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The Legacy Ecosystem Management Framework: From Theory to Application in the Detention Pond Case Study

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Abstract

The Detention Pond is a constructed and lined storm water treatment basin at Lawrence Livermore National Laboratory that serves multiple stakeholder objectives and programmatic goals. This paper examines the process and outcome involved in the development of a new management plan for the Detention Pond. The plan was created using a new ecosystem management tool, the Legacy Framework. This stakeholder-driven conceptual framework provides an interdisciplinary methodology for determining ecosystem health, appropriate management strategies, and sensitive indicators. The conceptual framework, the Detention Ponds project, and the use of the framework in the context of the project, are described and evaluated, and evaluative criteria for this and other ecosystem management frameworks are offered. The project benefited in several ways from use of the Legacy Framework, although refinements to the framework are suggested. The stakeholder process created a context and environment in which team members became receptive to using an ecosystem management approach to evaluate and support management alternatives previously not considered. This allowed for the unanimous agreement to pursue support from upper management and organizational funding to implement a progressive management strategy. The greatly improved stakeholder relations resulted in upper management support for the project.

Introduction

Many conceptual frameworks for ecosystem management have surfaced over recent years. These frameworks attempt to offer approaches and methodologies to support managers in their decision processes (Berry and Vogt 1999; Haeuber 1998; Grumbine 1997; Grumbine 1994). In addition, stakeholder-driven approaches for resolving management issues have been rising in popularity (Endter-Wada et al 1998). However, to date, few studies have been performed showing that conceptual frameworks or a stakeholder-based approach actually result in improved outcomes (Susskind et al 2001; Berry and Vogt 1999; Vogt et al 1999; Vogt et al 1997). This lack of testing (Brunner and Clark 1997), asking questions at the right scale (Vogt et al 2002), and case study analysis, may be impeding the more widespread adoption of conceptual frameworks for use in ecosystem management. Also, many of these theoretical frameworks lack a “user friendly” orientation, in which application of the theory toward on-the-ground management is straightforward and clearly understood. As a result, ad hoc management approaches are often used rather than implementing a systematic and holistic framework.

This paper offers a case study in ecosystem management, using a stakeholder-driven conceptual framework entitled the Legacy Framework (Vogt et al 2002; Vogt et al 1999) to develop a new management plan for the Detention Pond at Lawrence Livermore National Laboratory (LLNL). The goal of the analysis is to show how the use of a conceptual framework and a stakeholder-based approach can make for improved management outcomes. We begin by providing an overview of the framework for the Detention Pond project. We then evaluate the performance of the stakeholder process and the Legacy Framework in the context of their application to the Detention Pond project. On this basis, we make recommendations for refining the Legacy Framework, and offer general evaluative criteria for this and other ecosystem management frameworks, to help in their future design and implementation.

Overview of Legacy Framework

The Legacy Framework is an interdisciplinary analysis model used to determine an ecosystem's state, relative to a given set of goals for that system. The framework also evaluates alternative natural resource uses or management strategies for the ecosystem. The framework assumes that 1) natural and social systems dynamically interact through a continuous interface (Pierce Colfer et al 1995; Pickett et al 1997), 2) "complete" knowledge of an ecosystem is not required to acquire a sufficient understanding on which to base system evaluations and decisions (Rauscher 1999), and 3) past human activities and natural processes leave imprints on the landscape (legacies) that continue to modify ecosystem structure or function (Vogt et al 1997; Vogt et al 1999). The framework attempts to enhance the ability to predict the future state of ecosystem health by identifying and using sensitive indicators. These indicators are based on an understanding of the mechanistic links between key components and processes in the system. Uncertainties are acknowledged and accommodated for by adaptive management. The following description of the framework may seem abstract; however, the Detention Pond case study will make the on-the-ground application clear. Figure 1 represents a general process diagram for the framework.

The framework is driven by a stakeholder-based, collaborative, bottom-up approach. All individuals with a significant interest or capacity to influence the system are involved in applying the framework. The involvement of these stakeholders is critical, as strategies developed in a "vacuum" often fail to address all relevant concerns, and will likely be undermined. An unsuccessful outcome is highly probable without substantive stakeholder collaboration (Clark and Wallace 1998; Rothman and Robinson 1997).

The framework uses a process involving two dynamically and iteratively linked phases: analysis and implementation. In the analysis phase, a holistic and mechanistic understanding of the ecosystem is developed. The framework helps delineate key areas of the system in which to collect information. Each area informs progressive analytical steps. These steps intend to narrow information needs yet efficiently and effectively increase the understanding of the ecosystem.

As a first analytic step, the desired endpoints, or goals, are defined. These endpoints will be based on human values (Hyatt and Hoag 1997), and to make the analysis more transparent, these values should be made explicit at the outset (Wagner 1995). Further, rather than being static, endpoints should outline ranges of acceptable outcomes, taking into account social and environmental dynamics and stochasticity (Poiani et al 1998; Wyant et al 1995). Based on the endpoints, an initial set of indicators is developed. Indicators provide information about the state of system health, and movements in this state relative to the desired endpoints. Indicators should ideally be high order (i.e., providing an "umbrella" that captures information about an entire suite of variables), provide predictive rather than retrospective monitoring feedback, and offer sensitivity to the system's state and changes thereof (Vogt et al 1999). Indicators can monitor, among other things, ecosystem health and biodiversity, ecological services, human health, and economic productivity. The initial set of indicators, once developed, is set aside for use later in the analysis.

The next major step in the process involves investigating key characteristics or dynamics of the system, in terms of two broad system categories. These consist of natural and social legacies. Natural legacies include any past or current ecological events having a direct, measurable effect on current ecosystem structure or function. Social legacies include past or current human values influencing the current and potential use, productivity, and health of the ecosystem. Legacies affect the ecosystem indirectly through the driving variables.

Driving variables express the direct biological and ecological processes resulting from the legacies. Three aspects of ecosystems are examined through the driving variables: spatial dynamics, temporal dynamics, and disturbance cycles. The information regarding these legacies and driving variables is then integrated to develop a holistic understanding of the ecosystem.

The last step of the analysis phase involves identifying and selecting final indicators and evaluating alternative uses or management strategies for the system. A second set of indicators is selected based upon the completed integrative analysis and acquired system understanding. This new set of indicators is compared to those chosen at the outset; this comparison should highlight shortcomings of the analysis. For example, if the indicator sets are identical, a large potential exists that the framework was not fully followed or the analysis was not sufficient to increase understanding of the system. After due consideration, and reexamination of the system as necessary, a final set of sensitive indicators is selected.

Alternative uses or management strategies are developed, evaluated, and an appropriate one is chosen. During the implementation phase, the selected use or strategy will involve ongoing monitoring using the indicators. This monitoring will provide an early indication of the system's status. Predicative capacity, provided by the sensitive indicators, allows natural resource managers the ability to use adaptive management techniques to maintain the ecosystem's capacity to achieve desired end points (Ringold et al 1996).

At this point, the implementation phase begins, and the selected management strategy is carried out. Both initial and ongoing management occurs, and monitoring data are collected. Using the new information derived from the indicators, the analysis phase is revisited at regular intervals to evaluate performance and refine/redefine management goals and practices. This new analysis will guide adaptive management strategies. The implementation phase therefore feeds back into new iterations of the analysis phase, with adaptive management providing the dynamic link between the two phases of the framework. In this way, uncertainties identified throughout the application of this framework are addressed as enhanced understanding and new information becomes available for use.

Description of the Detention Pond Project

This case study describes an on-the-ground application of the conceptual framework described in the preceding section. The use of the Legacy Framework in this project presented an opportunity to test its effectiveness and provide insight into potential refinements.

Project Context

The Detention Pond is a 4-acre, 37 acre-foot, lined basin constructed in 1990 as a storm water treatment facility, a Best Management Practice (BMP), and a discharge point for treated ground water from ongoing remediation activities (Limnion 1991). The basin supports multiple goals from a number of diverse LLNL programs and stakeholders. These include: 1) improved water quality prior to discharge into community streams, 2) protection of special-status wildlife species, 3) flood control, 4) maintenance of the capacity to receive groundwater discharges, 5) ease of maintenance in associated areas and channels, 6) a research platform and educational resource, and 7) aesthetically pleasing conditions for the LLNL community. The laboratory consists of multiple directorates, each with varying programmatic missions and budgets. As a result, effectively achieving multiple objectives in a coordinated manner across these LLNL programs becomes quite challenging.

The basin receives runoff from both LLNL (a one mile square industrial and research oriented campus) and an approximately 900-acre agricultural and ranching watershed (Winzler & Kelly 1997). Water level management has hinged on maintaining flood control capacity. This approach resulted in periods of frequent and/or severe fluctuations in water level. In addition, the artificial construct of the pond has meant that consistent, natural influent sources are not available and water flow patterns are constrained. The Detention Pond has little vegetation, including a minimal population of submerged and emergent species. The trophic system also remains limited. Furthermore, the majority of plant and animal species are invasive, consistent with a relatively unhealthy and underdeveloped ecosystem. Prior to the current project, a systematic analysis had not been performed to understand these factors and the inability of the system to meet desired goals.

Project Objectives and Drivers

The impetus for the current project has been to revise the original management plan in an effort to more effectively, sustainably, and cost efficiently meet multiple objectives stemming from ecological, institutional/programmatic, and regulatory drivers. The first objective is to maintain the aquatic ecosystem in a healthy state. A critical facet of this objective is improving water quality. Second, the project intends to overcome the challenge of meaningfully incorporating the needs of multiple stakeholders through the use of a holistic analysis. A third objective is to identify sensitive and predictive indicators to track management goals. These are needed to replace the previous, retrospective indicators, and allow for a proactive and effective management approach.

The opportunity to simultaneously use the Detention Pond as a research platform to test the Legacy Framework in an applied setting was appealing due to the research and service orientation of LLNL. Further, protecting ecological and human health represents a key institutional mission.

Implementation of the Legacy Framework

The process of applying the Legacy Framework began in the autumn of 1998, and continues to present. Three distinct groups are involved: 1) the core team, a five member LLNL group that was assigned the task of developing a new management strategy for the Detention Pond, 2) the stakeholder group, a collection of about thirty parties with an interest in the project, approximately ten of which work actively and directly with the core team, and 3) the Yale team, a group of two graduate students and a professor at the Yale School of Forestry and Environmental Studies.

The first step toward implementing the framework involved garnering support for its use from the core team. It was determined that the project could benefit from the guidance provided by a conceptual framework due to several factors: project complexity, social drivers in the system that played a larger role than the ecological drivers, multiple stakeholders, and a need for a broad, holistic analysis. In particular, the Legacy Framework, due to its dynamic capacity to integrate social and ecological factors, offered an effective model upon which to guide the project.

Obtaining core team support for this approach was a significant challenge. Not only were the terminology and concepts foreign, but the use of a conceptual framework seemed "academic," time-consuming, and the benefits unclear. The core team, similar to many environmental professionals, possessed a strong "can do" and "let's just do it" perspective. The value in stepping back and looking at the "big picture" through an explicit process of analysis, and taking the additional effort and time to use the framework's process for identifying appropriate alternatives and indicators, required substantial justification. Through presentations and discussions highlighting weaknesses in the development of the former management plan, and consideration of the utility of the Legacy Framework toward resolving these weaknesses, buy-in was obtained from the core team. Also, the Yale team agreed to provide support and collaborative analyses in applying the framework.

The next step involved stakeholder identification and engagement. The core team outlined each stakeholder's role, perceived success criteria (or desired endpoints), potential project impact, and designated a team liaison for each. The Detention Pond Project and the Legacy Framework were then introduced to the stakeholders. Educational forums were held for prospective stakeholders in which substantive arguments were presented to garner support for using such a framework for developing the Detention Pond management plan, and an invitation was extended to participate in this interdisciplinary, collaborative, holistic project approach. All stakeholders accepted this invitation and the two groups planned the most effective and efficient manner in which to work together, including specifics regarding meeting frequency and structure, decision-making rules, and basic group norms. Trust and initial working relationships were formed during this startup phase. Although acceptance of this process occurred, in terms of a consensus agreement, varying degrees of this support existed amongst the stakeholders. The support within the stakeholder group for carrying out the framework remained tenuous throughout the process. Yet, despite this fragile state of collaboration and consensus, the overall project outcome proved positive as a result of this framework implementation.

Each stakeholder developed a "wish list" of desired endpoints for the Detention Pond. With these (in some cases conflicting) goals in hand (Roe 1996), the core team highlighted the fact that limited resources and the pond's physical specifications could not support every management goal. This understanding led to the development of a matrix in which the various goals were weighed and prioritized. Through this process, the stakeholders moved from a narrow focus on their singular, programmatic aims toward a commitment in achieving multiple stakeholders' goals and engaging in a consensus-based decision process. This successful prioritization provided evidence of the framework's value and garnered stronger stakeholder support for the process. Using these goals (desired endpoints, Table 1) as a basis, the core team developed an initial set of indicators. These indicators were divided into three categories: social, physical/biological, and chemical (Table 2).

The Yale and core teams used available data to define key issues surrounding the Detention Pond. The social and ecological processes underlying this state of ecosystem health were examined, and legacies and driving variables for the Detention Pond system were identified. The Yale team collaborated with the LLNL teams and aided in the identification of legacies and driving variables. Constraints presented by the legacies and the impacts of the various driving variables were made explicit. Final lists were compiled by the core team, and approved by stakeholder group (Table 3, 4). The LLNL and Yale teams then developed a second set of indicators based on this new understanding of the ecosystem.

At this time, four general management approaches were advocated: 1) no action, or status-quo management, 2) mitigation of problems (i.e., treatment of symptoms), 3) a limited biologically-based ecosystem, which would require heavy management for sustainability, and 4) a fully functioning, self-sustaining aquatic ecosystem. The extended stakeholder team unanimously agreed that the fourth option was most desirable, and a final set of indicators and conceptual management plan were selected on this basis. The next step involved marketing this strategy to upper management. Prior to doing so, a life cycle analysis was performed, comparing the alternative management strategies over a 25 year time period. This report concluded that the start-up costs of the full ecosystem approach were highest, but total costs were similar to other options. Yet, the estimated risks associated with these strategies were lowest for the full ecosystem approach. Given broad support from a diverse stakeholder constituency and substantive cost-benefit analysis, initial upper management support was obtained, and limited funds were released.

At present, the project has nearly completed the analysis phase and is beginning the implementation phase. A consultant team was hired to provide a more refined, independent analysis that might verify project conclusions, cost estimates, and feasibility. This consultant team--consisting of hydrologists, engineers, ecologists, and landscape architects--assessed the Detention Pond system and concurred with previous findings while further providing an enhanced understanding of the system's dynamics. The consultant team also provided a rough conceptual design to achieve project objectives (Title I). This resulted in enhanced management support for retrofitting the Detention Pond with an ecological system and funding was obtained to develop a detailed conceptual design and specifications (Title II). These were successfully completed and the Title III (construction phase) was scheduled, pending funding and regulatory approvals, for the summer of 2001.

To reduce the total costs of the project, excess onsite soil (20,000 cubic yards) was identified and sampling of this soil conducted. Concurrently, upper management pursued funds to retrofit the basin in accordance with the conceptual design, while staff pursued regulatory approvals (e.g., Department of Energy, U.S. Fish and Wildlife Service, and the San Francisco Regional Water Quality Control Board). However, the soil proved to contain extremely low levels of Polychlorinated Biphenyls (PCBs), resulting in the inability to acquire regulatory approval for its use. Currently, this project remains on hold due to a management perspective, based on this PCB event and subsequent regulatory decision, that future efforts to secure appropriate soil sources and regulatory approvals will be fraught with risks that outweigh the benefits of retrofitting the basin. This demonstrates the tenuous nature of building a capacity to overcome institutional and individual barriers to change.

As a consequence, future steps include working to reinvigorate stakeholder confidence in the ability to overcome project challenges and the conviction in the benefits in implementing the retrofit such that the challenges are deemed worthwhile. Given this outcome, next steps then include implementing the retrofit (Title 3) if funding is obtained in a resource limited organization and developing a monitoring plan based on the final set of indicators.

Results: Analysis of the Legacy Framework

Summary of Strengths

The Detention Pond case study proved to be fertile ground for testing the Legacy Framework. The nature of the pond system, i.e., the artificial construct and related physical and ecological constraints, as well as the institutional realities, provide one of the more complex, challenging, and socially driven systems within which to apply the framework. Because of these constraints, it was our contention that if the framework achieved even partial success within this context, the framework's utility, effectiveness, and flexibility had been substantiated to some degree. Overall, evidence of such an outcome was apparent throughout the project. The Legacy Framework, in this case, demonstrated the following strengths that have led to overall success: 1) an explicit and interdisciplinary methodology, 2) a stakeholder based approach, 3) integration of social and ecological factors, 4) selective use of information, and 5) selection of appropriate indicators.

First, by using an explicit analytic tool, problem investigation and the justification of decisions were more easily performed (Clark 1992). For example, substantive demonstration to upper management of the necessity and relative efficacy of adopting an ecological management approach for the Detention Pond ecosystem was easier and more effective due to the detail of the analysis and broad stakeholder support.

Underlying this outcome is the fact that the investigation process involved an interdisciplinary ecosystem assessment. We believe that this holistic analysis provided a strengthened evaluation capacity for effective comparison of alternative natural resource uses and management strategies. The framework's structure ensured that a sufficient appraisal of the situation was performed prior to selecting indicators and resource uses or management strategies. As such, the framework provided needed guidance and strengthened the analysis, while at the same time offering flexibility to encompass LLNL institutional and project needs. Although perceived as painstaking and ineffectual by some of the participants in the short-term, this approach proved invaluable for moving the Detention Pond project forward. It also was key to developing a greater openness, within the stakeholder group, to the serious assessment of alternative management approaches, including progressive (i.e., novel) ecological strategies.

Second, the Legacy Framework demanded an understanding of the connection between social and ecological factors. This holistic approach allowed the consideration of both aspects in an integrated manner, rather than separately. In this particular case, social forces have proved critical to system health, as they drive many of the important ecological variables. For example, institutional needs for maintaining flood control capacity influences the management of water level and, in turn, affects ecological components. The ability to choose an appropriate management strategy and sensitive indicators therefore hinged on understanding this interface.

Third, despite the holistic study, the use of the framework in this project also clearly demonstrated how ecosystem management approaches avoid the need to comprehensively collect data and information. For example, rather than investigate every disturbance cycle that potential affects the Detention Pond, the teams were guided to identify and further explore the key disturbances (e.g., widely fluctuating water level changes, influxes of contaminants, or limited resources driving management decisions that effect ecological outcomes). Similarly, the teams evaluated only key legacies, including regulatory mandates (e.g., Comprehensive Environmental Response, Compensation, and Liability Act) and physical constraints (e.g., grouted perimeter rip rap or ineffective outlet configuration). This holistic but focused analysis provided a way to delineate critical, and avoid unnecessary, information gathering. As a result, the framework successfully transcended the argument that the collection of exhaustive information is necessary for successful ecosystem management (Jasanoff 1996).

The selective nature of the framework (i.e., identifying key system areas for investigation) also proved consistent with its process for identification of sensitive indicators. The acquired understanding of the Detention Pond ecosystem and the framework process guided the teams away from choosing indicators solely because they mirrored the desired endpoints (the teams' first inclination prior to using the framework). Rather, the teams chose indicators based on their estimated capacity to offer early and accurate information about the ecosystem's movement towards or away from defined management objectives. Many frameworks rely on using a predetermined list of indicators associated with monitoring similar groups of systems (Pierce Colfer 1995). Instead, the Legacy Framework takes the perspective that each system, while perhaps similar to others, is unique and requires case-specific indicators for true sensitivity.

Recommended Refinements

Despite these strengths, several refinements would improve the effectiveness of the framework. To begin with, the framework lacks "user friendliness" mainly because of a description that is abstract and difficult to understand. On-the-ground application in the Detention Pond case study was therefore difficult. Throughout the project, the theoretical description required ongoing interpretation and the project participants needed continued reinforcement of basic concepts or actions related to the framework. On a more troubling note, the lack of user friendliness impeded the stakeholders' ability to maintain unwavering support for the framework. Rather, as questions or seeming insufficiencies surrounding the framework arose, the tendency surfaced to revert to former, known methods of selecting indicators and a management plan. An easily understood and applied framework description would greatly facilitate on-the-ground application and long-term support for using the process.

Second, although the framework is stakeholder-based, the conceptual model lacks defined and integrated stakeholder process descriptions. Rather, the user must adopt and implement a separate stakeholder model in conjunction with this framework, impeding a smooth, efficient, and integrated application of the framework. Efforts to embed a stakeholder process within the context of the Legacy Framework structure would alleviate this problem.

Further, this lack of an integrated stakeholder conceptual model inadvertently biases the framework towards an ecological, as opposed to social, analysis. The framework assumes a continuous, dynamic interface between social and ecological science aspects of an ecosystem. However, while the ecological tools proved to be quite useful, the social side is more weakly developed (i.e., the development of concepts, analysis techniques, and integration methods). In a heavily human-influenced system such as the Detention Pond, this stakeholder component, and more broadly, a strong social science analysis, is critical (Roe 1996). Yet, all ecosystems currently involve social dynamics, to varying degrees, given that no pristine ecological system (i.e., free of any human influence) exists. This underscores the need for a truly integrated and balanced ecological and social science approach.

A particularly important aspect of social analysis is lacking-- an assessment and accounting for institutional and individual barriers to use. Stumbling blocks, which apply to both the institution and the individual, include: 1) inertia, 2) control issues, 3) unwillingness to change, 4) risk aversion to unfamiliar or unknown approaches, and 5) an affinity toward "standard operating procedure," despite a track record which may be less than successful (Cortner et al 1998; Lee 1993). As demonstrated by the case study, the first major project setback (lack of regulatory approval due to PCBs in a potential soil source) reinforced individual risk aversion to a new approach (ecosystem management). Unfortunately, this resulted in an enhanced affinity for the standard operating procedure (status quo Detention Pond management and placing the Retrofit Project on hold). The framework would benefit from a method of effectively addressing and overcoming these issues.

Finally, it is not entirely clear that the process of the framework, consisting of progressive steps, one informing the next, leads to the selection of more sensitive indicators and appropriate management alternatives. This ambiguity is not necessarily a product of an ineffectual process but perhaps points to a limited capacity to measure effectiveness over a short time frame (Stevenson and Vogt 2002). However, this uncertainty ultimately weakens support for undertaking and supporting its application. This case study provides initial support for improved outcomes as a result of using the framework. Further demonstration that the framework effectively leads to better outcomes is necessary.

Evaluation of stakeholder process

The lack of a specifically defined stakeholder model necessitates developing an ad hoc stakeholder model or using a compatible pre-existing model if the user is committed to the framework's assumptions. The Detention Pond project used an ad hoc approach, tailoring a stakeholder process to the situation. Numerous strengths of even this loosely defined and untested methodology surfaced, reinforcing the fact that more effective outcomes are achieved by involving stakeholders (Pierce Colfer 1995). However, weaknesses also became apparent. These deficiencies emphasize the need for an integrated (and proven effective) stakeholder conceptual model within the analytical framework itself.

Strengths of this stakeholder approach included 1) enhanced communication, collaboration, and coordination between programs and individuals, 2) an ability to refine, prioritize, and agree upon a set of management goals, 3) consensus on an appropriate management strategy, 4) a shared vision for the pond's use and state of health despite varying stakeholder management needs, 5) much improved upper management support, and 6) enhanced visibility and support for the Detention Pond project. Many of these outcomes were previously thought to be unachievable, and had been, in actuality, difficult to reach as a result of ineffectual or absent stakeholder relations.

As typical for many institutions, stakeholder relations were initially characterized by mistrust as well as territoriality and control issues that combine to produce an incentive to minimize communication and collaboration (Peelle 1995). Engaging the key group of stakeholders and their participation within the context of the framework and the project's goals changed the nature of these interactions, incrementally and in an ongoing fashion. Each step that resulted in a positive outcome (i.e., in terms of each stakeholders' success criteria) worked to reduce stakeholder wariness, distrust, and tenuous support for using the framework and collaborating with other stakeholders. This enhanced trust resulted from carrying out the process of stakeholder participation and ecosystem management framework implementation (Eschenbach and Eschenbach 1996).

Open communication was fundamental to this process. For example, an ongoing commitment by the core team to communicate even the smallest of relevant issues surrounding the project to stakeholders has resulted in an increased trust for and confidence in the core team. It is also beginning to result in improved two-way communications. As the stakeholders experienced continued, unwavering commitment on the part of the core team to preserving the priority of previously agreed-upon management goals and protecting stakeholder interests, tensions amongst stakeholders incrementally decreased.

The use of a stakeholder process to drive the framework undoubtedly slowed the project. This deliberate pace produced frustration or a sense that the framework was not useful for some stakeholders at various points in the project. The stakeholders desired a collaborative analytical process that was streamlined and efficient. As a result, more energy was spent maintaining the "buy in" of stakeholders throughout the process. Collaboration frequently consisted of the core team developing "first cut" analyses (e.g., a list of potential legacies) that the stakeholders could then review, refine, and agree upon. In some cases, this may represent a positive outcome as small groups more efficiently make decisions. Yet, there is a potential that some interdisciplinary expertise is lost, due to this streamlined process, as well as a weakening of stakeholder "ownership" for the process. This ownership is critical to overall project success (Eschenbach and Eschenbach 1996).

Experience in implementing a stakeholder approach within the framework's context has resulted in positive outcomes thus far. Little doubt exists that enhanced upper management support would not have resulted if improved communication and collaboration between multiple stakeholders had not occurred. Although stakeholder relations and interactions still require some work and improvement, this project clearly demonstrated the positive effects of using such a model. Even with much work to still accomplish, tangible inroads have been made toward stakeholder ownership of the basin and its appropriate management.

Other recommendations and areas of further study

Several additional recommendations and areas of further study are appropriate to more fully develop ideas hatched in the present case study. To begin with, additional demonstration projects are needed to establish that the use of conceptual frameworks, such as the Legacy Framework, lead to improved outcomes. The evaluation of these projects will also help further develop and refine these frameworks (Cortner et al 1998; Cortner et al 1996). Second, to ensure the sustained use and usefulness of the Legacy Framework, a clearer and more comprehensive description of the process of applying the framework is necessary. Third, the Legacy Framework should be revised based on the results of comparing the framework to the below evaluative criteria. Fourth, the institutional barriers such as those encountered at LLNL that impede the use of integrated problem solving approaches should be examined, and techniques developed to overcome them and shift toward the use of tools like the Legacy Framework. Finally, institutions and organizations need to provide more opportunities for education in interdisciplinary techniques and approaches to environmental problem solving (Stevenson and Vogt 2002).

Evaluative criteria for frameworks

Based on the preceding strengths and areas of refinement found in the Legacy Framework as applied to the Detention Pond, we would like to introduce preliminary guidelines for evaluating this and other frameworks. These guidelines may be used to assist in the refinement and development of conceptual frameworks. These criteria, for clarity, are divided into two broad categories: process-oriented criteria and outcome-oriented criteria.

Process orientation refers to the functional operation of the framework itself, as distinguished from the outcomes generated by the framework. We propose five key criteria in this category (Table 5). First, due to the complexity of ecosystems, frameworks must be interdisciplinary, i.e. they should integrate expertise gleaned from a variety of disciplines (Grant and Thompson 1997). In particular, as is seen the current study, social and natural aspects of the ecosystem must be adequately identified and integrated (Roe 1996). Second, frameworks should be problem focused, meaning that they seek to identify critical management objectives and then work towards these goals. This focus will help ensure that the information and understanding generated by the framework is relevant, and that solutions are not pre-determined (Miller 1994). Third, a framework should be clearly structured and described (i.e., user friendly). Options for acheiving this include step-by-step instructions, and organizing the framework as a set of resolvable questions, yet many other forms may be effective (Poiani et al 1998; Rowley et al 1997). As was discussed, the Legacy Framework suffered an initial barrier to acceptance on the part of the core team and the stakeholder group which would have been partially alleviated by a clear and simple description of the framework. Fourth, the structure of a framework should be dynamic, or accepting of change (Pickett et al 1997). The Legacy Framework will likely be modified as understanding surrounding its strengths and weaknesses further develops. It may also take varying forms depending upon the context of its application. This dynamism will help accommodate the fact that no framework is perfectly designed at the outset, nor is it perfectly suited to every situation. Finally, a framework should have an effective approach toward the process that drives group analysis and decision making (Stevenson 2001). Again, this can take many forms, however, because most ecosystem management issues involve multiple interests, a stakeholder driven format is paramount. Such an approach will help build consensus and ensure ongoing and long-term success (Rothman and Robinson 1997).

Outcome oriented features are those that address the substantive conclusions generated by the framework. Again, we propose five criteria in this category (Table 6). First, the framework should provide an accurate definition of the management problem. This avoids the common "Type III" error, in which the wrong question is posed, generating conclusions that do not solve the problem (Dery 1984). The definition of the management problem will necessarily evolve during the use of the framework, as understanding surrounding the ecosystem is developed (Miller 1996). Second, the framework should properly identify the key factors in a system. As one cannot possibly attend to every aspect of an ecosystem, this necessitates that users become selective in information use (Lee 1993), although attention should be given to both social and ecological factors, as discussed earlier. To aid in this, the proper scale or scales of analysis for these factors, and the interactions between them, must be defined (Fox 1994). Third, the framework should integrate these key factors into a holistic understanding of the ecosystem (Wyant et al 1995). This is the endpoint of assessment upon which management strategies may be designed. Fourth, the framework should develop specific management strategies that are feasible, appropriate and effective. Finally, the framework should provide information on changes in social or environmental factors, through the development and monitoring of sensitive indicators, and integrate this information into adaptive management strategies. This will ensure that changing social and ecological conditions do not compromise the ecosystem's continuing health, and will allow understanding of the ecosystem to develop over time (Poiani et al 1998).

Summary and Lessons Learned

The use of the Legacy Ecosystem Management Framework for the Detention Pond Project proved a valuable case study. The translation of this conceptual framework--from theory to application--provided an opportunity to identify areas of the framework with which to refine and strengthen. It also allowed for an opportunity to develop recommendations for refining ecosystem management frameworks in general. The lessons learned from this case study may prove useful for enhancing the user-friendliness and relevance to on-the-ground application of ecosystem management frameworks. Additionally, the case study provided anecdotal evidence for the value-added nature of using a stakeholder process. Yet, in doing so, it demonstrated the criticality of using a systematic stakeholder process, rather than that ad hoc. This systematic and integrated approach is required to overcome the aforementioned institutional and individual barriers to implementing an ecosystem management strategy. As demonstrated in this case study, these barriers proved to be the true "show stoppers". Their impact continues to jeopardize the successful outcome of a project that had, over much time and effort, garnered full support by a diverse set of programs and their staff. As a consequence, in addition to the recommendations previously mentioned in this article, a few additional comments may be useful to the reader. These lessons learned include:

- A systematic and clearly identified stakeholder process must be fully integrated into any conceptual ecosystem management framework;
- This stakeholder process must include methodologies for addressing and overcoming institutional and individual barriers that may negate any progress made in holistically evaluating and developing a management strategy for a system of interest;
- Arbitrary decisions or events may act to severely impact the uncertainty or risk with which stakeholders associate with the project.
- Ecosystem management is both the art and science of effectively integrating the social and natural science underpinnings of a system. An emphasis on the science with a lesser focus on the art of a holistic approach may ultimately jeopardize the project success and outcome.

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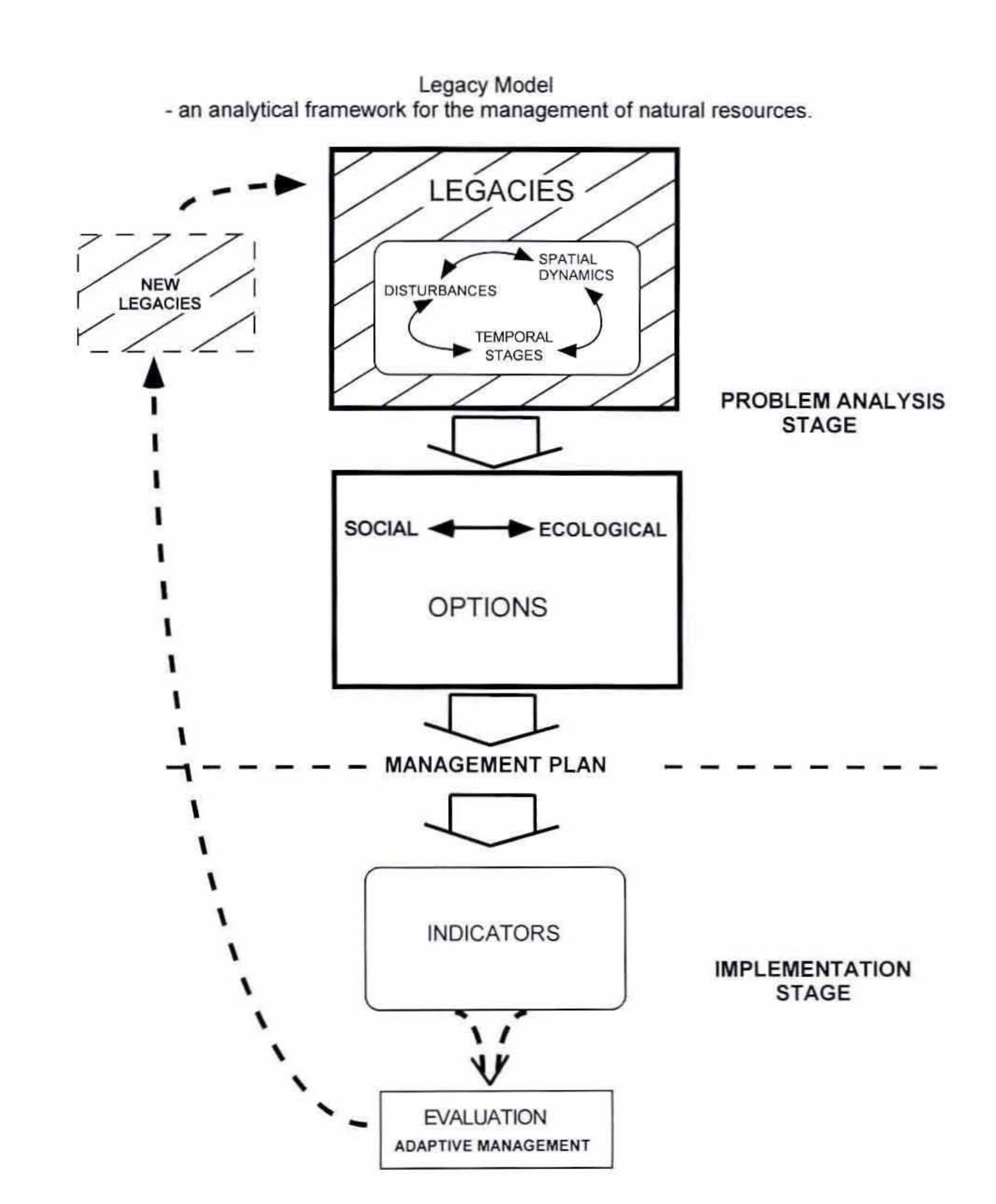

Figure 1. The Legacy Ecosystem Management Conceptual Model.

PRIORITY LEVEL	MANAGEMENT GOAL
1st	Manage the system for special-status wildlife protection and sensitive habitats according to State and Federal laws, policies, and guidelines.
1st	Comply with regulatory-mandated discharge limits for water quality parameters.
2nd	Maintain the DRB structure and operations to serve as an effective ERD discharge point.
3rd	Operate in a manner that provides adequate flood control for the LLNL facilities and grounds.
4th	Engage and facilitate collaboration between key stakeholders.
5th	Manage in accordance with acceptable operational procedures.
6th	Use cost-effective, operationally simple and safe methods of facilitating, encouraging and maintaining the establishment of a naturally functioning aquatic ecosystem.
6th	Maintain appropriate water quantity and quality to protect the integrity of the aquatic ecosystem (e.g. dissolved oxygen).
7th	Maintain aesthetically pleasing conditions in the DRB and within its inflow and outflow drainage areas.
7th	Minimize DRB water flow in downstream channels to facilitate ease of maintenance and to control vegetation growth.
8th	Use cost-effective, operationally simple and safe methods of providing an acceptable level of storm water quantity and quality.
9th	Operate to provide ground water finishing treatment and a storm water BMP.
9th	Mitigate potential threats to the integrity of the aquatic ecosystem originating from LLNL community and the surrounding drainage area.
10th	Facilitate and encourage the establishment of a naturally functioning aquatic ecosystem with endemic species diversity.
10th	Discourage the inhabitation and use of the DRB by non-native and nuisance species.
11th	Facilitate the use of the aquatic ecosystem as an experimental platform and educational resource.
12th	Facilitate and promote natural storm water pollutant removal mechanisms.

Table 1. Prioritized and refined list of management objectives for the Detention Pond System after use of the Legacy Ecosystem Management Framework.

PHYSICAL INDICATORS	SOCIAL INDICATORS	CHEMICAL INDICATORS
Flow rates in/out	Stakeholder surveys	TRI use report from gardeners
Water Fluctuation Patterns • Frequency of water fluctuation • Severity of water fluctuation\\ • Timing of water fluctuation	Surveys of Users • number of users, on quarterly basis • trend of increasing or decreasing number of users • types of users	Metals • concentration of specific metal • location of specific metal (sedimentation basin, DRB) • compartment within which specific metal is found (soil, benthic, water column)
Maintenance and observation of physical structures (trend)		
Liner integrity tubes water collection		
Turbidity		Conductivity
Depth	Trash can fill rate	TDS/TSS
Upstream tributaries: physical component • negative or positive trends in water quality (sediments, turbidity, TDS/TSS) • losses or gains in abiotic components (habitat, substrate, energy flows, etc.)	Track activity of key stakeholders • types of activity • key stakeholder planned activity schedules • key stakeholder uninformed activities • changes in programmatic missions of key stakeholders	Nutrients • concentration of nutrients (nitrate, phosphate, ammonia) • trend of increasing or decreasing nutrients (nitrate, phosphate, ammonia)
Dissolved Oxygen		Concentration of Regulated Chemicals • trend of increasing or decreasing quantity of specific chemical • trend of increasing or decreasing sources of specific chemical • changes in frequency of acute • occurrences of specific chemical
Temperature		
How does it look (i.e. color) and smell?		
Inability to maintain adequate water level (too low, floods)		
BIOLOGICAL INDICATORS		
Track nuisance species • trend of increasing or decreasing types of nuisance plant species • trend of increasing or decreasing physical coverage of nuisance plant species • polulation trends of each nuisance plant species	Microbiologic indicator species • population trends of specific species • changes in species composition of microbiologic community	Vegetation complexity • establishment trends of self-sustaining native species • trend of increasing or decreasing stratification of vegetative community • trend of more complex mosaic of vegetative community • successional change in composition
Riparian zone evaluation • trend of increasing or decreasing width • trend of increasing or decreasing stratification • trend of increasing or decreasing complexity of species' mosaic	Downstream changes • losses of previously self-sustaining species (losses above a baseline norm)	Diversity/richness (animal and abiotic) • species richness trends (assumes high number of species = stability/integrity) • guild dynamics • abiotic components • self-sustaining, established populations of keystone species (key functional roles)
Upstream and Downstream tributaries • trend of increasing or decreasing riparian zone (width, stratification) • changes in number of species • changes in mosaic of species (pioneer/opportunistic vs. later successional species)		

Table 2. Initial set of indicators developed just prior to using Legacy Ecosystem Management Framework.

<table>
<tr><th>NATURAL COMPONENTS</th><th>DESIGN COMPONENTS</th></tr>
<tr><td rowspan="7">Non-point source pollution
• storm water runoff (onsite and offsite)
✓ 10-15,000 population within 1 sq. mile
✓ automobiles, machinery, and equipment
✓ construction activities
✓ materials stored outside
✓ runoff from off-site
✓ pesticide and fertilizer applications
✓ mulch application</td><td>Liner</td></tr>
<tr><td>Sand basin bottom</td></tr>
<tr><td>Physical limitations on water control (basin bottom lower than dam outlet)</td></tr>
<tr><td>Perimeter rock slope protection (rip rap)
• limits perimeter vegetation
• inadequate creation of habitat for wildlife
• inadequate retention time of water</td></tr>
<tr><td>Shelf depth</td></tr>
<tr><td>Inadequate capacity (depth/width) of sediment traps</td></tr>
<tr><td>Lack of bottom structure</td></tr>
<tr><td>Point Source Nutrient Loading
• ERD treated groundwater</td><td>Depth of non-shelf area (too deep for vegetation in central areas)</td></tr>
<tr><th colspan="2">REGULATIONS & PROGRAMMATIC MISSIONS</th></tr>
<tr><td>Endangered Species Act
• management for California red-legged frog
• potential management for the Tiger salamander</td><td rowspan="5">Institutional Mandates
• flood control/prevention
✓ alters water levels
✓ herbicide use
✓ harvesting of vegetation
✓ drying out of sedimentation basins
• maintain DRB as a treatment system (DOE mandate)
✓ no aesthetic enhancements
• weed control & landscape missions
✓ herbicide use (potential source of toxic leachate)
✓ mulching (potential source of toxic leachate)
✓ ease of maintenance
✓ harvesting of vegetation
✓ construction activities
✓ sediment loads
✓ fertilizer (nutrients)
• human health/comfort/safety
• flood prevention
• vector prevention: mosquitoes
• prevention of noxious odors
• prevention of toxic conditions</td></tr>
<tr><td>Limited Resource Allocation</td></tr>
<tr><td>Fish and Game Code
• maintenance of habitat
• specifies allowed plant species
• water quality mandates
• endangered species mandates</td></tr>
<tr><td>Protection of public relations
• prevent noxious odors
• prevent overt harm to wildlife
• prevent algal blooms
• prevent releases that have poor or harmful water quality</td></tr>
<tr><td rowspan="2">CERCLA/ERD Operations
• water quality mandates
• treated groundwater discharge
• source of nutrient loads
• quantity of inflow
• finite longevity of water source</td></tr>
<tr><td>Porter-Cologne Act:
• minimal frequency of discharge
• water quality mandates
• beneficial uses (i.e. habitat)</td></tr>
</table>

Table 3. List of legacies that continue to modify the Detention Pond system.

Spatial: identification of driving variables that reflect historical land-uses that currently modify the resilience of the landscape mosaics. Scale should be higher than management unit, if appropriate.	
Treated groundwater discharge collection (influences water fluctuations, nutrient loads)*	Storm water flows/runoff* Urban/industrial activities (chemical contaminant releases) Landscaping activities (chemical contaminant releases, nutrient loads) Grazing/ranchlands activities offsite (nutrient loads, chemical contaminant releases)
Diversion/restructuring of hydrology (construction of DRB, storm channels, Arroyos)	
Temporal: may reflect the successional stage of the management unit or describe temporal characteristics of driving variables.	
Timing of aerator use*	Frequency and timing of temperature fluctuations*
Seasonal fluctuations in stream flow	Frequency and timing of herbicide influx
Frequency and timing of water level fluctuations	
Disturbances: driving variables that determine the range and extremes of variability within any ecosystem.	
Influxes of contaminants* Herbicide Applications	Water level fluctuations*
	Temperature Fluctuations

* Identifies those variables considered most influential in DRB system.

Table 4. List of driving variables for the Detention Pond system.

MANAGEMENT GOAL	PROPOSED INDICATOR
Engage and facilitate collaboration between key stakeholders.	1. Track quality of communication between stakeholders (asking a few key questions to ourselves on regular basis)
Maintain appropriate water quantity and quality to protect the integrity of the aquatic ecosystem (e.g. dissolved oxygen). Facilitate and encourage the establishment of a naturally functioning aquatic ecosystem with endemic species diversity. Discourage the inhabitation and use of the DRB by non-native and nuisance species.	1. Track frequency/severity/timing of water level changes 2. Track complexity (diversity) of system (components, processes) 3. Track species filling key roles in each trophic level (keep in management plan, in adaptive management section. If learn of keystone species for our system, may want to use this one in future) 4. Track non-native versus native species 5. Dissolved oxygen 6. Track temperature (track, but not as an indicator) 7. “Canary” toxicity test (if this exists, good one) 8. Benthic microorganisms (use these if when investigate #2, find need to track at microbiological level) 9. Aquatic microorganisms (use these if when investigate #2, find need to track at microbiological level)
Maintain aesthetically pleasing conditions in the DRB and within its inflow and outflow drainage areas.	1. Phosphates and nitrates (real time tracking) 2. Dissolved oxygen 3. Survey Results
Mitigate potential threats to the integrity of the aquatic ecosystem originating from LLNL community and the surrounding drainage area.	1. Track gardener’s herbicide and/or vegetation control schedule 2. Inspect upstream BMPs and activities

Table 5. List of indicators developed for the Detention Pond System after using the Legacy Framework.

Process oriented features
• Interdisciplinary approach
• Problem orientation
• Clear operational structure
• Dynamic structure
• Effective approach to group process
Output oriented features
• Accurate problem definition
• Identification of key factors
• Integration into holistic understanding of system
• Development of appropriate management strategies
• Use of sensitive indicators and adaptive management

Table 6. Process and output based characteristics for conceptual frameworks.

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The Legacy Ecosystem Management Framework: From Theory to Application in the Detention Pond Case Study

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EXTENDED ABSTRACT

Many conceptual frameworks for ecosystem management have surfaced over recent years. These frameworks attempt to offer approaches and methodologies to support managers in their decision processes. In addition, stakeholder-driven approaches for resolving management issues have been rising in popularity. However, to date, few studies have been performed showing that conceptual frameworks or a stakeholder-based approach actually result in improved outcomes. This lack of testing and case study analysis may be impeding the more widespread adoption of conceptual frameworks for use in ecosystem management. Also, many of these theoretical frameworks lack a "user friendly" orientation, in which application of the theory toward on-the-ground management is straightforward and clearly understood. As a result, ad hoc management approaches are often used rather than implementing a systematic and holistic framework. This paper intends to address these problems by offering a case study analysis in the context of the Detention Pond at Lawrence Livermore National Laboratory.

The Detention Pond is a 4-acre, 37 acre-foot, lined basin constructed in 1990 as a storm water treatment facility and a Best Management Practice. It serves multiple stakeholder objectives and programmatic goals. These include: 1) improved water quality prior to discharge into community streams, 2) protection of special-status wildlife species, 3) flood control, 4) maintenance of the capacity to receive treated groundwater discharges, 5) ease of maintenance in associated areas and channels, 6) a research platform and educational resource, and 7) aesthetically pleasing conditions for the LLNL community. The basin receives runoff from both LLNL (a one mile square industrial and research oriented campus) and an approximately 900-acre agricultural and ranching watershed. This paper examines the process and outcome involved in the development of a new management plan for the Detention Pond. The plan was created using a new ecosystem management tool, the Legacy Framework. This stakeholder-driven conceptual framework provides an interdisciplinary methodology for determining ecosystem health, appropriate management strategies, and sensitive indicators.

The framework uses a process involving two dynamically and iteratively linked phases: analysis and implementation. In the analysis phase, a holistic and mechanistic understanding of the ecosystem is developed. The framework helps delineate key areas of the system in which to collect information. Each area informs progressive analytical steps. These steps intend to narrow information needs yet efficiently and effectively increase the understanding of the ecosystem. Alternative uses or management strategies are developed, evaluated, and an appropriate one is chosen.

During the implementation phase, the selected management strategy is carried out. Both initial and ongoing management occurs, and monitoring data are collected. Using the new information derived from the indicators, the analysis phase is revisited at regular intervals to evaluate performance and refine/redefine management goals and practices. This new analysis will guide adaptive management strategies. The implementation phase therefore feeds back into new iterations of the analysis phase, with adaptive management providing the dynamic link between the two phases of the framework. In this way, uncertainties identified throughout the

application of this framework are addressed as enhanced understanding and new information becomes available for use.

This paper describes and evaluates the use of this conceptual ecosystem management framework in the context of the Detention Pond project. Strengths of the framework are identified as well as areas requiring further refinement. In this case study, the Legacy Framework demonstrated the following strengths that led to overall success: 1) an explicit and interdisciplinary methodology, 2) a stakeholder based approach, 3) integration of social and ecological factors, 4) selective use of information, and 5) selection of appropriate indicators. Areas of recommended framework refinements included 1) improving its "user-friendliness," 2) developing a more defined and integrated stakeholder process, 3) further strengthening the integration of social and ecological analyses, 4) incorporating methods to effectively address institutional and individual barriers to framework use, and 5) enhanced methodology for evaluating the framework effectiveness. Also proposed within this paper are process-oriented and outcome-oriented evaluative criteria for this and other ecosystem management frameworks. The lessons learned from this case study may prove useful for enhancing the user-friendliness and relevance to on-the-ground application of ecosystem management frameworks.