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# Defining ecological and economical hydropower operations: a framework for managing dam releases to meet multiple conflicting objectives

# 规划生态与经济型的水利发电运作: 通过监管大坝释放量来实现多种相互冲突目标的框架

Elise R. Irwin

*U.S. Geological Survey, Alabama Cooperative Fish and Wildlife Research Unit, Auburn University, Auburn, Alabama, 36849 USA*

*eirwin@usgs.gov*

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*Abstract* - **Hydroelectric dams are a flexible source of power, provide flood control, and contribute to the economic growth of local communities through real-estate and recreation. Yet the impoundment of rivers can alter and fragment miles of critical riverine habitat needed for other competing needs such as downstream consumptive water use, fish and wildlife population viability, or other forms of recreation. Multiple conflicting interests can compromise progressive management especially with recognized uncertainties related to whether management actions will fulfill the objectives of policy makers, resource managers and/or facility owners. Decision analytic tools were used in a stakeholder-driven process to develop and implement a template for evaluation and prediction of the effects of water resource management of multiple-use systems under the context provided by R.L. Harris Dam on the Tallapoosa River, Alabama, USA. The approach provided a transparent and structured framework for decision-making and incorporated both existing and new data to meet multiple management objectives. Success of the template has been evaluated by the stakeholder governing body in an adaptive resource management framework since 2005 and is ongoing. Consequences of management of discharge at the dam were evaluated annually relative to stakeholder satisfaction to allow for adjustment of both management scenarios and objectives. This template can be applied to attempt to resolve conflict inherent in many dam-regulated systems where management decisions impact diverse values of stakeholders**.

*Keywords* – **Decision analysis; hydropower; conflicting objectives; adaptive resource management**

摘要：水电大坝是一种灵活的能量来源,它可用于防洪并能以固有地产和休闲场所的形式有助于当地经济的增长。然而，河流的拦蓄能够改变和破坏下游数英里内的其他需求所依赖的河流环境，比如下游的消费用水，鱼类和其他野生动物的种群的生存力，以及其他形式的休闲活动。多种相互冲突的利益可以通过协调形成渐进式的管理而实现，尤其是在面临诸如管理行为是否能满足政策制定者、资源管理者以及设备所有者的需求等不确定因素的情况下。以美国阿拉巴马州塔拉普萨河 **R.L. Harris** 大坝为例，通过运用决策分析的工具建立和实施了一个用以评估和预测水资源管理的多重应用系统的模板。该模板为决策制定提供了一个透明且有组织的框架，并能整合已知和全新的数据以满足多个不同的管理目标。自 **2005** 年以来，作为一个资源管理框架的成功案例，该模板已得到了相关主管部门的肯定并一直沿用至今。大坝排放量管理的成效依据利益相关者的满意度，每年进行相应的评估以便调整管理方案和目标。该模板可应用于尝试解决与水坝系统相类似的许多系统中的固有冲突，这些系统中决策的管理影响着利益相关者的各种利益.

关键词：决策分析；水利发电；冲突目标；自适应资源管理.

## I. INTRODUCTION

Society's need for clean water and power is critical to human existence and progress. Hydropower represents a flexible, clean, renewable source of power that supports 20% of the world's power needs [1]. Because of the nature of river systems as societal conduits for important services such as water, transportation, food, and recreation, rivers are inherently multiple use systems. Although hydropower facilities supply many benefits to humans, dams can have negative impacts on both upstream and downstream uses of riverine systems [2]. Allocation of uses usually via regulatory policies for dam operation do not always account for conflicting objectives for system use. These conflicts revolve around different and often competing values by land-owners, municipalities, fishers and hunters, navigation and boating interests, environmentalists and natural resource managers [3]. Although creative exchanges, negotiations and cooperative arrangements to resolve disputes are more common than "water wars" [4], transparent frameworks for water allocation decision making have been called for [5], [6].

Adaptive resource management incorporates societal needs (or values) in a transparent open forum with managers and scientists and is a special iterative form of structured decision making [7], [8]. Water allocation decision making-including dam release applications-meets the criteria for adaptive management which strives to reduce structural uncertainty over time through application of management scenarios and measurement of success of those prescriptions on stated objectives. Therefore, adaptive management frameworks allow for decision making in the face of uncertainty, can account for changes in applicable policy and environmental states, and allow for learning about effects of management actions on water management problems in question[9], [10]. In this paper, I describe the long-term application of adaptive management to a river regulated by a large privately owned hydropower facility. Multiple conflicting objectives emerged decades ago shortly after the dam was closed. In 2002, an adaptive process was suggested to alleviate litigious threats and ultimately define solutions acceptable to the stakeholders [3].

## II. CASE STUDY-TALLAPOOSA RIVER, ALABAMA, USA

The Tallapoosa River below R.L. Harris Dam is a 78-km reach where river flow is strongly influenced by the daily generation schedule at the dam (Fig 1). Harris was constructed for hydropower, with other potential benefits including flood control, recreational opportunities on the reservoir created by the dam, and economic growth associated with the reservoir. The dam has two turbines (135 mega-watts) that account for about 10% of the total capacity of the 11 privately-owned hydropower dams in the eastern Mobile River drainage. Since completion in 1983, Harris Dam has been operated primarily as a hydropeaking facility, such that water is released in pulses, usually 4-6 hours in duration, through one or two turbines, each with the capacity to pass 226 cms. Historically, generation occurred once or twice daily, five days a week, and usually included no generation on weekends (i.e., pre-adaptive management flow regime). As a result of the hydropeaking operation, the flow regime was characterized by extreme low flows and high flows associated with one- or two-turbine generation (Fig 2). Comparison of pre- and post-dam flow data indicated that high flows were dampened, low flows were lower and more frequent and seasonal shifts in flow magnitude) were quantified [3].

In addition to flow alteration, the temperature regime below the dam has been affected; whereas, during spring and summer months, temperature decreases as much as 10°C during generation events [3]. During non-generation periods, the Federal Energy Regulatory Commission (FERC) license for Harris Dam requires that flow as recorded at the United States Geological Survey (USGS) stream gage at Wadley, Alabama (#02414500; 22 km downstream from the dam) is not to fall below the pre-dam historic record low-flow of 1.27 cms.

The river below the dam is one of the longest and highest-quality segments of Piedmont river habitat remaining in the Mobile River drainage, which is one of the most biologically diverse river drainages in North America [11]. Extensive areas of rocky shoal habitat are abundant along this portion of the river. The native fish that live there number at least 57 species, including a minimum five species endemic to the Tallapoosa River system. Prior to construction of Harris Dam, the river also supported productive sport fisheries for black basses (*Micropterus* spp.) and catfishes (primarily channel catfish *Ictalurus punctatus* and flathead catfish *Pylodictis olivaris*), as well as river boating activities (D. Catchings; Alabama Department of Conservation and Natural Resources, personal communication).

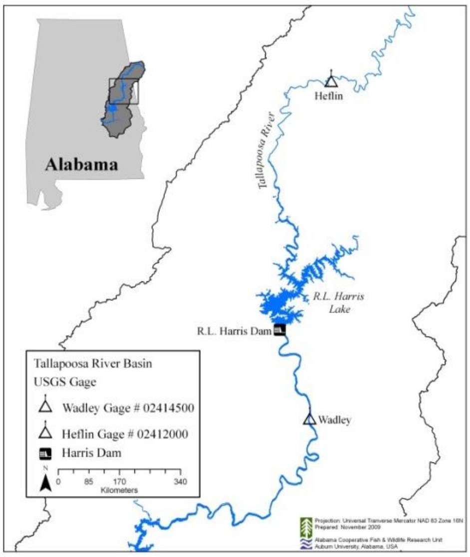

Figure 1.-Location of study site in the Tallapoosa River Basin. The river is regulated below Harris Dam, and unregulated above R. L. Harris Lake. USGS gages are maintained at Heflin and Wadley, Alabama, USA.

Declines in angler success rates and the loss of access to the river because of changes in flow regime have been major concerns since construction of Harris Dam. However, altering the peaking operation could threaten the power utility's flexibility to provide and sell electricity on demand during periods of peak consumption. Changes in dam operation could also affect water levels and therefore values for home owners and other recreationists that use the lakes in the system, particularly at Harris Reservoir.

Management issues in the study reach below Harris Dam were based on how dam operations impacted social values associated with power production needs, water availability for economic development, consumption, boating, angling and other recreational activities (upstream and downstream of the dam), and the general health of the Tallapoosa River ecosystem (Fig 3). These conflicting management objectives had been vocalized for many years, yet the ability of stakeholders to reach agreement over what and how to change management at the dam have not been realized.

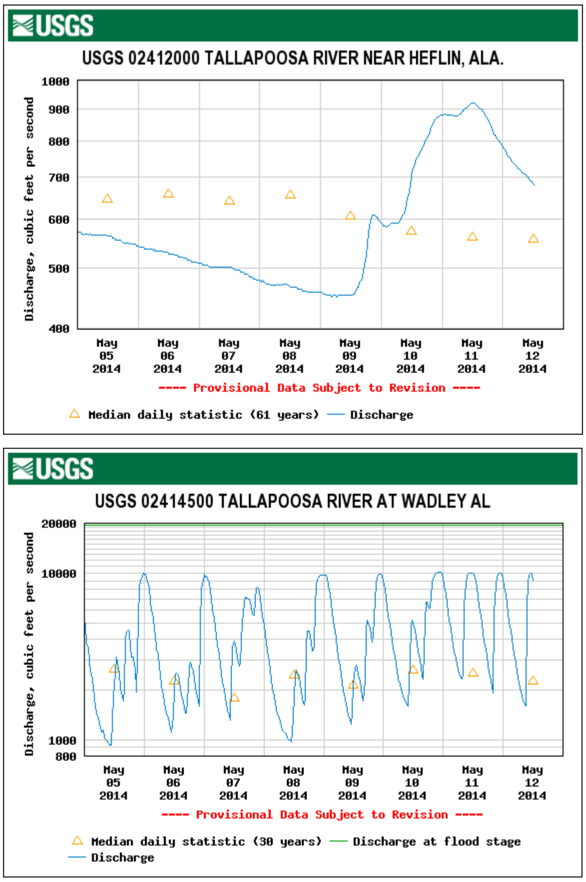

Figure 2.-Tallapoosa River discharge measured at USGS gage 02412000 (top panel-naturally occurring flows) located near Heflin, Alabama and USGS gage 02414500 (bottom panel-regulated by Harris Dam) located in Wadley, Alabama, 22km below the dam (5-12 May 2014; http://waterdata.usgs.gov; data reported in ft$^3$/s).

Multiple stakeholders wanted to develop of a plan of action. One alternative was to ask FERC to reopen the regulatory license and order evaluation of dam operation with respect to competing objectives. This option was not desirable to the utility owner, particularly in light of previous experiences where a reopened regulatory license resulted in a re-negotiated flow regime developed without options to amend the license based on meeting (or not meeting) stakeholders' objectives. Formal discussions with stakeholders and the publication of Irwin and Freeman's [3] framework provided a roadmap toward implementation of adaptive management below the dam. The stakeholders recognized that quantification of system function during management would assist with reduction in uncertainty related to future FERC regulations—the license is scheduled to be renewed in 2023.

## III. CONFLICTING STAKEHOLDER VALUES AND DECISION ANALYSIS

To begin the adaptive management process, a workshop was conducted to determine the stakeholder objectives (see www.RiverManagement.org for transcripts of the workshop). The goal of the workshop was to implement a structured process to make a decision about providing different flows at the dam that would satisfy the most stakeholders. The participants varied from biological experts to local landowners that reside on the reservoirs and the river, but all had a common interest in making positive progress toward making the right changes. Stakeholders (23 groups participated) were polled by professional facilitators (www.group-solutions.com) using an interactive session regarding the features about the river and reservoirs that were most important to them. The 10 resulting primary values (i.e., fundamental objectives [8]) that were identified are listed below (Table 1).

Stakeholders ultimately agreed upon these equally weighted fundamental objectives as complete and representative of the interests of all parties involved. In addition, stakeholders agreed to adopt the concept of adaptive management as a framework for future discussions and management decisions.

TABLE 1, FUNDAMENTAL OBJECTIVES OF STAKEHOLDERS.

| |
|---|
| Maximize economic development |
| Maximize diversity and abundance of native fauna and flora |
| Minimize bank erosion downstream from Harris Dam |
| Maximize water levels in the reservoir |
| Maximize reservoir recreation opportunities (e.g., angling, boating, swimming) |
| Maximize boating and angling opportunities downstream from Harris Dam |
| Minimize total cost to the power utility |
| Minimize river fragmentation |
| Maximize power utility operation flexibility |
| Minimize consumptive water use |

Objectives established at the workshop were used in a decision model to assist stakeholders in making complex decisions necessary to change the flow regime below Harris Dam. To make the initial decision, stakeholder's objectives were incorporated into a decision network using Bayes network software [12] that incorporated probability matrices associated with projected outcomes under different management options. For example, individual stakeholders understood that if too much water was released from the dam

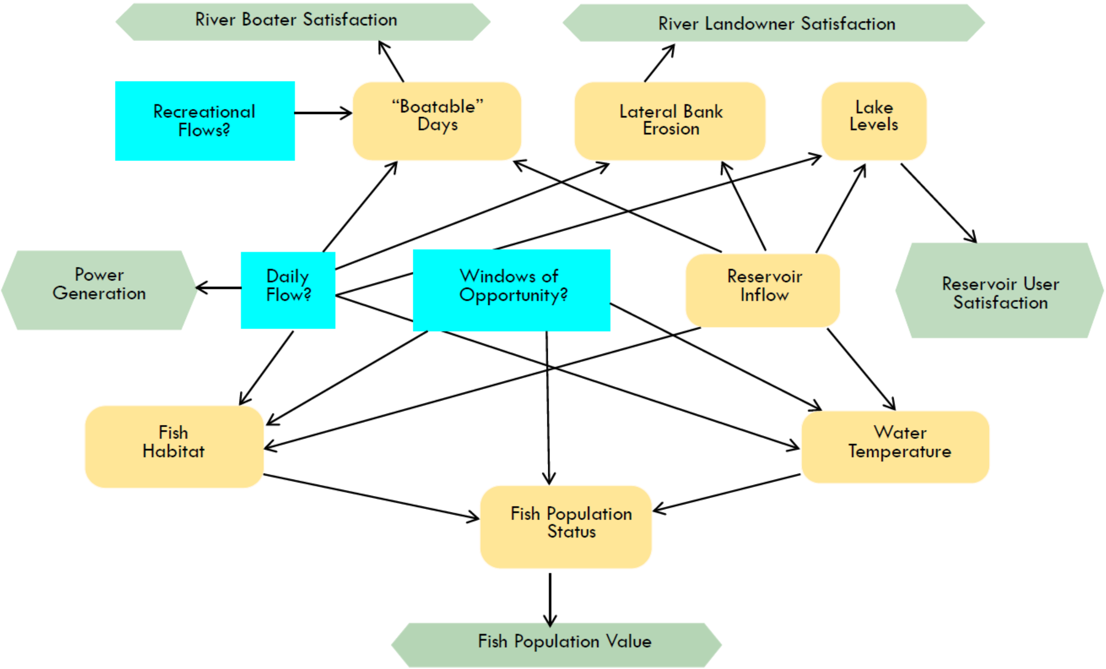

Fig. 3.-Simplified influence diagram showing the complexity of managing flows below R.L. Harris Dam. The blue rectangles are the decisions that were made about flow, the yellow ovals are stakeholder objectives, and the gray hexagons are "satisfaction" (utility) values of the different stakeholders. The initial flow management decision was the portfolio that maximized the satisfaction of the stakeholders.

for downstream needs then lake levels could be impacted. Constraints by stakeholders were defined before the model was parameterized to ensure that solutions that were completely impossible were accounted for. For example, the power utility needed to utilize peak power production procedures to maximize the flexibility of the facility to provide energy to the grid. Stakeholders then needed to find a way to evaluate tradeoffs associated with the impact of the management options on their different values; and given the complexity of the decision, the network was invaluable. Because the decision network was visual in nature (Fig. 4), the stakeholders could evaluate how their objectives were affected as different management scenarios were "tested." The network evaluated thirty-two management portfolios that were combinations of flow regimes, spawning conditions for fish and boating conditions. The model allowed for making an initial decision while acknowledging that uncertainty because it was not possible to know everything about how the system would respond to management. A governance structure was established that dictates the rules and periodicity for decision making by a governing board that is informed by both technical committees that consist of science and engineering experts and model updates based on collection of data of system response to management.

The decision model indicated that stakeholders would be most satisfied if more water from the dam was released, October boatable flows were provided, and stable flows (in spring and summer) were provided for fish spawning potential (blue rectangles; Fig. 4). This management portfolio was named the "Green Plan" and the daily amount of water that was released from the dam was determined by the daily volume of water at the USGS gage (#02412000; located upstream from the reservoir) on the previous day. Water was delivered through the turbines in 20-30 minute pulses or through regular power generation depending on the volume needed to meet the management target. Management was initiated in March 2005 and response to flow management on stakeholder objectives has been measured yearly (see Sec IV).

## IV. REDUCING SYSTEM UNCERTAINTY

The initial parameterization of the Bayes network was conducted with both expert opinion and empirical data (see Table 2 for variable descriptions, [13]). There was uncertainty related to how certain state parameters would respond to management. In particular, management of various aspects of the flow regime under the Green Plan was hypothesized to provide habitat stability for fishes and acceptable boatable conditions while maintaining suitable lake levels above the reservoir and ensuring flexibility for the utility but we were unsure of the specific responses of these and other variables. Therefore careful evaluation of response of variables to management was critical to reduction of uncertainty in the system. This was conducted using a carefully designed

TABLE 2, DESCRIPTION OF STATE VARIABLES, DATA SOURCES AND RANGES OF VALUES FOR THE INITIAL MODEL PARAMETERIZATION (SEE FIG. 4). NOTE THAT EROSION* IS AN UNINFORMED NODE BASED ON LACK OF DATA AND RESOURCES TO COLLECT DATA AND RESERVOIR INFLOWS** HAS FIVE RESPONSE LEVELS VERSUS THREE.

| State Variable | Brief Description; Source | Range | | |
|---|---|---|---|---|
| Boatable Days | # consecutive weekend days discharge between 12.7 and 56.6 cms; USGS gage data | High<br>> 70 d/yr | Medium<br>40-70 d/year | Low<br>< 40 d/yr |
| Erosion* | No data/Uninformed node | High | Moderate | Low |
| Lake Levels | # days/year that lake levels fall below rule curve; APC | High<br>< 10 d | Moderate<br>11-20 d | Low<br>> 21 d |
| Reservoir Inflows** | Exceedence flows (cms) for reservoir tributaries combined; USGS data | Flood<br>> 48.1 cms<br>Wet<br>42.5-48.1 cms | Normal<br>28.3-42.5 cms | Dry<br>17.0-28.3 cms<br>Drought<br>>17.0 cms |
| Flow Through Pools | Pool habitat percent with flow > 20 cm/s; Expressed for different inflows using PHABSIM model | High<br>Normal Year<br>> 50% | Moderate<br>Normal Year<br>20-50% | Low<br>Normal Year<br><20% |
| Shallow-fast Amounts | Shallow (<45 cm)-Fast (>45 cm/s) habitat percent; Expressed for different inflows using PHABSIM model | High<br>Normal Year<br>60-100% | Moderate<br>Normal Year<br>20-60% | Low<br>Normal Year<br><20% |
| Slow-cover Amounts | Slow(>20 cm)-Cover (present) percent; Expressed for different inflows using PHABSIM model | High<br>Normal Year<br>50-100% | Moderate<br>Normal Year<br>10-50% | Low<br>Normal Year<br><10% |
| Degree Days | #10-d periods where cumulative degree days exceeded 17.2°C; USGS data expressed as percent of days in growing season | High<br>>65% | Moderate<br>45-60% | Low<br><45% |
| Small Fish Abundance | Number of juvenile fish in 100 samples; USGS data | High<br>>50 | Moderate<br>20-50 | Low<br><20 |
| Bass Recruitment | Number of juvenile bass in 100 samples; USGS data | High<br>>20 | Moderate<br>10-20 | Low<br><10 |
| Redbreast Sunfish Spawning | Number of juvenile redbreast sunfish in 100 samples; USGS data | High<br>>60 | Moderate<br>30-60 | Low<br><30 |

monitoring program. Data regarding reservoir inflows and lake levels, number of boatable days and provision of spawning conditions were calculated each year based analysis of the hydrology data provided by the USGS gages or collected by the utility as part of their FERC license requirement.

The response of the biological parameters was evaluated by design and implementation of a program to quantify variation in fish occupancy in relation to system co-variates [14]. The response of fish habitat variables was evaluated by seasonal application of the post management hydrograph to a Physical Habitat Simulation Model (PHABSIM, [15]) that was developed at two of the sites.

Bayesian updating of probability distributions was performed yearly from 2005-2013 in Netica to learn how the management regime affected stakeholder objectives. The stakeholders have been apprised of the results periodically and formally through board meetings and through other methods such as publications and presentations and specific stakeholder briefings.

## V. FRAMEWORK FOR LEARNING AND THE DOUBLE-LOOP

In general, most stakeholders have been somewhat "satisfied" with the outcome of the management regime; however, it appears that improvements may be possible. For example, black bass recruitment (# of juvenile bass/sample) and "boatable" days (# of weekend days where flow is between 14.2-56.6 cms) targets were not consistently met under the green plan. In addition, when the decision model was updated with new information each year (i.e., Bayesian updating), the "right" flow decision varied indicating that a different management regime may be more beneficial.

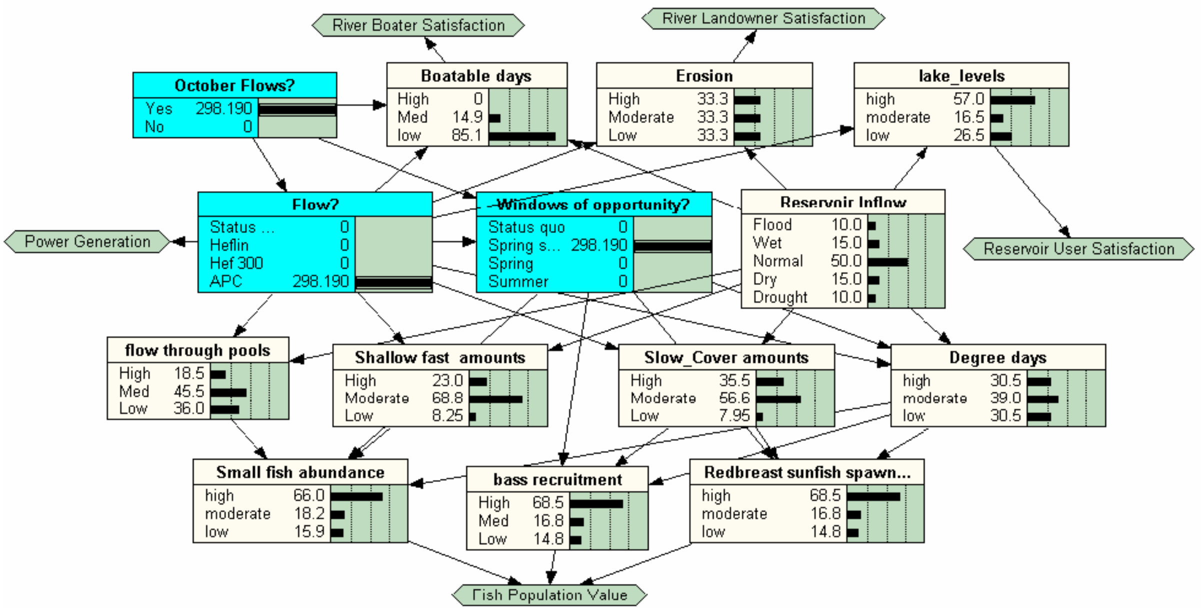

Figure 4. Bayesian decision network used to determine an initial flow prescription for adaptive management of Harris Dam, Tallapoosa River, Alabama. The initial decisions are illustrated in the blue rectangular boxes and the decision portfolio was to conduct the "APC" flow option, provide spring and summer spawning conditions (windows of opportunity) and October flows for boating. The other nodes display probability distributions for individual state variables that are attributes for the various fundamental objectives (see text for more detail). The hexagons represent utility values of the stakeholders and the decision was the one that optimized the satisfaction of the stakeholders (greatest sum of the utility values; equal to 298.190 and displayed in the three decision nodes). See Table 2 for descriptions of state variables and data sources.

The status of the project is ongoing with stakeholders considering a re-evaluation of their objectives in summer 2014. In an adaptive management context this is called double-loop learning [17] and is important because as stakeholders learn more about how a complex problem is constructed they also tend to adjust their expectations and desired outcomes. If this type of adjustment is done in a structured and transparent way then conflict over changing objectives will be minimized. Overall the project has been a success in that stakeholders have learned something about how their objectives responded to management and they remain committed to continuation of the project at least up to the time when the FERC license will be evaluated and renewed (2017-2023). In addition, the project is one of the few aquatic examples of adaptive management where the "loop" has been closed and re-evaluation will likely change future management [10].

## VI. DISCUSSION

Integrated and adaptive management of water resources is becoming a global paradigm that is beginning to replace command and control approaches [5], [18]. Integrated water resource management (IWRM) and adaptive management are different processes that have been applied to address complex management of water problems [18]. The case study presented here has elements of IWRM in that it is heavily stakeholder driven with a governance structure, while it maintains the elements of adaptive management. Because institutional barriers often derail adaptive processes [(Walters 1996)] frameworks that combine stakeholder driven cooperative management with structured decision making and learning are mechanisms for changing social-ecological systems into improved states [19]. Although the case of the Tallapoosa River is an example that only involves one dam, the complexities (and uncertainties) of the system along with the social-ecological demands are not trivial. The long-term commitment of the decision making board and the inclusivity of certain stakeholders in making management decisions together provide an excellent example of co-management that illustrates the benefits of governance structure even for seemingly localized problems at fine landscape scales.

## VII. CONCLUSION

Conflict resolution where water rights are involved requires communication, cooperation and trust and these terms may not apply when conflict over water arises. Adaptive management of the flows below Harris Dam allowed for modification of flows below the dam without re-opening the FERC license which was a win-win for the stakeholders because regulatory red-tape and potential litigation does not provide a framework for testing potential solutions to the actual problem. Consequently, the adaptive management framework has been proposed to find solutions to water allocation issues below several other dams in the Southeast United States (e.g. Weiss Dam, Coosa River, Alabama; Tim's Ford Dam, Elk River, Tennessee). Success of the project is attributed to stakeholder innovation, leadership and patience through the learning process and quantification and parameterization of the decision model that allowed stakeholders to evaluate of trade-offs associated with different management actions. Finally, because of population growth in the region coupled with potential changes in climate, demand for water resources may increase and additional conflict could arise. Embracing frameworks such as stakeholder-based adaptive management that consider social values and are informed with scientific findings will be important in the future.

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## REFERENCES

[1] N. L. Panwar, S. C. Kaushik and S. Kothari. "Role of renewable energy sources in environmental protection: a review," Renewable and Sustainable Energy Reviews, **15**, pp. 1513-1524, 2011.

[2] C. Pringle, M.C. Freeman and B.J. Freeman. "Regional effects of hydrologic alterations on riverine macrobiota in the New World: tropical–temperate comparisons", Bioscience **50**, pp 807-823, 2000

[3] E. R., Irwin and M. C. Freeman. "Proposal for adaptive management to conserve biotic integrity in a regulated segment of the Tallapoosa River, Alabama, U.S.A." Conservation Biology **16**, pp 1212-1222, 2002.

[4] A. Swain. "Water wars: fact or fiction?" Futures **33** pp 769-781, 2001.

[5] C Pahl-Wostl, M. Craps, A. Dewulf, E. Mostert, D. Tàbara, and T. Taillieu. Social learning and water resources management. Ecology and Society **12**, pp 5-23.

[6] N. L. Poff, J D. Allan, M. A. Palmer, D. D. Hart, B. D. Richter, A. H. Arthington, K.H. Rogers, J. L. Meyer, and J.A. Stanford. "River flows and water wars: emerging science for environmental decision making", Frontiers in Ecology and the Environment 6, 298-306, 2003.

[7] C.J. Walters. Adaptive Management of Renewable Resources. New York, MacMillan, 1986.

[8] R. T Clemen. Making hard decisions: an introduction to decision analysis. Pacific Grove, California, Duxbury Press, 1996.

[9] J. Peterson, C. Moore, S. Wenger, K. Kennedy, E. Irwin, and M. Freeman. "Adaptive management applied to aquatic natural resources" Proceedings of the 2007 Georgia Water Resources Conference, Athens, Georgia March 27–29, 2007.

[10] B. K Williams and E. D. Brown. Adaptive Management: The U.S. Department of the Interior Applications Guide. Adaptive Management Working Group, Washington, DC U.S. Department of the Interior, 2012.

[11] C. Lydeard, and R. L. Mayden.. "A diverse and endangered aquatic ecosystem of the southeast United States," Conservation Biology 9 pp 800-805, 1995.

[12] Netica 4.16 for MS Windows software. www.norsys.com, 2014.

[13] B. Marcot, J. D. Steventon, G. D. Sutherland, and R. K. McCann. Guidelines for developing and updating Bayesian belief networks applied to ecological modeling and conservation.

Canadian Journal of Forest Research 36 pp 3063-3074, 2006.

[14] MacKenzie, D. I., J. D. Nichols, J. A. Royle, K. H. Pollock, L. L. Bailey, and J. E. Hines. Occupancy estimation and modeling: inferring patterns and dynamics of species occurrence. San Diego, California Elsevier, 2006.

[15] Z. H. Bowen , M. C. Freeman and K. D. Bovee. “Evaluation of generalized habitat criteria for assessing impacts of altered flow regimes on warmwater fishes”, Transactions of the American Fisheries Society, 127, 455-468 1998.

[16] E. R Irwin and K. D. M. Kennedy. “Engaging Stakeholders for Adaptive Management Using Structured Decision Analysis.” pp 65-68 in U.S. Geological Survey Scientific Investigations Report 2009-5049, 2009

[17] D. Armitage, M. Marschke, and R. Plummer. “Adaptive co-management and the paradox of learning”, Global Environmental Change 18 pp86-98, 2008.

[18] N. L. Engle, O. R. Johns, M. Lemos, and D. R. Nelson. “Integrated and adaptive management of water resources: tensions, legacies, and the next best thing”, Ecology and Society 16, 19-29, 2011.

[19] C.T. Folke, T. Hahn, P. Olsson, and J. Norberg. “Adaptive governance of social-ecological systems”, Annual Review of Environmental Resources 30, pp. 441-473 2005.