MULTICRITERIA STRATEGIC PLANNING FOR REHABILITATION OF THE WIND RIVER IRRIGATION PROJECT, WYOMING

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ABSTRACT

This study uses multicriteria decision analysis to plan system-wide rehabilitation of the Wind River Irrigation Project in central Wyoming. The developed computerized decision support system analyzes the effects of alternative improvement strategies on various project goals. Potential improvements to the system include rehabilitation and replacement of existing facilities, reconfiguration of the system with gravity-delivery pipelines, increased water storage, on-farm improvements, managerial improvements and various combinations of each of these singular alternatives. Project goals include technical measures of increased adequacy, efficiency, dependability and equity of water delivery, as well as non-technical measures such as relative cost, social acceptability, institutional acceptability and environmental impact. The technical measures of system performance are analyzed using the MODSIM river basin network flow model and fuzzy membership functions. The non-technical measures of system performance are analyzed using either ordinal scales or ratio scales that are developed interactively with the project decision makers. Each performance measure is weighted to allow more importance to be placed on certain performance measures over others. A multicriteria decision analysis is then used to develop an aggregate ranking of each alternative based on the system performance ratio/scale and weighting. The final product gives decision makers a ranking of alternatives which can be used to identify desirable projects for future study.

INTRODUCTION

During the late part of the 19th century and early part of the 20th century, significant work was completed on irrigation systems throughout the western United States to promote settlement of the arid West. Since that time, a significant portion of these irrigation systems have fallen into various states of disrepair and are in need of significant rehabilitation and modernization if irrigation is to continue. In addition, due to the controversial nature of water development projects in the United States and throughout the world, attention is turning more

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and more towards repair and rehabilitation of existing irrigation systems rather than the construction of new systems. The controversial nature of water development also affects rehabilitation of existing systems. Opinions and requirements of entities other than end-user irrigators can have significant impacts on the course of action taken. Therefore, multicriteria planning analysis is an integral part of selecting feasible rehabilitation alternatives.

The purpose of this study is to employ multicriteria decision-making techniques to evaluate and rank various rehabilitation alternatives on the Wind River Irrigation Project in Wyoming. Previous studies have developed potential system rehabilitation alternatives, such as physical system improvements, on-farm improvements, management improvements and increased storage, and provided general estimates of their affects on water supply, as well as a general cost estimate (Roncalio 1982, SCS 1993a, NRCE 1994a, NRCE 1994b, NRCE 1995). However, ranking of the alternatives has not been performed. This analysis will utilize a system simulation model to evaluate the technical performance of each of the alternatives for a given set of objectives. In addition, surveys of decision makers will be used to develop the effects of each alternative on subjective criteria. Fuzzy set theory and multicriteria decision analysis techniques will be used to rank each of the alternatives given the preference criteria and weightings for each criterion.

The technical basis for the work performed in this study is work conducted by Gates, et al. (1991) and Heyder, et al. (1991) in the San Luis Valley of Colorado. The study presents a methodology and application of multicriterion strategic planning for irrigation system improvement considering multiple planning criteria. Several alternatives for irrigation system rehabilitation are evaluated in terms of several criteria used to rank the alternatives. Whereas traditional water resources planning problems have utilized constrained single-objective problems using traditional optimization techniques, this analysis utilizes multicriteria decision- making (MCDM) to assess rehabilitation strategies.

SITE DESCRIPTION

The Wind River Irrigation Project (WRIP) is located on the Wind River Indian Reservation in Central Wyoming. The Project is currently owned and operated by the Bureau of Indian Affairs of the United States Department of the Interior, although the Shoshone and Northern Arapaho Tribes are assuming increasing levels of responsibility for operations and maintenance. The Project has a gross acreage of approximately 40,000 acres, and can be divided into two hydraulically separate units. The Little Wind Unit diverts water from the Little Wind River. The Upper Wind Unit, Johnstown Unit and Lefthand Unit all divert water out of the Wind River. Only the Little Wind Unit will be analyzed in this study. The

Little Wind Unit is the largest of the units with approximately 25,000 potentially irrigable acres. A general map of the unit is shown in Fig. 1.

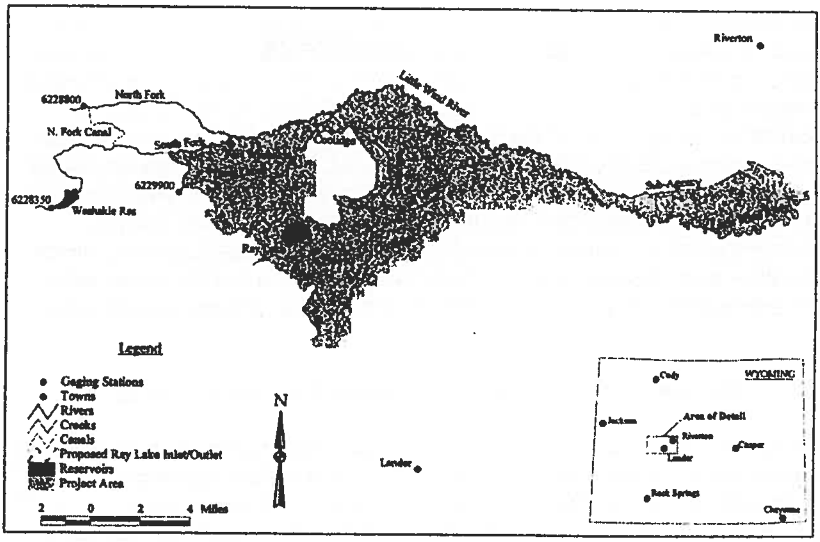

Fig. 1. Little Wind Unit, Wind River Irrigation Project

The Little Wind Unit contains two main sources of water supply: the North Fork of the Little Wind River, which has a mean annual discharge of 103,151 acre-feet; and the South Fork of the Little Wind River, which has a mean annual discharge of 93,728 acre-feet. Trout Creek and Mill Creek, which have a combined mean annual discharge of 11,031 acre-feet, are also available for diversion. All of the sources are fed primarily by mountain snowmelt and exhibit short, high duration peak flow events in late May to early June lasting only a few weeks. No groundwater is currently used as irrigation supply on the Project.

The Little Wind Unit consists of Ray, Coolidge and Sub-Agency main canals, as well as the North Fork diversion canal, which diverts water from the North Fork to the South Fork upstream of the Ray Canal headworks. Several non-project ditches, or private ditches, also divert off of the North Fork, South Fork, mainstem of the Little Wind River and Trout Creek. The Project diversion works, canal structures and canal channels are generally in poor condition. Two reservoirs serve the Little Wind Unit. Washakie Reservoir is an on-stream facility with a capacity of 7,440 acre-feet. Ray Lake is an off-stream facility with a capacity of 6,980 acre-feet. Water is primarily stored at the beginning of the irrigation season for use in the dryer months at the end of the irrigation season with little or no carryover storage. While Washakie Reservoir can serve the entire

Little Wind unit, Ray Lake currently only serves the lower portions of Coolidge Canal and Sub-Agency Canal.

The existing cropping pattern consists of 8.9 percent alfalfa, 30.3 percent grass hay, 25.6 percent pastures, 2.7 percent grains such as barley, and 3.0 percent row crops such as corn and sugar beets (NRCE 1994b). The remaining 29.4 percent of assessed lands are idle, resulting in 17,600 irrigated acres. Current irrigation methods primarily consist of flood and contour irrigation. The use of gated pipe has increased in recent years due to introduction of a cost-share program between the Tribes and individual irrigators. The use of sprinkler systems is very limited, with a few side-roll sprinklers used to irrigate alfalfa fields. Formal project drainage systems are primarily limited to earthen ditches ranging from five to ten feet below grade designed to move shallow return flows out of the ground water and back into the irrigation system. Few formal on-farm drainage systems exist.

IRRIGATION SYSTEM IMPROVEMENT ALTERNATIVES

Several structural and non-structural system improvement alternatives have been proposed for the Wind River Irrigation Project. Many of these improvements are not mutually exclusive. Therefore, combinations of the alternatives are considered in the analysis. A listing of the alternatives and their combinations are shown in Table 1. The effects of the system management improvements, on-farm improvements, rehabilitation and reconfiguration will be simulated in the model through increased efficiencies. The increase in storage will be simulated through changes in the model reservoir capacities.

Table 1. Irrigation System Improvement Alternatives

Alternative No.	Alternative Description
Singular Strategies	
1	Existing System
2	System Management Improvements
3	Rehabilitation of Existing System
4	Reconfiguration of Existing System
5	On-farm Improvements
6	Increased Storage
Combined Strategies	
7	Rehabilitation and On-farm Improvements
8	Reconfiguration and On-farm Improvements
9	Rehabilitation and Increased Storage
10	Reconfiguration and Increased Storage
11	Rehabilitation, On-farm Improvements and Increased Storage
12	Reconfiguration, On-farm Improvements and Increased Storage

Non-Structural Alternatives

The current irrigation project is primarily managed without many of the technologically advanced tools available to irrigation project managers today. The Project does not have a system simulation model, rule curves for reservoir operations or models which can predict system inflows based on available snowpack and precipitation. In addition, fee assessment collection and routine maintenance suffer due to understaffing. The improved management alternative has been included in the analysis to improve these tasks within the irrigation office, some of which are already underway in the irrigation office. In addition, all of the improvement alternatives considered in the analysis assume that some form of improved system management will occur along with the alternative.

Although current methods of irrigation can be effective, other irrigation alternatives exist which could more efficiently apply water to the crops and result in less diversion requirements for the system. The systems include the increased use of gated pipe, side-roll sprinklers and center-pivot sprinklers, as well as the training and increased management of irrigators. The Natural Resources Conservation Service (NRCS, formerly SCS) has provided several alternatives for increased on-farm efficiencies, ranging from simply increasing gated pipe use by 24 percent, to complete conversion of all farms to sprinkler irrigation (SCS 1993a). The most likely improvement scenario, as indicated by previous studies, was chosen. This scenario includes ten percent gated pipe, 44 percent gated pipe with surge, two percent concrete-lined ditches, two percent sprinkler, 30 percent contour flood and 12 percent uncontrolled flood (SCS 1993a).

Delivery System Alternatives

The rehabilitation alternative considers a general "as-is" replacement of the existing structures and repair to the channels. No significant realignment or re-engineering of the project would take place as part of the work, although structures that are obviously deficient in design or canals that can easily be realigned to take advantage of certain physical features could occur. In many cases, the technology currently available in terms of structural engineering and construction techniques could result in a system that would provide a longer life than the existing structures. Although the rehabilitated system would not offer significant changes or improvements other than increased efficiencies, the irrigators and operators are familiar with the existing system and a rehabilitated system would offer proven long term reliability in water deliveries.

The reconfiguration alternative is a replacement of nearly all laterals and sub-laterals with low-pressure reinforced concrete pipe (RCP) and polyvinyl chloride (PVC) pipe distribution systems. This system could take advantage of pressure head in closed conduits to traverse uphill gradients in the alignments. For this reason, following the existing lateral alignments would not necessarily be required, hence the project would be reconfigured. The advantages of reconfiguration include improved project viability, a decrease in operations and maintenance costs, increased system reliability, use of gravity pressure for sprinklers, reduced environmental impacts, and conserved water (NRCE 1994b).

Storage Alternatives

Due to topographical, hydrologic, geotechnical and environmental constraints, the enlargement of Ray Lake was considered as the only feasible storage enlargement alternative available for the Little Wind Unit (NRCE 1995). Studies have shown that there exists potential to enlarge Ray Lake to beyond 50,000 acre-feet (WWC 1995). The Ray Lake System Analysis report (NRCE 1995) indicates that an active pool volume of 26,000 acre-feet would provide full demand satisfaction for the 80 percent exceedence year (or that 20 percent of the years would experience some type of shortage). This 26,000 acre-foot alternative is used in the simulation model as the proposed Ray Lake enlargement capacity. In addition to reservoir enlargement, enlargement of the inlet canals would be required to adequately fill the reservoir and two additional outlet canals would be required to distribute storage to a larger portion of the irrigation system, including the upper portion of Coolidge Canal and the lower portion of Ray Canal.

Combinations of Alternatives

Many of the alternatives can be combined to offer more benefits to the project than the singular alternatives alone. Each of the system repair alternatives was considered in combination with on-farm improvements alone and the increased storage alternative alone. In addition, a combination of the system improvements, on-farm management and increased storage also were considered. Although the reconfiguration and rehabilitation alternatives considered in this analysis are mutually exclusive, further scenarios could be considered that involve partial rehabilitation and partial reconfiguration. This type of scenario has not been considered in this analysis, but it is anticipated that under the rehabilitation alternative, some reconfiguration of the project could occur, especially for laterals that contain numerous drop structures or larger laterals that run along major roadways and pose hazards to motorists.

SYSTEM SIMULATION METHODOLOGY

The Little Wind River basin was modeled to determine the criterion function values of the technical criteria. The simulation model considered major system inflows, WRIP diversions from the River and its tributaries, and major private ditch diversions from the river and its tributaries. Inflows to the system were based on USGS gaged flows that are generally located upstream of all diversions.

Irrigation system diversions were based on calculated crop water requirements, effective rainfall and irrigation system efficiencies.

The system simulation has been performed on a weekly time basis, with a study period from water year 1977 to 1997. Daily historical streamflow data were available from several stations throughout the Little Wind River Basin for various periods of record. The North Fork of the Little Wind, South Fork of the Little Wind, Trout Creek and Mill Creek gaging stations represent "natural" flows, as no accretions or diversions take place from the river upstream of the gaging station. Climatic data were available from Lander, Riverton and Fort Washakie. Missing data, primarily precipitation data, were filled in using regression techniques. In addition, North Fork, Trout Creek and Mill Creek data were correlated to the South Fork data using regression analysis techniques.

Irrigation Water Requirements

The main demands within the Little Wind River basin are irrigation water requirements. Because of the arid climate of the area, a significant portion of the crop gross water requirement comes from irrigation water. Evapotranspiration calculations were performed for each weather station (Lander, Fort Washakie and Riverton), and then prorated at each service area based on the proximity and relative similarity in climate to the base stations. The FAO-24 Radiation method developed by Doorenboos and Pruitt (1977) was selected for this analysis. This method allows computation of evapotranspiration on a weekly basis and generally predicts evapotranspiration in arid climates at or slightly above measured lysimeter evapotranspiration (Jensen 1990). Evapotranspiration calculations were calibrated at each weather station with the Penman-Monteith method calculated at the Lander station. Crop coefficients were derived from University of Wyoming Cooperative Extension data (Pochop et al. 1992) and SCS data (SCS 1993b).

Irrigation Efficiencies: Efficiencies were divided into two categories. Conveyance efficiencies were defined as the efficiency which accounts for losses between the time the water is diverted out of the river to the time the water reaches the farm turnout structure. On-farm efficiencies account for water losses that occur at the farm level, from the time the water is delivered to the farm to the time water is taken up by crops. Overall efficiency is the product of the conveyance efficiency and the on-farm efficiency.

Several studies have been conducted on the potential for increased efficiencies. Roncalio (1982) suggested that on a system-wide basis with redistribution of return flows the existing overall efficiency would be approximately 35 percent with potential for improvement to 40 percent by utilizing improved management practices. NRCE (1994a) found through water balances and basin-wide modeling that existing on-farm efficiencies are approximately 47 percent, and when factored with an 85 percent distribution efficiency, result in an overall efficiency of 40 percent. In addition, NRCE (1994a) estimated that conveyance efficiencies would increase by five percent due to rehabilitation and ten percent due to reconfiguration. Based on these analyses, Table 2 shows the efficiencies used for evaluation of alternatives in this study.

Table 2. Efficiencies Used in this Analysis

Scenario	Conveyance Efficiency	On-farm Efficiency	Overall Efficiency
Existing System	85.0%	41.2%	35.0%
Existing with mngt. improvements	85.0%	47.0%	40.0%
Rehab. with no on-farm improvements	90.0%	47.0%	42.3%
Rehab. with on-farm improvements	90.0%	50.2%	45.2%
Recon. with no on-farm improvements	95.0%	47.0%	44.7%
Recon. with on-farm improvements	95.0%	50.2%	47.7%

Notes:

(1) All improvement alternatives assume management improvements

Leaching Requirements: The overall salinity levels in the irrigation water supply at the Ray and Coolidge Canal diversions are within the range of no restrictions as identified by the NRCS (Grasso 1995, Daddow 1996). The Sub-Agency Canal diversions are within the range of slight restrictions. Basin inflows above Washakie Reservoir are within the low hazard class identified by the USGS. In addition, it is clear that existing irrigation water application is flushing a significant amount of salts from the soils and into return flow drains due to the increase in salinity from the upper portions of the basin to the lower portions of the basin. Because of the high soil salinity rating for over 50 percent of the arable soils within the unit, any improvements in on-farm efficiencies must take into account leaching requirements of the soils. However, estimations of leaching requirements using the standard NRCS approach indicated that return flows for all alternatives are greater than the maximum leaching requirements calculated. Therefore, it has been assumed in this study that all leaching requirements are satisfied on a system-wide basis through deep percolation, which is accounted for in on-farm efficiencies.

System Simulation Model

The system simulation model has been constructed using the MODSIM River Basin Network Flow Model. MODSIM is a generalized network flow model that uses an optimization algorithm to simulate water allocation in river basins according to physical, hydrological and institutional parameters and constraints (Labadie 1995). The network is represented by a collection of links and nodes that contain physical information regarding the network. Systems inflow, reservoir and demand points are represented by nodes. Canals, rivers and other conveyance mechanisms are represented by links. The model allows input of basic data requirements, as well as more complex network operating parameters such as water rights (including storage rights accounting), exchanges, instream flow requirements, augmentation plans, and rule curves, all of which can vary with each time period. Microsoft Excel has been used as the data preprocessor and postprocessor.

MULTICRITERIA DECISION ANALYSIS METHODOLOGY

Multicriteria decision analysis provides a systematic framework for evaluating and ranking alternative strategies based on several decision criteria. Criteria can range from technical water supply and distribution goals to subjective and non-commensurable goals such as social acceptability, cost and environmental goals. For this analysis, both technical and subjective decision criteria, or goals, were assigned commensurable values using fuzzy sets and ordinal scales as determined from interviews with decision makers. Each alternative could then be ranked based on their scores for each of the decision criteria. Two ranking methods were used in this study: the weighted average method and the PROMETHEE II method.

Criterion Functions

In conjunction with recommendations made by the Wind River Water Resources Control Board (Water Board), eight decision criteria were selected for the analysis, and are shown in Table 3. Four of these decision criteria are technical criteria that can be measured given the results of the system simulation model. The other four criteria are non-technical criteria that were evaluated using ratio scales based on interviews with decision makers. Each criterion was assigned a function for alternative ranking. Criterion functions for technical criteria were based on the system simulation model and fuzzy membership functions. Criterion functions for non-technical criteria derived from surveys of decision makers.

Table 3. Decision criteria

No.	Technical Criteria	No.	Non-technical Criteria
1	Adequacy	5	Capital Costs
2	Dependability	6	Operation and Maintenance (O&M) Costs
3	Equity	7	Long-term Viability
4	In-stream flows	8	Social/Tribal Acceptability

Each of the technical criteria are a measure of the ability of the irrigation system to serve demands, and have been defined in previous reports (Gates et al. 1991). The following equations present the definition of each of the measures as they relate to specific irrigation system variables:

Adequacy: $$P_A = \left(\frac{1}{T}\right)\sum_T\left[\frac{1}{\Re}\sum_{\Re}(p_A)\right] \tag{1}$$

Dependability: $$P_D = \left(\frac{1}{\Re}\right)\sum_{\Re} CV_T(p_A) \tag{2}$$

Equity: $$P_E = \left(\frac{1}{T}\right)\sum_T CV_{\Re}(p_A) \tag{3}$$

Where:

p_A = Q_D/Q_R for $Q_D \leq Q_R$
= 1, otherwise
(Note: in this analysis, Q_D was always less than or equal to Q_R);
Q_R = $Q_R\,(x_i, t_i)$ = the amount of water required at diversion points x_i during time period t_j (j = 1, N);
Q_D = $Q_D\,(x_i, t_i)$ = the amount of water delivered to diversion points x_i during time period t_j (j = 1, N);
CV_T = temporal coefficient of variation over the time period T;
$CV_{\Re}$ = spatial coefficient of variation over the region $\Re$.

The Project is currently not operated to maintain instream flows. Also, reserved water rights are not permitted to be used for maintenance of instream flows. However, the Tribes have realized the importance of instream flows to maintain a biological equilibrium in the river ecosystem. Therefore, instream flows have been included in this analysis as a technical criterion. The following equation represents the instream flow performance measure, P_{IF}:

Instream Flows: $$P_{IF} = \left(\frac{1}{T}\right)\sum_T\left[\frac{1}{R}\sum_{R}(p_{IF})\right] \tag{4}$$

Where:

p_{IF} = Q_A/Q_{RR} for $Q_A \leq Q_{RR}$
= 1, otherwise;
Q_{RR} = $Q_{RR}\,(r_i, t_i)$ = the amount of water required within reach r_i during time period t_j (j = 1, N);
Q_A = $Q_A\,(r_i, t_i)$ = the actual amount of water flowing within reach r_i during time period t_j (j = 1, N);
N_r = total number of reaches.

A Monte Carlo analysis was used to obtain the expected value, $E_\omega(P_i)$ of each performance measure over a number of possible realizations, ω. Each realization represented an irrigation season in this study. Therefore, the total number of time periods T was equal to the number of realizations, ω, and the expected values for each measure was the average over the total number of realizations. The number of realizations in this analysis is limited to the study period, or 21 years.

Because of the subjective qualifications, decision makers often do not perceive a linear correspondence between values of the performance measures and the degree of satisfaction of the respective criteria. Therefore, fuzzy sets are used to transform the expected values of each performance measure into membership functions for use in the multicriteria decision analysis. Fuzzy sets allow a degree of uncertainty and preference to be used in the assessment and ranking of alternative strategies. Data for the membership functions were obtained through interviews with the decision makers. Curves were then fitted through the data points to estimate the membership function, μ, for each of the performance measures. These curves are shown in Fig. 2.

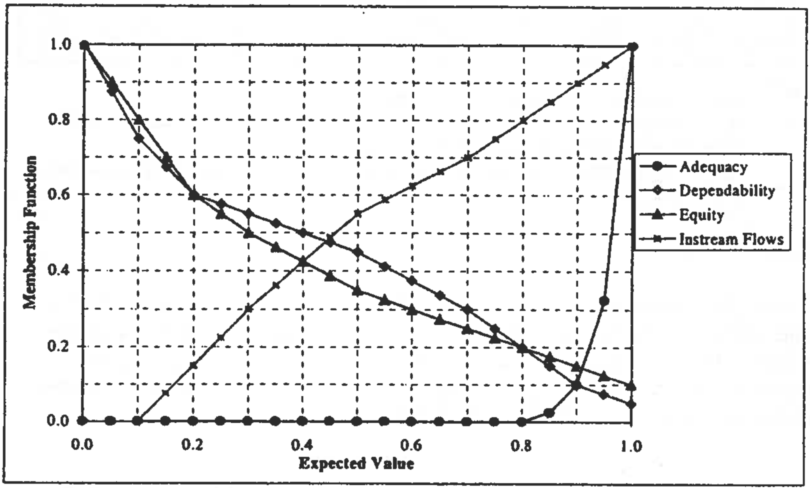

Fig. 2. Technical Criteria Fuzzy Membership Functions

Non-Technical Criteria: Non-technical criteria include capital engineering and construction costs, operations and maintenance costs, fulfillment of long-term project viability and social/Tribal acceptance. Unlike the technical criteria, the evaluation of these criteria cannot be obtained through simulation model results. Instead, the criteria are assigned values based on an ratio or ordinal scale. Ratio scales involve a ranking of values based on relative preference, such as an assignment of values between zero and ten for each alternative. Ordinal scales simply rank the alternatives in order of preference, with no gage for preference as related to each other. In this analysis, ratio scales have been used to assign values for all alternatives. To develop commensurable values for the weighted average method, a linear normalization of the scores for each alternative, i, was performed to develop criterion function values C_i, as shown in Table 4. For each criterion function value, 1.0 indicates the most preferred alternative.

Table 4. Non-technical Criterion Function Values

Alt. No.	Capital Costs (1)		O&M Costs (2)		Long-term Viability (3)		Social/Tribal Acceptability (4)	
	$ x 10^6	C_C	Rating	C_{OM}	Rating	C_V	Rating	C_A
1	$0	1.00	0	0.00	0	0.00	0.0	0.00
2	$0.15	1.00	4	0.40	5	0.50	10.0	1.00
3	$19.2	0.57	5	0.50	10	1.00	8.0	0.80
4	$14.0	0.69	10	1.00	10	1.00	10.0	1.00
5	$8.0	0.82	3	0.30	5	0.50	10.0	1.00
6	$12.5	0.72	8	0.80	5	0.50	10.0	1.00
7	$29.9	0.33	4	0.40	10	1.00	10.0	1.00
8	$24.7	0.45	6	0.60	10	1.00	7.0	0.70
9	$34.2	0.24	5	0.50	10	1.00	10.0	1.00
10	$29.0	0.35	10	1.00	10	1.00	8.0	0.80
11	$44.9	0.00	5	0.50	10	1.00	10.0	1.00
12	$39.7	0.12	8	0.80	10	1.00	7.5	0.75

Notes:

(1) Costs from (NRCE 1994b) indexed to 2000.

(2) Based on interviews with Water Board. Values indicate expected O&M costs, with highest rated alternatives requiring the least O&M costs.

(3) Ability of alternative to provide facilities necessary for long-term project operations.

(4) Based on interviews with Water Board.

Ranking Methods

The weighted average method is a more traditional method of ranking which ranks alternatives based upon the worth of the alternative, or the average of the weighted sum of its criterion function values. The alternative which has the greatest worth receives the highest ranking. The worth of the alternative can be defined as (Gates et al. 1991; Labadie 1999):

$$MC_j = \sum_{i}^{K} w_i C_{ij} \qquad (5)$$

where: MC_j = worth for alternative j

w_j = weighting factor for criterion i, where $\Sigma w_j = 1$.

C_{ij} = criterion function value for criterion i and alternative j

K = total number of criteria

Weights for each of the criteria also were included in the surveys of the Water Board. The Water Board was asked to weight each of the alternatives based on their importance in decision making. A ratio scale of zero to ten was used for the weights, with ten indicating the most important criterion. The advantage of the weighted average method is its simplicity and its traditional use as a ranking method. Its disadvantage is the requirement that quantitative scales, such as ratio scales, must be used to define the criterion function values.

The PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluation) II is an outranking method where the multicriteria are replaced by a single criterion that establishes a complete dominance relation between alternatives. Comparisons between alternatives are evaluated to measure a dominance relationship between the pair. Preference relations, $P(a,b)$, measure the intensity of the preference of given alternative a to a given alternative b. General preference relations include no preference, weak preference, strong preference and strict preference (Labadie 1999). Preference function values, $H(d)$, can be used to numerically describe the preference relation $P(a,b)$. Values of the preference function vary from zero for those alternatives which are indifferent to one for those alternatives in which one alternative is strictly preferred over the other alternative.

The PROMETHEE II method provides a complete preorder of alternatives. This is accomplished using a net outranking flow:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{6}$$

where: $\phi(a)$ = net outranking flow;
$\phi^{+}(a)$ = the amount by which alternative a outranks all other alternatives;
$\phi^{-}(a)$ = the amount by which alternative a is outranked by all other alternatives.

Outranking flows are calculated from preference function values for each pairwise comparison of alternatives. Ranking of the alternatives is then made with the alternative containing the most positive net outranking flow being the highest ranked alternative. Preference function structures are chosen based on the type of data and the general relative strength and structure of the dominance relation between alternatives. Criteria in which there is a high degree of uncertainty in the preference function values would have structures with some degree of indifference threshold, while those with strict preference may have a structure with no indifference zone. Criteria in which the preference is related to the magnitude of difference between the preference function values may use a function structure which allows this variable nature.

RESULTS

Average annual diversion requirements ranged from 108,092 acre-feet for alternative 1 (existing system) to 79,373 acre-feet for alternative 12, with average annual deliveries ranging from 92,215 to 78,159 acre-feet, respectively. The number of years with full demands met ranged from five percent for the existing system to 81 percent for alternative 12.

Criterion function values for the four technical criteria were determined from the performance indicators based upon the simulation results. Table 5 presents a summary of the performance indicators and criterion function values for each of the technical criteria. The alternatives which include increased storage (alternatives 6 and 9-12) all had adequacy measures which met or exceeded the maximum values for those alternatives that do not include increased system storage. This shows the importance of increased storage for improved system adequacy. Dependability, equity and instream flows generally improved with increasing project efficiencies.

Table 5. Performance Indicators and Criterion Function Value Results

Alt. No.	Adequacy		Dependability		Equity		Instream Flows	
	$E_a(P_A)$	μ_A	$E_a(P_D)$	μ_D	$E_a(P_E)$	μ_E	$E_a(P_{IF})$	μ_{IF}
1	0.85	0.03	0.17	0.65	0.08	0.84	0.40	0.43
2	0.89	0.08	0.15	0.68	0.06	0.87	0.41	0.44
3	0.90	0.10	0.14	0.69	0.06	0.88	0.41	0.44
4	0.91	0.15	0.13	0.71	0.05	0.90	0.42	0.44
5	0.90	0.11	0.14	0.70	0.06	0.89	0.41	0.44
6	0.97	0.58	0.07	0.82	0.02	0.97	0.43	0.46
7	0.92	0.17	0.12	0.72	0.05	0.90	0.41	0.44
8	0.93	0.21	0.12	0.72	0.05	0.91	0.42	0.45
9	0.98	0.66	0.06	0.84	0.02	0.97	0.42	0.46
10	0.98	0.73	0.06	0.86	0.01	0.97	0.42	0.45
11	0.98	0.74	0.06	0.86	0.01	0.97	0.42	0.45
12	0.99	0.81	0.05	0.88	0.01	0.98	0.42	0.45

Ranking

The results of both the weighted average and PROMETHEE II multicriteria decision analysis schemes are shown Table 6. Alternative 10, reconfiguration and increased storage, was the highest ranking alternative in both methodologies. In general, the highest ranked alternatives included increased storage and/or reconfiguration. The highest ranking rehabilitation alternative was alternative 9 in the weighted average method and alternative 11 in the PROMETHEE II method. Both of these alternatives incorporate increased storage with rehabilitation, and alternative 11 includes on-farm improvements.

CONCLUSION

The results clearly show the advantages of using a multicriteria decision analysis for investigation of irrigation system rehabilitation alternatives. Previous techniques primarily have considered only technical goals. But, for the Wind River Irrigation Project, as well as many other projects, non-technical goals can have equal or more importance than technical goals. In addition, multicriteria analysis allows a systematic procedure for ranking based on sometimes conflicting goals, such as increased irrigation adequacy, long-term project viability, capital costs and Tribal/social acceptability. This same benefit also allows a sensitivity analysis of alternative scoring schemes (fuzzy sets and ratio scales) and alternative weighting schemes to determine the overall affect of individual goals on the project. In this analysis, it was found that those alternatives which ranked highest in technical criteria also ranked high in the multicriteria analysis. However, the alternative with the highest technical ranking did not rank first in the multicriteria analysis.

Table 6. MCDA function values and rankings

Alt. No.	Alternative Description	Weighted Average		PROMETHEE II	
		MC_I	Rank	$\phi(a)$	Rank
1	Existing System	0.370	12	-8.01	12
2	System Management Improvements	0.592	9	-3.78	11
3	Rehabilitation of Existing System	0.611	8	-2.75	10
4	Reconfiguration of Existing System	0.727	2	1.60	6
5	On-farm Improvements	0.558	11	-2.72	9
6	Increased Storage	0.714	4	3.14	3
7	Rehab. and On-farm Improvements	0.588	10	-0.70	8
8	Recon. and On-farm Improvements	0.620	7	0.05	7
9	Rehabilitation and Increased Storage	0.689	5	2.57	5
10	Reconfiguration and Increased Storage	0.777	1	4.01	1
11	Rehab., On-farm Impr. and Inc. Storage	0.665	6	2.94	4
12	Recon., On-farm Impr. and Inc. Storage	0.721	3	3.65	2

The purpose of this analysis was to present the Water Board with a tool for making rational decisions regarding future irrigation system improvements within the Wind River Irrigation Project. The analysis is not intended to provide a firm answer to the question of which improvements should be selected. However, the results show that increased storage is the single most effective means to increase system adequacy, and is in the top-ranking alternatives in both analysis methodologies. However, increased storage alone does not address long-term viability of the project. Either rehabilitation or reconfiguration will be required if the project is to survive for the long term; the existing system will continue to degrade until many of the channels and structures can no longer deliver irrigation water and/or catastrophic failures occur. The results of the analysis could also be used to stage improvements. Since all high-ranking alternatives include increased storage, Ray Lake could be expanded first. Then, the chosen delivery system improvement, either reconfiguration or rehabilitation, could be implemented, followed by on-farm improvements.

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