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Synthesis of Nutrients and Springs: Knowns, Unknowns, Research Priorities and Management Implications

Mark T. Brown
Center for Environmental Policy and
Department of Environmental Engineering Sciences
University of Florida

Summary

This summary of the state of the knowledge related to nutrient effects on spring ecosystems and biota draws from the proceeding seven chapters of this report. It represents a synthesis of the most important findings; greater details can be found within each of the chapters. This synthesis chapter is organized into three parts:

1) a summary of the "knowns" regarding nutrient effects on springs and spring biota,
2) the unknowns and suggestions for future research, and
3) suggestions for a research and adaptive management program for spring ecosystems in Florida.

Florida springs are undergoing change. It is clear that nutrient loads within springsheds, particularly nitrate-N, from anthropogenic sources are increasing. These loads have apparently increased the quantities of nitrogen in shallow and deep ground waters. Nitrogen, but not phosphorus, concentrations in the discharges of many springs have increased in the past several decades. There are numerous other biotic and abiotic factors that have also changed in some, but not all springs, such as increased recreational use, decreased discharges, decreased O_2 concentrations in discharges, increased aquatic weed control, invasive species, and increased salinities. By themselves or in combination, these factors may explain the changes Florida's springs have experienced in the last several decades.

There is a general consensus in the management community that nitrate-N is an important cause of change in spring ecosystems and biota. In summary, control of nitrate-N appears warranted, indeed critical, since nitrate-N has been linked to many detrimental impacts in both ecological and human systems (obviously this is true of all watersheds, not just the karst regions of Florida). The fact that nitrate-N is likely to be nearly conservative in the groundwater, and since much of the increased loads are believed to be of human origin, suggests that efforts to control nitrate loads should be focused at the springshed scale and focus on its control prior to delivery to the soil and ultimately to the aquifer.

Few studies have been able to provide a threshold value for nitrate-N at which impacts begin. The literature suggests that in addition to nitrate-N, discharge and dissolved oxygen, which show short-term and perhaps long-term correlation with nitrogen should receive more attention in the

future as potential causes of ecosystem change in springs. Other stressors in combination or separately may be important causes of change in spring ecosystems as well.

After reviewing the literature, an adaptive management and research program that faces these uncertainties directly and uses them to learn and change is proposed. This proposal combines management interventions with targeted monitoring to make them more useful as scientific experiments that form the basis for learning and adaptive change. We call for a grand experiment through the creation of Adaptive Springshed Action Programs (ASAPs) as a way of developing a statewide response to the declines in ecosystem health observed of many springs. The proposed ASAPs will develop an environment within which meaningful research, education, social learning, and management can occur for the betterment of Florida's spring ecosystems.

INTRODUCTION

This review of the literature was conducted in response to a request by the Florida Springs Initiative of the Florida Department of Environmental Protection (DEP) for a summary and interpretation of the available information on the effects of nutrients on spring organisms and systems. DEP's mandate was to prepare a review of what is known about the interactions between nutrients and springs, what information gaps exist that inject substantial uncertainty into management and restoration of springs, and what policy and research could be used to address these gaps. This summary of knowledge related to nutrient effects on spring ecosystems and biota represents a synthesis of the most important findings from the literature related to Florida springs along with important findings studies in other aquatic systems.

To address the complexity of spring ecosystems, we developed a multi-chapter review conducted by several units at the University of Florida (UF) and Wetland Solutions, Inc.. The UF Water Institute provided project management, and other groups were responsible for different chapters in the literature review:

1. Springs as Ecosystems – Wetland Solutions Incorporated
2. Springshed Nutrient Loading, Transport and Transformations – UF –School of Forest Resources and Conservation
3. Biogeochemical Processes and Implications for Nutrient Cycling – UF –Department of Soil and Water Science
4. Nutrient Effects on Spring Flora and Fauna – UF Department of Fisheries and Aquatic Sciences
5. Invasive Aquatic Plants and Aquatic Plant Control in Florida Springs – UF –School of Forest Resources and Conservation
6. Effects of Nutrients on Spring Ecosystems – Wetland Solutions Incorporated
7. Managing Nutrient Inputs to Florida Springs: The Legal Framework – UF –Center for Governmental Responsibility
8. Synthesis of Nutrients and Springs – UF –Center for Environmental Policy

This chapter, organized into three parts, summarizes the details from other chapters in an attempt to synthesize knowledge regarding effects of nutrients; recommends additional research for discussion with a broad group of stakeholders; and outlines an approach to future policy and management.

PART 1 - NUTRIENTS and SPRINGS: State of the knowledge

Fate, Transport, and Transformation: *What we know*

There is growing evidence that nitrate concentrations are increasing in the water discharging from springs (Chapter 2). Indeed, increasing nitrate concentrations in freshwater is not just a Florida or karst problem, but rather a global problem. Human populations have altered the global nitrogen cycle and other biogeochemical cycles through land use changes, fertilizer use, fossil fuel combustion and other pathways. With population and land use change comes nutrient enrichment. Florida's karst region has experienced unprecedented population growth and changes in land use over the past several decades, with a consequent transfer of nutrients to the relatively unprotected groundwater.

Among the nutrients of concern, nitrogen, particularly nitrate, appears to be most problematic in Florida's karst region. There are four primary reasons for greater concern about nitrate-N than phosphorus. First, increases in concentrations of nitrate-N are nearly omnipresent in areas where anthropogenic loading to the land's surface has occurred. Second, once in the ground water, nitrate-N appears to be transported as a conservative solute, with denitrification apparently being negligible (Chapter 2). Third, although Florida's geology is naturally rich in phosphorus, there does not appear to be a trend of increasing phosphorus concentrations in spring discharges (Chapter 2, 4, and 6). Second, because springs are naturally rich in phosphorus, the majority of Florida springs may be historically nitrogen limited (Chapter 3, 6).

Given the importance of nitrate-N and its role as a driver of primary production in many aquatic systems, for better or for worse, the loading, fate, transport, and transformation of N appear to be the aspect of springs that has received the most study. Some general principles and caveats have emerged from this work (Chapter 2):

- Emphasis on nitrate-N loading has been prioritized because of strong evidence for anthropogenic enrichment on groundwater N in the karst environment of North Florida while contemporaneous evidence for broad-scale enrichment of P has not been accumulated.
- Because there is no geologic store of N, all of the nitrogen emerging in spring vents was deposited on the land surface.
- Where data exists, evidence suggests that overall, the increases in loading have resulted in 10 to 350 fold increases in concentrations of nitrate-N in spring discharges over the past 50 years. As a consequence of these increases in groundwater nitrate-N concentrations, downstream nitrate-N loads are increasingly rapidly in many watersheds. For example, a two to three-fold increase in nitrate export to the Gulf by the Suwannee River has been documented over the past 5 years.
- Delineation of springsheds has direct bearing on loading calculations but delineation is not an exact science.
- The underground reservoir from which spring flow derives may be extremely large, and hence nominal residence times can be long and extremely variable between springs.
- Some aging measurements of water emerging from springs suggest, on average, it has spent between 10 and 30 years in the subsurface, but that a significant portion of water (30-70%) has residence times less than 4 years. Relative age contributions can vary from spring to spring.
- Biological fixation of nitrogen has not been taken into account in most loading studies; an omission that may account for as much as 30 to 35% of the contemporary nitrogen budget.
- Based on differences between N loads applied to the land within springsheds and N in spring discharges, attenuation withing springsheds appears to be significant

(~90%), but this apparent attenuation may be the result of lag times between application and emergence.

- Estimates of nitrate and total nitrogen loading in various Florida springsheds suggest that over half the apparent loads to the land surface result from fertilizer application on either urban or agricultural lands. Additional loads result from livestock manure and wastewater septic systems. Atmospheric N deposition is generally less than 10% in most studies, but it can account for as much as 26% in some rural springsheds.
- Isotopic characteristics of nitrate-N emerging from springs appears to provide evidence of mixed sources (i.e., mineral fertilizers, organic wastes), but use of isotopes for management purposes requires flowpath tracking and consideration of transformations along the flow path.

Biogeochemical transformations of nutrients in spring systems (Chapter 3) have been little studied. What we know of elemental cycling and nutrient transformations is gleaned from the general literature on lotic environments:

- In general, transformations are most prominent in biofilms, algal mats, and the hyporheic sediments resulting from a variety of processes including: organic matter decomposition, nitrogen fixation, nitrification /denitrification, iron reduction, and sulfate reduction, among others. While these processes have been studied in other lotic environments, there is very little information regarding these processes in spring systems.
- In their historical natural state, most Florida springs contain high levels of bioavailable phosphorus (P) (Soluble Reactive Phosphorus [SRP] levels of between 30-60 ppb),
- There are suggestions that once established, algal mats may play a significant role in nutrient transformations and eventual nutrient storage, making reversal of current conditions where algae dominate spring primary producers problematic.

In summary, control of nitrate-N appears warranted, indeed critical, since nitrate-N has been linked to many detrimental impacts in both ecological and human systems (obviously this is true of all watersheds, not just the karst regions of Florida). The fact that nitrate-N is likely to be nearly conservative in the groundwater, and since much of the increased loads are believed to be of human origin, suggests that efforts to control nitrate loads should be focused at the springshed scale and focus on its control prior to delivery to the soil and ultimately to the aquifer. Given that springsheds are heterogeneous surfaces of topography, soils, and vegetation, with subsurface confining layers that are not ubiquitous, detailed land use planning should figure prominently in controlling loads. Best Management Practices (BMPs) in confined regions are of value (although, there is some disagreement on the effectiveness of BMPs), but in unconfined regions where groundwater recharges rapidly and there is little opportunity to store and treat stormwater on the surface, BMPs alone may be insufficient to prevent groundwater nitrate enrichment.

Effects of Nutrients on Spring Organisms and Systems: *What we know*

There is no question that Florida's spring ecosystems are undergoing change. An apparent increase in the dominance of filamentous algae in many springs, losses of desirable submerged aquatic vegetation (SAV, e.g., native vascular species such as *Vallisneria americana* or

Sagittaria kurziana), increases in invasive vegetation forms, and anecdotal evidence of the disappearance of grazers and higher order animals all point to significant structural and functional changes in spring ecosystems. It is a widely held belief that these observed changes are the result of anthropogenic enrichment of nutrient levels in groundwater discharges and the consequent eutrophication of the spring ecosystem. Certainly, the correlative evidence (in the time domain) points in that direction, yet the apparent correlation between increased nitrate loading and increases in filamentous algae in spring ecosystems has only anecdotally provided evidence for a causative relationship between these phenomena (Chapters 4 and 6). Further, the belief that increased algal biomass has led to the displacement of native macrophytes appears to be based largely on extrapolation from laboratory studies or qualitative observations (Chapter 4). Overall, this review of the literature suggests, that there is little direct evidence linking increases in filamentous algae observed in many springs with increased nitrate delivery to spring systems (Chapter 4). This is not to say that causality does not exist, only that direct quantifiable evidence has yet to be demonstrated.

These changes in springs parallel a eutrophication progression scheme proposed for shallow and relatively open coastal systems (see Duarte 1995). This scheme suggests that increased delivery of dissolved nutrients to aquatic systems will favor production of fast-growing algae that extract their nutrients primarily from the water column. These algae may ultimately out-compete and displace slower growing vascular plants that rely primarily on nutrients in sediment and require more light. In the scheme, algal growth can create feedback loops that exacerbate the shift to algal dominance and decouple the system from nutrient concentrations in the water column. For example, increased organic matter or eutrophication can lead to decreased oxygen levels that can stress vascular plants and displace or kill grazers that might control algae. Although the changes in Florida springs appear consistent with this scheme, other information from spring systems raises questions, including: 1) the possibility that flux of nutrients in springs is a more potent driver of primary productivity than water-column concentrations, 2) the potential that flux obviates nutrient limitation for most flora even at historical and low concentrations, and 3) the possibility that the observed parallels to the eutrophication scheme initially arose from changes to limiting factors other than nutrients, such as light (Odum *et al*. 1953; Odum 1957) or 4) the possibility that top-down effects such as loss of higher trophic level organisms have had a cascading effect on vegetative community structure.

Effects on Flora and Fauna

The general pattern that emerges from the review of the literature related to primary producers in Florida springs (Chapter 4) can be summarized as follows:

- Few studies of nutrient limitation for algae exist, and the available results indicate that, if limitation exists, both nitrogen and phosphorus limitation can occur.
- There are no experimental studies that unequivocally demonstrate any submersed vascular plant in a Florida, spring-fed system is consistently limited by either nitrogen or phosphorus.
- There are a number of empirical investigations that suggest the potential for a negative effect of epiphytes or macroalgae on vascular plants in Florida's spring systems, although none clearly demonstrated it or clarified causal mechanisms.

- Algal mat assemblages may be limited by the availability of dissolved inorganic carbon, in Florida's springs.
- Algal mat thickness in Florida's springs was weakly and positively correlated with nitrogen and phosphorus concentrations, but cover and biomass were not significantly correlated with nutrient concentrations.
- Empirical data suggest that there is no statistically significant link between surface water nutrients and production of macrophytes at this time; however, light availability, especially as mediated by riparian shading, has been implicated as a limiting factor for SAV growing in Florida's spring-fed streams.
- The literature suggests that nitrate concentrations currently observed in the water column of many springs should not limit the growth rates of algae comprising benthic mats. However, this does not preclude the possibility of nitrogen limitation in large, well-developed algal mats, where access to nutrients may be impacted by diffusion rates and nutrient gradients within the mat.
- The possibility that phosphorus may be a limiting factor for algal growth in some springs has been highlighted by recent observations of high N/P ratios in plant and algal samples from several Florida springs.
- Specific conductance (salinity) has been shown to affect the structure of vegetative assemblages in several of Florida's coastal, spring-fed systems, perhaps masking the effects of nutrient enrichment.
- There is some evidence from a survey of springs in Florida that a negative relationship exists between dissolved oxygen concentrations and benthic algal coverage.

Nutrients can affect fauna in springs through direct toxicity and indirect effects mediated by vegetation. In essence, effects can be generated in three primary ways: 1) toxicity, 2) changes to trophic webs, and 3) changes in habitats. The literature indicates:

- Nitrate levels in 92% of 130 Florida springs have been reported to average less than 2 mg L^{-1}; a value that is lower than most concentrations reported to cause effects on animals (Munch *et al.* 2006). However, nitrate concentrations exceed levels of concern in some springs, and they may reach levels of concern for short periods in other springs, especially after the application of safety factors.
- Invertebrate assemblages vary among different vegetated and unvegetated habitats, which suggests that changes in the types and amounts of vegetation (e.g., replacing rooted, vascular plants with algal mats) may lead to changes in invertebrate assemblages.
- Differences in invertebrate assemblages were correlated with dissolved oxygen concentrations, which points to the importance of factors beyond nutrients.
- Fish assemblages and standing stocks vary among different habitats, which suggests that changes in habitats may lead to changes in fish assemblages.
- Evidence of changes in fish assemblages based on repeated surveys in springs that have experienced increases in nitrate concentrations (e.g., Silver and Wekiva) is equivocal, with significant potential for confounding of drivers.
- Fish biomass and phosphorus concentrations were related in a nonlinear manner, with increases in fish biomass being correlated with increased phosphorus concentrations only for lower initial concentrations.
- Nonlinear interactions among fauna, flora and abiotic drivers are found in other aquatic systems, and they may operate in Florida's springs.

Thus, the effects of nutrients on flora and fauna in springs are likely to arise through interrelated and interacting mechanisms. The outcomes bear directly on the sustainable use and management of spring ecosystems.

Effects on Invasive Plants and Invasive Plant Effects on Springs

The literature from lake ecosystems demonstrates a positive relationship between nutrient levels and growth potential for non-native "invasive" plants. As a result, there is widespread concern that increases in nitrate-N in springs may be a primary factor driving invasive plant overgrowth. However, the available literature suggests that maximum stimulation of invasive plant growth by nitrate-N is likely to occur at the very low end of concentrations in Florida springs and thus the nutrient increases experienced in recent years may not portend increased likelihood of plant invasion. For instance, productivity measurements of *Eichhornia crassipes* (water hyacinth) and *Pistia stratiotes* (water lettuce) suggest that maximum growth potential was possible at nitrate-N concentrations characteristic of historical background concentrations, but that the reason they did not take over may have been the result of downstream export rather than nutrient limitation.

Overall the interrelationships between invasive plants and spring ecosystems can be summarized as follows:

- Available scientific studies have not definitively determined a concentration of nitrate-N in springs that would effectively limit growth of *E. crassipes, P. stratiotes,* or *Hydrilla verticillata* (hydrilla).
- There is evidence that growth of *H. verticillata* and its ability to out-compete *Vallisneria americana* (native tape grass) increases as a function of increased sediment N (albeit from tank experiments rather than *in situ* experiments).
- Field surveys in Florida lakes indicate a marginally significant relationship between dissolved total N and the extent of *H. verticillata* occurrence.
- In one long-term study of ecological communities associated with *E. crassipes* in the St. Marks River, faunal habitat values were demonstrated to be similar to that provided by native plant communities.
- Contrary to other ecosystem contexts in which large mats of *E. crassipes* have been clearly shown to depress DO, coverage by *E. crassipes* in the flowing waters of the St. Marks River did not result in significant oxygen profile differences as compared to *Sagittaria kurziana* (strap-leaf sag) or other native plant communities.
- The literature suggests that aquatic plant control techniques (e.g. herbicide applications or mechanical harvesters) that are used to suppress plant overgrowth have the potential to serve as severe disturbances that could promote succession towards algal dominated springs ecosystems.

Ecosystem Scale Effects

Frequently the changes observed in spring ecosystems are described as driven by "bottom-up" or "top-down" control processes (or combinations of both). Bottom-up control describes processes that originate at the bottom of the trophic ladder and are driven generally by exogenous forcing functions such as, light, flow regime, temperature, or nutrient availability that act to control growth and productivity of primary producers. Top-down control, on the other hand, originates at the higher end of the trophic ladder and generally takes the form of endogenous effects like changes in grazing pressure, seed dispersal, and other controlling feedbacks from within. However, the exogenous verses endogenous effects should not be taken to mean that top-down only implies factors originating within the ecosystem. In fact exogenous drivers like the removal of top carnivores or the loss of grazers can ultimately result in top-down cascades of impacts.

Detailed study of two spring ecosystems, Silver Springs and the Rock Creek, Wekiva Spring complex, suggests that there is evidence for ecosystem scale effects of nitrate-N enrichment. Using a subsidy stress theory to explain the decline in gross primary production (GPP), it is suggested that increases in nitrate-N act to increase productivity for a time, but then act as a stress to depress productivity above a certain threshold (Chapter 6). One study presents compelling evidence for a decrease in overall productivity in Silver Springs from values measured in a 1950 study as compared to today. This declining ecosystem productivity documented at Silver Springs was highly correlated with increasing nitrate nitrogen concentrations during the 50-year period of available data. Declining spring flows, increased shading by riparian trees, and altered fish populations were also observed to be correlated with declining ecosystem production at Silver Springs and could offer alternate or cumulative explanations of the observed ecosystem changes. The second study conducted in the Wekiva River and Rock Springs Run also found an inverse correlation between nutrient (total nitrogen and total phosphorus) concentrations and ecosystem metabolism. These spring run ecosystems also had other significant environmental stresses caused by humans, including decreases in discharge, intensive exotic plant management efforts, and disturbance due to recreational activities. Studies of whole ecosystem responses to nutrients that would result in direct evidence that increased nutrient levels alone could result in decreased ecosystem productivity and/or photosynthetic efficiency are not available (Chapter 6).

The Legal Framework

The legal framework for managing spring ecosystems exists primarily as a collection of regulations for the discharge of wastewaters through the National Pollutant Discharge Elimination System (NPDES). Additionally, certain sources of nutrient pollution that do not fall within the direct jurisdiction of the federal program, such as nonpoint sources, agricultural discharges, and additional discharges to groundwater are regulated by Florida through various programs (Chapter 7). Narrative nutrient standard for surface waters prohibits altering nutrient concentrations "so as to cause an imbalance in natural populations of aquatic flora or fauna." Numeric standards can also be developed, as Total Maximum Daily Loads (TMDL), however, development of TMDLs for a particular waterbody requires that it be "impaired". Local comprehensive plans and land development regulations can be developed to limit the intensity of land development to minimize potential nutrients contributions to springs. They can also provide for improved stormwater and wastewater management.

Overall, the current framework for managing spring ecosystems is focused on water quality with little or no ability to manage holistically or adaptively. Springs management would benefit from a framework that includes options for integrating program initiatives of a variety of agencies and programs including: Florida Department of Environmental Protection, Florida Department of Health, DEPs Bureau of Invasive Plant Management, Florida Water Management Districts, Florida Fish and Wildlife Conservation Commission, and local citizens representing important stakeholders.

PART 2: SPRINGS RESEARCH PRIORITIES

We present recommendations for research before we discuss management implications of the findings of this literature review, because what we don't know has serious implications for how and why we manage ecosystems. The management of complex, coupled human and natural systems, like Florida's springs, necessarily requires an "adaptive" approach, an approach that sees management as an evolving process rather than an end in itself. Management requires knowing, and while we can never know everything, a baseline of knowledge is always a good idea prior to meddling. Therefore, a concerted effort to more thoroughly study and understand springs and their springsheds is warranted.

Florida's 700+ springs are important resources that are undergoing significant change. They are under assault from a variety of stressors including reduced flows, increased nutrients (principally nitrate-N), human disturbance, changes in specific conductance, decreasing oxygen levels, invasions of non-native species, and so forth. While key elements of spring ecosystems resemble key elements of other lotic systems, Florida spring systems are unique, (indeed, even individual spring systems often differ in key elements) making generalizations using key principles and across all springs to be dangerous at best.

Our review of the available literature has shown that we do not have a systematic understanding of historic changes, fundamental processes, or mechanisms of ecosystem function sufficient to definitively manage springs and their contributing areas. Yet manage we must in the face of significant uncertainty. It is with this uncertainty in mind that we make the following recommendations regarding research needs. There are many areas of research that if undertaken would yield important information that should lead to better understanding of spring ecosystems. While we present these suggestions one at a time, it is our concerted belief that the research approach should be a systematic one. An approach that incorporates many of the individual suggestions into a holistic comparative, cross scale, cross stressor study of a half dozen springs. Obviously the springs need be carefully chosen.

Nutrient Fate, Transport, and Transformation: *What we don't know*

Some of the most fruitful research that will improve understanding of past changes and potentials for future management of spring ecosystems can be found in elucidating factors affecting fate, transport and transformation of nutrients at the scale of the springshed. We offer the following research objectives:

- Explicit accounting of nutrient budgets is essential to understanding attenuation in springsheds (or lack there of). Developing nutrient and water budgets for springsheds has already begun to yield a clear picture of source importance and will continue to help setting realistic target load reduction strategies. It is a critical factor necessary in the development of TMDLs for spring sheds. As part of a systematic research program, continued development of spatially explicit models of nutrient and water budgets is strongly encouraged to better understand the reasons for the observed attenuation between springshed and vent.

- Understanding the effective springsheds and flow-paths is essential to establishing baseline conditions and for targeting management for individual springs. The link between discharge and age is an important research need because of its implications for regulatory minimum flows and levels and for better understanding of the time lags between management action and water quality response. Detailed studies that elucidate spatial variability in recharge and resulting spring discharge are needed for management of individual springs.
- Indications are that Florida's karst geology does not have an unlimited capacity for P sorption and that future phosphorus release is a potential area of concern. As such, this should be an area of active research, with the primary objective to determine the degree of sorption saturation along principal groundwater flow-paths.
- Indications are that there may be significant spatial and temporal variability in DO of spring water that may be related to larger scale springshed dynamics (e.g., organic matter loading of ground waters, ground water age). Research is needed to determine if declines in DO or variability in DO levels are related to the increase in the dominance of filamentous algae in many springs, either through negative impacts on grazers, or impacts on SAV respiratory functions.

Within-system nutrient dynamics are not well understood and there is a general lack of data on characterization of spring systems for biogeochemical purposes. We propose the following studies that will elucidate biogeochemical pathways and processes, enhancing spring management in the long run

- Our understanding of nutrient dynamics in Florida spring systems resembles a black box approach, where changes in water column nutrients provide evidence that biogeochemical transformations are taking place within the hyporheic, detrital, and epiphytic zones, but with little understanding of how or what rate these transformations are occurring.
- Carbon (C) sources and distribution play a key role in structuring the biogeochemistry of the spring system; therefore, better understanding is needed regarding the sources and processing of C in spring systems and especially the role of aquatic plant management in the distribution and fate of C within particular systems.
- The role of internal nutrient supply and relative bioavailability of various nutrient forms stored in sediments and water column is important to document as are the fluxes between sediment, vegetation, and water column.
- Research is needed to understand the fate of nitrogen within the spring system. This would include understanding of biotic uptake processes (algal/macrophyte uptake), importance of different N sources (NH_4^+, NO_3^-, DON), and the occurrence, rates and importance of biological N_2-fixation. Whole spring run N budgets should be performed to better isolate these processes.

Nutrient Effects on Flora and Fauna: ***What we don't know***

The effects of nutrients on spring flora and fauna always will be uncertain for two primary reasons: 1) we cannot afford the amount of science that would come close to eliminating uncertainty and 2) unforeseen and unforeseeable responses will arise as emergent properties of these complex systems. In support of sustainable use and management of springs systems, we recommend a targeted research program comprising inventories, baselines, diagnostic studies and other scientific approaches, with choices driven primarily by management questions derived from human values. Given these relationships, input from diverse stakeholders becomes a requirement during development of both "answerable" questions, e.g., questions with well-defined scopes and appropriate levels of precision, and detailed research projects designed to provide useful answers. Issues that arose during this review serve as starting points for such discussions. Key unknowns and examples of research directions are:

- A lack of understanding regarding the roles of various types of flora in nutrient budgets hampers management decisions regarding assimilation of nutrients and setting of numeric criteria for nutrient loads or concentrations; and it can be addressed by diagnostic studies to determine assimilation of nutrients by vascular plants, macroalgae, epiphytes, microphytobenthos or microalgae found in sediments, and other types of flora.
- A lack of understanding regarding the links among nutrients and other drivers of primary productivity hampers efforts to predict impairment, such as overgrowth or shading of vascular plants by algae, set criteria to reverse impairment, or make decisions about restoration; and it can be addressed by diagnostic studies that determine how nutrients, other drivers, and interactions among drivers affect or limit production, competition, and other relationships among periphyton, macroalgae and vascular plants.
- A lack of understanding regarding the form and magnitude of faunal responses to changes in vegetated habitats hampers efforts to predict impairment, such as loss of grazers or valued species, set criteria to reverse impairment, or make decisions about restoration; and it can be addressed by diagnostic studies to 1) elucidate changes in composition and function of faunal assemblages related to changes in habitats and 2) determine palatability of flora to grazers, rates of grazing, and the form and magnitude of predation by primary consumers in an effort to identify flora, grazers, and trophic links to be protected or restored by management actions.
- A lack of understanding regarding the population and assemblage effects of ammonia and nitrate toxicity hampers efforts to set criteria and safety factors; and it can be addressed by diagnostic studies to identify and elucidate the toxic effects of ammonia and nitrate beyond physiological and individual levels of organization (e.g., population and assemblage effects) in an effort to determine threshold levels, safety factors and the need for management actions.

Invasive Plants and Springs: ***What we don't know***

It is surprising that more research has not been conducted on the impacts of aquatic weed and invasive plant management on spring ecosystems in general and specifically as it relates to changes in trophic structure, nutrient cycling, and ecosystem productivity. The pervasive nature of these management techniques should provide strong incentive for a more holistic approach to understanding their short and long term effects. The study of spring ecosystems offer ample opportunities to investigate the role of invasive plants and the possible detrimental effects of their management in the changes that are occurring within spring ecosystems. We offer the following research topics related to invasive plants and their management in spring systems.

- Diagnostic studies (nutrient and organic matter budgets and cycling as well as flora and fauna community structure) before and after aquatic plant control in springs ecosystems are needed to better understand and characterize the effects on sediment nutrient accumulation and ecosystem succession.
- Since the available literature suggests that even historically characteristic nutrient concentrations at Florida springs could support invasive plant growth, research into growth dynamics is needed to better target management interventions.
- The seemingly opposing views in the literature that invasive plants cause irreparable change to aquatic systems at all trophic levels and studies and observations that indicate major invasive plants often provide highly attractive habitat for key springs ecosystem fauna and may support some feedbacks that could be expected to reduce algal overgrowth needs further study. Are there circumstances that would potentially warrant the use or existence of invasive and/or non-native plants as a management intervention?
- Finally, given the wide range of concerns about possible algal selection, habitat loss, faunal toxicology, and dissolved oxygen suppression that may be associated with aquatic plant control, a significant diagnostic program of study is warranted. This should include detailed *in situ* studies of the above under differing aquatic plant control regimes (including both mechanical and chemical treatment). The funds for such studies should be included in aquatic plant control budgets as a matter of course.

Ecosystem Scale Effects: *What we don't know*

Spring ecosystems are exceedingly complex, but potentially understandable based on theories derived from the study of general systems. They do not possess a singularity that would suggest that there is a one to one correspondence between a stressor (such as nitrate concentrations) and a response (such as algal or plant growth and abundance). We know that springs, like other ecosystems, have feedback and control pathways that make predicting cause and effect relationships somewhat problematic. Yet that is exactly what management interventions require. Given X intervention, we expect Y result. Unfortunately the result is often Z; something we did not intend at all.

Ecological monitoring of the multi-level effects of stressors on ecosystems is important for understanding the full implications of management interventions. It is not sufficient to monitor only the target of a particular intervention, because frequently the target is not the true indicator of the problem we are trying to address with the intervention or the element that responds the quickest, or responds at all. Whole system monitoring is essential if management is to learn from past and refine future interventions. With this in mind we offer the following "whole ecosystem" research agenda.

- A critical need exists to establish a comprehensive baseline database for a large number of spring ecosystems, including their range of ecosystem metabolism, trophic structure, and key forcing functions. Data need to be collected at a spatial and temporal resolution to facilitate separation of transient behaviors from long-term trends.

- Elucidating changes in primary production, ecological efficiency, species composition, and succession, that result from changes in forcing functions such as nutrient concentrations, dissolved oxygen, salinity, temperature, and shading are necessary if we are to understand ecosystem management interventions. This can be accomplished through in-situ whole system studies in a variety of springs.
- Elucidating effects of changes in herbivory, which could lead to primary producer effects that appear similar in symptom to nutrient effects is an important are of research since the strength of bottom-up vs. top-down effects is a central question to be answered.
- *In-situ* mesocosm experiments are also needed that involve controlled manipulation of one or more environmental forcing functions (temperature, discharge, carbon dioxide concentration, nutrient concentrations, oxygen concentration, specific conductance or salt contents, and grazing pressure) and the responses of individual species and trophic levels. Any changes in individual organisms could then be related to changes in ecosystem structure and functioning and coupled with whole ecosystem studies (above) might help to elucidate feedbacks and heuristic potentials.
- Indicators and assessment tools for spring ecosystems are essential. Understanding change requires indices that are sensitive enough to detect change. DEP's Stream Condition Index has been developed and used to assess a wide variety of stream ecosystems of Florida, yet we are uncertain if it is applicable in its present form to Spring ecosystems. Research is needed to develop appropriate indices of biotic integrity for spring ecosystems.

Summary of Research Recommendations

During one of the public meetings that preceded the final production of this document, an attendee expressed extreme frustration because "we scientists" were pontificating on the cause while the patient was sick and dying on the operating table…a particularly vivid and apropos analogy and one that has stuck with us. To carry the analogy a bit further…we have the luxury of multiple sick patients, multiple potential diseases, and relatively low-risk of clinical trial error as a result of the ecological changes now being experienced by a diversity of Florida's springs. We propose using this opportunity to explore the causes and long-term implications of these changes. Therefore we propose that a number of smaller springs be selected that represent a variety of stressors acting separately and in combination as a means of testing various hypotheses regarding the impacts of stressors on spring ecosystems and biota. Tests might involve, for instance, choosing springs with low versus high DO, presence and absence of grazers, low versus high nitrate-N, absence versus presence of recreation and so forth; then changing environmental conditions such as nitrate-N concentrations or DO concentrations in springs to support grazers, etc. These experiments should be accompanied by sufficiently fine-grained monitoring, both spatially and temporally, to discriminate the effects of manipulations from other potential interactions. The experiments also need to be carried out over sufficient lengths of time to elucidate the possibility for alternative stable states and hysteresis effects in which, even after long periods of time, the state of the spring system may be determined by its history. In other words removing a stressor may not be sufficient to "restore" a spring ecosystem to a former state as there may be considerable lag in spring ecosystems between removal of a stressor and the effect of its removal.

In addition to the above, we suggest a relatively intense monitoring campaign in a like number of springs that is designed to elucidate spatial variability and temporal dynamics of stressors and impacts. Most of the current spring monitoring data has a resolution that makes discriminating spatial variability impossible and lacks the temporal sensitivity to account for potential pulse events that may have significant impact (low DO/nitrogen/high salinity events, for example).

Scanning though the list of research suggestions, it is apparent that answers to the many uncertainties surrounding Florida Spring management will not come quickly. A sustained research program will necessarily require a sustained source of funding. Here we suggest a simple source of funding that is tied directly to the resource and that is independent of water management district funding or state tax dollars….a source of funding that with appropriate social marketing can be thought of as a positive contribution to natural resource management instead of a tax. The term social marketing in this context means that through a marketing campaign we would enlist the cooperative buy-in of those affected as a contribution rather than imposing a tax.

The proposed source of funding is a "One-cent contribution" for sustainable springs research and management from each bottle of water sold in Florida. According to the International Bottled Water Association, total U.S. sales of bottled water volume surpassed 8.82 billion gallons, in 2007. That translates into an average of 104 single-serve bottles per person per year. With 18.68 million people in Florida, that equals 1.94 billion bottles of water sold in Florida in 2007. If one cent per bottle were contributed toward springs research, the sale of bottled water in Florida would generate $19.4 million/yr (this does not include tourism sales of bottled water which could easily push the total available funding to nearly $21 million per year). If marketed correctly this could result in a sustainable source of funding for research and management of Florida's spring ecosystems, obviously some of the most important natural resources the State possesses. The authors recognize that this is no easy sell, for the first reaction to the proposed funding source is that it looks like a tax. However, we emphasize that it is not a tax, we do not solicit legislative intervention to impose a tax, rather we believe that if presented correctly to the bottling industry they would be extremely willing to add a sentence on their bottling labels indicating that with the sale of each bottle of water they are contributing to research that will ultimately lead to sustainable management of Florida's springs.

PART 3: RECOMMENDATIONS for SPRINGS POLICY and MANAGEMENT

There is no question that Florida's springs are important, unique resources and as with most natural resources in Florida, they are under considerable pressure from changes in environmental drivers, direct human use, and indirect alteration of the chemical and physical environment in which they exist. Equally apparent is the fact that many Florida springs are exhibiting change in biological components. While exact causes are uncertain, in the previous sections, we document numerous stressors that might be grouped into at least four general classes: physical disruption, changes in quantity of discharges, changes in chemical composition of discharges, and changes in populations of higher trophic organisms which have top-down cascade effects on lower trophic levels. It is quite possible but highly unlikely that the observed changes in biological indicators in some springs may be caused by a single stressor. More probable is the possibility that springs exhibiting change are affected by combinations of stressors, acting in a cumulative manner. In some systems, management interventions can be tailored to a particular stressor and the trajectory of change it produces. However, it is unlikely at this time that our ability to understand causality between stressors and indicators in spring ecosystems is sufficient to allow such a fine grain approach to management. Thus, it is our opinion that a holistic (or systems) approach to management is required.

A systems approach is nothing new; there has been a call for an ecosystem approach to management of natural resources for some time (Agee and Johnson 1987). Defined as the integration of ecological, social, and economic objectives for the planning and management of natural resources, early attempts at *ecosystem management* sought to maintain and enhance biological diversity and ecosystem integrity (Grumbine, 1994). The focus on integration of these ecological objectives with the simultaneous attainment of social and economic objectives is what distinguished ecosystem management from earlier natural resource management approaches.

Recognizing the often pathological insistence of managers to stick to one narrative and one management scheme with little or no flexibility for new information, resulted in a call for an approach that addressed not only a whole systems approach to management but an adaptive one as well (Holling, 1978; Walters, 1986).

The Springs Initiative: Protecting Florida's Springs

In 2001, the Department of Environmental Protection (DEP) made springs protection a priority through the establishment of the Florida Springs Initiative (FSI). Since then, DEP committed several million dollars to fund scientific research, water quality and biological monitoring, education and outreach, landowner assistance projects, and springs restoration (FSI, 2007). In the six years since its establishment, the FSI has accomplished much in the four areas of its responsibility:

- *Research and monitoring;*
- *Landowner assistance in the form of planning, management, and restoration;*
- *Restoration/protection activities and educational outreach in state parks; and*
- *Environmental education and outreach.*

Cited as an "adaptive management approach" the resources and staff of the FSI are tailored to future management activities based on the past experiences of the program (FSI, 2007). While FSI's approach involves change and might be called adaptive in the sense that the FSI tailors future activities to what has been "learned" from past activities, it is not Adaptive Management (AM) by the strict characterization suggested by the Resilience Alliance (RA, 2008) and others (Holling, 1978, 1986; Gunderson et al. 1995; Habron, 2003: Folke et al. 2005). A casual understanding of Adaptive Management leads to the belief that monitoring management activities and occasionally changing them constitutes an Adaptive Management approach. Contrary to this commonly held belief, AM is much more than simply changing future activities based on past experience. This is not criticism of the current approach of the FSI, only clarification since the following proposals for policy and management of Florida's springs revolve around an AM strategy. We believe that the complexity of the issues as well as the complexity of the springs' social ecological system, comprised of a multitude of actors from microbes to state government, requires a true AM approach. What follows then, are suggestions for establishing an AM program and framework for Florida springs.

Adaptive Management: An Approach to Springs Protection

An adaptive approach to natural resource management involves exploring alternative ways to meet management objectives, predicting the outcomes of alternatives based on the current state of knowledge, implementing one or more of these alternatives, monitoring to learn about the impacts of management actions, and then using the results to update knowledge and adjust management actions (Murray and Marmorek, 2004). AM is a dynamic process that requires learning and adapting. This means that an AM program incorporates, as an integral part of the program, management interventions that are developed and carried out as scientific experiments. Through the experiments, the AM team learns about the systems but more importantly, they are learning whether the intervention is likely to result in the desired objective. As an experiment, the management intervention must be monitored and data that is gathered must be analyzed to yield information that can direct management. Finally, the management team must be flexible enough to incorporate new information and adjust management if the experiment suggests that adjustment is necessary. A main organizational principle of AM is that it requires partnerships of policymakers, managers, scientists, and other stakeholders who learn together how to create and maintain sustainable resource systems. In other words, AM is a social as well as a scientific process.

A Tragedy of the Commons

Unlike Hardin's (1968) over simplified dilemma of the commons involving herders use of rangelands, Florida's springs are nestled in a complex world of physical, ecological, economic and political realities. As such, Hardin's twofold institutional arrangement for protection, either centralized government or private property, cannot work to protect the "springs commons" over the long run in the face of over exploitation. The complexity of springs issues do not lend themselves to traditional single focus resource management that uses informed- trial-and-error of applying management interventions, watching the impacts, seeing what works, and then adjusting future interventions according to observations. Nor does their resolution lie in either private ownership or top-down government control. Instead, the complexity of issues and causes must be addressed in an informed process of Adaptive Management that is inclusive, holistic and responsive.

The springs' commons have a multitude of players: from herders, to agriculturalists, to boaters, to government, to scientists each with their own understanding of the issues, causes, impacts, solutions and futures of Florida's springs. The adaptive management framework not only must include all these stakeholders, but must have the capacity for social learning (Bandura 1963), or the ability for the entire framework to learn and exchange information that is linked to management decisions. Thus, central to the AM framework for springs is the development of a social fabric that is inclusive and that can address links between institutions, communities, knowledge, science, and power (Stringer et al. 2006). This requires that information flows be horizontal, among groups, as well as vertical, among institutional levels.

Managing in the Face of Uncertainty

The National Research Council (2004) defines adaptive management as a process that promotes flexible decision-making that can be adjusted in the face of *uncertainties* as outcomes from management actions and other events become better understood. The careful monitoring of outcomes both advances scientific understanding and helps adjust policies or operations as part of the iterative learning process. AM is not an end in itself or a trial and error process, but rather a means to more effective decisions and enhanced benefits through learning while doing.

Springs are complex, coupled natural and social systems, sometimes called social ecological systems. Their complexity leads to uncertainty about the exact structure of the system, the relationships between components, and causes and effects of actions, all of which lead to significant uncertainty regarding the outcomes of management decisions. In the face of some ecological change (or crisis), the approach most often used is to develop an informed trial and error approach to management that first tries the most obvious intervention. The intervention generally is the result of a rigid idea of cause and effect, which leads to relatively inflexible management in the face of new information and often results in effects that were counter to expected, sometimes called "ecological surprises". The alternative is the generation of several hypotheses for the observed change and then interventions based on the hypotheses and designed as scientific experiments. If posed correctly and followed up with sufficient monitoring, management interventions become the basis for learning, and if the management framework is sufficiently flexible, the basis for adaptive change.

In the face of changing springs ecosystems, the causes of which are somewhat uncertain, we must learn as we manage. The opportunity to impose an adaptive management framework on the process so that research generates new knowledge and information that flows directly from management decisions is irresistible and too good to pass up. Thus, we suggest a springs management framework that faces uncertainty head on and uses it to learn and change, instead of avoiding risk and uncertainty and preserving the management system. There is a fundamental difference in approach between management that is adaptive and Adaptive Management; the former stresses preservation of the status quo, avoidance of risk, and concern with the costs of management. The latter accepts change and the uncertainty that comes with it, and is willing to fund the processes necessary to avoid ignorance.

Adaptive Springshed Action Programs (ASAPs)

What is required are new institutions and institutional frameworks as well as new science and experimental frameworks. As a grand experiment, we propose the creation of up to six Adaptive Springshed Action Programs (ASAPs). Called Action Programs instead of management programs, we wish to stress that these programs are more than management. They are new management, research, and education structures that incorporate institutional verticality (i.e., state, regional, and local institutions) along with a horizontal group structure of socio-economic stakeholders, managers, and scientists organized as a working group to adaptively manage the spring and its springshed. They are akin to BMAPs but contrary to the BMAP/TMDL program, waters do not have to be declared impaired in order to implement an ASAP. All their implementation requires is the acceptance that a spring ecosystem is changing, a belief that through appropriate management it is possible to affect positive change, a willingness to implement interventions as scientifically valid experiments, the ability to monitor, collect and analyze data, and finally the readiness to change interventions should the data suggest it is appropriate to do so.

The springsheds should be chosen to represent a cross-section of geographical, ecological, physiological, sociological, and political settings. As a first cut, we suggest the following eleven spring systems, from which six could be chosen:

- ***Silver and Rainbow Springs in Marion County*** – two of the state's largest and most economically important springs with rising nitrate concentrations
- ***Ocala National Forest Springs (Alexander, Juniper, and Silver Glen)*** **–** three of the State's most protected springs that are currently unaffected by any nutrient increases or flow reductions
- ***Wakulla Springs*** – an important north Florida spring with a history of springshed interventions to reduce nitrate-N.
- ***Kings Bay/Crystal River Complex*** **–** a complex of springs with a long history of management interventions related to invasive species
- ***Homosassa Springs Complex*** **–** a system with significant baseline data and a recent loss of flora
- ***Chassahowitzka Springs Complex*** **–** a system adjacent to the Homosassa system with a similarly comprehensive baseline and less development in its springshed
- ***Weeki Wachee Springs*** **–** on the west coast of Florida the springshed has undergone significant development in the last two decades
- ***Ichetucknee Springs*** – a long history of recreational use with several different spring boils with differing chemistry and a newly urbanizing landscape
- ***Wekiwa /Rock Springs Complex*** **–** a highly urbanized springshed, with decreased discharged volumes, intense recreational use and important regulatory initiatives for protection
- ***Suwannee River Springs (Fanning and Manatee)*** **–** springs in an agricultural landscape with the highest nitrate N concentrations in the state
- ***Wacissa River Springs*** – springs in a relatively undeveloped rural landscape with minimal nutrient impacts

By choosing several spring systems simultaneously, we suggest that communication between spring ASAPs is just as important to management, learning, and science as within ASAP communication. Frameworks for communication between them must be facilitated, encouraged, and even required. Since each spring systems is a test case in a broader study of adaptive management it is imperative that cross system communication, comparison and ultimately learning take place.

Part of ASAP framework should be workshops that build a collaborative space for discussions between the policy, science, user, and manager groups. These discussions should focus, using a “systems approach”, on elucidating leading problems and issues within each of the spring systems, developing hypotheses concerning the causes of problems and effects of interventions, and develop scenarios about the future. These workshops should be a common form of participant interaction, feedback and formalization of the reflective/iterative processing of information that is required of the adaptive process. A deeper understanding of the resource issues, management options, and future scenarios are likely outcomes.

The current bag of spring management tools (PLRGs, TMDLs, BMAPs, MFLs etc.) is appropriate and usable within the context of the ASAPs. Ultimately whatever tools are used, the allocation of responsibility for reducing impacts on springs (whether impacts are from nutrients, reduce discharges or human disturbance) will require negotiation. Who pays and how much are part of reducing impacts. The proposed ASAPs represent a democratic, responsive bottom-up management structure that can garner support and allocate responsibility without heavy-handed top-down regulation.

It should be noted that the ASAP approach suggested here is in addition to the needed research proposed in the previous section of this chapter. There needs to be multiple layers to understanding and managing spring ecosystems with efforts at the large scale to control things that matter at that scale and science at the small scale to better understand which interventions are most likely to yield desired ecological effects. These are not mutually incompatible, and are likely wholly complementary. The research proposed in the previous section is designed to provide baseline information about spring ecosystems and responses of spring ecosystems to stressors. The ASAP program suggested here is a novel approach to management that includes science and the ability to test hypotheses concerning appropriate management interventions for problems believed to be at the root of changes in spring ecosystems. The proposed approach to management is similar to, and in fact could use the existing spring working groups as a starting point. So far, the working groups seem to be less about management and more about exchanging information, as suggested in the following statement by a participant in spring working groups:

> "Springshed working groups provide a marvelous opportunity for collaboration, exchange of ideas, and general education. As someone who has participated in a number of different working groups, my impression is that while there is clear success in bringing stakeholders together and sharing information, there is much room for improvement in terms of facilitating bottom-up discussion about how to process and use this information moving forward. All too often, working group meetings are characterized by a series of presentations that are not followed by serious discussion, synthesis, and argument among stakeholders about the information presented, much less the articulation of different ideas about how to proceed in the face of this information. Exchange of information is undoubtedly a good thing, but we need to come up with better ways to take advantage of multi-stakeholder expertise in progressively evaluating the big picture at each spring and adapting the research and policy agenda over time. The interest and energy to do this is there. What we need is a formal recognition that critical dialogue, collaborative development of research and management priorities, and collaborative evaluation of research and management results should be integral parts of the working group model."

Our proposal for the ASAPs would build on the working groups model, develop overall management goals and objectives, and then initiate a round of management interventions to test hypotheses concerning the causes of current apparent declines in spring ecosystem condition.

The social framework of the ASAP team should include a tripartite of individuals from government, science, and the citizenry at large. The ASAP team should be empowered to make management decisions and direct the relevant agencies to carry out the interventions. For instance, they may direct the appropriate agency to limit recreational use, or eliminate spraying of aquatic weeds as part of an overall management strategy to restore SAV vegetation in a spring run. The appropriate agencies as members of the ASAP team would develop the necessary policy and implementation strategy.

In summary, the key difference between the ASAPs and the current springs working groups is related to membership, organization, and empowerment. Through agreements between agencies, the ASAP will be empowered to take action after developing a program that includes goals and objectives, management interventions that are testable and capable of being validated through collection of data, the collection and synthesis of that data, and finally, real time reflection on whether the interventions are succeeding. The DEP's springs initiative could coordinate the ASAPs. We propose the DEP utilize a neutral facilitator whose primary job would be the development of consensus between the tripartite members of each ASAP.

Adaptive Spring and Springshed Research

Research within the AM context is designed for the purpose of producing results that may be applied to and answer management questions. Just as this concept of research differs from "basic research" (investigations of a phenomenon without reference to particular human needs and wants) the science that drives the AM research is different. Science within the context of AM differs radically from classical notions of "pure science" as it must respond to often-conflicting group demands of managers, politicians, citizens, developers, environmentalists, and users. It must be able to operate under conditions of complexity, uncertainty and risk, and generally be applied over large spatial and temporal scales. In addition AM research must cross many ecological and organizational boundaries increasing its complexity and the lead time required for accomplishing its objectives. Thus, the payoff from AM research should be measured over the course of years, not months. Often this is difficult for the management and policy arena to accept. Frequently policy makers want answers before science has even formulated the question, wishing for a synthesis of available information with inductive inference to the particular case in point. Managers want to move forward with scientific certainty that their intervention will achieve the desired result. Science is left wanting; wishing for the time to do the research, synthesize the results, and answer the questions.

The research within each of the ASAPs should ultimately be formulated by their participants, as they each have their particular ecological issues, management potentials, and socio-economic constraints. Overall, our understanding of Florida spring systems would benefit from cross system comparison. It is important that the science/research component foster the development of broad integrative studies that bring policy and management into focus and generate the kinds of knowledge and understanding that will inform and develop better management as well as social learning rather than just the accumulation of more information. In the absence of the ASAP system and the integrative program of study it would foster, the individual research questions given in the preceding section of this chapter remain as important research priorities. Most are significant questions about the controlling factors of ecological change in spring ecosystems. However, the creation of ASAPs and the opportunities for real time research, education, management and social learning that they will afford is truly a grand experiment and the most important opportunity provided by the crises of ecological change now being experienced by Florida’s springs.

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