Multiple Objective Decision Making
for "Lokahi" (Balance) in Environmental Management

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ABSTRACT

Innovative advances and applications in multiple objective decision-making (MODM) contained in the upcoming set of papers published in this special issue of Applied Mathematics and Computation are summarized, assessed, and compared with regard to their usefulness for tackling complex problems in environmental management. Since many of the MODM methods and associated decision support systems used in environmental management originate from the field of operations research (OR), techniques from OR are categorized with respect to their abilities to handle multiple objectives and multiple decision makers. The applications presented in the forthcoming papers clearly demonstrate that a range of OR and other scientific methods are usually required for properly modelling, analyzing, and solving real-world environmental management problems. © Elsevier Science Inc., 1997

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INTRODUCTION

The concept of humankind exploiting the natural environment in order to meet its multiple objective needs has been a part of civilization since the dawn of history. For example, even early civilizations utilized water for multipurpose uses such as irrigation, drinking water, and cleaning. Subsequent to the industrial revolution started in the seventeenth century in England, water, air, and land resources have been employed for a wide variety of industrial purposes. However, the current multigoal utilization of natural resources by large populations located throughout the world can potentially lead to disastrous consequences—deforestation, water pollution, global warming, and desertification, to name a few. In response to these concerns, the World Commission on Environment and Development [1] proposed the idea of *sustainable development* whereby economic growth and environmental protection are properly managed to benefit both present and future generations.

History provides valuable lessons on both successful and ill-conceived approaches to practicing sustainable development when the natural environment is subjected to multiple objective usage. An example of the complete collapse of a society brought about by ignorance, greed, and a lack of environmental concern, is the Maoi civilization which once flourished on Easter Island, an isolated island located in the South Pacific Ocean. Scientists now believe that deforestation caused by overpopulation and poor land management led to the extinction of the Maoi around 1680, just before the discovery of Easter Island by the Dutch explorer Jacob Roggereen on Easter Sunday in 1722 [2, 3]. Even though the Maoi people were capable of the complex engineering feat of erecting large stone statues throughout their island from about 1400 to 1680, they were still unable to manage the multipurpose utilization of the only world they knew.

Ruckelshaus [4] points out in his article in Scientific American that many premodernized peoples lived sustainably out of necessity. One of the shining illustrations of innovative environmental management is the admirable concept of ahupua’a carried out by the native Hawaiians. From the moutaintops, down the slopes, to the beaches and into the sea, the Hawaiians organized their agricultural, residential, recreational, and aquacultural activities as a harmoniously functioning system. Figure 1 illustrates elements typical of an ahupua’a. Note, for example, that concern for erosion and other factors that can contribute to water pollution is ensured by the fact that drinking water and recreational uses of water occur downstream from the cropland. Ordering or mixing crops that use or intercept the wastes of another is encouraged by this practice. The Hawaiians sum up their attitude toward the land within an ahupua’a by the following terms: aloha (respect),
laulima (cooperation), mālama (stewardship), and lokahi (balance) [5]. These same concepts and ideas are also held by the New Zealand Maori (another island people who actually reached the Hawaiian Islands). The Kaitiakitanga is a holistic approach that ensures balance and harmony with nature for the sake of future generations [6].
As a response to current global concerns about the multiobjective characteristics of sustainable development, a timely conference in a series called Mālama 'Āina (meaning 'preserve the land' in the Hawaiian language) was organized to take place in Honolulu, Hawaii, from July 23–28, 1995. The specific theme of this Mālama 'Āina '95 conference was *Multiple Objective Decision Support Systems for Land, Water and Environmental Management: Concepts, Approaches and Applications*. As noted in the Pre-Conference Proceedings [7].

"Mālama 'Āina'95 [provided] a forum for sharing experiences among participants on the rationale, design, and use of multi-objective decision making tools in addressing natural and renewable resource management issues. In particular, the forum [allowed] reviewing and assessing the states of the art and knowledge on, as well as research needs for, addressing the potentially conflicting objectives of productive land use and enhanced environmental quality."

The format of the conference included plenary and contributed paper presentations within the following four primary themes.

1. Addressing user needs and applications;
2. Multiple objective decision support system (MODSS) methodologies, tools, components and integration;
3. Economic, social policy, risk, and sustainable issues in MODSS;
4. The application of MODSS methods to global and regional issues, especially in Asia and the Pacific.

This interesting and timely conference was organized by Dr. S. A. El-Swaify, Agronomy and Social Science Department, University of Hawaii, as well as Dr. Diana S. Yakowitz and Dr. Leonard J. Lane of the Agricultural Research Service, U.S. Department of Agriculture, Tucson, Arizona. More than 170 participants from over 30 countries attended the conference held in the East-West Center located on the beautiful campus of the University of Hawaii in Honolulu. In addition to paper presentations, there were several interactive discussions with the audience, panel sessions, computer demonstrations of software, and a well attended concluding forum held during the final morning of the conference.

At the Hawaiian conference, each participant was given a Pre-Conference Proceedings which contained the conference program, extended abstracts, and a list of participants. Subsequent to the conference, papers submitted by presenters to the conference organizers for review were considered for publication in a Conference Proceedings which will be available for distribution in 1997. Another project was the creation of this special issue of
Applied Mathematics and Computation in order to provide its readership with some of the latest research findings and applications in Multiple Objective Decision Making in Environmental Management. To accomplish this, some of the authors who participated at the Hawaiian conference were invited to prepare research papers for possible inclusion in this special publication of Applied Mathematics and Computation. Following thorough reviews by international experts, accepted papers were returned to authors for revision, and the final manuscripts were then published in this journal volume.

In the next section, developments in MODM, which are especially useful in environmental management, are summarized and put into perspective. Subsequently, the key contributions of the accompanying papers contained in this issue are evaluated and compared. The many practical applications presented in these papers confirm the efficacy of employing a wide range of formal MODM techniques in environmental management. Finally, appropriate conclusions regarding present and future developments in MODM in the environmental field are put forward.

2. ENVIRONMENTAL DECISION MAKING

Problems arising in environmental management tend to be complex and interdisciplinary in nature. For example, the responsible harvesting of forests for commercial purposes can have tremendous impacts on the natural environment as well as the economical, political, and social structures of affected communities. Moreover, the various interest groups such as the developers of the forestry industry, environmental groups, and political organizations, may interpret the project from radically different viewpoints according to their own multiple objectives. Therefore, MODM techniques, conflict resolution, and other decision-making tools can often be effectively employed to assist decision makers in reaching fair and equitable solutions within a sustainable development framework. When MODM techniques as well as other basic scientific tools and procedures are computerized as user-friendly decision support systems (DSSs) [8], they can be employed in practice for helping to systematically study and effectively resolve complex environmental management problems. In the next section, it is pointed out how practitioners can utilize an array of decision techniques for solving a wide range of environmental and resource management problems.

Since the outbreak of the World War II, a rich variety of decision making tools have been developed within a field called operational research, or simply OR. The discipline of OR was initiated by the British in July, 1938,
to carry out research into operational aspects of radar systems [9, 10]. During World War II, the British and later the Americans, developed and used OR methods for systematically studying well-defined large-scale military problems in all branches of the military. The Americans preferred to refer to OR as operations research, while the Canadians used both terminologies. Subsequent to the war, OR has been extensively expanded for addressing decision problems arising in many different fields including systems engineering, transportation engineering, management sciences, military sciences, water resources, and environmental management. Often the collection of fields that develop and apply OR methods is referred to as the system sciences. Finally, OR societies have been formed in most industrialized countries in conjunction with the publication of many OR journals.

Initially, OR was designed for investigating highly structured problems that arise more frequently at the tactical level of decision making. Within environmental management, an illustration of a tactical decision is deciding how to efficiently operate a sewage treatment plant using appropriate optimization algorithms. Therefore, until recently, the accepted definition for OR was that OR is a systematic approach for scientifically studying well-structured problems that can be modeled using quantitative mathematical techniques. Quite often, the OR methods could only handle optimizing a single objective from a single decision maker’s viewpoint within appropriate quantitative constraints.

At the strategic level of decision-making, problems often involve multiple objectives and multiple decision makers. Moreover, frequently these strategic problems are less well defined than tactical situations, and both quantitative and qualitative information must be taken into account by the decision maker. When deciding upon, for example, the design, construction and operation of a water supply and sewage system for a region that may cross various political boundaries, decision makers must consider not only the traditional engineering aspects of the project but also environmental, economic, cultural, social, and political factors. Accordingly, researchers, including Ackoff [11], Checkland [12], Rosenhead [13], Radford [14, 15], Fang et al. [16], and Hipel and Mcleod [17], have suggested that the realm of OR be expanded in order to overcome an underlying paradigm crisis that would cause OR to decline as a leader in the field of decision making. Specifically, the definition of OR should be extended to encompass not only the systematic study of “hard” systems problems that take place at the lower levels of decision making but also the “soft” kinds of decisions that are made at higher levels, and usually involve multiple decision makers, each of whom has multiple objectives. Fields outside of OR that are currently tackling the highly unstructured soft types of decision-making problems include qualitative reasoning, artificial intelligence, and expert systems.
Introduction

When one considers the more enlightened definition of OR, the contributions from these areas that deal with decision making can be thought of as being part of OR.

Since OR methods have been found to be useful in so many disciplines, theoretical and practical developments are published in a wide range of publications. International journals that publish OR papers include the Journal of the Operational Research Society, Applied Mathematics and Computation, IEEE Transactions on Systems, Man and Cybernetics, Operations Research, European Journal of Operational Research, OMEGA, Information and Systems Engineering, INFOR, Group Decision and Negotiation, Theory and Decision, and Management Sciences. Introductory OR textbooks, such as the ones by Hillier and Lieberman [18] and Wagner [19], provide good descriptions of tactical OR techniques. For obtaining information about strategic decision making, one can refer to books by authors including, Checkland [12], Fraser and Hipel [20], Radford [15], Rosenhead [13], De Cleris [21], Flood and Jackson [22], Singh and Trave-Massuyes [23] and Fang et al. [16]. Other valuable publications concerned with decision-making methods include handbooks on systems analysis, [24, 25] and a comprehensive encyclopedia on systems and control [26].

Virtually every major engineering discipline has journals that regularly publish articles having OR applications. In water resources and environmental engineering, for instance, these journals include Water Resources Bulletin, Water Resources Planning and Management, Water Resources Research, and Environmental Management. Researchers who have written books regarding the employment of OR in water resources and environmental engineering include Maass et al. [27], Hall and Dracup [28], Haimes et al. [29], Haimes [30], Cohon [31], Loucks et al. [32], Chankong and Haimes [33], Votruba et al. [34], Fang et al. [16] and Hipel and McLeod [17]. Indeed, the great importance of OR methods in environmental management is further exemplified by the set of papers on MORD contained in this special issue. Many conference proceedings, including the Hawaiian proceedings mentioned in the introduction, as well as the proceedings of a hydrology and environmental engineering conference held at the University of Waterloo in 1993 [35], contain papers in which a range of OR methods are applied to challenging environmental problems. A monograph edited by Hipel [36] has papers on MORD in water resources. In 1993, Duckstein et al. [37] edited a special issue of Applied Mathematics and Computation on the topic of multiattribute decision making. In a very ambitious problem, Al Gobaisi [38] is currently preparing and editing a comprehensive encyclopedia entitled Encyclopedia of Life Support Systems (EOLSS) in the areas of water, energy, environment, food and agriculture, common sciences, and global issues. This encyclopedia will be made available in book form as well as on
CD-ROM. Information about the encyclopedia can be found on the World Wide Web.\textsuperscript{1} Many of the articles will be concerned with the employment of OR and systems engineering approaches for tackling challenging environmental problems.

One can think of OR as being both an art and a craft. The art consists of a general approach to addressing complex decision problems, while the craft refers to a wide variety of formal techniques which hopefully will provide reasonable results when properly applied to specific problems. Within this special issue of Applied Mathematics and Computation, both the art and the craft of OR are used in many of the accompanying set of papers. The art of OR is expressed in the way the authors use a set of specific OR techniques or crafts to obtain insights and a better understanding of the environmental problems that they are investigating. This ultimately results in better decisions being made in both the short and long term.

Table 1 portrays how the OR techniques or crafts of the trade can be classified according to the number of decision makers and objectives. An illustrative example of a technique having characteristics specified by the column and row criteria is given within each cell. First, consider techniques falling under the column labeled as single objective in Table 1. Most OR methods tend to fall within the representatory category of one objective from one decision maker’s viewpoint. As shown in the top left cell in Table 1, linear programming formulations for which there is a single objective come

\begin{table}
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\begin{tabular}{|l|l|l|}
\hline
Decision Maker(s) & Objective(s) &  \\
\hline
\multirow{2}{*}{Single} & Linear & Multiple Criterion \\
& Programming & Decision Making (MCDM) \\
\cline{2-3}
\multirow{2}{*}{Multiple} & Team & Graph Model for Conflict Resolution \\
& Theory &  \\
\hline
\end{tabular}
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\textsuperscript{1}http://www.laas.fr/eolss/eolss.html (Europe), http://ace.unm.edu/eolss/eolss.html (North America).
under this classification. One may wish, for instance, to minimize costs represented by a linear objective function subject to various linear constraints. This entire linear programming formulation would represent the way a single party has chosen to represent the problem. Team theory falls within the bottom left cell in Table 1 because in a sporting event, for instance, each team has the single objective of winning.

The decision techniques employed in the papers published in this special issue largely fall within the two cells under the multiple objective column in Table 1. A set of OR methods that is employed widely in practice is the multiple criterion decision making (MCDM) methods, which land within the top right cell in Table 1. Descriptions of MCDM methods include contributions by MacCrimmon [39], Saaty [40], Goicoechea et al. [41], Zeleny [42], Roy [43], Szidarovszky et al. [44], Arrow and Raynaud [45], Tabucanon [46], and Janssen [47] (who also emphasizes environmental issues). MCDM techniques are designed for finding the more preferred alternative solutions to a problem in which discrete alternatives are evaluated against criteria or factors ranging from a quantitative criterion, such as cost to a qualitative one like desirability. The basic matrix design of the discrete version of the MCDM formulation is shown in Table 2. As can be seen, the \( m \) alternatives are evaluated separately against each criterion. When cardinal numbers or utility values can be employed to represent the preferences \( V_{i1}, V_{i2}, \ldots, V_{im} \), of the decision maker for the \( m \) alternatives with respect to criterion \( C_i \), the criterion is said to be quantitative. For instance, a criterion such as cost may be evaluated using dollars or cardinal utility values. If a criterion cannot be assigned real number values, it is said to be nonquantitative. For example, a criterion like aesthetics is nonquantitative in nature. For this situation, ordinal numbers can be used to rank the \( m \) alternatives against this criterion.

Most MCDM methods differ on the types of information required for evaluating the alternatives as well as the definitions of the search procedures for finding the better solutions. The ELECTRE techniques of Roy [43], for example, utilize the information expressed in a fuzzy context so that

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<td>( C_i )</td>
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imprecise evaluations can be accommodated (see Bardossy and Duckstein [48] for a recent presentation of fuzzy set theory). Additionally, the idea of concordance and discordance are used as search procedures for isolating the set of more preferred alternatives. Some MCDM methods allow the criteria to be weighted prior to comparing the alternatives, when cardinal preference information is given. As a matter of fact, because so many MCDM methods are available, Gershon and Duckstein [49] suggest an MCDM technique for selecting the most appropriate MCDM method to employ in a given application. Likewise, Hobbs [50], and Karni et al. [51] carry out experiments for selecting a suitable MCDM technique.

As given in the bottom right cell, Table 1, the graph model for conflict resolution [16] is an example of a technique that can be employed for modelling and analyzing a dispute for which there are two or more decision makers and each decision maker can have multiple objectives. The range of solution concepts for determining the equilibria or compromise resolutions to a given conflict using the approach of Fang et al. [16] takes into account the possible strategic interactions among the decision makers as each decision maker seeks to move to more preferred possible positions. Indeed, one can think of conflict resolution as a type of optimization problem from a given decision maker’s viewpoint because the decision maker attempts to do as well as possible while subject to the social constraints imposed by the other participants. A wide range of game theory techniques can also be classified in the bottom right box in Table 1. Finally, Hipel et al. [52] investigate and expand the relationships among MCDM methods and the graph model for conflict resolution which are both listed under the multiple objective column in Table 1.

3. CONTRIBUTIONS TO MULTIPLE OBJECTIVE DECISION MAKING IN ENVIRONMENTAL MANAGEMENT

A summary of the major contributions of the subsequent papers published in this special issue of Applied Mathematics and Computation is presented in Table 3. Besides pointing out the key contributions of each paper, the table includes the main types of models that are used in each article. As can be seen, many of the models listed in Table 3 come from the field of OR discussed in the previous section. Moreover, the authors of the papers in Table 3 are from seven different countries and the applications presented in the papers involve five different countries. Finally, the international scope of the articles is confirmed by the fact that authors and/or applications represent all continents with the exceptions of South America and Antarctica.
Among those factors that the papers have in common beyond their multiple objective nature and concern with environmental criteria include the fact that all of the papers incorporate some economic considerations (some more than others) into the decision-making model or procedure. All but two papers (7 and 8) present examples involving real world problems and/or data. All except two of the papers are concerned specifically with land use (exceptions are paper 6, which is concerned with aquaculture, and paper 8, which deals with enforcement of environmental regulations). In fact, five of the papers (2, 3, 4, 5, and 6) deal with agricultural issues. Three papers (1, 2, and 8) address conflict resolution and two papers (3 and 8) are concerned with determining incentives for the affected parties to either adopt environmentally friendly practices or to comply with regulations.

Four of the papers (1, 3, 4, and 5) have associated Decision Support Systems (DSSs). These systems aid the decision makers by incorporating user friendly graphical interfaces and interactive capabilities with the associated models and decision techniques. An advantage of having a decision support system is that it is quite convenient to consider multiple viewpoint and to expeditiously carry out extensive sensitivity analyses. For example, the DSS used in Heilman et al. (paper 3) permits the user to examine a multicriteria decision-making problem from several interest groups’ points of view. In this case, the concern is with framing practices that could impact water quality. The ability to examine multiple points of view permits one to compare how the final results differ among interest groups and may promote compromise and consensus building. Therefore, decision support systems and their associated techniques provide a language whereby parties can conveniently communicate with one another in order to reach a better understanding of the problem by more fully appreciating each others’ viewpoint and thereby ultimately reaching fairer and more enlightened decisions.

As can be seen in Table 3, most of the papers employ a range of techniques to tackle a given real world problem. For example, Prathapar et al. (paper 5) use physical simulation, mixed integer programming, linear programming, and multicriteria optimization models within the decision support system called SWAGMAN Options and then apply this system to study rice production in Australia within a sustainable development framework. Antoine et al. (paper 4) employ the Aspiration-Reservation Based Decision Support (ARBDS) system, which contains a number of multiobjective optimization tools and fuzzy set concepts, to support multiple objective decision making with respect to land use in Kenya.

Some of the authors directly consider multiple stakeholders in their modeling and analyses. Specifically, Hipel et al. (paper 1) describe the basic design for their decision support system, GMCR II, which incorporates the
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<th>Authors</th>
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<tr>
<td>1. K. W. Hipel, D. M. Kilgour, L. Fang, and X. Peng</td>
<td>The decision support system GMCR in environmental conflict management</td>
<td>The graph model for conflict resolution and its associated decision support system called GMCR II.</td>
<td>The basic design for the decision support system CMCR II is described. To demonstrate how GMCR II works in practice, it is used to model and analyze an actual environmental conflict that took place between Canada and the United States.</td>
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<td>2. M. A. Ridgley, D. C. Penn, and L. Tran</td>
<td>Multicriterion decision support for a conflict over stream diversion and land-water reallocation in Hawaii</td>
<td>Multiobjective mathematical programming and analytical hierarchy process (AHP).</td>
<td>Multicriterion methods are used to aid decision making about stream diversion and land-water reallocation on the Hawaiian Island of Oahu.</td>
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<td>3. P. Heilman, D. S. Yakowitz, and L. J. Lane</td>
<td>Targeting farms to improve water quality</td>
<td>Physical simulation, economic accounting, symmetric-quadratic programming, and multiple criteria models; two associated decision support systems.</td>
<td>A multiple objective procedure is used to target farms that have an economic incentive to adopt conservation management systems having water quality benefits. The decision technology is applied to a region of western Iowa.</td>
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<td>4. J. Antoine, G. Fischer, and M. Makowski</td>
<td>Multiple criteria land use analysis</td>
<td>Multi-objective optimization, fuzzy sets, multicriteria decision analysis techniques implemented using the Aspiration-Reservation Based Decision Support (ARBDS) approach.</td>
<td>The ARBDS approach is used to support multiobjective decisions for land-use in Kenya.</td>
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<td>5</td>
<td>S. A. Prathapar, W. S. Meyer, J. C. Madden, and E. Alcolila</td>
<td>SWAGMAN Options: A hierarchical multicriteria framework to identify profitable land uses that minimize watertable rise and salinization. Optimization, physical simulations, economics, and multicriteria models within the SWAGMAN Options, decision support system. SWAGMAN is used for determining how rice production in New South Wales, Australia, can be conducted in an environmentally sustainable manner.</td>
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<td>6</td>
<td>K. A. Parton, and A. Nissapa</td>
<td>A nonlinear programming model for analyzing aquaculture policy decision making in southern Thailand. Nonlinear goal programming. Nonlinear goal programming is used to analyze the environmental economic trade-offs concerned with the expansion of aquaculture production in southern Thailand.</td>
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<td>7</td>
<td>G. Van Huylvenbroeck</td>
<td>Multicriteria tools for the trade-off analysis in rural planning between economic and environmental objectives. Multiple criteria, multiple objective, linear programming, and mixed integer programming models. A multicriteria approach combining a variety of decision techniques is used for analyzing trade-offs between economic and environmental objectives in rural transportation planning.</td>
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<td>8</td>
<td>L. Fang, K. W. Hipel, and D. M. Kilgour</td>
<td>How penalty affects enforcement of environmental regulations. Game theory, extensive form of the game, verification theory, and economics. Extensive game models are put forward for investigating how severity of penalties affects compliance to environmental laws and regulations.</td>
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graph model for conflict resolution to formally model strategic interactions among multiple decision makers involved in a dispute and to predict possible compromise solutions. To illustrate how GMCR II can be utilized in practice, the authors guide the readers through the systematic study of an actual environmental conflict involving decision makers in Canada and the United States over the potential pollution of an international river by a proposed open-pit coal mining development in the Canadian province of British Columbia. Fang et al. (paper 8) developed extensive game models for formally investigating how the severity of penalties levied by an environmental agency can affect compliance to environmental regulations by a firm.

Ridgley et al. (paper 2) elicit and structure criterion hierarchies for multiple objective analysis from multiple stakeholders to formulate potential solutions for environmental conflicts. They chronicle an actual ongoing legal dispute over stream diversion on the island of Oahu, Hawaii that involves 23 interested parties and describe the application of the multiple objective methodology to this problem by an advanced undergraduate class that was used as testimony in the case.

Heilman et al. (paper 3) also involve multiple decision makers by including the often conflicting points of view of the farmers and downstream water users in a region. The objective of their work is to target farmers who have the potential to improve water quality while also enhancing or maintaining their own economic status. An application of the procedure to farms in a region of western Iowa is described.

Finally, many of the papers in Table 3 involve the actual generation of alternative solutions for addressing a multiple objective environmental problem as a part of the MODM process (papers 2, 4, 5, 6, and 7). In particular, Parton and Nissapa (paper 6) use nonlinear goal programming to determine locations in a lake in southern Thailand where aquaculture can be expanded without a significant detrimental effect on the capture fisheries there. Van Huylenbroeck (paper 7) generates pareto-efficient road planning alternatives, that take into effect the environmental impacts of the plans. This example illustrates a methodology that uses discrete or integer compromise programming techniques and a method, also used in paper 3, to examine the sensitivity of the ranking of the alternative plans to the priority levels of the criteria.

4. CONCLUSIONS

As discussed in the previous two sections, significant work has been done in extending the frontiers of MODM in environmental management, including problems related to sustainable development. For example, many of the
authors whose papers are summarized in Table 3 employed a range of MODM techniques for improving environmental decision making with respect to actual real-world problems. Nonetheless, much research remains to be completed in order to confront many other pressing environmental problems and to be prepared for tackling yet unforeseen challenges. Accordingly, the guest editors of this special issue would like to encourage further research in decision making that has the potential for preserving our lands, water, and other natural resources while meeting realistic economic and social demands.

As an illustration of how scientific procedures (often single objective in nature) have greatly increased food production while also helping to preserve natural habitants, consider the information provided by Goklany [53] and portrayed in Figure 2. World population has increased rapidly (top curve, Figure 2), doubling between 1950 and 1989, while the number of hectares devoted to cropland (lowest curve, Figure 2) has increased by only 25%. This dramatic difference is due, in large part, to agricultural research and technological development that has raised production levels on cropland. The middle curve on the graph of Figure 2 indicates the additional amount of land that would have been necessary for equivalent production levels if technology had been frozen at the 1950 level. Clearly, one result of improved technology has been the reduced need to convert forests and grasslands to cropland. But, for example, while artificial fertilizers and pesticides have helped to ensure high crop yields, they have also been detrimental to our water supplies and wildlife. Methods suggested in this issue and others may help to improve environmental decision making that will enable us to avoid

![Figure 2](data:image/png;base64,iVBORw0KGgoAAAANSUhEUgAAAI0AAAD4CAMAAAA...)

Fig. 2. World population and cropland, 1900–1989 (data from Goklany [53]).
mistakes made in the past that were often a result of not considering the multiple impact nature of the decisions.

The renewed interest of some societies, such as in Hawaii and New Zealand, in successful ancient strategies that allowed communities to prosper while living in harmony with nature, is encouraging. Another example are organizations such as LEAF (Linking Environment and Farming) in England [54], which is part of the European Initiative for Integrated Farming (EIF), and who along with others are promoting integrated crop management and common sense farming practices that consider both environmental responsibility and economic viability. Indeed, as is evident from many of the papers reviewed here, there appears to be a concerted effort to include as many points of view as possible in the decision making process.

Application of mathematical and other decision making methods that help to discern between alternatives with competing environmental, economic, and social objectives, or that improve the chances for compromise to resolve conflict, can only help to insure that we meet our primary objective to have humankind and nature live in harmony.

ALOHA, and MĀLAMA 'ĀINA! (Greetings, and Preserve the Land!)

We wish to acknowledge the support and activities of the organizing committee and sponsors of Mālama 'Āina '95, particularly that of Dr. S. A. El-Swaify, whose efforts and guidance ensured a successful event. We would also like to thank the many anonymous reviewers of the papers in Table 3 for devoting some of their valuable time to our project. We wish to thank Dr. Leonard Lane and Dr. William Allen for their support and for the sources of some of the material used in this paper, and Xiaoyong (John) Peng for assistance on this manuscript. This work would not have been possible without the support of the U.S. Department of Agriculture–Agricultural Research Service, the University of Waterloo, and the Organisation for Economic Co-Operation and Development.

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Kindly refer to Table 3 for references for the papers appearing in this issue.


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