Stumbling Toward Success: A Story of Adaptive Law and Ecological Resilience

Mary Jane Angelo
University of Florida Levin College of Law

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Mary Jane Angelo*

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I. INTRODUCTION

In late 1998, birders and biologists in central Florida were thrilled to observe a record number of species visiting the Lake Apopka restoration project. Unfortunately, what initially appeared to be a great ecological restoration success story soon turned into an ecological nightmare. By March of 1999, hundreds of birds were sick and dying. As the National Audubon Society reported shortly thereafter, "hundreds of fish-eating birds were dying, some convulsing and bleeding from the eyes and beak, symptoms of pesticide poisoning." The poisoned birds included protected species such as American white pelicans, wood storks and even the bald eagle. By 1999, the St. Johns River Water Management District ("SJRWMD"), the agency in charge of the Lake Apopka restoration project, saw itself morph from the natural resources agency responsible for a successful project that attracted record numbers of birds to the subject of a federal criminal investigation for alleged violations of several federal laws including the Endangered Species Act ("ESA"), the Migratory Bird Treaty Act ("MBTA"), and the Bald and Golden Eagle Protection Act ("BGEPA"). At this point, SJRWMD could have chosen to throw in the towel on its Lake Apopka restoration efforts and shift all of its resources and attention to defending itself against the criminal allegations. Instead, SJRWMD chose to push on and continue with the restoration project, and use the bird kill tragedy to guide future research and restoration decisions. In other words, SJRWMD chose to "adapt" to the new information gleaned from the tragedy and learn from its mistakes, a process fairly characterized as "adaptive management."

For decades, scientific and legal scholars alike have promoted the concept of "adaptive management" as a necessary approach to meaningful environmental management, restoration, and regulation. Unfortunately, adaptive management success stories are few and far between. The Lake Apopka Restoration Project provides a real-world illustration of adaptive management at work. In this Article, I use adaptive management theory to explore mechanisms to make environmental law better able to address the uncertainties and changing nature of natural systems to restore and protect ecological resilience using the Lake Apopka restoration project as a case study. The case study involves more than fifty years of experience with environmental contamination, pollution control, clean-up, and restoration and dem-

onstrates the need for an adaptive approach to respond to new information, unintended consequences, and changed economic and ecological circumstances. The case study involves a number of federal and state regulatory and incentive-based programs. This Article evaluates which approaches used on Lake Apopka were "adaptive" and which were not and how a multifaceted approach using a number of complex regulatory and non-regulatory tools may be needed to adequately deal with environmental restoration issues. Specifically, this Article takes an in-depth look at what SJRWMD did to shift Lake Apopka back to its non-eutrophic state and to reintroduce resilience mechanisms back into the lake. The Article also evaluates the adaptations that were necessary at virtually every step in the restoration process to respond to legal losses, changed circumstances, new scientific understandings, unintended consequences of restoration activities, and even tragic mistakes. The Article concludes by offering observations on the lessons from Lake Apopka that can be used to make future environmental restoration projects more adaptive and more successful at restoring ecological resilience.

II. SUCCESS THROUGH ADAPTATION AND RESILIENCE

A. Adaptive Management

The adaptive management concept originated from the works of C.S. Holling and Carl Walters in 1978 and 1986, respectively, but can be traced back to Charles Lindblom's article The Science of "Muddling Through" published in 1959. Holling incorporated the concept of resilience into policy design as an alternative to environmental assessment, which he found to be a "reactive approach" that "will inhibit


4. HOLLING ET AL., supra note 2, at 19. Holling stated: The concept of resilience, in which the different distinct modes of behavior are maintained because of, rather than despite, variability, is suggested as an overall criterion for policy design. The more that variability in partially known systems is retained, the more likely it is that both the natural and management parts of the system will be responsive to the unexpected. The very process and techniques we recommend, while aimed in part at reducing uncertainty, are designed as a changing adaptive process of policy design.
laudable economic enterprises as well as violate critical environmental constraints." 

Holling described adaptive management as "integrat[ing] environmental with economic and social understanding at the very beginning of the design process, in a sequence of steps during the design phase and after implementation." 

Walters described adaptive management as a way to deal with scientific uncertainty when managing renewable resources, especially since resource managers had begun relying on quantitative modeling as a tool to predict responses to alternative harvesting policies. According to Walters, renewable resource scientists had failed by not putting greater emphasis on socioeconomic dynamics in their research and management and in their approach to dealing with scientific uncertainty. Instead of cautiously regulating harvests while seeking better understanding through more and more detailed analyses, Walters suggested using an adaptive management process "where management activities themselves are viewed as the primary tools for experimentation."

The need for an adaptive approach to management became apparent in light of new understanding of ecosystems as dynamic, rather than as having only one equilibrium state. Since then, government agencies have been trying to account for the disparity between science and environmental law and formulate a system that can adjust to confront scientific uncertainty. However, environmental regulation that can "provide feedback loops to update regulatory efforts as information increases" is counterintuitive to the American legal system.

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5. Id. at 1.
6. Id.
7. Id. at 1.
8. Id. at 2.
9. Id. at 2–3.
11. "The law tends to encourage regulatory inaction in the face of uncertainty." Thomas T. Ankersen & Richard Hamann, Ecosystem Management and the Everglades: A Legal and Institutional Analysis, 11 J. LAND USE & ENVTL. L. 473, 493 (1996). Adaptive management is being recognized and adopted in varying degrees by federal government agencies responsible for managing natural resources, including the National Forest Service, the U.S. Fish and Wildlife Service, the U.S. Department of the Interior, the Bureau of Reclamation, the U.S. Army Corps of Engineers, and the Bureau of Land Management. Coleman, supra note 2, at 187. Federal agencies have been using adaptive management for the restoration of critical ecosystems, such as the Pacific Northwest Forests, the Colorado River, and the Everglades. Id.
12. Profeta, supra note 10, at 86.
Thus, adaptive management has not been seriously incorporated into environmental law.\textsuperscript{13}

Environmental law often requires that regulation be based upon the "best available scientific knowledge," which is a principle of ecosystem management.\textsuperscript{14} According to J.B. Ruhl, "[e]cosystem management is exactly what it sounds like—managing ecosystem-level problems through ecosystem-level approaches—and it almost always calls for creative and adaptive use of policy instruments as varied as inflexible commands at one extreme to generous incentives at the other."\textsuperscript{15} Adaptive management, also a principle of ecosystem management,\textsuperscript{16} has become increasingly synonymous with ecosystem management.\textsuperscript{17}

In 1992, The National Research Council ("NRC") conducted a study on the use of adaptive management for the restoration of aquatic ecosystems.\textsuperscript{18} The study is cited as an example of how legal academics view adaptive management in terms of how resource management should be conducted.\textsuperscript{19} The study suggests using the Adaptive Environmental Assessment ("AEA") developed by C.S. Holling as an appropriate "process for involving scientists, resource managers, policy analysts, and decision makers interactively in designing resource management programs."\textsuperscript{20} In formulating a National Restoration Strategy, the NRC established adaptive management as a principle
for priority setting and decision-making in the face of scientific uncertainty.\textsuperscript{21} The example used by NRC was Chesapeake Bay's nutrient management strategy, in which the initial goal was set to reduce nutrient loading by forty percent.\textsuperscript{22} The policy makers committed to a continuous study of the goal itself, as well as the cost and effectiveness of the chosen means. As a result, both the goals and approaches of the nutrient management strategy are subject to revision over time.\textsuperscript{23}

Both the legal and scientific scholarly literature of the past several years is rife with calls for the increased use of adaptive management in a variety of environmental regulatory, management and restoration contexts.\textsuperscript{24} Unfortunately, although numerous examples exist where resource agencies adopted adaptive management policies, at least in name, as part of a variety of environmental management and/or restoration projects, examples of successful adaptive management are hard to find. One of the best known examples is that of the Columbia River Basin Fish and Wildlife Program, which is considered the first application of adaptive management in resource management\textsuperscript{25} and was the world's largest biological restoration program at the time it began in 1986.\textsuperscript{26} Intensive management of the Columbia River Basin began with the listing of several Snake River salmon populations as endangered.\textsuperscript{27} Congress passed the Pacific Northwest Electric Power Plan-

\textsuperscript{21} Id. at 357–58.
\textsuperscript{22} Id. at 358. Concerns over declining fisheries and rising pollutants in the bay arose in the 1970s. Profeta, supra note 10, at 89. In 1975, Congress authorized a five-year study of threats to the bay and, in 1983, Congress formed a structure to govern the ecosystem. Id. at 89–90. These efforts to protect the bay eventually evolved to incorporate adaptive management in order to fill informational gaps. Id. at 90. The program had some success, but failed to identify the exact relationship between water quality levels and habitat health. Id.
\textsuperscript{23} Nat'l Research Council Study, supra note 18, at 358.
\textsuperscript{25} See Ankersen & Hamann, supra note 11, at 495–98.
\textsuperscript{27} Profeta, supra note 10, at 91.
ning and Conservation Act (the "Act") in 1980, which established the Pacific Northwest Electric Power and Conservation Planning Council (the "Council"). The Act mandated that "[t]he Council shall promptly develop and adopt . . . a program to protect, mitigate, and enhance fish and wildlife . . . [T]he program, to the greatest extent possible, shall be designed to deal with that river and its tributaries as a system . . . ." The Act also requires "that fish and wildlife be accorded 'equitable treatment' among the multiple purposes of the hydroelectric projects . . . ." Finally, the Act requires that the "best available scientific knowledge" be used. The Council adopted an adaptive management policy as part of its action plan. Agencies involved included the Federal Energy Regulatory Commission, the Bureau of Reclamation, and the U.S. Army Corps of Engineers (the "Corps"). Professor Kai Lee, a member of the Council, suggested adaptive management in 1984. The Council found that using adaptive management as a policy framework "recognizes biological uncertainty, while accepting the congressional mandate to proceed on the basis of the 'best available scientific knowledge.'"

Since the development of the Columbia River program, several federal and state agencies have adopted adaptive management approaches in a number of settings. One such use by federal agencies was with regard to the Glen Canyon Dam, which stores water and generates power. The construction of the dam altered the flow of the river below the dam resulting in decreased sediment deposits that build canyon beaches, decreased river temperature, and fluctuating releases of water, all of which threaten listed indigenous fish. The resulting political pressure forced the Bureau of Reclamation to prepare $88 million worth of scientific studies, which then forced the Departments of the Interior and Energy to prepare environmental impact statements ("EIS") for the operation of the dam. The operat-
ing agencies have adopted adaptive management in order to be able to experiment with flow regimes and satisfy the National Environmental Policy Act ("NEPA") EIS requirement.\textsuperscript{39}

In addition, the U.S. Forest Service expressly adopted adaptive management in its plan governing federal lands in Oregon, Washington, and northern California.\textsuperscript{40} The goal of the plan was to resolve the conflicts arising from the protection of the spotted owl as an endangered species and timber harvesting.\textsuperscript{41} The plan designates Adaptive Management Areas ("AMAs") and regulates on the basis of ecosystem units.\textsuperscript{42} The governance of the AMAs eventually evolved into a decentralized system in order to address ecosystem complexity and allow public input.\textsuperscript{43}

The Corps has also adopted the concept of adaptive management in its 2001 Revised Draft Environmental Impact Statement (the "Revised Draft") for the Missouri River Master Water Control Manual (the "Master Manual").\textsuperscript{44} The Master Manual is a system of written operating instructions for the operation of the Missouri River Basin.\textsuperscript{45} The Master Manual was originally prepared in 1960.\textsuperscript{46} In 1989, the Corps agreed to revise the Master Manual.\textsuperscript{47} This would be the first time the Master Manual would be subject to review under NEPA.\textsuperscript{48} During the NEPA review process, the Corps asked the United States Fish and Wildlife Service ("FWS") for formal consultation under the ESA.\textsuperscript{49} It is important to note that in 1994 the FWS had announced a policy change that all of its regulatory and other functions would be guided by the concept of ecosystem management.\textsuperscript{50} One of the reasonable and prudent alternatives suggested by FWS in its biological opinion was the recommendation to adopt adaptive management.\textsuperscript{51} The FWS recommended two components of this new adaptive management process—establishment of an interagency coordination team and implementation of a monitoring program.\textsuperscript{52} All five EIS alternatives in the Revised Draft were to be "buttressed by a process known as adap-

\textsuperscript{39} \textit{Id.}; \textit{Bureau of Reclamation, U.S. Dep't of Interior, Operation of Glen Canyon Dam: Draft Environmental Impact Statement} (1994).
\textsuperscript{40} Profeta, \textit{supra} note 10, at 92.
\textsuperscript{41} \textit{Id.}; Ankersen & Hamann, \textit{supra} note 11, at 495.
\textsuperscript{42} Profeta, \textit{supra} note 10, at 92–93.
\textsuperscript{43} \textit{Id.} at 93.
\textsuperscript{44} Davidson & Geu, \textit{supra} note 24, at 819.
\textsuperscript{45} \textit{Id.} at 834.
\textsuperscript{46} \textit{Id.}
\textsuperscript{47} \textit{Id.}
\textsuperscript{48} \textit{Id.}
\textsuperscript{49} \textit{Id.} at 841.
\textsuperscript{50} \textit{Id.} at 837.
\textsuperscript{51} \textit{Id.} at 842.
\textsuperscript{52} \textit{Id.}
tive management." The Corps planned to refine the adaptive management process in the Revised Draft after it received the NRC report titled Missouri River Ecosystem: Exploring the Prospects for Recovery.

In addition, the Corps has used adaptive management as a tool to confront the ecological uncertainties in deciding what a restored Everglades ecosystem should look like. The Corps employed adaptive management in the Everglades Nutrient Removal Project and when experimenting with modified water deliveries. The Everglades Nutrient Removal Project (the "ENR Project"), authorized by the Everglades Forever Act of 1994, is an experimental program developed by the South Florida Water Management District (the "SFWMD") to treat agricultural stormwater runoff for excess nutrients prior to its discharge into a water conservation area. The U.S. Environmental Protection Agency ("EPA") required a National Pollutant Discharge Elimination System ("NPDES") permit for the program. Thus, the SFWMD had the burden of proving that experimental program would meet water quality standards. "The circular logic involved in requiring managers to give assurances that a project can meet a standard, when the project has been designed to test whether the standard can be met, could have a substantial chilling effect on adaptive management projects, particularly those on an ecosystem scale." The EPA eventually issued a NPDES permit for the ENR Project, but the permit was challenged by Friends of the Everglades "on the ground that the experimental nature precluded any assurance the discharge would meet water quality standards." Another issue raised in the permit challenge was the EPA's decision not to undertake NEPA review of the ENR project on the basis that it was not a "major action significantly affecting the environment."

The Congressional mandate to experiment with water deliveries to the Everglades National Park from the Central and Southern Flood Control Project is cited as one example of "legislative authorization to pursue an adaptive management policy . . . ." "The 1984 legislation

53. Id. at 843.
54. Id. at 844.
55. Ankersen & Hamann, supra note 11, at 492.
56. Id. at 496–500.
57. FLA. STAT. § 373.4592(4)(a) (2005).
58. Ankersen & Hamann, supra note 11, at 496.
59. Id.
60. Id.
61. Id.
62. Id. at 496–97.
63. Id. at 497 (quoting John E. Childe, Friends of the Everglades, Request for Evidence Hearing before the Environmental Protection Agency on NPDES Permit No. FL0043885, at 53 (1994)).
64. Id. at 498.
authorized the Corps, in conjunction with the water management district, to experiment with deliveries of water to the Everglades National Park based on a concept referred to as the 'rainfall plan.' The goal of the experiment was to develop an optimum water delivery plan for the Everglades National Park. The Corps selected a "modified raindriven plan" and initiated consultation with FWS under section 7 of the ESA. The FWS authorized the Corps' preferred alternative through an incidental take permit.

Despite the abundant examples of environmental and natural resources agencies adopting adaptive management policies as part of their environmental management and restoration efforts, the extent to which adaptive management is actually employed on the ground and the level of success with implementing adaptive management approaches is not clear. Although the projects described above all have adopted some form of adaptive management in their policy or management documents, it is not clear how much of this is merely giving lip service to the idea of adaptive management, how much is mere desire or intent to use adaptive management in the future, and how much of it is actual on-the-ground implementation of true adaptive management approaches. Many of the projects described above are ongoing projects, which have not yet been determined to have "succeeded" or "failed" in meeting their objectives.

B. Resilience

Ecological resilience has been described as "a measure of the amount of change or disruption that is required to transform a system from being maintained by one set of mutually reinforcing processes and structures to a different set of processes and structures." The concept of ecological resilience is based on the understanding that ecosystems can exist in multiple stable states. Ecological resilience should not be confused with "engineering resilience," which is a measure of the time it takes for a system to return to a steady state after experiencing a perturbation. In contrast, the concept of ecological resilience focuses on conditions that exist far from a steady state, where perturbations can shift a system into a different state, or in other words, into another "regime of behavior." As Holling and Gunderson

65. Id.
66. Id. at 498–99.
67. Id. at 499.
68. Id.
69. Garry D. Peterson, Contagious Disturbance and Ecological Resilience 216 (May 1999) (unpublished Ph.D. dissertation, University of Florida) (contrasting ecological resilience with engineering resilience, which is defined as "the rate at which a system returns to a single steady or cyclic state following a perturbation").
70. Id. at 218.
explain it, the fundamental flaw with using engineering resilience as a metric with regard to natural ecosystems is that it “reinforces the dangerous myth that the variability of natural systems can be effectively controlled, that the consequences are predictable, and that sustained maximum production is an attainable and sustainable goal.”71 Ecological resilience, a measure of the magnitude of a perturbation that a system can absorb before the disturbance causes the system to shift into a different regime of behavior with different controlling processes, provides a more realistic view of natural systems.72 As such, ecological resilience captures the strength of redundancies in the system stemming from reinforcing processes and compensating functions provided by more than one species. These redundancies endow the system with an ability to absorb disturbances and persist despite the disruption.73 When viewed in the context of environmental management, restoration, or regulatory decision-making, ecological resilience is a measure of a system’s ability to withstand failed management or regulatory decisions.74

Historically, environmental managers and regulators have operated on the outdated notion that the goal of environmental protection is to achieve or maintain a “balance of nature,” in which an ecosystem exists in one static “steady state.” New understandings of ecosystems suggest that ecosystems are not static because they are continually subject to a variety of both natural and human perturbations, which cause a range of changes. Most perturbations are within a range of type and magnitude such that, while certain changes may occur within the ecosystem, it does not “flip” into a new and different state. Certain changes, however, are either of a type or of sufficient magnitude that they can cause the ecosystem to change to an entirely different state. In many cases, the ecosystem may be able to revert to the prior state once the perturbation is removed, or if certain previous conditions are reintroduced to the system. If the perturbation is extreme enough, or if it is maintained for sufficiently long duration, however, the new state may become permanent and it may be virtually impossible for the ecosystem to revert to the original state absent some extreme circumstances. This new understanding of natural systems makes it evident that the objective of environmental managers and regulators should not be to achieve and maintain a “fixed” condition, but rather to seek to keep man-made perturbations within the

73. Id. at 6.
74. Id. at 6–7.
range of types, magnitudes, and durations that will not result in the system flipping to a different state, or at a minimum, such that if a system does flip to a different state, it is not a permanent irreversible condition. The goal, then, of environmental restoration projects often is to reintroduce the conditions necessary to revert the system back to the previous preferred state. By ensuring that the ecological resilience of an ecosystem is maintained or reintroduced, it is more likely that an ecosystem will be able to withstand a greater range of perturbations without undergoing a state shift. So how can environmental managers and regulators assure that ecosystems are resilient? First, it is necessary to understand what factors increase a system’s ecological resilience. Research suggests that one of the most significant factors to increasing a system’s ecological resilience is to increase its species richness. However, mere numbers of species may not be the complete answer. Scientists have developed a variety of hypotheses that attempt to describe how species diversity affects ecological resilience.

A number of factors can contribute to the stability of an ecosystem. One factor in ensuring stability is biological diversity. Because individual species are only able to perform limited ecosystem functions, the greater the species richness (i.e., the greater the number of species), the greater functional diversity in the ecosystem.\textsuperscript{75} Thus, the extent to which one species can compensate for the loss of a function previously provided by another species, impacts the ability for the system to be able to dampen the effects of perturbations.\textsuperscript{76} However, mere number of species may not tell the whole story. Ecologists have developed a number of hypotheses that attempt to discern the influence of species richness on ecological resilience. One such hypothesis analogizes species as “rivets” on an airplane wing. A certain number of rivets can be lost without the wing coming loose from the airplane. However, at some point a threshold is reached and the next rivet removed causes the wing to come loose. Under this hypothesis, a certain number of species can be lost from a system without the system flipping to another state, but at some point, the next species lost will result in the system flip.\textsuperscript{77}

The elimination of an important component of an ecosystem, such as the loss of a species that performs important functions, can result in the irreversible loss of a former stable state such that the system is no longer able to shift back into that state.\textsuperscript{78} However, once a system is disturbed to the extent that it shifts into a different state, it may be extremely difficult, if not impossible to revert the system back to the

\textsuperscript{75} Peterson, \textit{supra} note 69, at 209.
\textsuperscript{76} Gunderson et al., \textit{supra} note 72, at 9.
\textsuperscript{77} Ibid.
\textsuperscript{78} Ibid. at 7; Peterson, \textit{supra} note 69, at 221.
prior state, because the new state will exhibit its own ecological resilience. Resource managers and regulators must be cognizant of this fact as well as the fact that even a very slow and gradual erosion of an ecosystem's controlling processes can result in a flip into a different state.\(^7\) Thus, an objective of environmental management and regulation should be to maintain a level of ecological resilience, including a sufficient amount of redundancy ecosystem controlling processes, such that unexpected disturbances, whether anthropogenic or natural, can be absorbed without causing the system to shift states.

Another hypothesis, the "driver/passenger" hypothesis, posits that it is not the mere numbers of species that is critical, but rather it is the role that the species play that determines the impact to the system if that species is removed. This hypothesis identifies certain species as drivers—i.e., those playing a critical role in the controlling processes of the ecosystem. Loss of these driver species can have a much greater impact on the ecosystem than would loss of a passenger species.\(^8\)

One of the best understood examples of ecological resilience in a multi-state system is that of freshwater lakes. Shallow freshwater lakes exist in one of two alternative stable states depending on a number of factors, including turbidity, nutrient loading, and vegetation and fish production.\(^9\) The two alternative states are a clear lake dominated by aquatic vegetation or a turbid lake dominated by algae.\(^10\) Lakes will shift between the two alternative stable states in response to various perturbations such as increased nutrient loading, decreases in fish species that consume algae, the addition of sediments, or vegetation removal.\(^11\) Conversely, a lake in the alternative state of being turbid and dominated by algae, can shift to the clear stable state in response to changes including a reduction in a population of bottom-foraging fish or a reduction in the numbers of predators of algae-eating fish.\(^12\)

Freshwater lake systems normally are dynamic. The complex and redundant structures and processes of freshwater lakes normally enable the ecosystem processes of lakes to be maintained despite the regular disturbances that occur in the lake and its watershed.\(^13\) This ecological resilience results from a variety of structures and processes that are part of natural un-degraded freshwater lakes. Vegetated ri-

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79. Gunderson et al., supra note 72, at 7.
80. Id. at 9.
81. Peterson, supra note 69, at 218.
82. Id.
83. Id. at 219.
84. Id.
parian areas delay or prevent nutrient flows into the lake from upland or upstream run-off. These riparian zones also provide habitat for fish and other aquatic species that make-up the lake system food web. Wetlands adjacent to lakes filter and absorb run-off, thereby lessening nutrient flow into the lake itself. Predatory fish serve to structure the food web below them and zooplankton feed on phytoplankton such that influxes of phosphorus are stored in the biomass of higher trophic level species, rather than in lower trophic level species such as algae. In addition, littoral zone plants store nutrients, provide habitat and produce dissolved oxygen. These structures and processes serve as resilience mechanisms that mitigate the effects of disturbance. Healthy lakes are characterized by conditions wherein more than one species is able to provide the same or similar function. Thus, if disturbances occur that eliminate or reduce one species, other species will compensate for the loss of the functions provided by the lost species. However, if the perturbation is substantial enough, too many species will be lost, and thus functional compensation will not occur. For any given lake, only a small percentage of the total number of species provide critical functions. However, the specific species whose loss will cause a state shift are rarely identified.

Many anthropogenic and natural perturbations can contribute to a freshwater lake system shifting between states. Natural disturbances include fires, storms that stir up bottom sediments, and other weather conditions. Human-induced disturbances typically stem from agricultural or urban/suburban land uses. The typical causes of a shift of a lake from a clear to a eutrophic state are: (1) increased nutrient inputs from agricultural or urban land uses; (2) the stocking of game that eat phytoplankton-eating organisms; (3) the over-fishing of large game fish that prey on the fish that eat phytoplankton-eating organisms; and (4) increases in zooplankton-eating fish from over-fishing of their predators. A shift to a eutrophic state is evidenced by increases in bottom-feeding fish and declines in macrophytes due to reductions in water clarity and disturbances by bottom-eating fish. Most natural perturbances and many human-induced perturbations

86. Id. at 53.
87. Id.
88. Id.
89. Id. at 54.
90. Id.
91. Id.
92. Id. at 63.
93. Id.
94. Id. at 52.
95. Id. at 51.
96. Id. at 55-59.
97. Id. at 55.
are either relatively brief in duration or small in magnitude such that the lake system is able to absorb the disturbances. For example, a large storm may cause bottom sediments to be stirred-up or may increase run-off. However, because the storm is short in duration, the system is able to withstand these disturbances because the normal resilience mechanisms in place, such as plants that absorb nutrients from stirred-up bottom sediments and wetlands that slow run-off, tend to restore the normal system dynamics.\textsuperscript{98} However, more severe or longer duration perturbations can erode and ultimately destroy these resilience mechanisms. Many anthropogenic disturbances of lake systems tend to be of greater magnitude or longer duration than many natural disturbances. Accordingly, human-induced disturbances often are sufficient to overwhelm resilience mechanisms and ultimately result a qualitative change in the system—i.e., the lake system shifting to a turbid or eutrophied state.\textsuperscript{99}

To cause a shallow lake to shift to a eutrophic state, several resilience mechanisms must be broken down.\textsuperscript{100} New resilience mechanisms that tend to keep the lake in the eutrophic state will then form.\textsuperscript{101} Once a lake has been degraded to the point at which the resilience mechanisms breakdown and it shifts to its alternative eutrophic state, its new resilience mechanisms will have to be overcome to successfully restore the lake back to its previous clear state.\textsuperscript{102} The eutrophic state of a lake reinforces itself via a number of mechanisms. For example, phytoplankton may shade-out and prevent the growth of submersed plants, thereby preventing the bottom-stabilization and habitat functions provided by those submersed plants.\textsuperscript{103}

\textsuperscript{98} Id. at 54

\textsuperscript{99} Id. Technically, the hypothesis of alternative stable states posits two states distinguished by the relative dominance of two groups of primary producers: the clear state, which is dominated by macrophytes; and the turbid state, which is dominated by phytoplankton. The term "eutrophic" refers to the trophic level (level of primary production) of the system, and in some situations a lake could move from a turbid state to a clear state without a concomitant change in trophic level. See, e.g., Edgar F. Lowe et al., \textit{The Restoration of Lake Apopka in Relation to Alternative Stable States: An Alternative View to That of Bachmann et al. (1999)}, 448 \textit{HYDROBIOLOGIA} 11 (Apr. 2001); Claire L. Schelske et al., \textit{Abrupt Biological Response to Hydrologic and Land-Use Changes In Lake Apopka Florida, USA, 34 AMBIO} 192 (2005) [hereinafter Schelske, \textit{Hydrologic and Land-Use Changes}]; Claire L. Schelske et al., \textit{Wind or Nutrients: Historic Development of Hypereutrophy in Lake Apopka, Florida}, 55 \textit{ARCHIV FÜR HYDROBIOLOGIE SPECIAL ISSUES, ADVANCES IN LIMNOLOGY} 543 (2000). Thus, although from a scientific standpoint the two states are clear and turbid rather than clear and eutrophic, for purposes of this Article, the terms "eutrophic" and "turbid" will be used interchangeably.

\textsuperscript{100} Carpenter & Cottingham, \textit{supra} note 85, at 55.

\textsuperscript{101} Id.

\textsuperscript{102} Id. at 57.

\textsuperscript{103} Id.
Many shallow lake restoration projects have failed because they have failed to take into consideration the resilience mechanisms of the eutrophic state. In the past, lake restoration projects tended to focus on simply abating one disturbance (e.g., reducing the input of nutrients), rather than engaging in multi-faceted approaches that are aimed at overcoming the full suite of resilience mechanisms.104 Thus, these past approaches rarely provided a long-term solution.105 To have systemic, long-term and sustainable restoration, it is necessary to put into place mechanisms that mimic the natural self-regulating ecosystem.106 As Carpenter and Cottingham put it, "restoration requires shifting resilience mechanisms from those that maintain degraded systems to those that maintain more valuable systems."107 In freshwater lakes, this means restoring riparian areas and adjacent wetlands, and reducing harvesting of game fish, as well as reducing nutrient inputs from agricultural and urban land uses.108

C. The Relationship Between Adaptive Management and Resilience

Adaptive management and ecological resilience are two sides of the same coin. Ecological resilience is necessary for adaptive management approaches to be viable. Adaptive management theory teaches us that environmental management and regulatory decisions are unavoidably based upon incomplete information. This imperfect information coupled with the complexity and changes inherent in all ecosystems, suggests that ecological resilience is necessary to provide a cushion for humans to learn and adapt without risk of transforming a system into a different state.109 To allow for the experimentation and experiential learning that is required by adaptive management, a system must have sufficient resilience to be able to withstand the inevitable mistakes or unintended consequences that will manifest whenever we act in the absence of perfect knowledge.110

On the other side of the coin, adaptive management is an integral part of assuring that our environmental management decisions restore and/or maintain ecological resilience. In the past, many of our environmental management and regulatory decisions were based on the out-dated notion that if we chose the "right" technology or the "right" ecological indicators, we could maintain an ecosystem in a

104. Id. at 63.
105. Id.
106. Id. at 64.
107. Id.
108. Id.
110. Id. at 4.
steady state.\textsuperscript{111} We now know that there is no simple "right" answer and that attempts to maintain ecosystem stasis can cause its own set of environmental degradation. Ecosystems are complex and dynamic. The complexity and dynamic nature of ecosystems contributes to the resilience of ecosystems. Thus, to properly manage or restore an ecosystem, we must be certain that we do not intentionally or inadvertently dilute the complexity of the system or constrain the dynamic nature of the system such to reduce the ecological resilience of the ecosystem.

III. THE LAKE APOPKA STORY (THE HISTORY OF DEGRADATION AND RESTORATION)

A. The Degradation (The Shift to the Eutrophic State)

Lake Apopka is a large, approximately 31,000 acre lake in central Florida, which served as a major sports fishing venue dating back to the 1800s.\textsuperscript{112} At one time, more than twenty fish camps were located on the shoreline and sports fishermen traveled for long distances to take advantage of the excellent fishing and recreational opportunities on the lake.\textsuperscript{113} Starting very early on in the history of European peoples' use of the lake, human activity began to exert an influence on the dynamics of the lake system.\textsuperscript{114} During the 1890s, construction of the Apopka-Beauclair Canal began, which lowered the lake levels by approximately four feet.\textsuperscript{115} It was not until the 1940s, however, that the most serious environmental assault on the lake began.\textsuperscript{116} During the 1940s, the State of Florida gave away thousands of acres of wetlands along the north shore of the lake to encourage row crop, or “muck,” farming operations on the nutrient-rich peat soils.\textsuperscript{117} To farm these wetlands, it was necessary to build a large levee between the wetlands to be farmed and the open-water area of the lake and then to pump water out of the farmlands into the lake proper.\textsuperscript{118} Consequently, ap-

\textsuperscript{111} Id. at 7.
\textsuperscript{114} Lake Apopka Fact Sheet, supra note 112, at 1.
\textsuperscript{115} Schelske, Hydrologic and Land-Use Changes, supra note 99, at 192.
\textsuperscript{116} Id.
proximately 20,000 acres of sawgrass marsh was isolated from the remainder of the lake by levees.119

The water pumped from the farms into the lake was laden with high levels of phosphorus.120 Water continued to be pumped on a regular basis from the farms into the lake from the 1940s until the 1990s.121 In March of 1947, the first algal bloom was observed in the lake and a continuous bloom persisted.122 The algal blooms eliminated larger biota in the lake by shading and degrading the habitat.123 By 1950, much of the rooted aquatic vegetation in the lake had disappeared.124 This caused a precipitous decline in the sport fish population in the lake and resulted in Gizzard Shad becoming the dominant fish in the lake.125 Pesticides were used frequently—through both aerial and ground application. Wastewater contaminated by agricultural compounds and pesticides was discharged from the farms at an estimated twenty billion gallons annually (approximately one third of the lake's total volume).126 Consequently, by the mid-1960s Lake Apopka was Florida's most polluted large lake.127

Also during this time, other nutrient-rich discharges to the lake were occurring from treated wastewater discharges from shoreline communities, as well as from nearby citrus processing facilities.128 In addition to these anthropogenic changes to the lake system, in 1947 a hurricane destroyed most native aquatic vegetation and stirred-up bottom sediments.129 By 1963 major fish die-offs had been re-

119. Id. The sawgrass marsh contained rich peat soils that were ideal for growing crops for World War II food production. These farmlands were some of the most productive farmlands in the U.S., with three harvests per year. Novel technologies related to freezing, shipping, and processing, which were later adopted worldwide, were first developed on the agricultural lands of Lake Apopka. To keep the farmlands dry, particularly during periods of high rainfall, the farms pumped excess water to the lake as wastewater. LAKE APOPKA FACT SHEET, supra note 112, at 1. 120. LAKE APOPKA FACT SHEET, supra note 112, at 1. 121. Id. 122. INDUSTRIAL ECON. INC., FINAL LAKE APOPKA NATURAL RESOURCE DAMAGE ASSESSMENT AND RESTORATION PLAN 2 (June 2004), http://www.sjrwmd.com/lakeapopka/pdfs/DARP.pdf [hereinafter NATURAL RESOURCE DAMAGE AND RESTORATION PLAN]; see also Lawrence E. Battoe et al., The Role of Phosphorus Reduction and Export in the Restoration of Lake Apopka, Florida, in PHOSPHORUS BIOGEOCHEMISTRY OF SUBTROPICAL ECOSYSTEMS 511 (K. R. Reddy et al. eds., 1999) (estimating the increase in phosphorus loading associated with the onset of floodplain farming). 123. NATURAL RESOURCE DAMAGE AND RESTORATION PLAN, supra note 122, at 2. 124. Id. 125. Id. 126. Id. 127. Id. 128. LAKE APOPKA FACT SHEET, supra note 112, at 1. 129. HOGUE ET AL., supra note 117, at 400–01 (citing J.E. CRUMPTON, FLA. FISH & WILD. LIFE CONSERVATION COMM’N, EXPERIMENTAL GILL NETS IN LAKE APOPKA (2000)).
1971 marked a period of major die-offs of fish, soft-shell turtles and alligators. In addition, during the early 1970s, aquatic vegetation control efforts contributed to eutrophication and changing biodiversity. By the 1970s the sport-fish industry was decimated and Lake Apopka's reign as a premiere bass fishing lake in Florida was over. The fish-camps began to disappear.

The combination of these nutrient-rich discharges to the lake, coupled with the loss of nutrient filtering due to 20,000 acres of wetlands being converted into farmland, resulted in a substantial increase in nutrient loading to the lake. The increased nutrients caused an increase in algae production, which in turn clouded the water and prevented sunlight from reaching underwater vegetation. Without sufficient sunlight, the submerged vegetation died, resulting in even more nutrient releases to the lake, eliminating the bottom stabilization function of the vegetation and destroying habitat critical to fish and wildlife. In other words, the human-induced disturbances resulted in a shift of the lake into a eutrophied state.

The eutrophication of Lake Apopka not only destroyed one of Florida's premiere fishing venues, but it also put at risk the entire Ocklawaha chain of lakes, as well as the Ocklawaha and St. Johns Rivers because Lake Apopka serves as the headwaters of the entire Ocklawaha chain of lakes, which includes Lakes Beauclair and Dora, which ultimately flows into the St. Johns River. Pollutants traveling downstream from Lake Apopka were entering and endangering the health of the entire watershed.

To make matters worse, in addition to the natural and agricultural-related disturbances to the lake, in 1980 a major chemical spill, which included chlorobenzilate, dicofol, and DDT occurred from the Tower Chemical Company, a pesticide manufacturing facility along the south shore of Lake Apopka. The spill was of such a magnitude

Although the 1947 hurricane may have had some effect on the lake, studies conducted by SJRWMD indicate that the hurricane was not a major contributor to lake eutrophication. E-mail from Edgar Lowe, St. Johns River Water Mgmt. Dist., to Mary Jane Angelo, Assoc. Professor of Law, Univ. of Fla. Levin Coll. of Law (Jan. 9, 2009) (on file with author).

130. Hoge et al., supra note 117, at 305.
131. Id. at 306.
132. Id.
133. Id. at 38.
134. Id. at 59; Edgar F. Lowe et al., Setting Water Quality Goals for Restoration of Lake Apopka: Inferring Past Conditions, 15 J. Lake & Reservoir MGMT. 103 (1999) (examining the condition of Lake Apopka prior to cultural eutrophication).
135. Hoge et al., supra note 117, at 59.
136. Id. at 65.
137. Id. at 41.
that the site of the spill was designated as an EPA Superfund site. In 1982 scientists began to become aware of significant declines in the lake’s alligator population due to reproductive effects believed to have been caused by the spilled pesticides and their breakdown products. Scientists found a number of abnormalities and evidence of endocrine disruption in alligators. Abnormal reproductive effects found in the Lake Apopka alligators included: (1) decreased egg hatchability; (2) increased embryonic mortality; (3) abnormal sex differentiation (gonadal development); (4) abnormal sex steroid concentrations and patterns during embryonic development, for neonates, and juveniles; (5) decreased or abnormal phallus (penis) size for juveniles; (6) increased neonatal mortalities; (7) hypocellular immune tissues (spleen, thymus and bone marrow); and (8) evidence of immuno-suppression or immuno-toxicity. The feminization of male alligators, in particular, was widely discussed in the news media, raising public concerns about this bizarre discovery. At the time the alligator abnormalities were discovered, scientists in other parts of the U.S. and other parts of the world were beginning to suspect that many organo-

138. *Id.* Tower Chemical Co. ("TCC") manufactured pesticides from approximately 1957 through November 1980. TCC was located on a 30-acre site in Clermont, Lake County, Florida. TCC disposed of its pesticide wastes in an un-lined percolation/evaporation pond on-site. The pond was located over a sinkhole that served as a conduit to the Floridan aquifer. As a result of heavy rainfall, the pond overflowed into the neck of Lake Apopka, affecting vegetation and animal life. Subsequent to the over-flow, TCC constructed a spray irrigation filed for disposal of wastes. The field was never permitted. Additionally, at an unknown time, TCC burned and buried waste on a 1.5 acre plot. After two court orders, TCC ceased all discharges into the pond and stopped use of the spray irrigation field. In August of 1980, the EPA first inspected the property. High levels of DDT and related contaminants were found in the grounds of the main facility. Additionally, groundwater plumes of pesticides and organic contaminants were found on-site and in the adjacent wetland areas. In June 1983, the EPA issued an order to TCC under section 6 of the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA"). Because TCC did not respond to the order, the EPA began remedial work at the site, including setting up a water treatment system for the percolation pond, excavating the burn site, and removing the soil to an approved disposal site. The EPA excavated and disposed of 3,820 cubic yards of contaminated soil and 72 drums of other hazardous wastes. In 1990, the EPA re-sampled the area and found that while original contaminant concentrations were lower, there were other contaminants (metabolites) present. Because of this sampling, the EPA installed additional monitoring wells and conducted further soil sampling. These samplings found that metabolites and DDT contaminants are present at a depth of twenty-eight feet below ground surface. Subsurface soil delineation work and groundwater toxicity tests are ongoing. *Id.* at 41–42.

139. *Id.* at 42 (citing Allan R. Woodward et al., *Low Clutch Viability of American Alligators on Lake Apopka*, 56 FlA. SCIENTIST 52 (1993)).

140. *Id.* at 42–43.

chlorine pesticides ("OCPs") and other substances were causing endocrine disrupting effects on fish, wildlife and humans.\textsuperscript{142} Although the exact cause of the abnormalities is not yet fully understood and scientific research is ongoing, many scientists believe there is a causal relationship between the spilled pesticides and the reproductive abnormalities in the Lake Apopka alligators.\textsuperscript{143}

B. The Restoration (The Shift Back to the Non-Eutrophic State)

1. The Challenge

By the 1980s Lake Apopka had become a hyper-eutrophic lake that was highly polluted, had little vegetation and virtually no game fish. The lake was thick with algae, which gave it a "pea green" appearance, and was not a lake on which the public desired to fish or boat.\textsuperscript{144} The previously popular fishing and recreational lake had turned into a lake that was no longer suited for any recreational activity.\textsuperscript{145} More significantly, however, the polluted lake water was flowing out of the lake into a series of other lakes, into the Ocklawaha River, and ultimately to the St. Johns River.\textsuperscript{146} Consequently, Lake Apopka was causing the other downstream lakes and rivers to become polluted. To address this concern, in 1985 the Florida Legislature passed The Lake Apopka Restoration Act, which directed SJRWMD to develop an environmentally sound, economically feasible method to restore Lake Apopka.\textsuperscript{147} Two years later in 1987, the Florida legislature passed Florida's Surface Water Improvement and Management ("SWIM") Act, which authorized Water Management Districts ("WMDs") to develop surface water improvement and management plans and programs for the water bodies identified on a priority list.\textsuperscript{148} The legislation identified Lake Apopka as a priority for restoration.\textsuperscript{149}

The primary pollutant causing the eutrophication of Lake Apopka was phosphorus, which typically is the primary element that must be restricted to reverse eutrophication in fresh waters.\textsuperscript{150} The substan-

\textsuperscript{142} See, e.g., Theo Colborn et al., \textit{Our Stolen Future} (1996).
\textsuperscript{143} Jan C. Semenza et al., \textit{Reproductive Toxins and Alligator Abnormalities at Lake Apopka, Florida}, 105 \textit{Envtl. Health Persp.} 1030, 1031 (1997).
\textsuperscript{144} Hoge et al., \textit{supra} note 117, at 25.
\textsuperscript{145} Id. at 37–38.
\textsuperscript{146} Id. at 65.
\textsuperscript{147} Id. at iii.
\textsuperscript{148} FLA. STAT. § 373.453 (2005).
\textsuperscript{149} Id. § 373.453(1)(c).
\textsuperscript{150} This is because the natural supply of phosphorous often is most limited relative to demand. Due to the historic over-supply of phosphorus, nitrogen limitation often is secondary. Cyanobacteria can fix atmospheric nitrogen if supplies of phosphorus and light are sufficient, thereby eliminating excess nitrogen from the aquatic system. First the submersed vegetation is shaded out. Later the rooted
tial loadings of phosphorus into the lake from the farmlands for several decades had caused the lake to switch to a highly eutrophic state. Eutrophication in lakes can have a number of significant consequences including oxygen depletion, loss of cold/deeper water fish and other animals, algal blooms and a shift in algal species to toxin-producing cyanobacteria, increases in low-oxygen tolerant "trash" fish, loss of shallow water vegetation through shading and other effects, taste and odor problems, and loss of aesthetic and recreational value. SJRWMD scientists determined that by dramatically reducing phosphorus loadings, it would be possible to decrease the phosphorus concentrations in the lake, thereby reversing the eutrophication trend. With lower phosphorus concentration would come lower levels of algae, greater water transparency, increased submerged aquatic vegetation which would provide fish habitat, increased game fish populations, and improved aesthetic and recreational conditions.

Reducing phosphorus loadings to the lake proved to be a challenging task. At the time that restoration efforts began, it was estimated that approximately eighty-five percent of the phosphorous loading to the lake was coming from the agricultural lands, with the remaining fifteen percent coming from a combination of atmospheric deposition, sewage treatment facilities, citrus process facilities, and other miscellaneous minor sources. Accordingly, restoration efforts focused on reducing the phosphorus inputs from farming. However, even if it were possible to completely eliminate all future phosphorus loading to the lake from the farms, the SJRWMD still had to address the problem of decades of polluting that had already occurred. In addition, the recycling of phosphorus already stored in lake bottom sediments could prolong recovery. Finally, SJRWMD scientists also were not certain of how quickly it would take algae to respond even if phosphorus levels were greatly reduced. Nevertheless, the decision was made to proceed with both regulatory and non-regulatory steps to reduce phosphorus loadings.

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152. LAKE APOPKA FACT SHEET, supra note 112, at 1.


A critical factor in developing a plan to reverse eutrophication by reducing phosphorus loadings is to determine the extent to which the loadings must be reduced to achieve the desired result. SJRWMD began developing what it referred to as a Pollutant Load Reduction Goal ("PLRG") for the lake. The setting of the PLRG for phosphorus in Lake Apopka was akin to establishing a total maximum daily load ("TMDL") pursuant to the federal Clean Water Act ("CWA"). The CWA requires that TMDLs be established for each waterbody not meeting state water quality standards. A TMDL represents the amount of loading of a particular pollutant that a particular waterbody can assimilate without resulting in a water quality standard violation.

To establish the appropriate PLRG, a number of steps needed to be taken. First, SJRWMD had to develop restoration goals. Next it had to identify the sources of all loadings and the extent of each source's contribution to the problem. Then, SJRWMD had to determine the target phosphorus concentration for the lake water that would meet the restoration goal. Finally, SJRWMD had to determine the loading target(s) necessary to meet the target concentration. Using these approaches, SJRWMD determined that the target steady-state phosphorus concentration in the lake water was 55 µg/l, and that to achieve such a con-

156. 33 U.S.C. § 1313(d)(1)(c) provides that "[e]ach State shall establish for the waters identified in paragraph (1)(A) of this subsection, and in accordance with the priority ranking, the total maximum daily load, for those pollutants which the Administrator identifies . . . as suitable for such calculation. Such load shall be established at a level necessary to implement the applicable water quality standards with seasonal variations and a margin of safety which takes into account any lack of knowledge concerning the relationship between effluent limitations and water quality." (emphasis added). In April 1998, several environmental organizations filed suit against the EPA for failing to identify Florida's water quality-limited waters and establish TMDLs. Florida Wildlife Fed'n Inc. v. Browner, No. 4:98-cv-00356-WS (N.D. Fla. Aug. 9, 1999). In August 1999, the EPA entered into a Consent Decree with the Environmental plaintiffs. Id. The Consent Decree was approved by Court and adopts the Florida DEP's 13-year rotating basin schedule for establishing TMDLs for all water quality-limited segments in Florida. Id.
158. Id.
To sufficiently reduce the phosphorus loadings to the lake and to adequately decrease the phosphorus concentration in the lake to the necessary levels, SJRWMD developed a multi-faceted approach. The approach included both regulatory and non-regulatory components. As described in detail below, SJRWMD's approach evolved over time in response to new information, legal challenges, and experiential learning. Ultimately, the restoration strategy involved eliminating phosphorus discharges from farms by taking farms out of production, converting farm lands back into wetlands, reducing available stored phosphorus by harvesting Gizzard Shad, removing stored phosphorus by wetland filtration, and promoting the reestablishment of beneficial rooted plants by a combination of planting and fluctuating water levels.

2. The Regulatory Approaches

At the same time that SJRWMD was developing plans to remove nutrients from the lake water, the agency also was trying to find a way to reduce new nutrient inputs to the lake from the surrounding agricultural lands. To achieve the necessary levels of phosphorus reduction, both in terms of decreasing future loadings and removal of phosphorus already in the lake water, SJRWMD developed a number of regulatory strategies. Initially SJRWMD sought to reduce phosphorus loadings from the farms through regulatory means aimed at forcing farm owners to treat wastewater in treatment ponds prior to discharging it back into the lake. Starting in the 1980s, SJRWMD attempted to impose such regulatory requirements through negotiated consent orders with farms. While some farms voluntarily agreed to subject themselves to regulation rather than face potential enforcement actions, others were not as cooperative. Thus, by the 1990s only a small amount of the total wastewater discharge was being treated prior to discharge back into the lake. Consequently, SJRWMD next sought to impose stringent restrictions on wastewater discharge through promulgation of a new regulation. Because Florida did not have numerical water quality standards for nutrients, enforcement against recalcitrant polluters proved to be difficult, if not impossible.
Thus, the agricultural wastewater entering the lake in the late 1980s and early 1990s continued to contain high levels of nutrients. In 1994, SJRWMD proposed a rule that would require the farms to treat their agricultural wastewater to a specified level prior to discharging into the lake.\textsuperscript{163} The basis for the rule was to address the hyper-eutrophic nature of the lake by reducing the nutrient loading to the lake from the farms.\textsuperscript{164} The rule would require dischargers within the Apopka basin to obtain a permit for their discharges.\textsuperscript{165} The rule also established a maximum number of pounds of phosphorous per year which could be discharged into Lake Apopka from controllable sources ("nutrient limitation").\textsuperscript{166} The nutrient limitation was allocated to several source categories including "pumped agriculture." Collectively, pumped agriculture would be limited to discharging 10,351 pounds of phosphorus per year.\textsuperscript{167} To meet its allocation, the Zellwood Drainage and Water Control District ("Zellwood"),\textsuperscript{168} one of the largest dischargers, would have to reduce its yearly phosphorus discharge from 40,675 pounds to 6,873 pounds.\textsuperscript{169}

Because the State of Florida did not have a numeric water quality standard for nutrients, SJRWMD relied on the state's narrative water quality standards for nutrients\textsuperscript{170} and transparency,\textsuperscript{171} which SJRWMD alleged were being violated due to the high levels of algae in the lake.\textsuperscript{172} The rule established a numeric phosphorus concentration of fifty-six parts per billion ("ppb") that would have to be met to assure compliance with the narrative water quality standards. The concentration was developed using a combination of measurements of phosphorus concentrations in reference lakes that were not eutrophic and modeling to predict the effect of various phosphorous loadings.\textsuperscript{173} By

\textsuperscript{163} Zellwood, 1995 WL 1052911, at *6.
\textsuperscript{164} Id.
\textsuperscript{165} Id. at *3.
\textsuperscript{166} Id.
\textsuperscript{167} Id. at *2.
\textsuperscript{168} Zellwood Drainage and Water Control District is a legislatively created water control district authorized to provide drainage and water supply for farms within the District's jurisdiction. Id. at *3.
\textsuperscript{169} Id.
\textsuperscript{170} Florida's narrative water quality standard for nutrients provided that "[i]n no case shall nutrient concentrations of a body of water be altered so as to cause an imbalance in natural populations of flora and fauna. Fla. Admin. Code Ann. r. 17-302.530(48)(b) (1994)."
\textsuperscript{171} Florida's narrative water quality standard for transparency provided that "[d]epth of compensation point for photosynthetic activity shall not be reduced by more than one percent as compared to natural background. Fla. Admin. Code Ann. r. 17-302.530(68). The "compensation point for photosynthetic activity" is the depth at which one percent of the light intensity at the surface remains unab- sorbed. Fla. Admin. Code Ann. r. 17-302.200."
\textsuperscript{172} Zellwood, 1995 WL 1052911, at *3
\textsuperscript{173} Id. at *4.
developing an external nutrient budget by measuring inputs and outputs of all sources of phosphorous over four years, SJRWMD was able to determine the amount of phosphorus from all sources that could be put into the lake to allow the lake to achieve water quality standards. By subtracting the amount of phosphorus from uncontrollable sources for the total allowable loading, SJRWMD determined the amount of phosphorus from controllable sources that could be added to lake without violating water quality standards. This number was the nutrient limitation that was imposed on the agricultural discharges.

Zellwood challenged the rule alleging it was arbitrary and capricious. Zellwood had previously refused to sign a consent order agreeing to construct water treatment ponds. To meet the requirements of the proposed rule, Zellwood would have to use 800–1,200 acres of its 8,700 acres as a wastewater treatment pond. Zellwood argued that the farms were not the primary source of the eutrophication problem and that many natural and unnatural historic events contributed to the existing water quality standard violation. Zellwood also argued that the method used by SJRWMD to reach the fifty-six ppb standard was arbitrary and capricious, that SJRWMD used the wrong sedimentation coefficient because it ignored certain samples, that SJRWMD's sampling for atmospheric deposition and loading from spring was improper, that SJRWMD's failure to address internal loadings was arbitrary and capricious, that SJRWMD exceeded its grant of rulemaking authority, and that the proposed rule enlarged, modified or contravened the law.

The Administrative Law Judge ("ALJ") found in favor of SJRWMD on some issues and in favor of Zellwood on other issues. Specially, the ALJ found that SJRWMD's method for determining the fifty-six ppb standard was not arbitrary and capricious, that the model used by SJRWMD was appropriate and was not arbitrary and capricious, that SJRWMD's sampling for atmospheric deposition was reasonable, that SJRWMD's estimation of loading from spring was not unreasonable, that it was not necessary to address internal loadings because limiting external loading is sufficient to meet water quality standards, and that there was no showing that compliance with the rule would be economically infeasible. However, the ALJ found in favor of Zellwood on certain critical issues. Specifically, the ALJ found that it was arbitrary and capricious for SJRWMD not to take into account all

174. Id. at *5.
175. Id.
176. Id.
177. Id. at *6.
178. Id. at *17.
179. Id. at *31.
sample sites in determining whether an increase in the muck layer had occurred between 1968 and 1987, and this caused an underestimation of the sediment coefficient per year.\textsuperscript{181} Most significantly, however, the ALJ found that SJRWMD did not have the legal authority to establish basin-wide water quality standards because under Florida law, the setting of water quality standards is within the sole purview of the Florida Department of Environmental Protection ("DEP").\textsuperscript{182} Thus, the ALJ concluded that SJRWMD exceeded its grant of rulemaking authority and modified and enlarged the law in violation of Florida law and accordingly, the rule could not stand.\textsuperscript{183}

In response to SJRWMD's failed attempt to regulate phosphorus discharges entering Lake Apopka from the surrounding farms, the Florida legislature passed a new law in 1996 which expressly granted SJRWMD the legal authority to regulate such discharges.\textsuperscript{184} In this statute, the legislature made clear that it intended to accelerate the restoration process that had begun as a result of the SWIM program.\textsuperscript{185} To accelerate the restoration, the legislature directed the SJRWMD to take a number of actions, including purchasing the farm properties, developing a phosphorous discharge limitation to bring the lake into compliance with state water quality standards, and to establish a numerical phosphorous criterion by which to measure compliance with such water quality standards.\textsuperscript{186} The legislation established a phosphorus criterion of fifty-five ppb, which would apply if the SJRWMD failed to adopt a rule establishing a different criterion.\textsuperscript{187} The legislation further provided that the state would share in the costs of the construction of any necessary stormwater treatment facilities to treat discharge from the farming operations.\textsuperscript{188}

After the legislature directed SJRWMD to purchase the farmlands and establish a nutrient limitation for phosphorus, SJRWMD revised its restoration plan to focus on purchase of farmlands and conversion farmlands to wetlands to reduce phosphorus inputs, reducing the availability of stored phosphorus by removing Gizzard Shad,\textsuperscript{189} removing stored phosphorus by wetland filtration through a constructed

\textsuperscript{181.} Id. at *16–17.
\textsuperscript{182.} Id. at *27.
\textsuperscript{183.} Id. (citing FLA. STAT. § 120.52(8)(b) & (c) (2005)). On appeal, Florida's First District Court of Appeals affirmed the ALJ's order. St. Johns River Water Mgmt. Dist. v. Zellwood Drainage & Water Control Dist. 677 So. 2d 342 (Fla. Dist. Ct. App. 1996).
\textsuperscript{184.} FLA. STAT. § 373.461 (2005).
\textsuperscript{185.} Id. § 373.461(1)(a).
\textsuperscript{186.} Id. § 373.461.
\textsuperscript{187.} Id. § 373.461(3).
\textsuperscript{188.} Id. § 373.461(4).
\textsuperscript{189.} Hoge, supra note 117, at 86.
marsh flow-way, promoting beneficial rooted plants by planting and by fluctuating water levels.190

3. The Marsh Flow-Way

In 1987, SJRWMD developed the idea of creating a “marsh flow-way,” to act as a nutrient removal system for lake water.191 The concept involved taking a portion of farmland and restoring it as marsh.192 The marsh flow-way was designed with a series of “cells,” through which water gravity-fed from the lake would flow before returning to the lake.193 As lake water travels through the marsh flow-way, nutrients bound to particulate matter will settle out into the marsh.194 The marsh flow-way that was ultimately constructed was designed to treat approximately seventy-five percent of the lake water per year.195 In 1988, the first $5 million was appropriated for acquisition of the land where the marsh flow-way would be constructed.196 In that same year, DEP delegated the authority to regulate agricultural discharge into Lake Apopka to SJRWMD.197 In 1989, the second $5 million was appropriated for marsh flow-way land acquisition and SJRWMD began construction of the marsh flow-way demonstration project.198 In 1990, the final $5 million was appropriated for marsh flow-way land acquisition.199 Also in 1990, SJRWMD began operation of the 1,850 acre marsh flow-way demonstration project.200 One obstacle SJRWMD faced in the restoration was that due to decades of farming on the previous marshes, approximately six feet of soil had

190. LAKE APOPKA FACT SHEET, supra note 112, at 1.
191. HOGE ET AL., supra note 117, at 86.
192. Id.
193. Id.
194. Id. The concept for the marsh flow-way was developed in two scientific papers: Edgar F. Lowe et al., Potential Role of Marsh Creation in Restoration of Hypertrophic Lakes, in CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT: MUNICIPAL, INDUSTRIAL & AGRICULTURAL 710 (Donald A. Hammer ed., 1989); and Edgar F. Lowe et al., Particulate Phosphorus Removal via Wetland Filtration: An Examination of Potential for Hypertrophic Lake Restoration, 16 ENVTL. MGMT. 67 (1992). Examination of the performance of the demonstration flow-way can be found in M. F. Coveney et al., Nutrient Removal From Eutrophic Lake Water by Wetland Filtration, 19 ECOLOGICAL ENGINEERING 141 (2002); M. F. Coveney et al., Performance of a Recirculating Wetland Filter Designed to Remove Particulate Phosphorus for Restoration of Lake Apopka (Florida, USA), 44 WATER SCI. & TECH. 131 (2001).
195. It now appears that the flow-way is actually treating approximately fifty percent of the lake water annually.
196. HOGE ET AL., supra note 117, at 172.
197. Id. at 307.
198. Id. at 184.
199. Id. at 8.
200. Id. at 134.
been lost to oxidation and erosion.\textsuperscript{201} Thus, if SJRWMD were to simply reconnect the lake with the farmlands, the farmlands would become open-water areas rather than the shallow marsh that they were historically. Consequently, SJRWMD decided to leave the levees intact and to simply re-hydrate the farmlands back to a shallow marsh condition.\textsuperscript{202} Once the water has traveled through the flow-way, the clear water is returned to the lake.\textsuperscript{203} In designing the flow-way, it was critical for SJRWMD scientists to determine the exact proper speed for the water to flow through.\textsuperscript{204} If the speed was not right, phosphorus in the soil would leach into the water causing it to be even more nutrient-laden.\textsuperscript{205} To determine this exact right speed, it was necessary for the scientists to experiment and incorporate the results of the experiments into the design.

The marsh flow-way has proven to be a success. In 2003, the completed 760-acre marsh flow-way began operation, and by December 2008, the equivalent of two lake volumes had been filtered through the system, removing suspended solids, nitrogen and phosphorous.\textsuperscript{206} Since November 2003, almost 31 million pounds of suspended solids, 20,000 pounds of phosphorus and 685,000 pounds of nitrogen have been removed by the flow-way.\textsuperscript{207}

\textbf{4. The Gizzard Shad Removal Program}

One of the more creative solutions that SJRMWD staff came up with, which turned out to be one of the most significant parts of the restoration project, was to remove large quantities of a native fish—Gizzard Shad—which was dominating the eutrophic lake.\textsuperscript{208} Gizzard Shad thrive in cloudy turbid waters.\textsuperscript{209} In a clear non-eutrophic lake in Florida, Gizzard Shad make up approximately five to ten percent of the total biomass of the lake.\textsuperscript{210} The harvesting of Gizzard Shad helps to reverse eutrophication in a number of ways. It reduces recycling of phosphorus caused by bottom feeding, reduces turbidity caused by bottom disturbance, removes phosphorous in fish bodies, and may in-

\begin{itemize}
\item \textsuperscript{201} Id. at 34.
\item \textsuperscript{202} Id.
\item \textsuperscript{203} Id. at 84.
\item \textsuperscript{204} Edgar Lowe, St. Johns River Water Mgmt. Dist., Address at the Universoty of Florida Levin College of Law (Apr. 3, 2007).
\item \textsuperscript{205} Id.
\item \textsuperscript{206} JOSH SWEIGART, Ocklawaha Rebounds, STREAMLINES, Fall 2005, http://www.sjrwmd.com/streamlines/2005fall/.
\item \textsuperscript{208} HOGE, supra note 117, at 86.
\item \textsuperscript{209} Id.
\item \textsuperscript{210} Gianfranco Basili, St. Johns River Water Mgmt. Dist., Address at the University of Florida Levin College of Law (Jan. 30, 2007).
\end{itemize}
crease cropping of algae by zooplankton.\textsuperscript{211} By the time the restoration began in Lake Apopka, the lake’s biomass consisted of more than ninety percent Gizzard Shad.\textsuperscript{212} SJRWMD recognized that the Gizzard Shad were contributing to maintaining the lake in a eutrophic state. In other words, the fish were contributing to the resilience of the eutrophic lake, by feeding on the lake bottom, and defecating in the water, thereby introducing phosphorus that had previously been bound in the bottom sediments back into the water column.\textsuperscript{213}

The Gizzard Shad removal program has proved to be one of the most effective phosphorus removal tools. Harvesting has been occurring since 1993. Between 1993 and 2007 SJRWMD removed more than fifteen million pounds of Gizzard Shad, with 4,545,258 pounds being removed from 2002 to 2006 alone.\textsuperscript{214} One million pounds of Gizzard Shad represents approximately 34,000 pounds of phosphorus.\textsuperscript{215} Because the TMDL for Lake Apopka is 35,000 pounds of total phosphorus per year, one million pounds of Gizzard Shad accounts for almost the entire allowable phosphorus load. Thus, removal of the Gizzard Shad is a critical factor in reaching the TMDL. By removing the shad, more than 100,000 pounds of phosphorous contained in the Gizzard Shads’ bodies was removed and the transfer of phosphorus from bottom sediments to the water column, due to Gizzard Shad feeding in the lake sediments and defecating in the water, was greatly reduced.\textsuperscript{216} As the lake shifts back to a non-eutrophic state, predatory fish will come back and will feed on Gizzard Shad, helping to return their numbers to the five to ten percent of biomass found in non-eutrophic lakes. The success of the Gizzard Shad removal program in dramatically reducing phosphorus from the lake has contributed to water quality improvements which have been followed by growth of submerged plants. More than 350 new eelgrass beds have been established in the lake.

\textsuperscript{211} Hoge \textit{et al.}, supra note 117, at 86.

\textsuperscript{212} Gianfranco Basili, St. Johns River Water Mgmt. Dist., Address at the University of Florida Levin College of Law (Jan. 30, 2007).

\textsuperscript{213} Hoge \textit{et al.}, supra note 117, at 86.

\textsuperscript{214} Lake Apopka Fact Sheet, supra note 112, at 2.

\textsuperscript{215} Gianfranco Basili, St. Johns River Water Mgmt. Dist., Address at the University of Florida Levin College of Law (Jan. 30, 2007).

\textsuperscript{216} An interesting problem SJRWMD faced in its shad removal project was what to do with the removed fish. Natural resource management agencies typically are not called upon to find markets for fish. The only viable market SJRMWD could find for the fish was for crayfish and crab bait, but the market is not sufficient to cover the costs of shad removal and SJRWMD must pay for this. SJRMWD un-successfully attempted to promote shad fish in other markets, such as the pet food market. \textit{See, e.g.}, Charles C. Thomas, St. Johns River Water Mgmt. Dist., Rough Fish Market Survey: Final Report (1991), available at http://www.sjrwmd.com/technicalreports/pdfs/SP/SJ91-SP2.pdf.
An existing legal barrier to the SJRWMD’s planned Gizzard Shad removal program was that in 1994 the Florida constitution was amended to ban gill net fishing.217 Gizzard Shad are harvested through gill netting.218 Thus, to implement this aspect of the restoration project, SJRWMD had to obtain special permission for the Florida Fish and Wildlife Conservation Commission (“FWCC”) to use gill nets in its shad harvesting. SJRWMD was able to obtain such permission provided it abided by specified requirements to minimize by-catch.219

5. The Conversion of Farmlands Back to Wetlands

As described above, after SJRWMD’s loss in the rule challenge case, the Florida legislature decided to take action to force the lake restoration.220 This time, instead of merely directing the SJRWMD to develop a plan to restore the lake, the legislature gave SJRWMD the clear legal authority to regulate discharges to the lake. Moreover, the legislature directed SJRWMD to purchase the farmlands and take them out of agricultural production.221 In doing so, the greatest source of phosphorus loading to the lake would be completely eliminated, not merely reduced via water treatment ponds.222 However, the legislation did not identify the source of the funding to purchase the lands. As a fallback position, the statute provided that if SJRWMD was not able to obtain the funding necessary to purchase

217. FLA. CONST. art. X, § 16.
219. HOGE ET AL., supra note 117, at 400 (citing J.E. CRUMPTON, FLA. FISH & WILDLIFE CONSERVATION COMM’N, EXPERIMENTAL GILL NETS IN LAKE APOPKA (2000)).
221. HOGE ET AL., supra note 117, at 77.
222. See FLA. STAT. § 373.461. Although the purchase of the farmlands did eliminate agricultural discharges, relatively high rates of phosphorus loading still occur for two reasons. First, there is an ongoing need to pump to maintain desired water levels in recreated wetlands. Because the farmlands subsided by more than a meter in most places, water levels in these wetlands can only be kept suitably shallow by pumping excess water to the lake; this will load phosphorus to the lake. As flooding continues, some legacy phosphorus will be incorporated into refractory compounds and some will be flushed from the system. Since further production of soluble phosphorus from decomposition of organic matter is slowed in flooded soils, phosphorus release will gradually subside, eventually enough to meet the TMDL. Although SJRWMD treats discharges to the lake with alum, treatment is not 100% effective, some of the alum floc enters the lake, and some portion of the alum-bound phosphorus may be released. Second, SJRWMD continues to keep some fields dry to prevent exposure of wetland birds to the OCPs. Organic material in the dry soil oxidizes and frees organically-bound phosphorus. This creates new stores of available phosphorus. As remediation is completed, the areas presently kept dry will be flooded. E-mail from Edgar Lowe, St. Johns River Water Mgmt. Dist., to Mary Jane Angelo, Assoc. Professor of Law, Univ. of Fla. Levin Coll. of Law (Jan. 9, 2009) (on file with author).
the farmlands, there would be a cooperative effort to construct a 600–700 acre pond to treat the agricultural wastewater.223 Funding for the estimated $6 million construction project would come from a combination of sources including from the farmers, SJRWMD and the legislature.224 SJRWMD was ultimately able to secure funding for the farm buy-out.225 The buy-out involved twenty-six different property owners. Total purchase costs exceeded $100 million. The funding for the buy-outs came from both Florida’s Preservation 2000 land acquisition program and from the Federal Wetlands Reserve Program (“WRP”).

In 1996, SJRWMD purchased more than $46 million worth of farmlands. While $20 million came from the state, SJRWMD was able to obtain $18.5 million from the federal government’s WRP, a program designed to restore converted wetlands back to their previous state.226 Because the Lake Apopka project was one of the first major WRP purchases, the WRP program did not yet have established rules or procedures. What turned out to be a major shortcoming in the WRP at that time was that it was assumed that individual ESA consultations for each restoration project would not be necessary because WRP staff believed that all of the projects would be covered by a programmatic consultation that had been conducted on the WRP as a whole.227

Prior to purchasing any of the farmlands, SJRWMD conducted environmental site assessments.228 If significant contamination was discovered, SJRWMD required the seller to clean up the property prior to the purchase.229 In response to the site assessments, approximately 33,000 tons of soil was removed by the landowners, for a total remediation cost of more than $1.4 million.230 The environmental assessments revealed low levels of contamination over most of the farm fields tested, with higher concentrations in areas of the fields that had been used for the mixing and loading of pesticides. The federal partners in the WRP agreed to go forward with the purchases provided that SJRWMD conducted a risk assessment to determine what level of risk would be acceptable.231 SJRWMD conducted soil sampling on
portions of the land to be flooded and used the data to conduct the risk assessment on which the WRP partners signed off.\textsuperscript{232} The conclusion of the risk assessment was that the risk posed by OCPs could be managed through wetland creation and natural attenuation.\textsuperscript{233} Although the scientists had concerns that the lower concentrations of pesticide residues in the field could pose a risk, the best scientific judgment based in part on information from the scientific literature regarding how pesticides act in the environment and are metabolized by fish and wildlife, the scientists concluded that the risks were not significant and the project could proceed.\textsuperscript{234}

By August 1998, the SJRWMD, in partnership with the WRP, had purchased most of the farms on the north shore of Lake Apopka.\textsuperscript{235} SJRWMD’s plan was to reflood the farmlands to mimic their pre-agricultural wetland state. Ultimately, SJRWMD planned to treat the fields with alum prior to reflooding to trap excess phosphorus before it entered the water column.\textsuperscript{236} The farmers in Unit 2, a 6,000 acre area on the northeast side of the lake, were asked to leave their fields shallowly flooded following their final crop harvest in the summer of 1998.\textsuperscript{237} Short-term shallow flooding before pumping wastewater back into the lake was standard farming practice at the end of each year’s growing season.\textsuperscript{238} Historically, during late summer and early fall some farmers flooded their fields to minimize soil subsidence and erosion and to control nematodes.\textsuperscript{239} This pumping covered the area with approximately eighteen inches of water for up to six weeks.\textsuperscript{240} The shallow-water habitats created by the flooding attracted large numbers of shorebirds, wading birds and other aquatic species.\textsuperscript{241} Even though the decades of farm flooding in late summer and early fall coincided with shorebird migration and many birds visited the

\textsuperscript{232} ATRA, INC., ST. JOHNS RIVER WATER MGMT. DIST., ENVTL. RISK ASSESSMENT OF A LAKE APOPKA MUCK FARM WETLANDS RESTORATION, available at http://sjr.state.fl.us/technicalreports/pdfs/SP/SJ98-SP7.pdf [hereinafter ENVTL. RISK ASSESSMENT]. In addition to the federal partner’s agreement with risk assessment, the Florida Department of Environmental Protection also agreed to the conclusions of the risk assessment. E-mail from Edgar Lowe, St. Johns River Water Mgmt. Dist., to Mary Jane Angelo, Assoc. Professor of Law, Univ. of Fla. Levin Coll. of Law (Jan. 9, 2009) (on file with author).

\textsuperscript{233} ENVTL. RISK ASSESSMENT, supra note 232, at 4.

\textsuperscript{234} HOGE ET AL., supra note 117, at 89.

\textsuperscript{235} Id. at 146.

\textsuperscript{236} Edgar Lowe, St. Johns River Water Mgmt. Dist., Address at the University of Florida Levin College of Law (Apr. 3, 2007).

\textsuperscript{237} Id.

\textsuperscript{238} Id.

\textsuperscript{239} HOGE ET AL., supra note 117, at 146.

\textsuperscript{240} Id.

\textsuperscript{241} Id. (citing P.W. Sykes, Jr. & G.S. Hunter, Bird Use of Flooded Agricultural Fields During Summer and Early Fall and Some Recommendations for Management, 6 FLA. FIELD NATURALIST 36–43 (1978)).
flooded fields for decades, there had never been any reports of bird die-offs during previous flooding. In 1998, however, because the lands would no longer be farmed, the water was allowed to remain on the farms through the fall and into the winter. By eliminating the post-season pumping, the influx of phosphorous and pesticides to the lake would be reduced, and the growth of terrestrial vegetation on the farm fields would end.

The fields were to be drained during the winter and treated to prevent phosphorus release. The late summer weather and farming conditions of 1998 were similar to previous years. However, as water levels began to rise with seepage and rainfall, and as fields remained flooded into late fall and early winter, more and more birds arrived. In December, the Audubon Christmas Bird Count ("CBC") documented more than 46,000 birds consisting of 174 species—the highest recorded species diversity at an inland site in North America in the 100-year history of the CBC. More than 3,500 American white pelicans were seen on a single day in December 1998 in the former farming area—an unprecedented number.

Lake Apopka is one of the most diverse areas for birds of any place in the southeast U.S. For example, the total species list for Lake Apopka is 336, as compared to the only slightly longer list of 343 species for the Florida Everglades. Because Lake Apopka is located in a migratory flyway, it is on the path of many thousands of migratory birds. Birders and scientists alike were excited about what promised to become one of the premiere birding sites in the world.

Excitement over bird diversity was tempered by the first reported mortalities of American white pelicans in November 1998. Over the next four months, 676 birds, including 441 American white pelicans, 58 great blue herons, 43 wood storks, 34 great egrets and smaller numbers of 20 other bird species died on-site. The deaths

242. Id.
243. Id.
244. Id.
245. Id.
246. Id.
247. Id.
248. Id.
249. Id.
251. Id.
252. NATURAL RESOURCE DAMAGE AND RESTORATION PLAN, supra note 122, at 10. The first signs of the die-off appeared on November and December of 1998. The major die-offs occurred in January and February of 1999. A total of 676 birds died on the site itself. The in-site deaths included: 441 American White Pelicans; 43 Wood Storks (a federally-listed species); a total of 135 Herons and Egrets (7 spe-
were attributed to OCP poisoning.253 Most of the poisoned birds were fish-eating birds.254 It is believed that as the farm fields were flooded, fish left the canals adjacent to the fields and swam into the flooded fields where they were contaminated by OCPs, such as DDT and its breakdown products DDE, toxaphene, dieldrin, and chlordane.255 Although farm fields had been flooded regularly for years without ill-effect, in the past the fields were not flooded during the winter months and white pelicans are only in Florida during the winter months.256 It is interesting to note that most of these OCPs were banned by the EPA in the 1970s or 1980s.257 The EPA cancelled the registration of DDT in 1972,258 the registration for most uses of dieldrin in 1969, the registration for most uses of chlordane in 1978, and the registration for most uses of toxaphene in 1982.259 However, when toxaphene was banned for most uses in 1986, the EPA allowed its continued use on corn at Lake Apopka.260 Thus, pesticides that were banned by the EPA decades ago are still causing environmental harms and must be considered during any agricultural restoration project.

Avian injuries include both lethal effects in the form of mortality (i.e., birds found dead on-site), and sub-lethal losses based on adverse

253. HOGE ET AL., supra note 117, at 146.
254. Id. at 309.
255. Id. at 43–44.
256. Id.
259. The registrations for all remaining uses of dieldrin were cancelled by 1982, the registrations for all remaining uses of chlordane were cancelled by 1988, and the registrations for all remaining food crop uses of toxaphene were cancelled by 1993. U.S. Envt'l Prot. Agency, Persistent Organic Pollutants: A Global Issue, A Global Response, http://www.epa.gov/international/toxics/pop.htm#domestic (last visited Jan. 13, 2009).
260. Id.
reproductive effects of on-site exposure to organo-chlorines for two generations.  

These sub-lethal effects could be experienced by the birds after they have left the North Shore Restoration Area ("NSRA") and the Lake Apopka area, but are virtually un-traceable. Total losses sustained by the birds at the NSRA are estimated to be 5,213 "bird-years," a measure that incorporates the losses sustained by both adult birds and their progeny over time. At the onset of the bird deaths in the fall of 1998, SJRWMD began draining the site. Pumping accelerated in January 1999, and by mid-February 1999, the entire north shore farming area had been drained. Since then, the fields have been kept dry and have become vegetated with upland grasses, herbs, and shrubs.

Analysis of soils and birds showed that the lake resources and specifically the NSRA were mainly contaminated by OCPs. Commonly applied to agricultural lands for decades, OCPs include chemicals such as dichlorodiphenyltrichloroethane ("DDT"), toxaphene, dieldrin, and chlordane. Flooding the fields caused these contaminants to become available for accelerated bioaccumulation to the birds which, according to the FWS constituted a release that was not exempt under the pesticide provisions of the Comprehensive Environmental Response, Compensation, and Liability Act ("CERCLA").

Documented effects of these compounds on avian species include "behavioral changes, reproductive impacts, and death." Although other compounds such as polychlorinated biphenyls ("PCBs") and heavy metals (e.g., cadmium, copper, and lead) were also detected, "concentrations were low and any adverse effects sustained by birds due to exposure to these other chemicals were considered small compared to the effects of OCPs." Therefore, the FWS considered the bird deaths to be a result of exposure to OCPs in the area.

Birds at the NSRA experienced injury due to the lethal effects of exposure to OCPs. Some birds present on-site during the incident may have experienced sub-lethal, reproductive effects as a result of

261. NATURAL RESOURCE DAMAGE AND RESTORATION PLAN, supra note 122, at 5.  
262. Id.  
263. Id. at 5–6.  
264. Hoge et al., supra note 117, at 146.  
265. Id.  
266. Id.  
267. Id. at 146–49.  
269. NATURAL RESOURCE DAMAGE AND RESTORATION PLAN, supra note 122, at 8.  
270. Id.  
271. Id.  
272. Id.
exposure to these same contaminants.273 The lethal effects of OCP exposure are immediately evident in the large avian die-offs that occurred; over 670 birds were found dead on-site between November 1998 and April 1999.274 “Chemical analyses of a sub-set of birds that died during the event showed that most individuals had concentrations of OCPs in their tissues that have been documented, in published studies, to be lethal to other avian species.”275 OCPs are considered to be the primary causative factor in, or the cause of, death for many of the birds found in the NSRA.276 “Losses due to all bird deaths are evaluated based on the life history information of American white pelican[s], wood stork[s], and great blue heron[s] . . . .”277 In addition to lethal effects, potential reproductive effects as a result of the exposure of adult birds to the OCP dichlorodiphenyl dichloroethylene (“DDE”) are a concern.278 In general, OCPs can cause a range of adverse effects on birds, including effects on reproduction, eggshell thinning, and physiological function.279 Losses due to sub-lethal effects and reproductive effects are determined based solely upon exposure to and accumulation of DDE, the most common and most toxic metabolite of DDT.280 In addition to the large body of scientific, peer reviewed literature documenting the effects of DDE on birds, avian adverse effects thresholds are lower for DDE than for most other OCPs found on-site. Therefore, it is expected that measuring losses using DDE thresholds will incorporate losses due to other OCP compounds.281

Shortly after discovering the bird deaths, scientists from SJRWMD, FWS, and the Florida Audubon Society, began working together to try to determine what was causing the bird deaths and what should be done to address the problem.282 However, once the U.S. Justice Department (“DOJ”) initiated its criminal investigation into the bird deaths, cooperation ceased.283 The federal government went into criminal investigation mode and the scientists were no longer able to work together or to share information. The DOJ seized all of

273. Id. at 5.
274. Id. at 9.
275. Id. (citing D.J. Call et al., DDE Poisoning in Wild Great Blue Heron, 16 BULL. ENVTL. CONTAMINATION & TOXICOLOGY 310 (1976)).
276. Id.
277. Id.
278. Id. at 11.
279. Id. (citing L.J. Blus et al., Brown Pelican: Population Status, Reproductive Success, and Organochlorine Residues in Louisiana, 1971-1976, 22 BULL. ENVTL. CONTAMINATION & TOXICOLOGY 128 (1979)).
280. Id. at 12.
281. Id.
283. Id.
the bird carcasses as evidence so that the scientist no longer had access to them to conduct testing to determine the cause of death. The criminal investigation hindered the ability of scientists and environmental managers to be able to cooperate to determine what steps should be taken to address the problem and prevent further harm. After years of investigation and more than two years of legal negotiations, the DOJ and SJRWMD reached a settlement agreement. The settlement is a global agreement that addresses the criminal issues under the ESA, MBTA, and BGEPA, as well as civil natural resources damages under CERCLA.

On October 8, 2003, SJRWMD and the United States entered into a Memorandum of Understanding ("MOU") to resolve the criminal and civil issues related to the bird kill. The MOU addresses both the civil and criminal issues involving CERLCA, the ESA, the MBTA, and the BGEPA and resolves the federal investigation as to both the SJRWMD and its employees. The MOU sets forth a number of processes governing future action by the SJRWMD. First, the MOU, sets up a clear framework for conducting ESA consultations for actions that may affect listed species. Second, the MOU contains an Avian Protection Plan ("APP"), which will guide SJRWMD's land management activities to avoid or minimize impacts to migratory birds. Under the MOU, SJRWMD will compensate for damages to

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284. Id.
285. SJRWMD MOU, supra note 268.
286. Id.
287. Id.
288. Id.
289. Id.
290. Pursuant to the APP, SJRWMD is required to address thirty-eight management areas related to the Migratory Bird Treaty Act and the Bald and Golden Eagle Protection Act. The APP covers projects within the thirty-eight management areas that will "more than minimally" alter the condition of land or vegetation, and therefore the habitat value and bird use of those areas. Each project was then assigned a potential avian impact level—low, medium, or high—to determine where risk minimizing efforts should be concentrated. The impact levels are based primarily on the contaminants found at the site. Each project is then given a project description, a definition of the habitat prior to start of the project, a predicted definition of the habitat upon completion of the project, a description of the avian use of the area, a prediction of the potential effect of the project on avian composition, a risk assessment and, finally, a plan of action for minimizing risks and impacts on habitat. Finally, the APP includes a Post-Project Monitoring Plan and a Contingency Plan. The Post-Project Monitoring Plan covers projects with a high potential impact level that is not significantly offset by the project design. In those cases, the birds on site will be monitored on a regular basis. SJRWMD will report any sick, injured or dead birds to the USFWS within forty-eight hours, in accordance with the MOU. Further, SJRWMD will report any large die-offs of amphibians, as indicative of poor system health. The Contingency Plan will be used if monitoring identifies early warning signs of a bird die off (birds acting strangely, not responding to loud noises or human activity, wob-
natural resources by purchasing, preserving and managing land containing a major wood stork rookery. The rookery site purchased by the SJRWMD is an 8,465-acre property that contains approximately 150 wood stork nests, making it the second largest breeding colony of wood storks in northeast Florida. The site includes five miles of frontage along the Matanzas River and its acquisition creates a nearly 16,000 acre conservation area. SJRWMD contributed $10 million to the purchase price of the site. This property provides multiple restoration benefits, including protection for a breeding colony of the endangered wood stork, and habitat for a myriad of other bird species such as American white pelican and great blue heron. The MOU also requires SJRWMD to do employee training on federal laws that protect avian wildlife and to participate in a number of cooperative efforts with wildlife agencies.291

Subsequent to the extensive soil testing and research that occurred in response to the bird kills, SJRWMD has experimented with a variety of remediation plans for the portions of the farmlands that have unacceptable levels of pesticide residue.292 Based on the new research, SJRWMD's plan is to restore farmlands to vegetated marshes rather than open-water to reduce the risk of future poisonings.293 To reduce pesticide levels in areas that exceed acceptable levels, SJRWMD has tested a variety of remediation methodologies including removing soil and bringing in clean soil to replace it, a "soil blending" approach in which the top several feet of soil are mixed to dilute the pesticide levels in the higher strata of the soil, and using a special plow which takes the top two to four feet of soil and flips it over so that the contaminated portion of the soil is buried.294 By 2005, SJRWMD had begun to re-flood a portion of the former farmland along the north shore.295 In the late 1980s, the concentration of phosphorus in Lake Apopka was more than 200 ppb.296 In the mid-1990s, after initiating the Gizzard Shad harvesting program and the marsh-flow way project, the concentration had decreased to approximately 150 ppb.297

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291. SJRWMD MOU, supra note 268.
293. Id. at 149.
294. Land Management Plan, supra note 250, at 56. The total project is 5,050 acres, including 4,150 acres of wetlands. Id.
297. Id.
6. Regulating for the Future

Resolution of the avian mortality incident and plans to complete the marsh flow-way and re-flood the farmlands that were found to be clean or adequately remediated, was not the end of the story. SJRWMD's success in reducing phosphorus inputs and removing excess phosphorus to flip the lake back into a non-eutrophic state proved to bring with them another unintended consequence. As the nutrient levels in the lake decreased and consequently the algae populations receded, the lake become clearer and more attractive as an aesthetic and recreational asset. Being in relatively close proximity to the rapidly developing areas surrounding the City of Orlando, the land on the south side of Lake Apopka (i.e., land that had not been purchased by the SJRWMD) began to attract the attention of residential developers who could envision a demand for lake front or lake view homes once the lake was sufficiently clear. Anticipating the additional nutrient loadings that would result from increased suburban development in the Lake Apopka drainage basin, SJRWMD decided to act preemptively to ensure that future development would not result in a reintroduction of high levels of phosphorus to the lake reversing the substantial efforts that SJRWMD had made to reduce phosphorus inputs.

In 2000 SJRWMD completed the phosphorus budget for all dischargers to meet the fifty-five ppb criterion that had been established by the legislature. The budget took into account atmospheric deposition, natural background, the existing permitted sewage treatment plant, inputs from existing natural streams, discharges from the purchased farms, and other run-off from within the basin. The budget demonstrated that even with the dramatic decreases in phosphorus loadings resulting from taking the farms out of production, existing loadings essentially used up all of the budgeted phosphorus. To achieve the fifty-five ppb criterion, it would be necessary to prohibit virtually all future loadings.

Accordingly, in 2002 the SJRWMD Governing Board adopted a new regulation specific to the Lake Apopka Basin which placed severe restrictions on the amount of phosphorous that can be discharged into the lake or its tributaries. In the new rule, SJRWMD adopts the legislatively-created fifty-five ppb as total phosphorus criterion for

298. Mike Coveney, St. Johns River Water Mgmt. Dist., Address at the University of Florida Levin College of Law (Feb. 20, 2007).

299. Id.

Lake Apopka and pursuant to the authority granted by legislation, adopts discharge limitations to meet the criterion. The rule requires that post-development phosphorus discharge will not exceed pre-development phosphorus discharge and prohibits the import of phosphorus from inter-basin diversion unless an offset from another phosphorus source is provided. In other words, the rule prohibits any net increases in phosphorus discharge to the lake from any new development in the Lake Apopka basin.

7. Results of the Restoration

With the combination of restoration efforts designed to shift Lake Apopka back into a non-eutrophic state and restore ecological resilience to the clear-lake system, Lake Apopka's water quality has dramatically improved. Phosphorus levels in the lake are down fifty-six percent and water clarity is fifty-four percent improved. The improvements have occurred despite years of droughts and hurricanes which result in perturbations that can offset restoration efforts. Due to the reduced nutrient levels and concomitant improved water clarity, native submersed plants have reestablished themselves in hundreds of locations around the lake. Overall, the Lake Apopka restoration has been a significant success, despite the complexities, uncertainties, and unexpected consequences. Although the Lake Apopka restoration was on a much smaller scale than that of the Glen Canyon Dam or Everglades, as presented by Professors Gunderson and Zelmer elsewhere in this Issue, and certainly does not involve anywhere near the complexity or scale of Professor Glicksman's discussion of resilience at the global level, found elsewhere in this Issue, several important lessons can be learned from the Lake Apopka experience, which could help to guide future restoration efforts.

301. Applicant's Handbook, supra note 300, § 11.7.
302. Id.
303. Lake Apopka Fact Sheet, supra note 112, at 2. For a more detailed scientific discussion of the results of the Lake Apopka restoration, see generally M. F. Covenev et al., Response of a Eutrophic, Shallow Subtropical Lake to Reduced Nutrient Loading, 50 Freshwater Biology 1718 (2005).
304. See Lake Apopka Fact Sheet, supra note 112, at 2.
305. Id.
IV. THE LESSONS OF ADAPTATION AND RESILIENCE

The Lake Apopka story can be used as a guide for future environmental restoration projects. Although the project was beset with uncertainty, complexity, legal setbacks, and unintended consequences—even resulting in tragedy—ultimately, the project not only succeeded in its original objectives, but also succeeded in developing cutting edge scientific research with broad application, and providing legal protections to address anticipated future impacts. Perhaps the most enduring success, however, is as a roadmap for how to accomplish environmental restoration in the face of scientific uncertainty and unintended consequences.

A. Admit We Don't Know What We Don't Know

The first lesson from Lake Apopka is a reminder that the natural world is complex and dynamic and that our scientific understandings of the natural world are extremely limited. At the onset of the Lake Apopka restoration project, there was no certainty that the planned phosphorus removal projects would work. Although, based on previous studies demonstrating the relationship between phosphorus loading and the trophic state of lakes, there was reasonable certainty that the marsh flow-way would result in phosphorus removal and that the lake would respond to the reduced phosphorus loading, there was much uncertainty regarding the proportionality of the lake's response and the time it would take to see any response. SJRWMD scientists could not predict with high certainty the extent to which, or for how long, sediment resuspension and recycling sedimentary phosphorus would prevent improvements in water quality. The marsh flow-way component of the project required ongoing experimentation with testing different flow rates to determine the most effective rate for phosphorus removal. The likely benefits of the shad harvesting program were far from guaranteed. If SJRWMD had waited until it had perfect information or complete certainty that its proposed project would work, the project probably would never have begun. Moreover, it simply was not possible to develop the information needed without actually experimenting with the project. Of course, the idea that we

310. Although work conducted in Europe in the 1980s indicated that shallow lakes respond to phosphorus load reduction with lag times averaging about five years, other scientists had predicted that recovery could take hundreds of years. E-mail from Edgar Lowe, St. Johns River Water Mgmt. Dist., to Mary Jane Angelo, Assoc. Professor of Law, Univ. of Fla. Levin Coll. of Law (Jan. 9, 2009) (on file with author); Lake Restoration by Reduction of Nutrient Loading: Expectations, Experiences, Extrapolations, (Hein Sas, ed., 1989).
will never have complete or perfect information about natural systems is the basis of the concept of adaptive management. The Lake Apopka story merely serves as a real world confirmation of this fact. Finally, as is discussed further below, even when we think we know something, such as with the reliance on the information contained in the existing scientific literature regarding the bioaccumulation of OCPs, the Lake Apopka story reminds us of the fallacy of believing we know anything for certain. As adaptive management theory provides, we must constantly be vigilant and open to the possibility that we may not know as much as we think we know or that, at a minimum, there is always more to know. Then, we must be willing to seek out and acknowledge new information as it becomes available and to use it as appropriate to increase the odds of a successful outcome.

The fact that environmental management and restoration projects are dealing with ecosystems, and presumably designed to maintain ecosystem function, a priori means that such projects are dealing with highly complex systems for which we will never have a complete understanding. Moreover, if the goal of such projects is the maintenance or restoration of ecosystem function, we must be willing to accept the fact that we must maintain a high level of complexity, which brings with it a certain level of uncertainty. To manage or restore natural systems such that they maintain or regain a high level of ecological resilience, it is necessary to embrace the complexity. Attempting to manage natural ecosystems to meet a fixed simplistic goal is antithetical to ecological resilience.

Unfortunately, political pressures often push resource managers to overstate the level of certainty about their proposed actions. Legislators, high level administrators, and taxpaying citizens typically are loathe to commit resources to projects with uncertain outcomes. Neither lawmakers nor taxpayers want to hear that we are not sure what is going to happen. Thus, resource managers often feel pressure to ignore the uncertainties and at least portray a high level of confidence. Moreover, once resources are committed and a project is underway, it may not be politically expedient to admit that certain choices were made on what has turned out to be flawed information or that things are not happening the way we anticipated they would. Again, resource managers may feel pressure to simply ignore new information, or to "spin" new information in a way that does not make them look like they have erred in their judgments. Resource managers may feel it is better to simply push ahead with their plans even in

312. Id. at 54–56.
313. Id.
the face of new information that may suggest that the proposed plan is flawed to avoid having to admit they made a mistake and "wasted taxpayer money." Pretending that we are certain about what we are doing or about the outcomes of our proposed actions, while perhaps politically expedient, is antithetical to successful environmental restoration.

B. Stuff Happens

An outgrowth of our limited understanding of the natural world, and perhaps simply a fact of life, is that stuff happens. No matter our best intentions or best efforts to prevent problems from occurring, we can never anticipate every potential consequence of our actions. As described above, unanticipated consequences may result from basing decisions on incomplete or imperfect information. However, many other variables can contribute to unexpected outcomes. Whether it be climatic conditions, changed political climates, changed human land use or other practices, or other unanticipated factors, it is simply impossible to perfectly predict the future. Thus, even the best-informed decisions may result in serious ecological, economic, or political adverse consequences. We may need to be willing to tolerate some level of risk to proceed with important restoration efforts. The Lake Apopka case clearly demonstrates this. From the time that SJRWMD began planning the restoration and at virtually every step of the way, unanticipated events occurred. The discovery of the endocrine disrupting effects on the alligators in the lake presented new scientific complexity. The significant judicial loss of the challenge to the nutrient limitation rule in 1996 was a major unanticipated setback.

Of course the most serious unintended consequence was the bird kills that occurred in 1998–1999. The bird kills were completely unanticipated for a number of reasons. First, Florida had many years of experience with farm restoration projects and never experienced anything like the 1998 event. Second, the farmland on the north shore of Lake Apopka had been flooded for nematode control every year while the farms were in operation without any problem. Finally, SJRWMD conducted an environmental assessment, in which soil samples were taken from the farmlands and tested for the presence of toxic substances and risk analysis prior to flooding the fields. The risk assessments considered risks from residual toxaphene and DDT on the farm fields, but concluded that there was not a significant risk of bird mortality and that the only moderate risk was for long-term reproductive effects.

In addition to the actual bird deaths, however, the decision of the U.S. Department of Justice to pursue a criminal case and the concomi-

tant sequestration of bird carcasses and relevant information, was something that could not reasonably have been anticipated. Thus, at every step of the way, adjustments had to be made to accommodate new information or changed circumstances that resulted from these unanticipated events. The ability to make such adjustments, to be flexible and to respond to unanticipated events is the hallmark of adaptive management.

C. Learning From Experience

1. Three Models of Learning and Success

C.S. Holling—the father of adaptive management—and his colleagues describe three types of changes that occur in any complex system, whether an ecosystem or a political or legal system: (1) incremental; (2) abrupt; and (3) transformational.315 Each of these types of changes can result in a correspondingly different type of learning and success. The Lake Apopka story provides a real-world illustration of each of these types of learning and success. Incremental change occurs in a predictable manner based on the assumption that existing knowledge is correct.316 This type of learning involves collecting data during the course of the project and feeding the data back into existing models to update and adjust the models.317 Many aspects of the Lake Apopka story are characterized by incremental learning. For example, experimentation with the speed of water moving marsh flow-way and making adjustments in response to data from such experiments can be considered incremental learning. Likewise, from a legal perspective, SJRWMD's response to a number of legal challenges, such as the failed 1994 wastewater discharge rule adoption, resulted in adjustments to the law through legislative changes to provide the legal authority to pursue the necessary phosphorus loading reductions.

Abrupt change and spasmodic learning involves the episodic and discontinuous learning in response to surprises.318 Surprises, or unintended consequences that occur in the course of carrying out the project, will reveal inadequacies of current knowledge or model.319 The unanticipated surprises of the bird die-offs and the adjustments that were made in response, such as draining the fields, conducting additional soil testing and remediating contaminated soil can be viewed as examples of abrupt learning.

316. Id. at 404.
317. Id.
318. Id. at 405.
319. Id.
Transformational learning is the most dramatic form of learning.\textsuperscript{320} It involves the creation of completely new paradigms.\textsuperscript{321} As discussed below, one example of this type of transformative learning is the completely new scientific understanding of the way that OCPs move and are stored in the environment and in the bodies of birds, which came out of the research conducted by SJRWMD in response to the bird die-off. By taking advantage of the bird kill tragedy to develop this new research, rather than merely viewing the bird kill as the death knell of the restoration project, SJRWMD was able to significantly change our understanding of these pesticides. This new research will undoubtedly play an essential role in any future restoration projects on previous agricultural or industrial lands that may have been contaminated with OCPs.

Moreover, perhaps the Lake Apopka experience as a whole can be viewed through this lens as one of the few large-scale examples of successful adaptive management and restoration of ecological resilience in the face of scientific and legal uncertainty and a large number of legal and scientific setbacks. Lake Apopka can provide a real-world new paradigm to guide future restoration efforts.

2. Learning From Our Mistakes

Adaptive management by its very nature involves experimentation and adjustment in response to new information, mistakes, or unexpected results. Adaptive management requires that we monitor our actions and use new information to adjust appropriately. When mistakes occur, they must be viewed as opportunities for learning rather than as reasons to derail a project. One unavoidable consequence of adaptive management is that unanticipated outcomes are an inherent part of such actions. Unfortunately, these mistakes and unintended consequences may involve adverse environmental and/or economic impacts. Consequently, if we decide to proceed with adaptive management, we must accept that we are taking certain risks and be prepared to respond quickly and appropriately if adverse unintended consequences occur. In addition, we must not chill adaptive management behavior by punishing environmental managers who make informed reasonable decisions merely because an adverse unintended consequence results. The actions of the U.S. Department of Justice in the wake of the Lake Apopka bird-kill are the types of actions that will discourage the type of experimentation that is necessary to have successful adaptive management. We must be willing to accept that sometimes bad things will happen. If we punish the people who are doing their best to adaptively manage a system within the realities of

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\textsuperscript{320} Id. \\
\textsuperscript{321} Id.
\end{flushleft}
scientific uncertainty and complexity, we will deter future adaptive management and remain stuck in the old rut of front-loaded one-time "safe" decision-making that will never achieve true ecological resilience. Alternatively, we will never act because we will be waiting indefinitely for science to develop the elusive "perfect information." We simply must allow environmental managers to proceed based on the best scientific evidence and do our best to minimize the harms from the inevitable unintended consequences that undoubtedly will occur. This is not an easy task. It is difficult to accept harms such as deaths of endangered species and it is tempting to shut down projects that result in such harms. However, if our goal is to use adaptive management to maintain and restore ecological resilience, we must have the courage to take the long view and to embrace and take advantage of unanticipated results as "opportunities" to learn and improve.

The mistakes that resulted in the unintended bird kills, while tragic in themselves, provided an opportunity for learning. In response to the bird kills, SJRWMD began extensive scientific study to determine what went wrong and how such problems could be avoided in the future. After the die-off, more than 1,000 additional soil samples were taken. These samples revealed a large variation in the concentration of pesticide residues among the various farms. The variation was another factor that was not anticipated because all of the farms had been growing the same crops in the same conditions, so it was presumed that similar farming practices were used. Based on this assumption, when the environmental assessment was conducted prior to the reflooding, the sampling did not extend to what turned out to be the farm fields with the highest pesticide residues. Moreover, the post-die-off sampling revealed that one pesticide "hot spot" had been missed in the earlier testing. This site had extremely high levels of fresh toxaphene, suggesting a recent spill had taken place that was not discovered in the environmental assessment.

Even the toxaphene hot spot and the higher levels of pesticide residue on certain farms, however, could not account for the high levels of pesticides that were actually found in the carcasses of poisoned birds. The higher than expected levels of pesticides in the bird bodies could be attributed to a number of different possible factors. Hypotheses to explain the unanticipated high levels included: (1) the birds came on the site with a preexisting high burden of pesticides; (2) the bioaccumulation factors that were derived from the scientific literature and used in the risk assessment were too low; (3) the half-life for excreting the pesticides derived from the literature and used in the risk assessment was too short; and (4) unanticipated translocation from one body

323. Id.
component to another was occurring in the birds. The first hypothesis—that the birds came on the site with preexisting high body burdens of pesticides—was ruled out because the control group birds (i.e., birds known to be killed by other causes) did not contain high levels of pesticides.

Many of the pesticides of concern simply had never been studied in depth and their modes of action were not well understood. For example, after years of research on DDT, and all of the controversy surrounding the pesticide, the mode of action of DDT is still not understood. To complicate matters, some of the pesticides of concern, such as toxaphene, are mixtures of many chemicals (toxaphene itself consists of 200 different compounds) most of which have not been well studied.

To determine if the bioaccumulation numbers from the literature were too low, SJRWMD conducted a series of microcosm studies in tanks and one-quarter acre mesocosm studies in the field. The studies involved raising fish in the microcosms and mesocosms that contained varying soil concentrations of OCPs. In a separate series of laboratory studies, fish raised in on-site mesocosms were fed to great egrets to determine the amount of accumulation in the various tissues. SJRWMD's studies demonstrated that bioaccumulation numbers in the literature significantly underestimated the actual bioaccumulation. Moreover, these studies measured accumulation rates for pesticides that had degraded through years of exposure to microbial processes in the soils, whereas previous studies involved force feeding or injecting birds with fresh toxaphene. Because the SJRWMD study fed birds fish that had accumulated degraded pesticides from field mesocosms, they more closely mimicked real-world conditions. Additionally, the studies indicated that the bioaccumulation factors would be higher for birds feeding on fish from unvegetated areas than in vegetated areas because the open water fish would have higher levels of OCPs. The farm fields were rapidly flooded to depths that prevented plant colonization. This created open water conditions, rather than vegetated wetlands. Thus, this study suggests that there is less risk associated with flooding vegetated fields than with unvegetated fields. Wetland vegetation can be established by very shallow flooding until plants have become estab-

324. Id.
325. Id.
326. Id.
327. Id.
328. Id.
329. Id.
330. Id.
331. Id.
332. Id.
333. Id.
lished and this method has been applied in safely reflooding thousands of acres. One hypothesis that has been developed to explain this difference is that because marsh-like sites have more vegetation than open-water sites, they develop a food web that includes substantial amounts of new organic matter (created by plant photosynthesis) that is lower in OCPs than the organic matter of soils; whereas, in unvegetated sites, the highly contaminated organic matter in the soils dominates the base of the food web.\textsuperscript{334}

To test the translocation hypothesis, the SJRWMD determined that the fat tissue of the birds had much higher concentrations of the toxins per volume of lipid than did the brain tissue.\textsuperscript{335} Thus, SJRWMD developed a hypothesis that the birds accumulated the pesticides in their fat, and if they stop feeding, the pesticide moves from the fat into the bloodstream and ultimately to the brain.\textsuperscript{336} To test this hypothesis, SJRWMD conducted studies that demonstrated that the pesticide concentrations in the brain increased when the birds were deprived of food. They also found that high doses of pesticides suppressed the appetite of birds, which led to reduced feeding and, in turn, more pesticide traveling to the brain where it exerts its neurotoxic effect.\textsuperscript{337}

In sum, the testing conducted by SJRWMD in response to the bird deaths led to several completely new understandings about how pesticides accumulate and are metabolized by fish-eating birds in the real world. These test results demonstrated that the data in the scientific literature, which environmental managers have relied on for decades, are fundamentally flawed and that, depending upon specific circumstances, the risk posed by a given concentration of pesticide in soil may be significantly higher than previously believed. Additional research prompted by the bird die-off tested a variety of approaches to remediation of soils contaminated with OCPs.\textsuperscript{338}

Based on this new information, SJRWMD revised its risk assessment and developed remediation plans for the areas of farmland containing unacceptable concentrations of pesticide residues.\textsuperscript{339} SJRWMD also was able to determine an acceptable level of residue that must exist prior to re-flooding any farmlands and also learned that risks are much lower if farmlands are only flooded to a vegetated

\textsuperscript{334} Id.
\textsuperscript{335} Id.
\textsuperscript{336} Id.
\textsuperscript{337} Id.
\textsuperscript{339} Gianfranco Basili, St. Johns River Water Mgmt. Dist., Address at the University of Florida Levin College of Law (Jan. 30, 2007).
marsh condition rather than flooded to an open water condition. SJRWMD was able to re-flood several parcels. The newly re-flooded parcels attracted thousands of wading birds with no adverse consequences. Thus, the marsh restoration based on the new information regarding pesticide residues appears to be working.

More important than the lessons SJRWMD learned for the Lake Apopka restoration, however, is the fact that only by having tried restoration and only by responding to the unintended consequences of restoration with serious study, was SJRWMD able to determine the extent to which prior scientific data and understandings were flawed. The new data, based on conditions that more closely mimic real world conditions, are proving to be critical for farmland restoration projects throughout the world. For example, the science that came out of the Lake Apopka experience has been considered in the restoration efforts in the Florida Everglades, the Klamath Basin, the Mississippi River, and the Illinois River.

No one can deny that mistakes were made during the Lake Apopka restoration project. Most significantly, SJRWMD erred in failing to conduct adequate soil testing throughout the entire area to be re-flooded and instead relied on soil testing in limited areas, which turned out to be cleaner than other areas. Although SJRWMD believed, perhaps reasonably at the time, that all of the farms would have similar pesticide levels because they were all growing the same crops in the same place in a similar manner for the same length of time, these beliefs turned out to be inaccurate. Accordingly, one lesson Lake Apopka teaches us is not to assume anything and, in particular, not to make assumptions about farming practices, which as we have learned can vary dramatically from one neighboring farm to another. This lesson should inform future agricultural restoration projects. As a related matter, SJRWMD erred in using information regarding the assessment of risks from pesticides derived from the scientific literature which underestimated the risks. Although this mistake may have been harder to avoid because it seems reasonable to be able to rely on information contained in scientific literature, perhaps the lesson to be learned is that where there are potential significant

340. Id.
341. Id.
342. Id.
343. It should be noted that even if additional soil sampling had been done, the conclusions of the risk assessment may have remained the same. This is because the scientific literature in existence at the time underestimated the level of risk from OCPs. It was only after SJRWMD conducted years of research that this was understood. For a detailed description of the approach to soil sampling, see ATRA, INC., ST. JOHNS RIVER WATER MGMT. DIST., COMPARISON OF MUCK FARM RESTORATION LEVELS TO CONCENTRATIONS IN LAKE APOPKA NORTH SHORE RESTORATION AREA (1998) (on file with author).
risks, we should not simply rely on pulling numbers out of books, particularly if such numbers are based on studies that do not appear to replicate real-world conditions. A related lesson is as a reminder of how much we do not know and how even matters that have been subjected to scientific study often are not fully understood. The most obvious lesson from this mistake, of course, is that our understanding of the accumulation of OCPs was flawed and the studies conducted by SJRWMD provide much better information for future restoration projects on lands that may contain residues of these pesticides.

Another lesson from the Lake Apopka experience is that even where mistakes lead to tragic results, this is not necessarily a reason to abandon restoration efforts. Instead, as occurred following the Lake Apopka bird-kill tragedy, environmental managers should first attempt to minimize harm and prevent additional harm, and then use the experience to develop better information to use in proceeding with the restoration and to inform future similar restoration projects.

When human activity shifts a stability domain to an undesirable state, three different options for responding exist. First, we can do nothing and hope that eventually the system will return to a desirable state. Due to resilience mechanisms that develop in the undesirable state, however, this is unlikely to occur. Second, we can try to actively restore the system to the desirable state. Third, we can simply accept the new stability domain. Prior to the Lake Apopka restoration, it would have been easy to simply write off Lake Apopka as an irreversibly polluted lake. It would have been easy to conclude that the $100 million plus that were spent for purchasing the farm-lands would have been better spent on acquiring and preserving other more pristine land, or for another environmental restoration project that was not quite as daunting. Yet, even during the times of the endocrine disruptor crisis and the bird-kills and the ensuing criminal investigation, the project continued and today it is fair to say that Lake Apopka has reverted (or is on the verge of reverting) back to its non-eutrophic stability domain. However, the success story of Lake Apopka restoration may be a much-needed real-world example of an adaptive management success story. Every stage of the process leading to the ultimate success required experimentation with science, with management strategies, and with legal approaches. The experiments would have meant little if the managers had not learned and adjusted in response as new information and changed circumstances came about. Mistakes were made along the way—some with tragic

344. Gunderson et al., supra note 72, at 258.
345. Id.
346. Id.
347. Id.
consequences. However, the environmental managers were ultimately given the legal and political leeway to learn from these mistakes and, by doing so, to develop a body of new scientific understanding that not only guided the remainder of the restoration project, but which is also serving as a guide to other similar restoration projects throughout the world. Scientific information gleaned from the Lake Apopka restoration project is currently being used by environmental decision-makers in a number of other restoration projects, including in the Everglades, the Klamath basin, the Missouri River, and the Illinois River, all of which face similar challenges as those in the Apopka case.

Of course, there may be instances where the risks are simply too high and where inaction is the preferable choice. As Professor Holly Doremus has pointed out, in situations where the proposed action poses high risk to an endangered species, but where the risk to the species of inaction is relatively low, inaction may be the preferable choice.\(^{348}\) In may cases, the status quo will pose the lowest risk to an endangered species, at least in the short term.\(^{349}\) However, where management or restoration projects are designed to restore long-term ecological resilience, which in the long run may have substantial benefits not just to a single species, but to the function of an ecosystem as a whole, it may be preferable to take the risk.

The Lake Apopka case illustrates one of the primary inconsistencies between U.S. species protection law and adaptive management. Statutes such as the ESA, MBTA, and BGEPA, focus on the protection of one individual species at a time. However, to achieve ecological resilience through adaptive management, it sometimes may be necessary to allow some risk to individual species for the good of the functioning of the ecosystem as a whole. Frequently, the short-term goals of protecting one species may conflict with the long-term protection of other species and with goals of ecological resilience restoration. For example, when degraded conditions in the Everglades caused the endangered Everglades Snail Kite to find a new habitat further to the north in the Blue Cypress Conservation area owned by SJRWMD, a different choice had to be made as to whether to continue to manage the hydrologic regime of the area in a manner that would provide the best habitat for wood storks and other species, or whether to adapt to the new circumstances and manage the area to maximize the benefit to the new Snail Kite residents that had been forced out of their original everglades habitat.

Another challenge of adaptive management is that it may be difficult to incorporate substantial public participation. Professor Holly

\(^{348}\) Doremus, supra note 311, at 70.
\(^{349}\) Id.
Doremus has discussed how the focus on public participation in the Everglades restoration project has made it difficult to make the type of quick decisions and adjustments that are needed for effective adaptive management. If we need to wait to convene all stakeholders and achieve consensus or near consensus before every action, we simply will not be able to have the quick reaction time necessary for adaptive management. Moreover, it may be extremely difficult to obtain stakeholder consensus for experimentation based on new or untested ideas which carry with them a level of risk. The consensus-building process itself may lead only to less risky ideas being acceptable. Thus, we may have to rethink the role that public participation should play in adaptive management. Professor Doremus has expressed concern over the risks posed by issuing incidental take permits under the ESA. However, one option would be to impose a different standard for obtaining incidental take permits (or incidental take statements) when the primary purpose of the proposed action is to maintain or restore ecological resilience to an ecosystem. In these cases, a lower standard for obtaining an incidental take permit than in cases where there is some other primary purpose may be appropriate. With Lake Apopka, the primary purpose of the project was clearly environmental restoration of the ecosystem. Thus, some incidental takes may be warranted. Whereas, in the case where the primary purpose of a project is, for example, construction of a highway, a higher standard should be met to obtain an incidental take permit.

Public participation is critical for the success of any environmental management or restoration project. Without providing the opportunity for all interested stakeholders to be heard, and without at least some level of consensus, decisions will not endure because dissatisfied stakeholders will be more likely to bring legal challenges, to seek legislative changes, or to mobilize communities to politically pressure agencies to undo such decisions. However, it is worth considering which components of an adaptive management project and/or which stages of the development of such a project are best suited for public participation. For example, public participation is critical to identifying policy objectives, restoration objectives or management objectives, to ensure such objectives are acceptable to a range to stakeholders. However, once such objectives have been identified and it is time to determine specific actions to be implemented to meet such objectives, public participation may have to take a backseat to permit adaptive management to occur. The scientists charged with developing specific actions must be given wide latitude to experiment and to “try” new

350. Id. at 82–83.
351. Id.
352. Id.
353. Id.
things even in the absence of complete or perfect data. The scientists must also be given the flexibility to react and adjust quickly as new information becomes available or as circumstances change. Of course, we must still demand that risks be reduced to the extent practicable by insisting that scientists use the best scientific information available. Without giving wide latitude to scientists, however, we will not be able to adaptively manage. The Lake Apopka story illustrates that when scientists are given sufficient discretion and flexibility they often can come up with creative, although perhaps untested ideas, such as the marsh flow-way and Gizzard Shad harvesting, that may ultimately prove successful.

One challenge of giving scientists wide latitude is that the public may not have sufficient trust in scientists or public institutions to be willing to sit back and let experimentation occur. In recent years there has been an undermining of trust in public institutions in general, and of science coming out of public institutions in particular. During the George W. Bush administration, the news was rife with reports of science coming out of agencies such as the EPA being heavily influenced, if not altered, to support particular political agendas. Scientific information that did not support such political agendas often was squelched or “spun.” As a result, the public is highly distrustful of science. For the public to be willing to give government scientists discretion and flexibility, it will be necessary to restore scientific integrity with government agencies and for such agencies to regain the public's trust.

In addition to the pure scientific knowledge that has been gleaned from the Lake Apopka experience, the project and its associated problems have also resulted in learning on behalf of the WRP. As a result of the problems that occurred during the Lake Apopka restoration, the WRP modified its practices. The lessons learned at Lake Apopka, the WRP’s first major project, helped to ensure that restoration will not have negative unintended consequences on the more than one million acres of other WRP projects.

The actions of the DOJ in pursuing the criminal case against SJRWMD for the bird deaths were counter to the concept of adaptive management. The DOJ’s actions turned what started as a cooperative effort between SJRWMD, federal and other scientists to determine the cause and extent of the problem and come up with a way to address the problem and prevent further harms, into an adversarial process in which the parties either were prohibited or at least feared sharing in-

354. See Mary Jane Angelo, Harnessing the Power of Science in Environmental Law: Why We Should, Why We Don't, and How We Can, 86 Tex. L. Rev. 1527, 1564 (2008).
355. Id.
356. Id. at 1569.
formation and working together to find a solution. By pursing a criminal case against both the agency and the individuals who were attempting in good faith to carry-out an important environmental restoration effort, the DOJ’s actions had a chilling effect on other restoration projects. Anecdotal information suggests that several planned environmental land acquisitions were halted or delayed because of fears that toxaphene residues in agricultural fields could result in criminal actions being brought against other resource management agencies. There is also information to suggest that other agencies, such as the FWCC, in an effort to protect its staff from legal risk, directed staff members not to work on the Lake Apopka project, thereby removing the expertise and work of FWCC in helping to find a solution. Some SJRWMD land acquisition staff have expressed reluctance to purchase and restore agricultural lands. Fortunately, however, the new scientific information that was developed in response to the Lake Apopka crisis has yielded improved risk assessment methodology for organo-chlorines. With this new information and new protocol, resource managers are regaining confidence in agricultural restoration. In fact, the new protocol, which is now being used world wide, is commonly referred to as the “Apopka method.”

D. Mother (Nature) Knows Best

As the Lake Apopka story demonstrates, the best way to restore ecological resilience to an ecosystem is to use nature as a blueprint. Nature is complex and dynamic. Thus relying on overly simplistic approaches, such as merely removing one anthropogenic disturbance, may not be sufficient. Similarly, attempting to “over-engineer” a solution may serve to eliminate important resilience mechanisms. The successes of the Apopka restoration stems from decisions to mimic the pre-eutrophic conditions of the lake and drainage area. Examples of restoring or mimicking pre-eutrophic conditions include dramatically reducing phosphorous inputs by purchasing farmlands and taking them out of agricultural production; reconnecting the lake to its historic littoral zone wetlands; using wetlands (i.e., the marsh flow-way) to filter nutrients and sediments out of already polluted lake water; removing large numbers of bottom-feeding fish (i.e., Gizzard Shad) which in a non-eutrophic lake would comprise only about ten percent of the total fish population; planting submersed vegetation to stabilize the lake bottom and remove nutrients; and adopting rules that would prohibit future increases in anthropogenic nutrient inputs to the lake.

One of the most significant shortcomings of previous environmental management and restoration attempts that failed was that they ignored the complexity and changing nature of natural systems. By attempting to find simple solutions by addressing only one type of disturbance, or by attempting to manage natural systems in a static con-
dition, managers ignored the critical role that resilience mechanisms play in achieving long-term success. The species richness, species diversity to include driver species as well as passenger species, redundancies in ecosystem structure and function, and other resilience mechanisms that contribute to the complexity of natural systems are what enable natural systems to absorb certain types, magnitudes and durations of perturbation without shifting into a different state. Accordingly, environmental managers would be wise to follow nature's blueprint and to seek to maintain or reintroduce these mechanisms into managed or restored systems. The Lake Apopka story provides a clear illustration of how mimicking nature by reintroducing multiple resilience mechanisms, such as littoral zones, adjacent wetlands, restructuring of the fish populations, planting bottom-stabilizing vegetation and reducing nutrient inputs, can result in restoration success.

An important lesson from the Lake Apopka story is that to protect natural or restored resilience, it is necessary to ensure that future perturbations do not exceed natural perturbations in terms of type, magnitude or duration. In the Lake Apopka situation, SJRWMD anticipated that there would likely be future development in the basin which, if not adequately regulated, would result in long term inputs of nutrients which would outstrip the restored lake's ability to absorb. Accordingly, SJRWMD developed a nutrient budget that identified a level of nutrients the lake could assimilate and allocated the allowable nutrient loadings to existing dischargers. Moreover, SJRWMD adapted a regulation that would prohibit future net increases in phosphorous loadings. This was a critical step in ensuring that disturbances from phosphorus discharges would stay below the level at which the lake could absorb the effects without flipping to a eutrophic state.

E. If At First You Don't Succeed . . .

Complex restoration efforts will undoubtedly involve setbacks and temporary failures. Some attempts simply may not work and it may take several tries to get it right. We must stay focused on the long-term goals—admitting failure too early will not lead to long-term success.

The chronology of the Lake Apopka story is rife with setbacks and temporary failures. In response to each of these failures, SJRWMD made adjustments necessary to continue toward its ultimate restoration goal. Starting in the early 1980s, SJRWMD's efforts to gain the cooperation of farm owners in removing nutrients failed. SJRWMD responded with a new regulation to limit phosphorus discharges from the farms. When SJRWMD lost the legal challenge to the new rule, SJRWMD shifted gears and initiated a program to purchase the farm-lands and take them out of agricultural production. When the con-
verted farmlands caused the bird deaths and the DOJ initiated criminal investigations of SJRWMD and its employees, SJRWMD responded by acting to minimize future risk to birds while it launched an ambitious research program to develop better information to understand risks to birds from pesticide-contaminated converted farmlands. At the same time, SJRWMD worked with the DOJ to develop a settlement that would allow continued restoration of Lake Apopka with improved processes to minimize future risks. SJRWMD used the new scientific information to guide its remediation efforts and its future restoration decisions for Lake Apopka.

Thus, one important lesson from the Lake Apopka story is that for environmental restoration to be successful, it may take several tries using different approaches. Circumstances change, laws change, new scientific data emerges, and new information is gleaned from the trial and error of adaptive management. If we allow setbacks, even those as substantial as the Lake Apopka bird-kills, to defeat our restoration efforts, we will rarely succeed in the long term. As difficult as it might seem, we must accept short term failures and setbacks as part of adaptive management. We must be nimble enough to respond to those setbacks in meaningful ways, but we must continue to pursue our long term environmental goals. In other words, we must learn from experience, change course as necessary, and then persevere in pursuing environmental restoration. Admitting failure too early will never lead to long-term success. Likewise, allowing uncertainty or setbacks to cause us to not try or to act too cautiously will not achieve success.

V. CONCLUSION

The goal of environmental management and restoration should be to maintain, or restore, ecological resilience. Without strong resilience mechanisms in place, ecosystems cannot withstand the inevitable natural and anthropogenic perturbations that will occur. Resilience mechanisms enable systems to absorb a certain type, magnitude and duration of perturbation without flipping to a different, and often undesirable, state. Ecosystems are complex and dynamic. Our knowledge of the complex and dynamic processes of ecosystems is very limited. Accordingly, to manage or restore ecosystems, we often must proceed in the face of uncertainty. Adaptive management enables environmental managers to proceed in the face of scientific uncertainty and to use the management process itself for experimentation and experiential learning. The Lake Apopka restoration story provides a useful illustration of restoring ecological resilience to a system through a long term process of trial and error. Several lessons emerge from the Lake Apopka story. We can never know everything or anticipate every change, complication, or unintended consequence. This
should not prevent us from acting. Instead, we must be prepared to learn from experience and adjust to changed circumstances and new information with a view to the long term. Our ultimate goal should be to use nature as a blueprint to maintain or restore the types of resilience mechanisms that are necessary for long term environmental success. Finally, we must not give up. Environmental restoration projects are not easy and are certain to be fraught with setbacks along the way. They are not clean or simple. However, if environmental restoration is the goal, we have no choice but to persevere.