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AN APPLICATION OF MULTIDISCIPLINARY WATER RESOURCES PLANNING AND MANAGEMENT FOR THE SAN CARLOS APACHE INDIAN RESERVATION: GILA RIVER CASE

by:

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INTRODUCTION

The purpose of this paper is to briefly describe the formation and function of a new unit established at the University of Arizona, to provide technical assistance for natural resource development for southwestern Indian tribes; and the special institutional and cultural environment within which this function is to be carried out. The cost-effectiveness methodology is used to address a resource development problem on the San Carlos Apache Indian Reservation because of its general nature and rather special features.

PROBLEM SETTING

CULTURAL SETTING

The Laboratory of Native Development, Systems Analysis and Applied Technology (NADSAT) was established within the Office of Arid Lands Studies, University of Arizona, in June, 1976, to provide technical assistance to Southwestern Indian tribes to aid them in the development and economic utilization of their natural resources according to their goals and objectives. Imbedded within this committment is the obligation of technology transfer to assist the tribes in attaining an increased level of self determination. Current technology is to be applied to Indian resource development problems by NADSAT and transferred to the Tribes so that they can deal with similar problems in the future with a greatly reduced level of reliance upon outside assistance.

A primary consideration in this regard is the difference in cultural perception between the American Indian and the non-Indian analyst concerning the natural environment. Natural resource development and management is essentially a manipulative process whereby the planner and/or manager assesses a development problem in terms of its various elements and their interrelationships and in quantifiable terms whenever possible. Elements within are manipulated to enhance the output or value of the resultant product (s) sought over a particular time period depending upon the objectives.

However, Indian culture, with few exceptions, is essentially non-manipulative in its perception of the natural environment. Historically, the Indian has viewed himself as living in harmony with nature instead of being engaged in a contest with it, as has typified non-Indian society; however, it has become increasingly obvious to Indian societies that the economic development of their natural resources can yield considerable benefits. Development of their natural resources, consonant with the Indian desire of self determination, can not only provide sizeable social and economic advantages to individual tribes; but contribute to the gross national product as well. As was pointed out by Anderson, 1976, the three conditions necessary for economic development are, 1) jurisdictional control over tribal natural resources, 2) availability of capital, and 3) management assistance. Hence, there is a need for strengthening tribal resource ownership and sovereignty for if Indians lack control over their resources, they lack control over their economy.

NADSAT's role is assistance and technology transfer and therefore has adopted a passive, rather than an active role in decision making. The emphasis is on alternative formulation and performance analysis, relative to their costs and effectiveness in attaining tribal objectives, and a means to communicate the technological approach to

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tribal decision makers. The primary function of the technology transfer objective is to provide tribal decision makers and planning personnel with an appreciation for the non-Indian method of resource problem conceptualization, the factors to be considered in the analysis, and the formation of alternatives that a multidisciplinary analytical team perceives.

The cost-effectiveness methodology has been adopted for this study not only because it provides a systematic methodology for problem conceptualization and subsequent analysis, but it also is a coherent framework to interface various disciplines in a multi-criterion problem and affords a mechanism for technology transfer.

PHYSICAL SETTING

The San Carlos Apache Tribe has requested that NADSAT formulate possible alternatives for utilization of the land and water resources of the Gila River Basin portion of its reservation, emphasizing use of its decreed surface water allocation from the river.

The Gila River portion of the reservation lies in the Basin and Range Physiographic Province and is part of a northwest trending structural trough, bounded by volcanic mountains on the north and granitic and gneissic mountains on the south. Ground water occurs in a deep, basin-fill aquifer of low permeability, under semi-confined conditions and a shallow alluvial aquifer occupying the terrace and floodplain alluvium. The drainage area of the Gila upstream of the reservation gage is 11,470 square miles. Rainfall averages over 13 inches per year with precipitation dominated by winter frontal and summer cyclonic storms. Some 390 acres are currently being irrigated with pumped river water, and shallow ground water during the low river flow periods. Crops raised are alfafa, barley, and grain sorghum. Water quality of the Gila varies inversely with discharge exhibiting a very high sodium hazard during low flow periods. Ground water is pumped for irrigation from the alluvium; but is of poor quality presenting a high to very high sodium hazard to its use for irrigation. Numerous thermal springs discharge to the surface from the basin fill in close proximity to the river on the north, contributing to the salinity problem.

COST-EFFECTIVENESS (CE) METHODOLOGY

The CE methodology grew out of military applications and was standardized by Kazanowski, 1968, to comprise the following 10 steps:

1) Define the desired goals, objectives, or purposes that alternative systems are to meet or fulfill.

2) Identify the requirements essential for the attainment of the desired objectives.

3) Develop alternative system concepts for accomplishing the objectives.

4) Establish system evaluation criteria that relate system capabilities to re-requirements.

5) Select fixed cost or fixed effectiveness approach.

6) Determine capabilities of alternative systems in terms of the criteria.

7) Generate system versus criteria array (evaluation matrix).

8) Analyze merits of alternative systems.

9) Perform sensitivity analyses.

10) Document the rationale, assumptions, and analyses underlying the previous steps.

The methodology has been used to compare water resources systems in the Mekong Basin by Chaemsaithong, Duckstein, and Kisiel, 1974; in analyzing waste water reuse schemes by Ko and Duckstein, 1972; in the analysis of large scale water development alternatives in the Hungarian Great Plain by David and Duckstein, 1976; and for evaluation procedures for water quality control analysis in river basins by Duckstein and Kisiel, 1972. They also pointed out that the Water Resources Council guidelines for water resources development falls squarely within the cost-effectiveness methodology.

Bokhari, 1975, used CE to accomplish *ex post* evaluation of river basin development in Pakistan and Popovich, et al, 1973, used the methodology to evaluate various solid waste disposal alternatives. Kisiel and Duckstein, 1972, employed the methodology to evaluate the economics of hydrologic modelling.

Kazanowski, 1972, emphasized the major sources of uncertainty in the use of CE as being in the determination of the goals/objectives, the criteria, and the uncertainty surrounding cost estimates of alternatives.

The CE methodology is a general approach to resource development problems that seems to find significant differences in the costs or requirements of alternatives that are formulated to attain desired objectives (Duckstein, 1975). The methodology, as is illustrated in the above 10 steps, is a systematic framework that leads analysts and decision makers alike throughout the process of conceptualization, the formulation of alternatives, and analysis of a resource development problem. Opportunities for the interfacing of multidisciplinary team expertise are present in all the steps. Decision makers are offered the latitude of decisions based either on a fixed cost (budgeting constraints) or a fixed effectiveness standpoint. Sensitivity analyses on the steps provides an element of feedback for both analysts and decision makers, the latter being able to view how perturbations in system elements can affect alternative outcomes relative to their fixed cost or fixed effectiveness decision basis. Finally, by virtue of step 10, the methodology is an invaluable tool to examine the outcome of implemented decisions, in an ex post fashion, in the light of new data or decision making imperatives at some future time. As such, the methodology is akin to an adaptive control process on resource development; whereby the methodology can be used successively, whether for project updating or for new ventures, incorporating past mistakes at each juncture.

COST-EFFECTIVENESS APPLICATION

The application of CE to the San Carlos Apache Indian Reservation will be discussed in a general manner since the inclusion of specifics would detract from the thrust of this paper, that of its importance as a comprehensive and systematic methodology for resource development problem in general, and an effective framework for multidisciplinary teams and a mechanism of technology transfer in developing situations.

The ordering of the steps is not of upmost importance since each problem may present significant differences. The order that we are utilizing in this problem is 1, 2, 4, 5, 3, 6, 7, 8, 9, 10. The salient difference is the procedure of step 4 over step 3, to avoid possible bias towards formulating MOE to conform to alternatives.

OBJECTIVES

Agricultural production. Maximize irrigated agriculture production from the available land resources along the Gila River.

Water resources. Increase the utilization and economic development of the valley's water resources.

Resource utilization. The use of natural, social, economic resources to implement and operate alternative systems should be minimized but may be conditioned by tribal and non-tribal institutional and cultural imperatives.

Salinity. The salinity impact from resource development should be minimized.

Flood protection. Flood protection should be provided to lessen deterioration of the natural resources of the valley.

Flexibility. Alternative system development should be flexible enough to meet the needs of the future and avoid foreclosures of future options open to the Tribe.

It is important to note that the combined efforts of a multidisciplinary team can perform an important function here. Since the objectives condition the entire process, it is important that the tribal objectives reflect as much as possible, the "true" desires of the tribal decision makers. The input from team and tribe can complement one another so that important omissions may be neglected or that preference hierarchies can be ascertained. This is a difficult process in any resource development problem and may require several consultations to ensure their appropriateness.

SYSTEM SPECIFICATIONS

These should be specified as completely as possible and follow in one-to-one order with the objectives.

Agricultural production. As much of the available agricultural land along the Gila should be used as possible. Yield increases of 20% could be realized in the presently cultivated 390 acres with improvements in water deliveries and farm management practices. Agricultural lands can be categorized as presently irrigated; having high, medium and low potential; and improved pasture. Categories are based on accessibility, soil characteristics, and potential for inundation from specified flood return periods.

Potential crops are wheat, barley, grain sorghum, cotton, jojoba, and alfafa. Farm budgets can specify break-even production levels. Unit cost-production/acre curves will assist in defining management requirements and target yields. Production periods are a function of time (years) for jojoba and annually for the remaining crops.

Water resources. The San Carlos Tribe has a decreed allottment (Globe, Equity No. 59) to 6000 AF/year from the natural flow of the Gila for reclamation and irrigation of 1000 acres of land. The amount of withdrawals are further constrained as not exceeding 12.5 cfs at any one time or 1/80 cfs per irrigated acre. Use of the shallow ground water system should be minimized but conditioned by the objectives. This constraint can be released with potential of quality improvement under a given alternative. Different contingency pumping schedules can arise from different alternatives. Monthly crop water demand can be determined from consumptive use figures for various crops. Different farm management specifications can alter total crop deliveries, and diversion requirements can be determined from efficiency specifications.

Resource utilization. The resource categories are water, land, manpower, energy, capital, and environmental resources.

Water losses represent a valuable resource and should be minimized. Losses can be determined by specifying water use and conveyance efficiencies for sprinkler and flood irrigation, and leaching requirements, if any.

Land resources are specified through the results of a basin-wide soil survey and flood inundation potential.

Manpower requirements occur both in the implementation and the operational stage of development. The potential for manpower utilization may be considerable and should be maximized to increase personal income and social well being and other benefits.

Energy consumption should be minimized. The prospects of additional energy from the existing source is highly uncertain and additional power from any source will be expensive and uncertain in the light of the present energy situation. The current average monthly consumption for 1 existing irrigation well is 1,336 Kwh with a peak demand of 100 Kw, assuming a peaking load factor of 1.1. Estimated irrigation horsepower is 165, based on total power use per year of 208,416 Kwh at 1650 Kwh horsepower (Loftin and Associates, 1977).

Capital resources may be broken down into categories to assist decision makers (DM) and lending institutions in financial feasibility analyses. Categories are land development costs, equipment costs, production costs, and the cost of irrigation facilities. These costs may be tempered by considerable uncertainty. In general, one would tend to minimize initial capital investment.

Environmental resources should be protected from any deterioration as much as possible. It is likely that wildlife populations may be enhanced by relatively large scale farming in the valley since the available land will be in parcels spread through the valley, affording populations cover and food supplies.

Salinity. A plot of specific conduct vs. discharge and a plot of the sodium absorption ratio (SAR) vs. discharge allows specification of discharge thresholds to irrigation suitability.

Surface water irrigation suitability and SAR specifications are as follows: a) 35 cfs, SAR = 12.3, very high sodium hazard, b) 90 cfs, SAR = 8.7, high sodium hazard, and c) 260 cfs, SAR = 4.5, medium sodium hazard.

Ground water quality is specified as it bears on its use for irrigation purposes or its impact on river and/or alluvial aquifer quality. Ground water issuing from 10 thermal, limestone springs north of the river, indicated total dissolved solids (TDS) from 1,357 to 4,037 ppm and a SAR range of 7.86-25.37. Analyses of irrigation well water from the alluvial aquifer exhibited a TDS range from 2,107 to 3,409 ppm and SAR's from 7.02 to 12.46. These waters fall either in the C4-S4 or C4-S3 class.

Analyses from stock wells that penetrate the basin fill aquifer indicate low TDS, low SAR's, and irrigation classifications from C2-31 to C3-S1.

Return flows should be minimized to avoid downstream problems. Pesticide residue levels 15-20 miles downstream at San Carlos Reservoir is already near FDA standards (Arizona Water Quality Council Hearings, 1976). Flows should subscribe to Federal Standards. State standards specify only boron and turbidity limits for agricultural purposes.

Flood protection. Annual peak floods are distributed as log Pearson III. Basic descriptive statistics for 46 years of record are, mean of 10,400 cfs, standard deviation of 13,700 cfs, skew of 3.27, and a coefficient of variation of 1.32 for the unlogged data. Return periods of 2, 5, 10, 25, 50, and 100 years have been computed and will be processed through the Army Corps of Engineers' HEC-2 water surface profile program to yield flood inundation levels, validated by remote sensing techniques. This information will yield protective measures for irrigation facilities and assist in crop selections for flood prone areas. Some crops such as barley can suffer flooding while jojoba can suffer no loss at all, constituting a no risk decision.

The set of specifications should be defined as precisely as possible since they identify the specifications or requirements that formulated alternatives are to fulfill to approach objective attainment. The word approach is used since it is probable that no particular alternative will satisfy all the desired objectives exactly. In addition, objectives are usually specified to meet higher order goals that correspond to broad society needs, and these are transitory.

Uncertainties in the specifications can be encoded into probability distribution functions, if possible, and can be used later in the sensitivity analysis.

SYSTEM EVALUATION CRITERIA

The criteria or measures of effectiveness (MOE) are used to evaluate how well a given system performs with respect to meeting the specifications, and hence the objectives. Systems responses may be quantitative such as crop production, system water deliveries, volume of ground water pumped, and the level of flood protection required; or may be expressed qualitatively for system flexibility; likelihood of tribal acceptance, tribal employment potential, and potential for soil improvement. The criteria list should be complete but not exhaustive and should follow the specifications sequence. The following is only a partial list for brevity.

Agricultural production. The MOE for agricultural production is #/acre or #/acre-year, for a rate criteria.

Water resources. Use is source specific and to quantity used, a) surface water in AF/year, and b) ground water pumped in AF/year.

Resource utilization. Land MOE is acres in production per year. Capital MOE may be in terms of land development costs, rate-of-return, and total investment. Energy MOE may be expressed as Kwh/year. Water losses MOE are similar to water use in AF/year. Environmental impact may be very good, good, fair, and bad. Manpower MOE may be expressed in terms of high, medium, and low potential for employment.

Kazanowski, 1972 pointed out that a complete listing of MOE is critical since it not only relates directly to objective attainment but plays an important role in the next step. With a fixed cost approach, decisions among alternatives are based on the evaluation criteria or MOE.

SELECT FIXED COST OR FIXED EFFECTIVENESS

This step is of considerable importance in the decision making process and is not a trivial matter. The "true" preference hierarchy of the Tribe's goals and objectives may be imbedded in the selection process and will become more obvious once the final selection is made and implementation begins. Goals are high order statements and specific objectives may be difficult to vocalize, especially regarding natural resources development. Ill specified objectives are recognized as an important source of uncertainty in multiobjective-multicriterion problems, as pointed out previously.

In the fixed cost approach, a definite budgetary expenditure is given, and the alternatives are compared in terms of levels of effectiveness. On the other hand, the fixed effectiveness approach requires that the alternatives be compared through alternative implementation costs. Analysts cannot dictate which approach should be taken since each decision approach will really be based on value judgements of the decision makers. The role of cost uncertainties, inherent in any problem, takes on a special significance in this step. Kazanowski, 1972, emphasizes this point and considers costs as a major uncertainty source.

It should be added that, despite scarce financial resources, a fixed effectiveness approach is still feasible because there may be a viable effectiveness level due to the availability of funds from outside sources. In addition, it is illuminating to comment on the phrase "it is cost-effective" that can often be heard conversationally or in the literature. As discussed above the two words are not correlative but speak to two different approaches in decision making. The desire for maximum effectiveness for the least cost is fallacious since minimum cost (zero) corresponds to minimum effectiveness (zero).

DETERMINE ALTERNATIVE SYSTEMS

Various systems formulated to achieve specified objectives should be distinct so that their costs and measures of effectiveness (MOE) can be explicitly related to each.

Extremal alternatives will tend to broaden a decision makers satisfaction space within which he operates, whereas marginal alternatives (not too distinct) will narrow the space so that trade-offs may be difficult to evaluate. This should be tempered with practicality and a foreknowledge of what institutional and cultural frame the DM is situated in. For the purposes of discussion, three preliminary alternatives are discussed in general terms, since their inclusion is not really germane to the tenor of this paper.

System I considers planting the entire valley with jojoba to take advantage of the salt tolerant aspects of the plant. The plant is indigenous to the Southwest and thrives on lesser amounts of water, in addition, its long maturation period, economic future, and production capacity/acre can create spillover effects for farm management training, personal income, and tribal welfare by strengthening the existing Apache Tribal Marketing Co-operative. Raising jojoba commercially is a no risk decision, requiring considerable flood protection.

System II would continue irrigation of crops in the conventional manner using river pumping plants and ground water wells to augment river supplies during low flow periods. This alternative would entail improvement of existing facilities, including flood proofing and refurbishing of poor productive irrigation wells; and the installation of new systems.

System III could entail fixed river pumping plants at various points, with flood protection that can function as System II and also lift river water up to gravity distribution points for distant fields or to spreading basins with small retention structures built on highly permeable alluvial fan areas. The structures can also function as a retardant for tributary flood waters. Recharge from these spreading areas can promote the flushing of poor quality ground water in the shallow alluvium by steepening the gradient towards the river. Environmental effects may be both good and bad.

DETERMINE ALTERNATIVE SYSTEM CAPABILITIES

This step analyzes the capabilities of alternative systems in terms of various MOE. The methods employed can range from simulation processes, stochastic hydrology, to pilot plant studies, analogues, and economic analysis.

GENERATE SYSTEM VS. CRITERIA ARRAY

For this step, an array is constructed that assembles all the system capabilities, as they relate to the specifications through their measures of effectiveness (MOE). This allows the decision makers (DM) an alternative by alternative comparison regarding their individual cost requirements, water deliveries, energy consumption or requirements, manpower potential, management requirements, etc.

The usefulness of the array tableau is heightened by the inclusion of quantitative and qualitative MOE's avoiding the fallacy that everything important is quantifiable or that all measures can be lumped into a sole criterion (Chaemsaithong, 1973, and Kazanowski, 1968).

ANALYZE THE MERITS OF ALTERNATIVES

The merits of the alternative systems require ranking in order of importance and is largely a subjective process. Ranking is the responsibility of the Tribe; however, assistance can be offered in examining the problem with specified cost and effectiveness levels to illustrate the process and perhaps generate an appreciation of the nontriviality of the matter. It is also important to appreciate that all the information in the array is assumed correct at this juncture, and that the ranking is not determined by arbitrary weighting. Various ranking techniques can be employed if serious conflicts arise.

PERFORM SENSITIVITY ANALYSIS

Sensitivity analyses are performed on all the previous steps to introduce a feedback element into the procedure. Perturbations are introduced to the various MOE's specifications, parameters, approach, etc. to observe changes in the system/criteria array. The effect of uncertainty categories can be assessed in this manner, e.g., economic and strategic uncertainties.

DOCUMENTATION

The essential value of the standardized CE methodology lies in its ability to order ones thinking regarding water resources planning and development, both on the part of the analysts and the decision makers. The organized approach is not only valuable in evaluating alternative courses of action, prior to implementation, and expected results; but also holds considerable value in looking back on actions taken and evaluating the results in the light of current information. The methodology can be used successfully for project planning, and subsequent reevaluation before new projects or updating is required, thereby retaining control over development and retaining flexibility. To accomplish the foregoing it is essential that the assumptions, rationale, and methodology employed are fully documented.

CONCLUSIONS

The following concluding points may be drawn from the above discussion:

1) The CE methodology is a general method to approach natural resource development problems.

2) CE can avoid the common fallacies inherent in other approaches, e.g., sole criterion as in benefit-cost, the trade offs are determined in the fixed cost or fixed effectiveness approach.

3) The methodology offers a systematic approach for analysis of resource development problems, with a built in feed back element to avoid omissions of important factors.

4) The methodology is able to account for all categories of uncertainty, e.g., natural, model, parameter, economic, strategic and technological.

5) Cost effectiveness methodology provides an important mechanism for technology transfer in that the conceptualization, factors, and alternative formulation and analysis, are communicated to decision makers in an orderly framework; and the interrelationships among important factors are revealed through the entire process.

6) CE offers a means of *ex post* evaluation of decisions, can incorporate new data for subsequent planning and implementation, and allows decision makers to retrace their steps through the entire decision process.

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