# Summary and Synthesis of the Available Literature on the Effects of Nutrients on Spring Organisms and Systems


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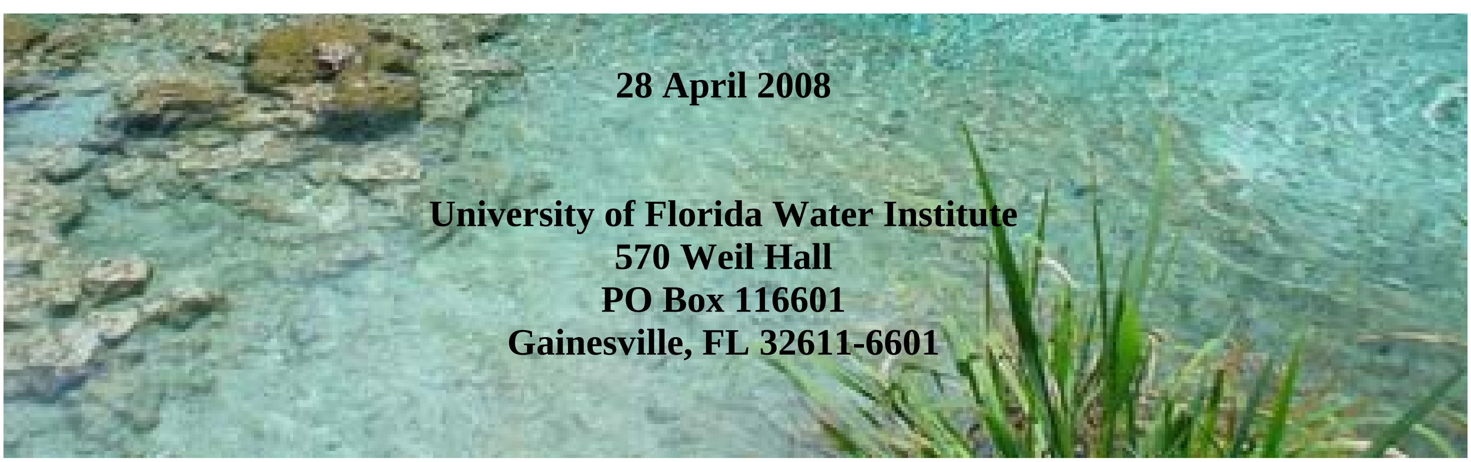

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# Executive Summary

This summary of the state of the knowledge related to nutrient effects on spring ecosystems and biota represents a synthesis of the most important findings from the literature. The report was commissioned by the Springs Initiative of the Florida Department of Environmental Protection (DEP) to review the pertinent literature related to nutrient effects on spring ecosystems and biota.

To address the complexity of spring ecosystems, this literature synthesis was prepared by a diverse team of spring researchers at the University of Florida's Water Institute, Center for Environmental Policy, School of Forest Resources and Conservation, Department of Environmental Engineering Sciences, Department of Soil and Water Science, Department of Fisheries and Aquatic Sciences, and The Center for Governmental Responsibility; as well as expertise from the environmental consulting firm, Wetland Solutions, Inc.

The report is organized into eight chapters:

1. Springs as Ecosystems
2. Springshed Nutrient Loading, Transport and Transformations
3. Biogeochemical Processes and Implications for Nutrient Cycling
4. Nutrient Effects on Spring Flora and Fauna
5. Invasive Aquatic Plants and Aquatic Plant Control in Florida Springs
6. Effects of Nutrients on Spring Ecosystems
7. Managing Nutrient Inputs to Florida Springs: The Legal Framework
8. Synthesis of Nutrients and Springs

DEP's mandate was threefold: 1) to prepare a review of what is known about the interactions between nutrients and springs, 2) to identify what information gaps exist that inject substantial uncertainty for springs restoration and management, and 3) make recommendations for public policy and research to address these gaps. The following summary draws the most important highlights from each chapter according to this mandate.

# Chapter 1: Springs as Ecosystems

This chapter focuses on describing the abiotic and biotic components of spring and spring run ecosystems, their forcing functions and inputs, and the known ecology of these unique aquatic ecosystems.

## The Literature: What is Known

From this review of the existing literature on spring ecosystems there are several conclusions that can be drawn:

- ***Springs and spring runs represent a unique class of aquatic ecosystems*** typified by high water clarity, relatively constant water temperature and chemical conditions, and complex biotic interactions.

- ***In their natural state, springs persist in a quasi environmental steady-state*** and due to this stability have developed complex biological systems that are highly efficient at converting solar energy into useful productive work.

- ***During the past century humans have been exerting an increasing variety of external and internal stresses on spring ecosystems in Florida,*** the most pervasive include:

    - Alteration of discharge regimes resulting from increased groundwater withdrawals,

    - Increased levels of nutrients, particularly nitrate-N in groundwaters discharging from springs,

    - Extensive recreational disturbance of springs and spring runs, and

    - Increased disturbance in the form of management actions, for instance exotic species control.

## The Literature: What is not Known, with Emphasis on Future Research Directions

Several studies suggest that multiple stressors can affect the productivity of spring ecosystems, suggesting that the measurement of ecosystem metabolism may allow for the quantification of these stressors as well as the *health* of spring ecosystems. To further develop these concepts the following research directions are suggested:

- ***Development of a holistic management strategy for springs to foster better understanding*** of the relative importance and synergism of direct stressors at the local level and indirect stresses that occur at the regional scale.

- ***Ecosystem-level information such as monitoring of ecosystem metabolism may provide a more sensitive and quantifiable indicator*** of the response of springs to nutrient increases and the myriad other anthropogenic stresses.

- ***Use of whole-spring and in situ mesocosm manipulation experiments to clarify the effects*** of individual forcing functions on spring ecosystem response.

## Chapter 2: Springshed Nutrient Loading, Transport and Transformations

This chapter focuses on nutrient loading to springsheds, with an emphasis on processes of transport and attenuation that are germane to their delivery to springs. It discusses intrinsic vulnerabilities of karst areas to nitrogen loading, and examines the effects of changes land use/land cover and hydrology on various aspects of water quality decline. The chapter ends with an examination of the state of our understanding of springsheds as closed systems of water and solutes, with an emphasis on areas of uncertainty that are relevant questions for future research.

### The Literature: What is Known

From this review of the existing literature on nutrient loading there are four essential areas for which managers can proceed with relative certainty:

- ***Complex flowpaths and a wide distribution of residence times characterize the hydrogeology of the Floridan Aquifer.*** The timeline and source area of water delivered to springs is of critical importance to springshed management,

- ***Karst landscapes are vulnerable to pollutants from anthropogenic activities at the surface.*** It is clear that the risks of aquifer contamination are greatly attenuated in regions of the state where regional confining layers (e.g., Hawthorn Formation) limit the rate of interaction between surface and Floridan Aquifer waters.

- ***Water quality is changing in dramatic ways including:*** nitrogen enrichment, hardness, dissolved oxygen concentrations, and trace quantities of pharmaceuticals.

- ***The preponderance of N pollution appears to be from fertilizer sources.*** While there are several reasons to treat this finding as an over-generalization, most of the accumulated evidence from mass balance computations and isotopic tracer studies suggests that mineral fertilizers, and therefore not septic tanks and wastewater sprayfields, are the principal sources of N pollution. However, since fertilizer use is highly diffuse and based on hundreds of thousands of individual decisions, control of N from point sources such as municipal wastewater effluent disposal activities may be a more cost effective form of N load reduction.

**The Literature: What is Not Known, with Emphasis on Future Research Directions**

What is not known about loading, transport and transformations injects substantial uncertainty that has key implications on pollutant delivery in karst systems and thus represent important areas of future research.

- ***What are the temporal dynamics of water age?*** It is clear from the literature that there remain large uncertainties about the age mixture of water discharging from spring vents.

- ***What is the natural variability in spring flow, and how vulnerable is this to human appropriation?*** Ongoing efforts to set minimum flows and levels (MFLs) should consider the role of flow in water quality response variables.

- ***What are the sources of N in springsheds?*** While there is accumulating evidence that the source of N is principally mineral fertilizer, there remains significant uncertainty about the interpretation of bulk stable isotope measurements in complex karst hydrologic systems.

- ***What are the causes and effects of water quality changes beyond elevated nitrate?*** The synthesis of the literature on springs is dominated by information about nitrogen, but essentially devoid of similarly detailed studies of other water quality parameters.

- ***What is the assimilative capacity of the landscape and aquifer for nutrients and other contaminants?*** Understanding the assimilative capacity and how it might be affected by development and enhanced by management, should be a research priority.

- ***How responsive are springsheds to management interventions?*** As we begin to understand the links between springshed activities and declining water quality in spring ecosystems, evaluating the extent to which parameters are management-sensitive is relevant to both timelines for recovery and prioritization of management efforts.

## Chapter 3: Biogeochemical Processes and Implications for Nutrient Cycling

The potential biogeochemical reactions and pathways occurring in springs are numerous, and have been studied in varying levels of detail. In this chapter the following three issues are presented: 1) a description of the biogeochemical processes related to nutrient cycling in spring systems, 2) a summary of the available literature related to biogeochemistry in Florida spring systems, and 3) a discussion of the needs and directions for future spring research.

**The Literature: What is Known**

- ***In springs and spring runs, biogeochemical processes occur in the water column, sediments and flood plains and can regulate the role of springs as a 'source' or 'sink' for nutrients and pollutants.*** The effect of biogeochemical processes on spring water composition begins immediately upon emergence from the boil and continues throughout the entire length of a spring run.

- ***Key interfaces involved in elemental cycling in springs environments are biofilms, algal mats and hyporheic sediments zones.*** A variety of processes can occur in these zones of high microbiological activity including organic matter decomposition, nitrogen fixation, nitrification, denitrification, iron reduction, sulfate reduction, and associated processes involving phosphorus.

- ***Organic matter compositions and distributions greatly affect the variety and importance of biogeochemical processes*** especially those requiring anaerobic conditions (e.g., denitrification).

- ***There is a high likelihood that the effect of increased nitrate may be coupled to other nutrient levels*** (e.g., phosphorus or metals) or physico-chemical parameters (e.g., dissolved oxygen). Some of the observed association of increased nitrate with increased algal growth could be the result of other reactions occurring during groundwater emergence (e.g., sulfide oxidation and calcium carbonate precipitation).

## The Literature: What is Not Known

- ***Because there are so few data characterizing the physical, chemical and microbiological conditions in most springs, it is extremely difficult to describe the exact nature and extent of biogeochemical reactions that are occurring in these systems.***

- ***There is little information to ascertain the involvement of other nutrient processes/cycles in controlling nitrate levels,*** including nitrate conversion and loss (e.g., iron and sulfur involvement in denitrification or alternative loss processes)

- ***Among the studies which could advance our understanding of springs as sinks, sources, and transformers of nutrients are:***

    - Expanding water quality data collection to include additional geochemical parameters (e.g., sulfide) could improve our ability to explain and predict individual spring responses to nutrients.

    - Increasing the frequency of water quality data collection (e.g., diel patterns) will offer additional insight into our ability to identify pathways (e.g., aerobic vs. anaerobic, phototrophic vs. heterotrophic) involved in spring processing/cycling of nutrients.

    - Basing the collection of water quality data on upstream and downstream locations of stream segments will improve our ability to understand processes and spring run characteristics contributing to nutrient uptake and transformation.

    - Characterization of sediments (e.g., nutrient storages, organic matter distributions, mineral composition) would enable better assessments of benthic and hyporheic processes affecting current and future storages and fluxes of sediment nutrients (sediment memory).

- Studies are needed to document the potential for aquatic plant management efforts to alter biogeochemical conditions (i.e., creating anoxic zones) and nutrient cycles (e.g., increasing denitrification loss of nitrate or increasing release of ammonium and phosphorus).

- More studies are needed to document the involvement of individual system components in observed declines in nitrate with distance in spring runs (i.e., dilution vs. biotic uptake vs. denitrification).

- More exploratory work is necessary to determine the existence and importance of novel pathways of nitrate conversion (e.g., anammox and lithotrophic nitrate reduction).

## Chapter 4: Nutrient Effects on Spring Flora and Fauna

Many of Florida's springs and spring runs are enriched in nitrate due to broad-scale contamination of groundwater supplies, which fosters two primary and interrelated concerns regarding the effects on flora and fauna in spring systems:

1) high nitrate concentrations can promote eutrophication that can lead to a variety of changes in flora and fauna

2) high nitrate concentrations in Florida's springs and spring runs can affect fauna directly through toxicity.

**The Literature: What is Known**

- ***A eutrophication progression scheme suggests that increased nutrient delivery to aquatic systems may induce change,*** by favoring production of fast-growing algae that ultimately out-compete and displace native vascular plants (see Duarte 1995).

- ***In some of Florida's spring systems, both the apparent proliferation of nuisance algae and the apparent decline of native vascular plants are consistent with the proposed eutrophication progression scheme,*** which a cue that management actions are needed.

- ***In general, nutrients can affect the faunal assemblages in aquatic systems in three primary ways:*** 1) toxicity, 2) changes to trophic webs and 3) changes in habitats.

    - Elevated concentrations of ammonia and nitrate can lead to increased mortality and sublethal effects.

    - At this time, lethal effects are not an overwhelming concern in most spring systems.

- Toxicity needs to be factored into management of spring systems, especially given uncertainty factors that could be applied to most criteria

- The potential for changes in trophic webs and habitats, along with flow-on effects on faunal assemblages does exist.

- The form and magnitude of any changes are determined by complex interactions among bottom-up and top-down processes, such as grazing pressure, habitat use and predation pressure.

- The outcomes of ecological interactions clearly relate to sustainable management of spring systems

## The Literature: What is Not Known

- ***There are few quantitative data that definitively link changes comprising the eutrophication progression scheme to increased nitrate loads in spring systems***

  - The eutrophication progression scheme predicts that nonlinear responses may have "decoupled" these systems from contemporary concentrations of nutrients in the water column.

  - Currently, patterns in the distribution and abundance of plants and algae do correlate with other physical and chemical parameters, such as light availability.

  - Little is known about the individual or combined effects of the various forcing factors or the form and strength of potential feedback mechanisms, including those linked to nutrient concentrations.

- ***There are no data to support rigorous evaluation of bottom-up and top-down influences on faunal communities***

  - Changes in faunal assemblages have not been linked to changes in vegetated communities and changes in grazer abundance have not been linked to changes in floral assemblages.

  - Sublethal effects of nitrate may not translate to effects on populations, assemblages or ecosystems.

## Recommendations for Future Research

- ***Management of nutrients in spring ecosystems would benefit from compilation of inventories and collection of baseline data.*** Initial suggestions for discussion include inventories and baseline data collection designed to:

  - Measure nutrients, oxygen, carbon, light, flow, substrates, grazing, algae, plants, invertebrates, fish, and other key drivers and valued components of spring systems chosen with the best available information and, eventually, with guidance from the results of diagnostic studies.

  - target systems where effectiveness of management can be assessed (e.g., systems with total maximum daily loads, minimum flows and levels, pollution load reduction goals, surface water improvement plans or basin management action plans).

  - Sample synoptically or at spatial and temporal scales that support rigorous analyses of interactions (note that these inventories and baselines form the platform for adaptive management).

  - Balance breadth with depth (e.g., optimize taxonomic detail and replication).

- ***Diagnostic studies focused on bottom-up and top-down interactions are also critical.*** Initial suggestions include the following recommended diagnostic studies to:

  - Determine assimilation of nutrients by flora as a key component of nutrient budgets, including assimilation by epiphytes, macroalgae, vascular plants and microphytobenthos or microalgae found in sediments.

  - Determine how nutrients and other drivers affect overgrowth, shading and other relationships among periphyton, macroalgae and vascular plants in an effort to ascertain the need for management actions, including aquatic plant management and restoration of native species.

  - Clarify limitations to growth of algae and plants by:

    - focusing on species of algae and plants that are hypothesized or known to play major roles in nutrient assimilation
    - including potentially limiting factors other than nitrogen and phosphorus and interactions among limiting factors that can significantly influence the outcomes of management (e.g., micronutrients, iron, oxygen, carbon, light, flow and substrate type)
    - exploring relationships and consequences across multiple levels of biological and ecological complexity, including uptake and other physiological responses, growth and reproduction of individual organisms, and ecological changes in populations or assemblages to promote the success of management actions at the system level (note that some of the key, large-scale relationships form the core of an adaptive management approach)
    - elucidating the direction, magnitude and form of limitations (e.g., nonlinear and nonreversible) to identify suitable targets and goals for management actions.

  - Identify and elucidate changes in composition and function of faunal assemblages related to changes in habitats in an effort to identify habitats to be protected or restored by management actions.

- 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.

- 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.

## Chapter 5: Ecosystem Implications of Invasive Aquatic Plants and Aquatic Plant Control in Florida Springs

Nonnative and nuisance plants such as water hyacinth, water lettuce, and hydrilla are a primary management concern in many Florida springs. In fiscal year 2005 – 2006, the DEP's Bureau of Invasive Plant Management spent approximately $173,000 to control these plants in springs, primarily through the use of chemical herbicides.

This chapter reviews a broad range of literature to outline what is known and, in some cases, unknown about: 1) the history of these plants and their control in Florida, 2) the growth potential of the nonnative plants in springs as a function of elevated nitrate-nitrogen concentrations, 3) the social and ecological consequences of aquatic plant overgrowth, 4) the ecological risks associated with current aquatic plant control methods, and 5) the potential benefits of alternative aquatic plant management approaches in some springs systems. The following are the chapter's major findings and research suggestions:

**<u>The Literature: What is Known</u>**

- ***Major problems with nonnative plants in Florida began with the introduction of water hyacinth, into the St. Johns River in the late 19$^{th}$ century***. Water hyacinth was documented in several springs ecosystem along the St. Johns River by the mid 1890s. Chemical control programs have maintained water hyacinth populations at low levels throughout Florida since the mid-1970s.

- ***Historical sightings by William Bartram indicate that water lettuce, a floating aquatic plant, has been present in a number of Florida springs since at least 1765.*** Scientists disagree as to whether water lettuce was present in Florida before European colonization, or was introduced by early Spanish settlers. Chemical control programs have maintained water lettuce at low levels throughout Florida since the mid-1970s.

- ***Hydrilla became established in several areas of Florida, including the Kings Bay/Crystal River springs complex, by 1960.*** Sustained control of hydrilla, a submersed aquatic plant, has proven more difficult than the floating plants in Florida. Most aquatic plant management costs in Florida springs ecosystems over 2005 – 2006 were associated with chemical control of hydrilla.

- ***Observations from several springs suggest a "boom-bust" successional sequence in which nonnative plants first out-compete native plant communities, and then suffer catastrophic population crashes associated with aquatic plant control or natural disturbances.*** Succession of springs into algal-dominated ecosystem states may be promoted by the nutrient pulses and ecological openings associated with the rapid loss of aquatic plant populations.

- ***Water hyacinth and water lettuce emit allelopathic compounds capable of suppressing a number of algal taxa.*** The effects of such allelopathic compounds on algal dynamics in springs ecosystem are not presently known.

- ***Ecosystem surveys indicate that water hyacinth, water lettuce, and hydrilla provide attractive habitat for crayfish, apple snails, amphipods, fish, manatees, and other springs fauna at moderate levels of coverage.***

- ***Observational accounts suggest that aquatic plant control activities may sometimes have significant adverse effects on springs fauna.*** Depression of dissolved oxygen due to decaying biomass is a primary concern to animals following aquatic plant control. Copper and diquat herbicides also pose concerns in terms of direct toxicity to some animals at levels used for aquatic plant control.

- ***Water hyacinth and water lettuce are currently being managed for algal-suppression, nutrient recovery, and biomass utilization in a number of tropical countries, including places in which they are considered nonnative.*** Careful experimentation with similar ecosystem recovery methods may be worthwhile in highly degraded springs ecosystems where these plants are established.

- ***Biotypes of hydrilla that are resistant to fluridone, a systemic herbicide commonly used for hydrilla control in Florida lakes, have been documented in recent years.*** Thus, there is increased concern about the potential evolution of hydrilla strains that are resistant to Aquathol®, the contact herbicide most commonly used to control hydrilla in springs.

- ***Establishment of selective biological control organisms is increasingly viewed as a priority for sustainable control of hydrilla in Florida.*** A potential biological control for hydrilla, the hydrilla tip mining midge (*Cricotopus lebetis)*, has been documented in Kings Bay/Crystal River, and may be suitable for experimental introduction into other springs systems.

## <u>The Literature: What is Not Known</u>

- ***Although scientific literature indicates clear relationships between nitrogen enrichment and increased growth of water hyacinth, water lettuce, and hydrilla in non-flowing aquatic systems, the few studies available for springs and other flowing waters have not definitively determined a concentration of nitrate-nitrogen in springs that would be limiting to any of the nonnative plants.*** Nutrient assays in flowing water mesocosms would be necessary to develop nitrate-nitrogen limitation values for these plants in springs conditions.

- **Although the scientific literature suggests that copper and diquat herbicides can have significant adverse effects on algal community dynamics, these potential effects have not been well-studied in the specific context of Florida springs.** *Lyngbya wollei*, a filamentous cyanobacterium of great concern in many Florida springs, is notable for its relative resistance to these compounds as compared to other common algal and cyanobacteria taxa.

## Chapter 6: Effects of Nutrients on Spring Ecosystems

There exists a wide-spread recognition of the environmental and economic importance of artesian springs in Florida. An ecosystem approach is essential to provide a greater understanding of the relative interactions between the myriad physical, chemical, and biological fluxes present in springs and their normal responses to rising nutrient levels. A focused and logical research agenda will be critical to pulling these precious but threatened natural resources back from their current declining path.

### The Literature: What is Known

- ***The best evidence suggesting a decline in the health of Florida's spring ecosystems comes from studies that have been conducted over a half-century time period in Silver Springs.*** Both the direct measurements and the estimated system metabolism analyses indicate that the Silver Springs ecosystem may be considerably less productive than it was fifty years ago (Munch *et al.* 2006). The key findings from that study are:

    - *Sagittaria kurziana* remains the dominant submersed aquatic plant species in Silver Springs and represents one of the main physical features of the ecosystem.

    - Biomass estimates for submersed aquatic plants in the summer season were not significantly different from estimates made by Odum in the early 1950s. However, estimates for winter biomass were 31% lower than Odum's, who reported no seasonal difference in submersed aquatic plant biomass.

    - Biomass estimates for the epiphyte community in the summer were approximately three-fold higher than those reported by Odum, while winter values were not significantly different between the two studies.

    - The largest disparity between the Munch *et al.* (2006) estimates of primary producer community biomass and those of Odum from the 1950s was the substantial increase in biomass for the benthic algal mat community.

    - Total species richness for birds, fish, and reptiles in the Munch *et al.* (2006) study were similar to historical records at Silver River.

    - Estimated annual average fish live-weight biomass in the Munch *et al.* (2006) study has declined in Silver Springs since Odum's study in the early 1950s by about 96%; and by 61% since Knight's 1978-79 study (Knight 1980).

    - Annual average gross primary productivity (GPP) and community respiration declined 27% and 26% respectively in the period between the 1950s and today and net community production declined by about 59%.

- ***Recent studies of the Wekiva River and Rock Springs Run (WSI 2007a) (spring runs averaging 0.69 and 0.84 mg/L of nitrate nitrogen, respectively)found similar results as those observed at Silver Springs with significantly lower gross primary productivity and photosynthetic efficiency demonstrating an inverse correlation between rising nitrate concentrations and reduced aquatic ecosystem metabolism.***

### The Literature: What is Not Known, with Emphasis on Future Research Directions

Despite a wide variety of springs' research, there remains a significant knowledge gap between the real and perceived threats that nitrate pollution plays on the ecology of spring ecosystems. In summary the following recommended applied research activities are suggested:

- ***Baseline data on ecosystem-level structure and response to key forcing functions, including sunlight, flow, and nutrient levels are lacking.*** Studies are needed that are fairly long-term (multiple years of repeated measures) and conducted over a representative sample of springs with a range of forcing functions including discharge rates, groundwater chemistry, nutrient concentrations, and recreational intensities;

- ***Community response to increasing nutrients under controlled conditions are lacking.*** We suggest the design of *in situ* complex (multi-species) mesocosm studies to allow replication of spring plant community responses to a range of nutrient conditions under realistic and relevant spring environmental conditions;

- ***Understanding of impacts and effects of management interventions are lacking.*** Whole-spring manipulation studies are suggested to test the effects of possible management techniques such as controlling levels of springshed nutrient loading, human recreational activities, alternative control methods for invasive species, and estimation of optimal consumer carrying capacities (*e.g.*, manatee density).

## Chapter 7: Managing Nutrient Inputs to Florida Springs: The Legal Framework

The legal framework for managing the nutrient pollution of Florida springs is potentially as broad as the scope of human activities that contribute nutrients to the springshed. Regulations on the discharge of wastewater are key elements.

## <u>The Literature: What is Known</u>

- ***The federal Clean Water Act provides a set of mandates and incentives for state programs.*** The focus of the Clean Water Act is protecting surface waters through the regulation of point source discharges under the National Pollutant Discharge Elimination System (NPDES). Discharges to groundwater may be regulated under this program if there is a "significant nexus" to the quality of navigable surface waters.

- ***The Safe Drinking Water Act (SDWA) protects public water supplies by establishing minimum criteria for drinking water quality and requiring states to regulate the underground injection of pollutants.*** Groundwater quality standards for nutrients are thus focused on the protection of public health. Florida has been delegated NPDES permitting authority by the Environmental Protection Agency (EPA) and implements an Underground Injection Control (UIC) program that is consistent with the SDWA. In addition, Florida regulates 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.

    - The regulatory program requires discharges to achieve effluent limitations based on the application of specified levels of technology or to achieve water quality standards, whichever is more stringent. Domestic wastewater treatment plants are generally only required to use secondary treatment, except in areas where the Legislature has required advanced wastewater treatment (AWT). Concentrated Animal Feeding Operations (CAFOs) are currently regulated under state rules pending the adoption by EPA of a new federal rule. Those stormwater dischargers subject to NPDES permitting are required to reduce the discharge of pollutants to the Maximum Extent Practicable.

    - Florida's surface water quality standards must be reviewed and approved by EPA every three years. They consist of designated uses, narrative and numeric criteria for each of those uses, and moderating provisions.

- ***Waters designated as Outstanding Florida Waters (OFW) have a general limitation on their degradation.*** A narrative nutrient standard prohibits altering nutrient concentrations "so as to cause an imbalance in natural populations of aquatic flora or fauna." Numeric standards can also be developed, most commonly as Total Maximum Daily Loads (TMDL).

- ***The TMDLs process begins with determining whether a particular waterbody is "impaired" and demonstrating it does not meet water quality standards for a specific criterion.*** If there is sufficient data demonstrating the concentration of the specific pollutant causing the impairment, it can be added to the verified list. A TMDL is then calculated and the load reasonably and equitably allocated to the various sources and basins contributing pollutants. A Basin Management Action Plan (BMAP) is developed for implementing the adopted TMDL.

- ***Stormwater is a significant source of pollutants that can be regulated as a point source, because much of it is collected into pipes or channels, or as a nonpoint source, because much of it comes from diffuse sources and activities.*** The NPDES program regulates many of the larger stormwater systems and stormwater associated with industrial activities. Systems subject to NPDES permitting must be periodically reviewed and ways to reduce pollution must be considered in permit renewals.

- ***Most stormwater systems in Florida are either unpermitted or regulated under an Environmental Resource Permit program***. Although they must be operated and maintained, there is no program for periodic review for compliance or enhancements.

- ***Septic tanks and other Onsite Treatment and Disposal Systems (OSTDS) are another major potential source of nutrient pollution.*** The Department of Health has adopted regulations for the construction and siting of septic tanks and drainfields. In some areas where nutrients are a concern, such as the Florida Keys, performance-based systems have been required. Local governments can adopt more stringent requirements.

- ***Local governments are required to periodically revise and implement comprehensive plans that can provide a framework for local springs protection.*** Local comprehensive plans and land development regulations can limit the intensity and design of land development to limit the contribution of nutrients to springs. They can provide for improved stormwater and wastewater management.

- ***The Florida Legislature may require special protections or enact other legislation that could protect springs and springsheds.*** The Legislature has specifically required local governments in the Wekiva Study Area to amend their comprehensive plans to enhance springs protection. It has also limited the ability of local governments to regulate agricultural land uses and the conversion of agricultural land to urban uses. A Consumer Fertilizer Task Force has recommended new restrictions on the ability of local governments to regulate the application of fertilizers.

# Chapter 8: Synthesis of Nutrients and Springs: Knowns, Unknowns, Research Priorities and Management Implications

This chapter 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.

## Part 1: NUTRIENTS and SPRINGS: State of the knowledge

There is growing evidence that nitrate concentrations are increasing in the water discharging from springs. Given the importance of nitrate-N and its role as a driver of primary production in many aquatic systems, N appears to be the aspect of springs that has received the most study. Chapter 8 summarizes the current state of knowledge concerning nutrients in springs.

## PART 2: SPRINGS RESEARCH PRIORITIES

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. Summarized in previous sections of this Executive Summary are topic areas in need of research related to spring and the effects of nutrients and other stressors on spring biota.

Overall we propose a rather holistic research agenda that includes diagnostic studies, paired comparative studies of springs, manipulation studies, and fine grained monitoring to elucidate cause and effect relationships and to test various hypotheses regarding the impacts of stressors on spring ecosystems and biota. In particular we suggest:

- 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

- 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.

Sustaining this long term research program will require a sustained source of funding. We suggest a simple source of funding, tied directly to the resource that is not a tax, but rather is a contribution for springs research.

- One-cent per bottle of water sold in Florida contributed for spring research will raise up to $21 million per year.

- Companies who contribute will use the contribution as a marketing tool with a green sustainable water logo on each bottle.

## PART 3: RECOMMENDATIONS for SPRINGS POLICY and MANAGEMENT

Florida’s springs are important, unique resources and are under considerable pressure from changes in environmental drivers, direct human use, and indirect alteration of their chemical and physical environment.

- Our ability to understand causality between stressors and indicators in spring ecosystems is not sufficient to allow a fine grain approach to management.

- 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 an ***Adaptive Management*** (AM) approach.

- An AM approach required are new institutions and institutional frameworks as well as new science and experimental frameworks. W propose the creation of up to 6 ***Adaptive Springshed Action Programs*** (ASAPs).

- The proposed ASAPs build on the Springs Working Groups model by developing overall management goals and objectives, and then initiating 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.

- Research within the AM context is designed for the purpose of producing results that may be applied to and answer management questions.

    - It must be able to operate under conditions of complexity, uncertainty and risk, and generally be applied over large spatial and temporal scales.

    - AM research crosses many ecological and organizational boundaries increasing its complexity and the lead time required for accomplishing its objectives

- 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.

## TABLE OF CONTENTS


**Chapter 1 - Springs as Ecosystems** ... 1

Summary ... 1

INTRODUCTION TO FLORIDA SPRINGS ... 1

Background ... 1

Springs as Ecosystem Laboratories ... 3

Spring Stability and the Evolutionary Time Scale ... 4

SPRINGS ECOSYSTEM DIAGRAMS ... 5

Global/Regional Scale ... 5

Springshed Scale ... 5

Spring Scale ... 9

ENVIRONMENTAL FORCING FUNCTIONS ... 13

Solar Inputs ... 13

Atmospheric Forcing Functions ... 15

Groundwater Inputs ... 16

Anthropogenic Forcing Functions ... 20

ENERGY/MATERIAL STORAGES IN SPRINGS ... 22

Spring Basin/Spring Run ... 22

Water and Dissolved Constituents ... 24

Primary Producers ... 25

Primary Consumers ... 27

Higher-Level Consumers ... 29

Decomposers ... 29

Spring Biomass Pyramid ... 30

ECOSYSTEM-LEVEL PROCESSES ... 31

Primary Productivity ... 31

Community Respiration ... 34

Productivity/Respiration Ratio ... 34

Photosynthetic Efficiency ... 34

Community Export 35
Pollutant (Nutrient) Assimilation 35
Secondary Productivity 35
HUMAN AND AESTHETIC USES 36
Recreational Uses 37
Visitation Seasonality 38
Visitation Numbers 39
Economic Impacts 42
Effects of Recreation on Spring Ecosystems 42
Human Use Carrying Capacity 43
DISCUSSION 44
REFERENCES 46

**Chapter 2 - Springshed Nutrient Loading, Transport and Transformations** 53
Summary 53
The Literature: What is Known 53
The Literature: What is Not Known, with Emphasis on Future Research Directions 54
INTRODUCTION 57
HYDROGEOLOGY 61
Hydrology in a Karst Environment 61
Typology of Florida's Springs 65
Springshed Delineation 67
Hydrogeology and Nutrient Loading 73
Assessing Aquifer Vulnerability 74
Timescales of Water and Nutrient Fluxes 75
TRENDS IN WATER QUANTITY AND QUALITY 77
Water Quantity 77
Nitrogen 79
Phosphorus 85
Carbon 87
Other Water Quality Parameters 89

SOURCES OF NUTRIENTS ........ 92
Nitrogen ........ 92
Natural Sources ........ 94
Inorganic Sources ........ 95
Organic Sources ........ 99
Isotope Tracing of N Sources ........ 101
Synthesis of N Springshed Budgets ........ 104
Phosphorus ........ 107
Carbon (BOD) ........ 108
Other Water Quality Parameters ........ 109
SINKS AND TRANSFORMATIONS OF NUTRIENTS ........ 110
Nutrient Sinks in Karst Landscapes ........ 111
Nitrogen ........ 111
Phosphorus ........ 113
Carbon ........ 114
Other Water Quality Parameters ........ 114
Springshed nutrient budget – Synthesis of Sinks ........ 114
UNKNOWNS AND RESEARCH PRIORITIES ........ 118
Hydrologic and Geochemical ........ 118
Nutrient Loading ........ 118
Subsurface Nutrient Processing ........ 119
REFERENCES ........ 121

**Chapter 3 - Biogeochemical Processes and Implications for Nutrient Cycling** ........ 135
Summary ........ 135
The Literature: What is Known ........ 135
The Literature: What is Not Known ........ 136
INTRODUCTION ........ 137
SPRING ENVIRONMENT ........ 137
Spring water chemistry ........ 137

Reactive Zones ... 139
Biofilm ... 140
Benthic Algal Mats ... 141
Sediments ... 142
BIOGEOCHEMICAL PROCESSES ... 144
Carbon ... 144
Carbon Sources ... 144
Decomposition ... 145
Nitrogen ... 148
Biological Nitrogen Fixation ... 149
Nitrogen uptake ... 150
Nitrogen mineralization ... 151
Denitrification ... 152
Alternative N pathways ... 153
Overall N Cycle ... 156
Phosphorus ... 156
Forms of phosphorus in water column and sediments ... 157
Mineralization of organic phosphorus ... 159
Biotic and Abiotic Ca Interactions ... 160
Biotic and Abiotic Fe Interactions ... 161
Overall P Cycle ... 162
Sulfur ... 162
Sulfide Oxidation ... 162
Sulfate Reduction ... 163
Overall S Cycle ... 164
EFFECTS OF INCREASED NUTRIENTS ... 164
Carbon/Organic Matter Impacts ... 164
Nitrogen Impacts ... 164
Phosphorus Impacts ... 165
Sulfur Impacts ... 166
SUMMARY AND CONCLUSIONS ... 166

Management and Policy Implications ..... 167
RESEARCH NEEDS ..... 168
Specific Research Recommendations ..... 168
Biogeochemical Characterization ..... 168
Source and Fate of N ..... 169
Carbon Dynamics ..... 169
Sulfur Distribution and Function ..... 170
Coupled Biogeochemical Cycles ..... 170
REFERENCES ..... 171

**Chapter 4 - Nutrient Effects on Spring Flora and Fauna** ..... 179
Summary ..... 179
The Literature: What is Known ..... 179
The Literature: What is Not Known ..... 179
Recommendations for Future Research ..... 180
INTRODUCTION ..... 182
Nitrate as a Compound of Concern ..... 183
PRIMARY PRODUCERS IN SPRING ECOSYSTEMS AND FACTORS AFFECTING THEIR ABUNDANCE AND DISTRIBUTION ..... 183
Light ..... 184
Carbon and Oxygen Balance in Macrophytes ..... 186
Stream Velocity and Substrate ..... 187
Nutrients ..... 188
Community Responses to Increased Nutrients ..... 192
EFFECTS OF NUTRIENTS ON FAUNA ..... 194
Components of Spring Ecosystems ..... 195
Relationships Between Nutrients and Invertebrates in Florida Springs ..... 196
Relationships Between Nutrients and Fish in Florida Springs ..... 200
Summary of Relationships Between Nutrients and Fauna in Florida Springs ..... 207
Nutrient Effects Operating Through Ecosystem Processes ..... 207
Nutrient Effects Operating Through Toxicity ..... 210

Toxicity of Ammonia ..... 211
Toxicity of Nitrate ..... 213
Summary of Nutrient Effects on Fauna in Springs ..... 217
RESEARCH TO IMPROVE MANAGEMENT OF NUTRIENTS IN SPRINGS ..... 218
REFERENCES ..... 220

**Chapter 5 - Ecosystem Implications of Invasive Aquatic Plants and Aquatic Plant Control in Florida Springs** ..... 231
Summary ..... 231
The Literature: What is Known ..... 231
The Literature: What is Not Known, and Recommendations for Future Research ..... 232
INTRODUCTION ..... 234
Major Invasive Aquatic Plants: HIstory and Control in Florida ..... 235
Water Hyacinth ..... 235
Water Lettuce ..... 239
Hydrilla ..... 240
NITRATE-NITROGEN AND NONNATIVE PLANTS IN SPRINGS ..... 242
Water Hyacinth and Nitrogen Limitation ..... 242
Water Lettuce and Nitrogen Limitation ..... 244
Hydrilla and Nitrogen Limitation ..... 244
NONNATIVE PLANTS AND ALGAL COMMUNITY DYNAMICS ..... 245
Boom-Bust Hypothesis ..... 245
Allelopathy Hypothesis ..... 247
AQUATIC PLANT CONTROL AND ALGAL SUCCESSION ..... 248
Herbicide Selection Hypothesis ..... 248
Copper ..... 249
Diquat ..... 249
Endothall ..... 250
Glyphosate ..... 250
2,4-D ..... 251
Attractor – Catastrophe Hypothesis ..... 251

Habitat Values of Water Hyacinth ... 251
Habitat Values of Water Lettuce and Hydrilla ... 253
Non-Target Concerns ... 254
RECOMMENDATIONS FOR FURTHER RESEARCH ... 256
Alternative Management of Floating Plants ... 258
Alternative Management of Hydrilla ... 259
CONCLUSION ... 260
REFERENCES ... 261

**Chapter 6 – Effects of Nutrients on Spring Ecosystems** ... 271
Summary ... 271
ECOSYSTEM STRUCTURE ... 273
Primary Producers ... 273
Algae ... 274
Vascular Plants ... 279
Primary Consumers ... 280
Invertebrates ... 280
Vertebrates ... 280
Secondary Consumers ... 281
Fish ... 281
Higher-Level Consumers ... 281
Humans ... 282
ECOSYSTEM FUNCTION ... 282
Community Metabolism ... 282
Gross and Net Productivity ... 283
Respiration ... 287
Productivity/Respiration Ratio ... 287
Photosynthetic Efficiency ... 287
Community Metabolism Conclusions ... 288
HUMAN AND AESTHETIC USES ... 289
Visitor Satisfaction ... 289

Economic Impacts ... 289
Effects of Eutrophication on Human Recreation ... 289
DISCUSSION ... 290
RECOMMENDATIONS FOR FURTHER RESEARCH ... 296
Proposed Research Priorities ... 297
Recommendations ... 298
REFERENCES ... 299

**Chapter 7 - Managing Nutrient Inputs to Florida Springs: The Legal Framework** ... 305
Summary ... 305
REGULATION OF DISCHARGES ... 307
Clean Water Act ... 307
State Discharge Permitting ... 309
Domestic Wastewater ... 310
Industrial Discharges and Concentrated Animal Feeding Operations (CAFO) ... 311
WATER QUALITY STANDARDS ... 312
Groundwater Quality Standards ... 312
Surface Water Quality Standards ... 313
TOTAL MAXIMUM DAILY LOADS ... 315
Impaired Waters ... 316
The Verified List ... 317
Calculation and Allocation ... 317
Basin Management Action Plans (BMAP) ... 318
STORMWATER ... 319
NPDES Stormwater Permitting ... 321
SEPTIC TANKS ... 321
LAND USE PLANNING AND REGULATION ... 322

# Chapter 8 - Synthesis of Nutrients and Springs: Knowns, Unknowns, Research Priorities and Management Implications

**Chapter 8 - Synthesis of Nutrients and Springs: Knowns, Unknowns, Research Priorities and Management Implications** .................................. 327
Summary ..................................................................................................... 327
INTRODUCTION ............................................................................................ 329
PART 1 - NUTRIENTS and SPRINGS: State of the knowledge ......................................... 329
Fate, Transport, and Transformation: *What we know* ................................................... 329
Effects of Nutrients on Spring Organisms and Systems: *What we know* ....................... 331
Effects on Flora and Fauna ............................................................................... 332
Effects on Invasive Plants and Invasive Plant Effects on Springs ................................. 334
Ecosystem Scale Effects ................................................................................... 334
The Legal Framework ..................................................................................... 335
PART 2: SPRINGS RESEARCH PRIORITIES .................................................................. 336
Nutrient Fate, Transport, and Transformation: *What we don't know* ........................... 336
Nutrient Effects on Flora and Fauna: *What we don't know* ........................................... 338
Invasive Plants and Springs: *What we don't know* ...................................................... 338
Ecosystem Scale Effects: *What we don't know* ............................................................ 339
Summary of Research Recommendations ..................................................................... 340
PART 3: RECOMMENDATIONS for SPRINGS POLICY and MANAGEMENT ............. 341
The Springs Initiative: Protecting Florida's Springs ..................................................... 342
Adaptive Management: An Approach to Springs Protection ....................................... 343
A Tragedy of the Commons ................................................................................ 343
Managing in the Face of Uncertainty ...................................................................... 344
Adaptive Springshed Action Programs (ASAPs) ............................................................ 344
Adaptive Spring and Springshed Research ................................................................... 347
REFERENCES ............................................................................................... 349