RESEARCH

A Case Study of Resources Management Planning with Multiple Objectives and Projects

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ABSTRACT / Each National Park Service unit in the United States produces a resources management plan (RMP) every four years or less. The plans commit budgets and personnel to specific projects for four years, but they are prepared with little quantitative and analytical rigor and without formal decision-making tools. We have previously described a multiple objective planning process for inventory and monitoring programs (Schmoldt and others 1994). To test the applicability of that process for the more general needs of resources management planning, we conducted an exercise on the Olympic National Park (NP) in Washington State, USA. Eight projects were selected as typical of those considered in RMPs and five members of the Olympic NP staff used the analytic hierarchy process (AHP) to prioritize the eight projects with respect to their implicit management objectives. By altering management priorities for the park, three scenarios were generated. All three contained some similarities in rankings for the eight projects, as well as some differences. Mathematical allocations of money and people differed among these scenarios and differed substantially from what the actual 1990 Olympic NP RMP contains. Combining subjective priority measures with budget dollars and personnel time into an objective function creates a subjective economic metric for comparing different RMP's. By applying this planning procedure, actual expenditures of budget and personnel in Olympic NP can agree more closely with the staff's management objectives for the park.

Management of natural resources by public agencies has become increasingly complex. Resource managers must protect a wide array of natural resources, including measurable commodities, esthetic values, and ecosystem processes (Hinds 1984; Fox and others 1987; Silsbee and Peterson 1991, 1993). Legal and political factors are often at least as important as biological and sociological factors in the development of long-term management plans. Decisions are commonly made in the absence of sufficient technical data or background information. This necessitates the use of expert judgment to evaluate the relative merit of proposed elements of a management plan and to plan for expenditures of time and money.

The first step in designing RMPs is to carefully define objectives (Garton 1984, Hinds 1984, Hirst 1983, Johnson and Bratton 1978, Jones 1986). Most management units (such as national parks or national forests) can readily develop a broad "ideal" plan that encompasses a diversity of projects. However, plan implantation is constrained by budget, so decisions must be made about the relative value and feasibility of the various projects within the plan. These decisions are complex and involve a wide range of issues and potentially hundreds of individual judgments. Technical information, as well as resource managers' personal knowledge and judgments, are needed to develop the plan. An analytical approach is needed to provide an organized planning framework and to incorporate valuable personal knowledge.

Schmoldt and others (1994) describe a procedure for prioritizing projects and allocating expenditures for inventory and monitoring programs. In that formulation, the analytic hierarchy process (AHP) (Saaty 1980) helps to prioritize alternatives in complex decisions. After priorities have been set using the AHP, specific projects can be implemented based on a 0/1 integer programming solution. This paper extends the methodology outlined in Schmoldt and others

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(1994) in two ways: (1) to allow noninteger budget and personnel allocation for individual projects over multiple years, and (2) to encompass the more general RMP in which inventory and monitoring are components. In realistic situations it may not be desirable or feasible to conduct a project as an all-or-nothing activity. First of all, some projects may be too large to commit the entire allocation that a large project might need. Second, because personnel and budget resources can be allocated in noninteger amounts, it is possible to obtain more optimal allocation than using an all-or-nothing (or integer) allocation. Consequently, the all-or-nothing allocation described previously may be useful in a strategic planning sense, but it fails to capture some of the realities, such as multiple year planning and partial allocation, that are common in tactical planning problems.

In this paper, we: (1) examine current RMP procedures at a large national park, (2) briefly describe the fundamental structure of the AHP, (3) report the results of an application of the AHP to prioritize projects in the RMP for the Olympic National Park (NP), and (4) compare RMPs that are based on different park management objectives, using the Olympic NP as a case study.

Resources Management Planning at Olympic National Park

We chose to study the Olympic NP in Washington State, USA, because it is large (380,000 ha) and has a diverse array of natural resources, including coastal environments, temperate rain forest, and alpine glaciers. It also has a diversity of management issues, including several with prominent legal and political ramifications. We felt that a large park with complex management problems would provide a rigorous test of the AHP approach.

RMPs are required for all national park units in the United States. A standard written format, including budget information, is prescribed and RMPs are recommended by the park superintendent and approved by the regional director. They are reviewed and revised at least every four years; the Olympic NP conducts a review every two years. However, the plan can be amended at any time between reviews.

Interviews with members of the resources management staff at Olympic NP were used to compile a picture of exactly how planning is conducted here. Nine people from a variety of resource areas have lead responsibility for developing the topics contained in the RMP. The complexity of resources management at Olympic NP is evidenced by the fact that the RMP is over 700 pages (Olympic National Park 1990). This is not atypical for a large national park, because the RMP is a long-term, comprehensive document for planning and project development.

The existing planning process at the Olympic NP is not highly structured. As one member of the staff put it, they use the “BOGSAT (bunch of guys/gals sitting around a table) method of planning.” In other words, the management staff compiles a wide range of topics, discusses them, prioritizes them, and develops the RMP with minimal quantitative evaluation and without formal decision-making tools. The result is a large and rather cumbersome document.

Despite its shortcomings, the RMP provides the park with a common reference applicable at all levels of park and regional planning. All staff members agreed that it is much better than plans or guidelines used in the past. It assesses the entire physical and biological realm of park resources and helps to organize a wide diversity of programs and projects. Park staffers indicated that at least 80% of the RMP consists of resource inventory and monitoring projects (Silsbee and Peterson 199 1). Such projects are related to the collection of basic information about the existence and condition of natural and cultural resources. A comprehensive list of these projects helps to identify existing information and critical gaps in knowledge about park resources.

Most members of the Olympic NP staff indicated that the RMP needed to be upgraded from a reference document to an action plan. Of particular value would be specific information that would facilitate implementation of projects in the field and improve coordination between the main park office and district personnel at various locations. Projects must be written so that field personnel can implement them, and budget and personnel requirements over time must be clearly listed to aid planning. Park staffers also called for a dynamic document that is flexible enough to be easily modified over time. Most of them felt that frequent evaluation is necessary to articulate new issues and delete irrelevant projects.

The RMP provides a formal goal-setting process for national parks. A comprehensive summary of an ideal management strategy is a valuable source of information, but it is also a source of frustration for park personnel. There is nearly always a huge gap between the management programs described in the RMP and the actual programs that are constrained by budget and personnel limitations. Park managers see many critical needs for information, but they also realize that many of these needs will never be filled. As a result, they must continually make decisions in the absence of adequate data. They also must choose between an extensive program (many projects at a low level of detail) and an intensive program (a few projects at a high level of detail). Finally, they know that political and operational constraints may override decisions based on scientific information and resources management expertise.

Allocating funds among different resource areas within a national park is a difficult process because of the wide range of resources, personnel, and issues involved. It is only normal that a fisheries biologist would support projects related to fish populations or that a wildlife biologist would advocate greater study of certain wildlife species. Nevertheless, the park staff must prioritize projects. Olympic NP currently has no formal process for prioritizing among and allocating budgets to projects. Park staffers are frustrated by unpredictable annual budgets. The two-step process of prioritization and allocation presented below introduces analytical rigor into resources management planning. It removes some of the mystery from decision-making and allows plans to be reexamined and modified more easily.

Prioritizing Projects: The Analytic Hierarchy Process

Many decision-making situations involve preferential selection among some finite set of alternative items or events or courses of action. For a family, the list of alternatives might contain, for example, cars to buy, colleges to attend, or vacations to plan. If possible, there should be some intuitive measurement scale that can be used for comparison and the best choice among the available alternatives should have a high score along that scale. By ranking alternatives on the basis of numerical scores, we create an implied priority for those alternatives. When the selection criteria is “least cost” for example, the measurement scale is obvious and choosing becomes easy. In most real-world situations, however, there is not a single, simple scale for measuring all competing alternatives. More often, there are at least several scales that must be used and often those scales are related to one another in fairly complex ways.

The AHP (Saaty 1980) is designed to help with these types of decisions. Two important components of the AHP that facilitate the analysis of complex problems are: (1) the structuring of a problem into a hierarchy consisting of a goal and subordinate features of the problem and (2) pairwise comparisons between elements at each level. Subordinate features that are arranged into different levels of the hierarchy may include such things as objectives, scenarios, events, actions, outcomes, and alternatives. The alternatives to be considered are placed at the lowest level in the hierarchy. Pairwise comparisons are made among all elements at a particular level with respect to each element in the level above it. Comparisons can be made according to preference, importance, or likelihood—whichever is most appropriate for the elements considered. Saaty (1980) developed the mathematics necessary to combine pairwise comparisons made at different levels in order to produce a final priority value for each of the alternatives at the bottom of the hierarchy.

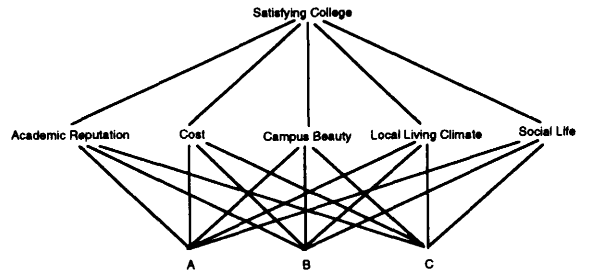


Figure 1. A simple hierarchy for selecting a satisfying college from three alternatives, A, B, and C, makes use of five criteria.

Consider the hierarchy in Figure 1, which is designed to enable one to select a satisfying college. The goal, “satisfying college,” appears at the top of the hierarchy. The criteria appear on the next level: “academic reputation,” “cost,” “campus beauty,” “local living climate,” and “social life.” The colleges to be considered are labeled A, B, and C at the lowest level. First, the criteria are compared pairwise with respect to their importance for producing a satisfying college experience. Then the alternative colleges are compared regarding the likelihood of each having these criteria. A more detailed example of the AHP process appears in Schmoldt and others (1994). The final result of the AHP is a numerical priority value for each alternative. The decision maker may then select the highest scoring alternative as the “best,” as determined by the decision process that has been made explicit in the hierarchy and by the comparisons.

If the number of alternatives to be compared in the AHP exceeds seven, a variant of the pairwise comparison technique can be used. Under these circumstances, an arbitrary rating scale is developed for each element in the hierarchy against which the alternatives are compared. Then each alternative is scored along the scale for each rating element. For example, if there were ten colleges to be compared in the example above, we might create a rating scale for "academic reputation" that contained the values "bad," "fair," "good," and "excellent." Relative numerical scores would be created for each of these "academic reputation" values by comparing them in the usual pairwise fashion. Then each of the colleges would be assigned a score, "good," "bad," etc., from this scale. A similar rating scale would be constructed for each criterion. After all the rating scales are developed, a long list of alternatives can be scored quite quickly in a spreadsheet-like format. Because of the number of alternatives examined in this resource management planning study, the rating scale method was used.

Prioritizing Projects: An Example

Five members of the Olympic NP staff—a resource assistant, a resources management specialist, a wildlife biologist, a fisheries biologist, and a GIS specialist—agreed to help prioritize RMP projects. Discussions were conducted over a two-day period while all members of the group were present. Eight projects were selected for the exercise, one from each of the resource disciplines in the natural resources section of the RMP:

Monitor ambient air quality. Olympic NP is known for its pristine air quality relative to most of the rest of the continental United States. Ambient air is monitored for sulfur dioxide, oxone, total suspended particulate, and visibility.

Monitor avalanches. Subalpine slopes are subject to avalanche hazard in winter, creating problems on developed areas, roads, and ski trails. Avalanche forecasting is critical for visitor safety.

Monitor water quality. Basic physical, chemical, and biological data are needed for water resources throughout the park in order to identify potential changes caused by acidic deposition and human impact.

Study and monitor plant communities affected by mountain goats. Exotic mountain goats potentially threaten plant communities, including some endemic species. Long-term studies are needed to determine if the goats are impacting the growth and distribution of vegetation in alpine and subalpine areas.

Conduct studies or management programs for fish or wildlife species of special concern. There are several threatened, endangered, or sensitive animals in the park, including the northern spotted owl. Populations must be studied to determine their status, and appropriate management actions should be taken if necessary.

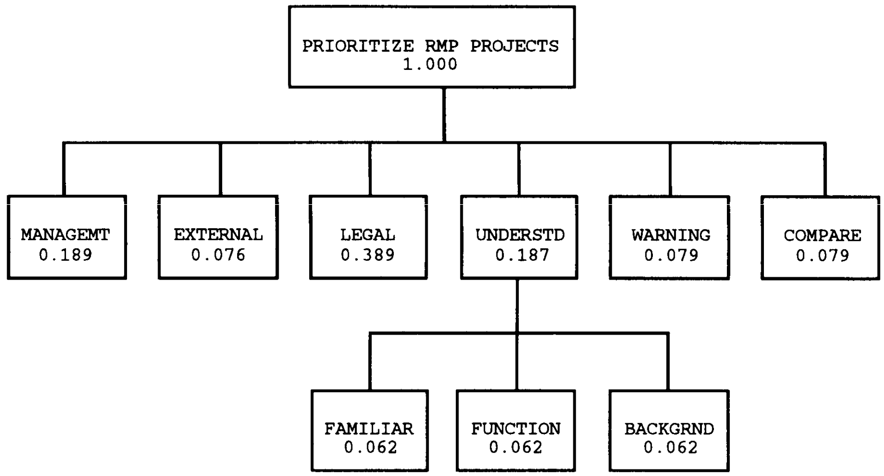
Inventory and monitor selected anadromous fish stocks that are subject to harvest. Many fish stocks in the park are managed cooperatively with other agencies and Native Americans. More information is needed on size and distribution of anadromous fish in the park, especially for stocks that have been reduced by harvest and habitat loss.

Study and monitor the Elwha watershed. Two dams on the Elwha River have dramatically changed the aquatic and terrestrial ecosystems in this area. Proposals to remove these dams dictate the need for data on the impact of the presence and subsequent removal of the dams on physical and biological characteristics of the watershed.

Conduct an integrated pest management (IPM) program. Control and eradication of native and nonnative species defined as "pests" (wood-rot fungi, carpenter ants, rodents, etc.) are necessary in some developed areas of the park. The use of pesticides and other methods must be monitored and managed responsibly.

We used the AHP in cooperation with the five Olympic NP staff members to prioritize these projects. The AHP has been implemented in software under the tradename Expert Choice [Expert Choice, Inc., Pittsburgh, Pennsylvania (tradenames are used for informational purposes only; no endorsement by the US Department of Agriculture or the US Department of the Interior is implied).] We have found that this software greatly simplifies construction of hierarchies and calculation of priorities; consequently, it was used in this study. Pairwise comparisons and project ratings within the AHP were developed interactively by projecting each view from a computer monitor directly onto an overhead screen so everyone could discuss the same topic simultaneously. All subjective judgments were reached by consensus of the resources management team through group discussion. In circumstances where consensus cannot be reached easily, separate judgments can be combined by using a geometric average. Because our group was able to mitigate differences through discussion, there was no need to resort to mathematical aggregation of responses.

After the Olympic NP team became comfortable with the format of the AHP procedure, decisions could generally be reached with a minimum of discussion. The authors were frequently consulted to clarify wording or meaning of various sections of the exercise. Although there was often disagreement about subjective assessments, there were few cases in which staff members' judgments differed by more than one score.



MANAGEMT --- SUPPORT MANAGEMENT DECISION-MAKING
EXTERNAL --- INFLUENCE OUTSIDE DECISION-MAKERS
LEGAL --- SATISFY LEGAL MANDATES
UNDERSTD --- BETTER UNDERSTAND RESOURCES
FAMILIAR --- MAINTAIN FAMILIARITY WITH RESOURCES
FUNCTION --- UNDERSTAND ECOSYSTEM FUNCTION
BACKGRND --- PROVIDE BACKGROUND INFORMATION
WARNING --- EARLY WARNING OF GLOBAL OR REGIONAL PROBLEMS
COMPARE --- PROVIDE COMPARISON WITH UNEXPLOITED AREAS

Figure 2. Objectives selected and ranked by park resources management staff are displayed in this hierarchy. Numbers associated with each objective are the global priority values that indicate each objective's importance for ranking of resources management projects.

In addition to rating individual projects with respect to each objective and subobjective, the Olympic NP team developed relative weights for the objectives themselves. Specific objectives and their organization (Figure 2) were described previously (Schmoldt and others 1994). We expected the Olympic N P team to create its own hierarchy for this exercise, but instead, it opted to use the authors' proposed structure for park objectives. The global priority values in Figure 2 were determined by pairwise comparisons between each of the elements at each level. For example, each of the six objectives in the first level was compared with the others with respect to its importance for prioritizing RMP projects (the goal of the exercise). Then each of the three subobjectives in the second level was compared with the others with respect to its importance for "better understanding resources" (the objective immediately above it in the hierarchy). The three objectives in the second level provide a more detailed breakdown of the objective "better understand resources." A separate rating scale was then developed for each of the eight objectives and each of the projects was scored based on each of these scales. A final rating score for each project was calculated as the sum of all ratings, which were weighted by each objective's priority. Final rating scores were then normalized so that they summed to unity.

Two additional scenarios of objective importance were evaluated for comparison with the results of the staff-assigned objective priorities. In the first, all objectives were ranked equally-each had the same priority value (Figure 3). For the second additional scenario (Figure 4), each had a priority value of zero, except for "support management decision making," which had a value of one. For both of these scenarios, the rating scores generated by the park staff for each of the projects across all criteria are the same as above. Different emphases on park management objectives, however, distinguish these scenarios from the original one. These two park management alternatives were chosen because they represent reasonable competing policies for managing park resources.

To compare these "classroom" findings using the AHP with some real-world results, the actual allocation of resources to these eight projects in the 1990 RMP was also used to prioritize them. Projects were prioritized based on each project's ratio of allocated to requested expenditures (specified as a percentage) in the actual 1990 RMP. These rankings appear in the last column of Table 1. Four unfunded projects out of the eight from the 1990 RMP were given an arbitrary ranking of 5 to indicate that they have a lower priority than those ranked 1, ..., 4, but otherwise are indistinguishable in rank. We have assumed that the conversion from expenditures to ranking provides some insight into the 1990 RMP decision makers' implicit priorities for these projects, i.e., higher priority projects would receive a higher percentage of re-

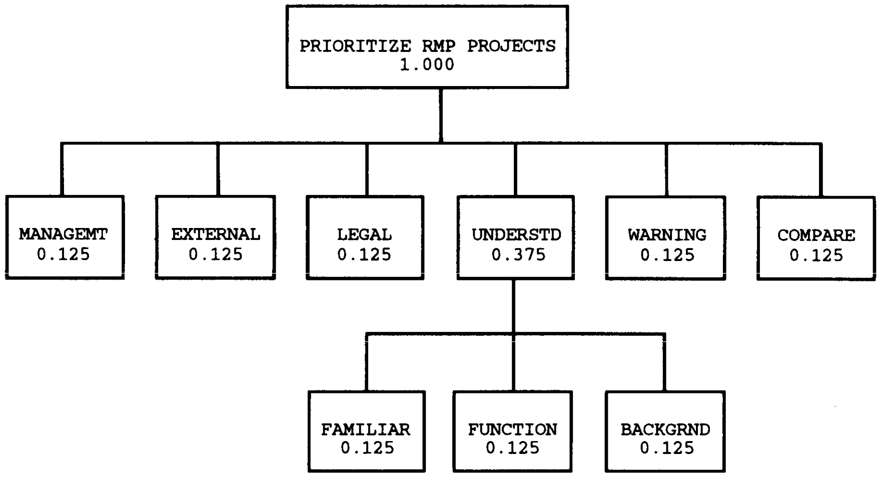


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Figure 3. All objectives are ranked equally important in this hierarchy. Numbers associated with each objective are the global priority values indicating each objective's importance for ranking resources management projects.

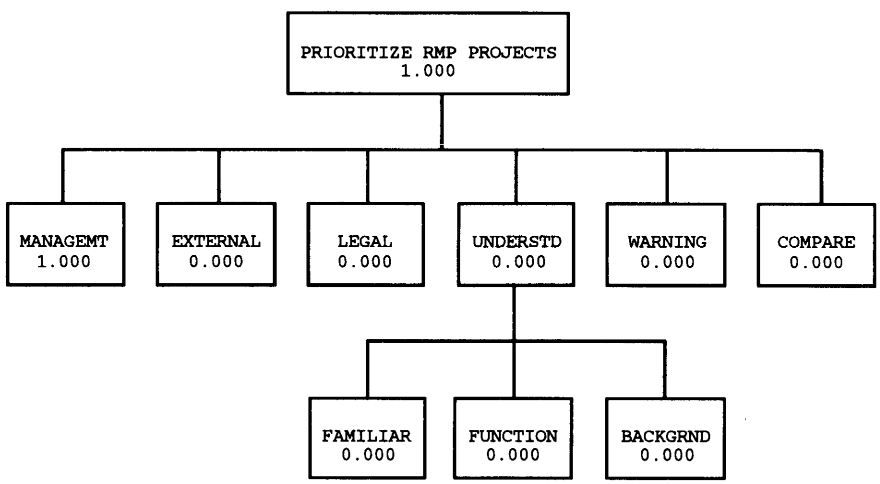

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Figure 4. Support of management decision making is the only objective in this hierarchy. Numbers associated with each objective are the global priority values indicating each objective's importance for ranking resources management projects.

Table 1. Priority ratings and rankings for each project under different management objective priorities

Project	Objective importance assigned by park staff		All objectives ranked equally		Management decision making has highest priority		Actual funding level in the 1990 RMP implicitly determines rankings	
	Priority	Ranking	Priority	Ranking	Priority	Ranking	Priority	Ranking
Air quality	0.137	5	0.130	6	0.099	7	—	3
Avalanche monitoring	0.069	8	0.057	8	0.111	6	—	2
Water quality	0.140	4	0.146	3	0.122	5	—	5
Goat impacts	0.141	3	0.135	5	0.179	1	—	1
Sensitive wildlife	0.143	2	0.149	2	0.134	4	—	5
Anadromous fish	0.128	6	0.143	4	0.145	3	—	4
Elwha watershed	0.148	1	0.163	1	0.168	2	—	5
IPM program	0.095	7	0.077	7	0.042	8	—	5

[a]Staff ratings for each project, along with the relative importance of management objectives under each scenario, produced the final priority value in this table.

quested expenditures. An exception to this assumption about the expenditur-priority relationship is the avalanche forecast project; its funding is mandated because it is part of an extensive effort by many land management jurisdictions and is relatively inexpensive to implement.

Allocating Expenditures for Resources Management

General Formulation

A typical RMP sketches the outlays of available resources for four years. In general, any portion of a project's requested funding and personnel needs can be allocated during any one of these periods, or none at all. This generalization differs from the all-or-none allocation of inventory and monitoring resources applied in Schmoldt and others (1994). Our methodology in the present study allocates budget and personnel resources to specific projects based on project priorities using a standard linear programming formulation. The objective function maximizes the product of priority (as determined using the AHP above) and expenditure. Beyond this purpose, the actual objective function value has little practical importance. The intent is to obtain the greatest program value for each unit of expenditure, where the unit value of each project to the overall program is determined by project priorities.

Objective function:

$$\text{Max } Z = \sum_i \sum_j \sum_k p_i c_j X_{ijk} \qquad (1)$$

where p_i is the priority of project i, c_j is the conversion factor for expenditure type j, and X_{ijk} is the expenditure of type j for project i in period k.

Subject to:

$$\sum_k X_{ijk} \leq R_{ij} \text{ for } i = 1, \ldots, n \text{ and } j = 1, \ldots, m \qquad (2)$$

$$\sum_i \sum_k X_{ijk} \leq T_j \text{ for } j = 1, \ldots, m \qquad (3)$$

where n is the number of projects, m is the number of expenditure types, R_{ij} is the total requested expenditure of type j for project i, and T_j is the total available expenditure of type j.

Personnel and budget expenditures are interrelated. For example, it would make no sense to allocate personnel to a project if no budget funds were allocated to pay them and support their work (equipment, travel, etc.). One can also envision situations where there may be constraints linking personnel and budget expenditures. Although neither of these situations occurs in our brief example, we felt that it was necessary to allow for these possibilities in our general formulation. Thus, separate analysis of budget and personnel is not a viable approach, and some method is needed to ensure that budget and personnel allocations are made in a relatively "paired" manner. To do this, we included both budget and personnel expenditures in a single objective function. However, in order to add units of dollars and full time employees (FTEs), we applied a conversion factor c_j to unify dimensional units. The conversion method is described in the next section.

In the basic case, two types of constraints bound the solution space. These are: (1) total expenditures of each type must be less than or equal to the expenditure available for that type, and (2) expenditures for each project must be less than or equal to requested expenditures. Minimal bounding of the optimization problem and similar coefficients for some decision variables creates a degenerative solution. Hence, there are several optimal solutions. To find one, it is only necessary to assign expenditures to projects in descending order of priority until all expenditures have been exhausted. This solution will then be optimal, as specified in the objective function. As more constraints are introduced, however, optimal solutions become fewer and finding one becomes much less obvious.

Specific Formulation

Our case study example deals with only a small number of projects. The actual 1990 RMP for the park contained 147 projects that were considered for inclusion in the park's management plan, To make this eight-project exercise comparable to the actual 1990 RMP of the park, we were forced to make some assumptions and to extrapolate some numbers. The following paragraphs describe the transformations that we applied.

The specific conversion factors c_j in this example were calculated as follows, We arbitrarily decided to convert FTE units to budget units. Because dollars remain unconverted, $c_1 = 1$. Without any change in the final solutions, we could alternatively have converted budget units to FTE units instead. We then reasoned that the actual allocation of dollars and person-years in the 1990 RMP for these eight projects could be used as a comparative expenditure scale for budget units and FTE units. In other words, these actual values represent an implicit association between budget and FTEs in this park and at this time. Of the eight projects considered in our example, only four received allocations, which amounted to $142,600 and 5.2 person-years. This results in a conversion factor $c_2 = 142{,}600/5.2$ for FTE units; therefore, each person-year is associated with $27,400 of budget expenditure. It is certainly reasonable to use differential conversion factors to reflect the relative merits of budget and FTEs within different projects. In this study, however, we had no rationale or data to support differential conversion factors, so we used the same conversion value throughout.

The coefficients c_j are merely scaling factors so that we are able to optimize the allocation of budget and personnel coincidentally, $c_1 = 1$ and $c_2 = 27.4$. We could just as well have scaled the R_{ij} and T_j values, using c_j, prior to mathematical optimization. Then the only parameters in the objective function would have been the p_is. Although the scaling term c_j gives FTE decision variables much larger coefficients than the budget decision variables, the FTE decision variables only compete among themselves for allocation, not with the budget decision variables. Because the scaling term is specific to each expenditure type and is a constant, it does not obfuscate the impact of priority values p_i. The final optimal solution is not affected by scaling terms, only the order in which optimal solutions are searched is affected.

Requested expenditures R_{ij} and total allocation figures T_j were taken directly from the 1990 RMP. Actual allocations for budget and FTEs for all eight projects were assigned to T_1 and T_2. Several additional constraints were included to mirror more closely the implicit allocation methods used in the actual RMP.

First, actual 1990 RMP allocations exhibited a nonincreasing flow of expenditures over the four-year planning period. Uncertain future budgets and the problems associated with overly optimistic expectations are a likely reason for this type of planning. This nonincreasing characteristic was reflected in each individual project as well as in the total program. In fact, for each funded project in the 1990 RMP either all expenditures occurred in the first year or there was an even flow of expenditures over the four years. Because our linear programming software does not allow "exclusive-or" constraints, we used a straightforward nonincreasing inequality. The following set of constraints was added to our formulation to reflect these apparent long-term planning realities. An additional set of constraints like those in equation 4, except with "=" replacing "$\geqslant$," was used for strict even-flow expenditures for "avalanche monitoring."

$$\begin{aligned} X_{ij1} - X_{ij2} &\geqslant 0 \text{ for } i = 1, \ldots, n \text{ and } j = 1, \ldots, m \\ X_{ij2} - X_{ij3} &\geqslant 0 \text{ for } i = 1, \ldots, n \text{ and } j = 1, \ldots, m \\ X_{ij3} - X_{ij4} &\geqslant 0 \text{ for } i = 1, \ldots, n \text{ and } j = 1, \ldots, m \end{aligned} \tag{4}$$

Second, not only were expenditures nonincreasing, but for the entire RMP, expenditures in the first year amounted to more than 35% of the total expenditures for the four years. Approximately equal budget and FTE units were expended for the subsequent three years of the plan, with greater than 15% of the total for each of those years. We relaxed these actual findings slightly to allow for more latitude in final solutions.

$$\sum_i X_{ij1} \geq 35\% \text{ of } T_j \text{ for } j = 1 \ldots, m$$

$$\sum_i X_{ijk} \geq 15\% \text{ of } T_j \text{ for } j = 1, \ldots, m \text{ and } k = 2, \ldots, 4 \quad (5)$$

Third, the 1990 RMP allocated expenditures for four of the eight projects in our example. We assumed that, except for expenditures for "avalanche monitoring," these four projects implicitly represented the highest priority projects of the eight. Due to the special case for "avalanche monitoring," the following discussion will focus on the other three funded projects. Because the actual RMP dealt with 147 projects and not just our eight, it is possible that substitution effects were acting so that the actual three projects funded were not funded based solely on comparisons among our eight projects. Rather, selection of funding for those three projects may have been influenced by funding levels for other projects, related and unrelated. For the purposes of this study, however, we have chosen to ignore these potential effects and assume that no substitutions or rank reversals would occur if additional projects were introduced into our example. In fact, the use of a rating procedure rather than pairwise comparisons in the AHP eliminates the possibility of substitutions and rank reversals (Forman 1987).

Three of the four projects funded in the 1990 RMP were funded at a level greater than or equal to 18% of requested allocations. The exception was "anadromous fish," which was supported at 8.9% and 5.4% for budget and FTEs, respectively. Projects numbered 1, 2, 3 in the following constraints are the highest ranked projects other than avalanche forecasting. To be consistent with the most conservative allocation from the 1990 RMP, we constrained solutions by requiring that both budget and FTE allocations for each of these three projects be greater than or equal to 5.4% of requested expenditures. A constraint was added to allocate 50% of requested expenditures for "avalanche monitoring" to make our allocation reflect exogenous stipulations used in the 1990 RMP.

$$\sum_k X_{ijk} \geq 5.4\% \text{ of } T_j \text{ for } i = 1, \ldots, 3 \text{ and } j = 1, \ldots, m$$
$$\sum_k X_{[\text{avalanche forecast}]jk} \geq 50\% \text{ of } T_j \text{ for } j = 1, \ldots, m \quad (6)$$

Based on the objective function Equation 1 and constraints Equations 2-6, optimal allocation of budget and FTE units was performed for the different sets of project priorities in Table 1. The results for staff-assigned priorities, for the scenario of equal objective priorities, for the scenario of "management decision making" as the only objective, and for the actual 1990 RMP appear in Tables 2–5. To afford comparisons with 1990 RMP allocations, at least four projects under each scenario were allocated expenditures as specified in the last constraint (equation 6).

Results and Conclusions

Project ratings in Table 1 were based on judgments developed by the five Olympic NP staff. In the first set of priority/rankings, both the importance of park management objectives and the importance of each project for each objective were estimated by the park staff. In the second and third priority/rankings, the importance of park management objectives were preestablished. The final column of Table 1 reflects implicit priorities based on actual funding levels in the 1990 RMP.

Different scenarios of importance for the objectives in the AHP model produced different project priorities and rankings. Based on objective weights developed by Olympic NP staff, the Elwha watershed was ranked as the highest priority project. The projects with the five highest rankings all have relatively high priority scores, while the three lowest priority projects have considerably lower scores. A different scenario in which all objectives in the model are ranked equally produces only minor changes in the order of project priorities; the highest and lowest ranked projects maintain their positions, while the middle four projects are reordered. However, a scenario in which "management decision making" is the only important objective causes a considerable shift in priorities. Most notably, "goat impacts" is the highest-ranked project and "anadromous fish" has moved up to third. Results for the final scenario column, in which rankings are based on the 1990 RMP, differ markedly from each of the previous sets of rankings. Apparently, the BOGSAT process follows a nonexplicit set of objectives that diverge from those of the explicit scenarios.

When looking at groups of projects, one notices that four out of five projects—water quality, goat impacts, sensitive wildlife, anadromous fish, and Elwha watershed—are the highest ranked projects in each of the first three (non-RMP) scenarios. Although some reordering of rankings does occur, these five projects seem to be important regardless of what explicit objectives influence park management.

Our analysis shows that the ranking of the eight projects in our exercise differs from the ranking indi-

Table 2. Optimal expenditure of budget ($ thousands) and FTEs over four-year planning horizon with objective importance assigned by Olympic NP using AHP

Project	Objective importance assigned by park staff				
	Planning year	Outyear 1	Outyear 2	Outyear 3	Total
Air quality					
Budget					
FTEs					
Avalanche monitoring					
Budget	5.50	5.50	5.50	5.50	22.00
FTEs	0.15	0.15	0.15	0.15	0.60
Water quality					
Budget					
FTEs					
Goat impacts					
Budget	6.91				6.91
FTEs	0.25				0.25
Sensitive wildlife					
Budget	8.61	8.61	8.61	8.61	34.45
FTEs	0.33	0.33	0.33	0.33	1.33
Anadromous fish					
Budget					
FTEs					
Elwha watershed					
Budget	28.90	16.79	16.79	16.79	79.24
FTEs	1.08	0.64	0.64	0.64	3.02
IPM program					
Budget					
FTEs					
Totals					
Budget	49.92	30.90	30.90	30.90	142.6
FTEs	1.81	1.12	1.12	1.12	5.2

cated by expenditure values in the 1990 RMP. The air quality and avalanche monitoring projects, which did not receive high rankings in any of the non-RMP scenarios, were ranked fairly high in the scenario based on actual expenditures. It should be noted, however, that a recent (1992) policy change has placed significant emphasis on the Elwha watershed as a scientific study area. Consequently, current management objectives for the park have changed from what they were in 1990. The analytical aspect of the AHP allows one to track shifting priorities on a basis other than allocation of management resources, which may be influenced by other factors.

Despite the addition of constraints (equations 4-6), the linear programming problem is still degenerative, so the solutions listed in Tables 2-4 are not unique, but they are optimal. By including more projects (an actual RMP exercise might contain hundreds) or more constraints regarding the relative expenditures between projects or the timing of those expenditures, it should be possible to create a situation in which there is a unique optimal solution, or even no feasible solution. However, the presence of multiple optimal solutions should not be interpreted negatively, as it provides the park manager with additional latitude to choose a final plan and to react to annual changes in park budgets.

Binding constraints in each of the non-RMP scenarios include the total expenditures for budget and FTEs and the constraints in equation 6, which do not include the highest ranked project. As expected, increases in budget and FTE expenditures will permit greater allocations to the projects and therefore increase the value of the objective function (equation 1). Furthermore, by constraining the problem to allocate a minimum of 5.4% to each of the second and third priority projects and to avalanche monitoring (constraint in equation 6, less is allocated to the highest priority project, and the objective function is reduced. Relaxation of the constraint in equation 6, first for avalanche monitoring, will provide the greatest increase in the objective function under each non-RMP scenario.

From the priority lists in Table 1 it is apparent that the first two scenarios are fairly similar in their ranking of projects. This similarity becomes even more

Table 3. Optimal expenditure of budget ($ thousands) and FTEs over four-year planning horizon with all objectives equally ranked

	All objectives ranked equally				
Project	Planning year	Outyear 1	Outyear 2	Outyear 3	Total
Air quality					
Budget					
FTEs					
Avalanche					
Budget	5.50	5.50	5.50	5.50	22.00
FTEs	0.15	0.15	0.15	0.15	0.60
Water quality					
Budget	20.01				20.09
FTEs	0.05	0.05	0.05	0.05	0.20
Goat impacts					
Budget					
FTEs					
Sensitive wildlife					
Budget	8.61	8.61	8.61	8.61	34.44
FTEs	0.33	0.33	0.33	0.33	1.32
Anadromous fish					
Budget					
FTEs					
Elwha watershed					
Budget	16.51	16.51	16.51	16.51	66.04
FTEs	1.29	0.60	0.60	0.60	3.09
IPM program					
Budget					
FTEs					
Totals					
Budget	50.64	30.63	30.63	30.63	142.6
FTEs	1.82	1.13	1.13	1.13	5.2

apparent when we examine the allocations listed in Tables 2 and 3. Except for switching expenditures on water quality and goat impacts, their implementations in terms of actual allocations, indicate that they are similar. The final RMPs resulting from this example suggest that staff-assigned priorities are implementationally most similar (for the scenarios we have compared) to treating all objectives as equal. A similar comparison, between scenarios of staff assigned priorities and support management decision making, produces numerous differences (Tables 2 and 4), including projects funded, levels of funding, and annual allocations. Thus, despite relatively close project rankings in Table 1, these two scenarios differ substantially in their final LP solution. This follows naturally, because the allocation of resources in our LP model is a function of actual priority values, and these values may generate very different resources management plans even in the face of similar project rankings.

Table 6 lists the final objective function values for each of the different scenarios in Table 1. Because the objective function (equation 1) contains priority values, it was necessary to use current park staff priorities in the calculation of the 1990 RMP value. In the limiting case, when a single project has absolute priority (=1) and all budget and FTEs can be allocated to that project, then the value of that dominant project program is the sum of all budget and FTEs (converted to dollars × 1000), which in this example is 2 × 142.6, or 285.2. This represents the maximum program dollar value and, in effect, creates a priority-dollar metric. This metric can be viewed as a subjective economic measure, where each dollar spent (either as budget or FTE) is weighted by project priority. All programs that have two or more projects with greater than zero priority values must necessarily have a submaximal total program value in terms of our objective function's priority-dollar metric. Table 6 also lists each program's value as a percentage of this maximum. By combining project importance (as priority) and dollar expenditures into a priority-dollar metric, we are treating some allocations of budget and FTEs as more valuable, or "better," than others. This also occurs in the existing BOGSAT process, but it is nonquantitative and not explicit.

From Table 1 we can see that the second and third scenarios have some projects with higher priority val-

Table 4. Optimal expenditure of budget ($ thousands) and FTEs over four-year planning horizon with management decision making the only objective for resources management in the park

	Management decision making has highest priority				
Project	Planning year	Outyear 1	Outyear 2	Outyear 3	Total
Air quality					
Budget					
FTEs					
Avalanche					
Budget	5.50	5.50	5.50	5.50	22.00
FTEs	0.15	0.15	0.15	0.15	0.60
Water quality					
Budget					
FTEs					
Goat impacts					
Budget	67.21	10.17	10.17	10.17	97.72
FTEs	2.51	0.43	0.43	0.43	3.80
Sensitive wildlife					
Budget					
FTEs					
Anadromous fish					
Budget	2.43	2.43	2.43	2.43	9.72
FTEs	0.10	0.10	0.10	0.10	0.40
Elwha watershed					
Budget	3.29	3.29	3.29	3.29	13.16
FTEs	0.10	0.10	0.10	0.10	0.40
IPM program					
Budget					
FTEs					
Totals					
Budget	78.43	21.39	21.39	21.39	142.6
FTEs	2.86	0.78	0.78	0.78	5.2

ues than in the first scenario. These higher priority values result in a higher total program value. In general, as park management objectives become more specialized and focused, as in "support management decision making only," certain projects that are specific to those particular objectives will be targeted as very high priority. This results in a high total program value. On the other hand, when park management objectives cover a broader scope of resources, they generate approximately equal priority values for several projects and total program value is reduced because each dollar spent goes toward a lower average priority. Thus, in some sense the difference between total program value and the maximum program value represents a cost for RMP diversity. Less diverse plans tend to produce higher program values while more diverse plans (i.e., more objectives are important) often produce lower priority-dollar values.

In the case study conducted for Olympic NP, we found that the resource managers are highly receptive to alternative approaches to the evaluation of the RMP. The overwhelming complexity of multiple objective planning and project prioritization was actually simplified with the use of the AHP. Furthermore, resources management staff felt that they could present the RMP to other park staff and the general public with greater confidence if it were based on a more analytical framework grounded in quantifiable decisions. Although this case study assessed only a few projects and objectives, there was considerable support for integrating the AHP approach into more complex aspects of resources management planning.

Discussion

Resources management planning is a major responsibility for all National Park Service units and for other federal agencies. It is the basis for long-term management of millions of hectares of public lands. Most agencies currently have an established structure for their management plans, but the plans are often lengthy and cumbersome, because of efforts to make them comprehensive. Nearly every RMP with which the authors are familiar has been well-conceived and highly informative.

Table 5. Actual expenditures of budget ($ thousands) and FTEs for the 1990 RMP[a]

	Actual funding levels present in 1990 RMP				
Project	Planning year	Outyear 1	Outyear 2	Outyear 3	Total
Air quality					
Budget	12.4	12.4	12.4	12.4	49.6
FTEs	0.50	0.50	0.50	0.50	2.0
Avalanche					
Budget	5.5	5.5	5.5	5.5	22.0
FTEs	0.15	0.15	0.15	0.15	0.60
Water quality					
Budget					
FTEs					
Goat impacts					
Budget	55.0				55.0
FTEs	2.2				2.2
Sensitive wildlife					
Budget					
FTEs					
Anadromous fish					
Budget	4.0	4.0	4.0	4.0	16.0
FTEs	0.10	0.10	0.10	0.10	0.40
Elwha watershed					
Budget					
FTEs					
IPM program					
Budget					
FTEs					
Totals					
Budget	76.9	21.9	21.9	21.9	142.6
FTEs	2.95	0.75	0.75	0.75	5.2

[a]Resources management objective importance and project rankings are implicit in these actual funding levels.

Table 6. Final objective function values and their percentage of total expenditure (sum of budget and FTEs for each in Table 1[a]

Scenario	Objective function value from equation 1 ($1000)	Percentage of maximal priority-dollar value
Staff assigned priorities for objectives	38.73	13.58
All objectives have equal priority	40.98	14.37
Support "management decision making" only	47.46	16.64
1990 RMP	36.66	12.85

'The value for the 1990 RMP plan was calculated using the staff-assigned priority values.

Tactical implementation of plans is generally much less structured. The selection of individual project priorities is rarely quantified, and the rationale for those priorities is not documented. Allocation of limited financial and human resources is often based on criteria that are not quantified or clearly articulated. In general, considerably less effort is devoted to project prioritization and plan implementation than to the development of the RMP itself.

Public planning and the management of public lands are being subjected to increasing levels of scrutiny. Appeals and litigation often delay the implementation of projects that were conceived with great effort and expense. The complexity of management issues, and the reality of limited budgets, make it imperative that federal agencies have rational, consistent, and defensible management systems. We encourage all agencies to consider using more analytical approaches in resources management planning and decision making.

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Literature Cited

Forman, E. H. 1987. Relative vs absolute worth. *Mathematical Modeling* 9(3-5): 195–202.

Fox, D. G.,J. C. Bernabo, and B. Hood. 1987. Guidelines for measuring the physical, chemical, and biological condition of wilderness ecosystems. USDA Forest Service General Technical Report RM- 146. Rocky Mountain Research Station, Fort Collins, Colorado.

Garton, E. O. 1984. Cost-efficient baseline inventories of research natural areas. Pages 4045 *in* J. L. Johnson, J. F. Franklin and R. G. Krebill (coord.), Research natural areas: Baseline monitoring and management symposium proceedings. USDA Forest Service Intermountain Research Station, Ogden, Utah.

Hinds, W. T. 1984. Towards monitoring of long-term trends in terrestrial ecosystems. *Environmental Conservation* 11:11–18.

Hirst, S. M. 1983. Ecological and institutional bases for long-term monitoring of fish and wildlife populations. Pages 175–1 78 *in* J. F. Bell, and T. Atterbury (eds.), Renewable resource inventories for monitoring changes and trends conference proceedings. College of Forestry, Oregon State University, Corvallis, Oregon.

Johnson, W. C., and S. P. Bratton. 1978. Biological monitoring in UNESCO biosphere reserves with special reference to the Great Smoky Mountains National Park. *Biological Conservation* 13:105-115.

Jones, B. K. 1986. The inventory and monitoring process. Pages 1–9 *in* A. Y. Cooperrider, R. J. Boyd, and H. R. Stewart (eds.), Inventory and monitoring of wildlife habitat. Bureau of Land Management, Denver, Colorado.

Olympic National Park. 1990. Olympic National Park resource management plan. Olympic National Park, Port Angeles, Washington.

Saaty, T. L. 1980. The analytic hierarchy process. McGraw-Hill, New York, 287 pp.

Schmoldt, D. L., D. L. Peterson, and D. G. Silsbee. 1994. Developing inventory and monitoring programs based on multiple objectives. *Environmental Management* 18(5):707–727.

Silsbee, D. G., and D. L. Peterson. 1991. Designing and implementing comprehensive long-term inventory and monitoring programs for National Park System lands. Natural Resources Report NRR-91/04. National Park Service, Denver, Colorado.

Silsbee, D. G., and D. L. Peterson. 1993. Planning for implementation of resource monitoring programs. *Environmental Monitoring and Assessment* 26:177-185.