative evaluation procedure. Essentially, numerical values are obtained for each r_{ij} and weights are assigned to each criterion. The most important step in multi-criteria evaluation methods is the assignment of weights. Weights reflect the relative importance of the various impacts considered. To obtain weights, the decision maker is asked to distribute a constant number of points (let us assume 100) among the criteria so that the number of points allocated to an criteria

reflects its relative importance.

Let $\{w_i; i=1,2,...,m\}$ represent the set of weights assigned to each criterion. Also, let r_{ij} represent a numerical value developed for the i criteria and j alternative. The worth, U_j , for the j alternative can be represented as:

$$U_j = \sum_{i=1}^m w_i r_{ij} \quad (3)$$

The decision rule is to select the alternative with the greatest worth, that is,

$$U_{optimal} = \max_{all j} U_j \quad (4)$$

Before applying the weighing average method, a standardized method should be applied on the impact matrix. The formula for standardize is:

$$modified \ r_i = \frac{(r_j - \min r_i)}{(\max r_i - \min r_i)} \quad for \ all j \quad (5)$$

where $\max r_j$ and $\min r_j$ indicate the maximum and minimum value for criteria i among all alternatives j .

4.2 Example

An example of how this same methodology could be applied to another management situation. Consider a County Government that is evaluating three alternative highway projects A,B and C, meant to replace or upgrade existing roads. Assume that the following criteria are important:

- 1 - Travel time, measured as the achieved reduction in the number of motor vehicle hours per year.
- 2 - Noise, measured as the achieved reduction in the number of dwellings for which the noise level caused by traffic exceeds a certain acceptable level.
- 3 - Road safety, measured as the expected reduction in the number of vehicle accidents per year.

An impact analysis gives rise to the following evaluation matrix, with the alternatives listed horizontally and the criteria listed vertically:

$$r = \begin{bmatrix} 50000 & 100000 & 80000 \\ 500 & -100 & 100 \\ 80 & 60 & 50 \end{bmatrix} \quad (6)$$

Hence, in Equation (6) the value for alternative 1 and criteria 1 would be 50,000, alternative 2 and criteria 1 would be 100,000, alternative 1 and criteria 2 would be 500, and so on.

Assume that the weights (determined by distributing 1 point) are:

$$w = [0.4 \ 0.2 \ 0.4] \quad (7)$$

These weights may not be applied in Equation (1) unless the impact matrix is standardized by Equation (2), since otherwise the result would depend in an arbitrary way on the dimension chosen for the criteria. For example, if travel time would be measured as the number of motor vehicle hours per day, quite different result would be obtained. Applying Equation (2) will result in the following matrix:

$$r = \begin{bmatrix} 0 & 1 & 0.6 \\ 1 & 0 & 0.333 \\ 1 & 0.333 & 0 \end{bmatrix} \quad (8)$$

by applying the weighted average method, the utility values will equal:

$$U = (U_1, U_2, U_3) = (0.6, 0.533, 0.307) \quad (9)$$

The alternative A (U_1) has the largest utility (worth) which means that alternative A is the best alternative. This method has been applied in different areas and gives satisfactory results.

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