Governing by Algorithm?

Deploying quantitative and semi-quantitative socio-ecological modeling to inform and improve watershed management

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Executive Summary

With the rise of smartphones, apps, and artificial intelligence that can teach itself, algorithms have become a buzzword in much of today's discourse on science. Government decisions have long been influenced and informed by algorithms even if the word has no official place in a country's legislation or policy. Algorithms are mathematical formulas that have various applications, including mimicking reality when they compose what is known as a model.

Models are a way to help understand a complex system and alter possible future conditions of that system to predict what factors will cause the most change. Models can be extremely useful to policymakers when used to inform their decision-making about environmental sustainability and resilience, especially when an adaptive management strategy, that is, one that is open to uncertainty of the future, is adopted. The cyclic nature of adaptive management is able to use models in both the realization of the best policy as well as the evaluation of how a policy has been affecting an ecosystem. While adaptive management and traditional administrative law conflict in their willingness to embrace uncertainty, some countries and states within the United States have successfully employed adaptive management regimes that make use of models to influence policy surrounding the environment and wetlands.

Dynamical systems models are one option to better understand resilience and management strategies in complex social ecological systems. While there are many ways to model coupled human natural systems, this approach allows for the development of quantitative metrics of resilience. This can be a valuable tool for regional policy makers hoping to take a proactive approach to resilience in a time of increased uncertainty. However, this modeling approach can reflect a disconnect between local stakeholders and academic researchers.

The model development process holds many opportunities for subjective choices which can bias the results away from what really matters in the system. To bridge this gap, scenario planning was conducted with a diverse group of stakeholders in the Tempisque basin. From this workshop, a framework for converting knowledge learned through scenario planning into a simple dynamical systems model is explored. They key element of this framework is using the intermediate steps of scenario planning wherein stakeholders list and evaluate drivers of change to inform model parameterization. By using a data collected from stakeholders directly, dynamical variables can be chosen according to what stakeholders identify as the key issues. Additionally, from the robust discussion involved in exploring the scenario narratives, more information on which processes are well defined, coupled, and interesting arises.

Algorithms and Policymaking: An Introduction
Brandon Pownall

With the rise of smartphones, apps, and artificial intelligence that can teach itself, algorithms have become a buzzword in much of today's discourse on science. Government decisions have long been influenced and informed by algorithms even if the word has no official place in a country's legislation or policy. From deciding how much an induvial owes in taxes to setting an offender's bail, algorithms have long been embedded in the legal process.[1] For example, in Florida there are long standing algorithms embedded in legislation to calculate what a divorced parent owes for child support.[2] So how can algorithms be better utilized by government officials to inform more abstract areas of policymaking, especially when maximizing environmental sustainability and minimizing environmental degradation in wetlands?

A buzzword, by definition, is often misunderstood or misused by both the layman and people in the field. Simply put, an algorithm is a mathematical formula. In a report by United Kingdom's Parliament, algorithms are defined as, "a set of instructions usually applied to solve a well-defined problem."[3] Algorithms are best used to influence policy in the form of models. In short, "[a] model is simply any device that represents an approximation of a real phenomenon."[4] In other words, "in order to predict how the world works, climate scientists develop computer algorithms that model the real world by inputting the data that they gathered from measuring environmental conditions."[5] Models are tied to algorithms in that models are composed of algorithms that are designed mimic conditions of reality such that a change to the input variables of the algorithms will help predict how reality will be altered.

Models are especially applicable to natural environmental processes that are influenced by both human and non-human changes. In atmospheric science, the University Corporation for Atmospheric Research (UCAR) makes use of global climate models to better understand how climate can possibly change in the distant future.[6] Global climate models "use mathematical equations to describe the behavior of factors of the Earth system that impact climate. These factors include dynamics of the atmosphere, oceans, land surface, living things, and ice, plus energy from the Sun".[7] Each factor is another input in the algorithm used to create an accurate model. A change in an input, in theory, predicts how an actual change in a factor will affect the system as a whole. UCAR provides these climate models to thousands of scientists in order to predict how things like greenhouse gas emissions will change our atmosphere and the climate.[8]

Due to the complex nature of earth's systems and unpredictability of human and non-human behavior, there exists a level of uncertainty in climate modeling.[9] This uncertainty leads to the creation of multiple scenarios based on the possible input changes. All of these scenarios can be utilized in policy making to determine what factors deserve the most attention and which factors are unlikely to affect a system's behavior as a whole.

When determining what policy to implement to increase sustainability, models have the potential to focus policymakers on the most vulnerable factors. Good government policy making can be viewed as a cyclical process in which smaller cycles of learning about the policy take place.[10] These cycles are a part of an approach to policy implementation that adapts to the uncertainty of future conditions called adaptive management.[11] Adaptive management is best defined as a way to embrace uncertainty by actively learning from policy implementations that are cyclically adjusted based on new findings.[12] A simplified way of understanding adaptive management is “policies become hypotheses, and management actions become the experiments to test those hypotheses”.[13] Models should be utilized in the first stage of policymaking to determine whether a proposed policy will be effective as well in the final stage of the cycle to monitor the effectiveness of a policy in place.[14] Even though the benefits of modeling and adaptive management in policy implementation and evaluation are clear, many legal system, such as that of the United States, often require a level of certainty that is possible when dealing with complex systems such as wetlands.[15]

While the United States may be behind in the use of algorithms and policymaking, the use of algorithms in policymaking surrounding environmental sustainability within watersheds has an international history. Denmark has government officials at every tier of government who have been educated on modeling guidelines set forth by law.[16] Since 2003, Denmark has been managing their watersheds with a national model of ground-water surface known as the DK-model.[17] The DK-model can be used on a national and local level and has been utilized for purposes such as a “nationwide analysis of sustainable groundwater abstraction and climate change impacts on the hydrological cycle.”[18] At the local level, the DK-model allows decision makers to find support for their choices utilizing the model and their regional knowledge in tandem.[19] One of the key reasons the DK-model is innovative is its use across all agencies from the national and local level.

By 2005, the Netherlands took note of Denmark’s successful use of the DK-model to create a national model known as the National Hydrological Instrument (NHI).[20] The NHI developed out of a 1970s model that was created for the Policy Analysis for Water after facing a severe drought.[21] NHI is unique for its 5-model composition that are physically different but are systems that are interconnected.[22] NHI was developed to serve two purposes: policy making with "real-time forecasting for daily water management" and as a tool for Dutch hydrologists to access and utilize in studies.[23] By 2013, all Dutch hydrologic management organizations were making use of the NHI to support their policy decisions.[24] Together, the Dutch and Danish governments serve as examples of practical and constructive use of modeling to inform policymaking at local and national levels with the added benefit of using government funds to increase scientist’s data pool. The models show the importance of giving every agency uniform access to well-researched and well-funded algorithms that become the basis for policy decisions on how to best manage watersheds.

Following the trend of the rest of Europe, the United Kingdom called for scientists' input to ultimately decide the place of algorithms in governance in a 2017 Parliamentary inquiry. The input of stakeholders was considered by the Science and Technology Committee and a report was published in 2018 on their findings. Among other fields, the UK was already using algorithms in criminal justice with the Harm Assessment Risk Tool, a model that made use of machine-learning algorithms to teach itself how to predict whether a criminal would reoffend.[25] The commission ultimately embraced the idea of algorithms in governing and reached two conclusions similar to the Danish and Dutch models: the government "should continue to make public sector datasets available, not just for 'big data' developers but also algorithm developers" and "should produce, publish, and maintain a list of where algorithms with significant impacts are being used within Central Government, along with projects underway or planned for public service algorithms, to aid not just private sector involvement but also transparency."[26] The report notes that the findings will be officially codified in statutes in "due time" indicating the seriousness of the commission on continuing algorithmic research and availability backed by government funding.[27]

Canada has also followed suit and implements policy based on modeling that is available to all agencies. In Ontario, groundwater resources were threatened in the 1980s and 1990s by increased human development in the area.[28] While there was a lack of government action until the turn of the century, by 2001 the Oak Ridges Moraine Groundwater Program was formed.[29] Recently, a modeling expert was hired and multiple modeling software packages have been acquired to ensure models built in the past can be updated and checked for accuracy.[30] Like Denmark and the Netherlands, the program is a single centralized collection of models for multiple agencies to use and modify.

These examples are not to prove that the United States does not embrace algorithms and examples from Florida prove states have effectively utilized adaptive management and modeling in environmental sustainability. In Florida, the Everglades makes use of models in pursuit of an adaptive management regime that will overcome uncertainties caused by climate change in conservation efforts "to find the best method for balancing the restoration, water supply, and flood control goals by combining data mining, historical analysis, physical models, and evaluation tools."[31] Conservation was necessary after attempts at controlling flooding and managing other water regimes in the park led to a lowered resilience of the ecosystem.[32] The Water Resources Development Act of 2000 effectively made adaptive management the law for managing the restoration of the park.[33] The first project to fully utilize adaptive management was called the Decompartmentalization Adaptive Management Plan (DAMP) which made use of historical approaches, data collection, and hydrologic models to influence decision-making within the park.[34] While the Everglade still faces uncertainty, adaptive management that incorporates modeling is a part of the legal framework governing how the park will be managed.

In the case of New Jersey, scientists have created a state-wide model of land-use that can predict how the land will react to uncertain future conditions.[35] The use of models is not new for the state, going back to 1973, the Environmental Protection Agency made use of computers to decide how possible developments would affect the air quality of the Meadowlands, a highly polluted and abused wetland in northeastern New Jersey.[36] While modeling has been used in policymaking in the past, currently, New Jersey has the models but is not using them to effectively implement policy that adapts their wetlands to climate change.[37]

Taken in the abstract, the current state of modeling in watershed management is most successful when 3 key factors are present. The first is that the models are created with government funding such that the experts behind them have the ability to work for the purpose of accuracy and not profitability. An added benefit of government sponsored modeling is that scientists outside governmental agencies can have access to the data troves for purposes outside of decision-making. Next, the models must be available at all levels, to all decisionmakers and stakeholders surround a watershed to both have input and make use of the output of the models. Finally, the models must actually be integrated into an adaptive management scheme for success such that uncertainty is embraced in policy making. Even an ineffective policy is beneficial in the long run through an adaptive management technique that finetunes algorithms to truly match complex systems while policymakers learn from failures. Policymakers must embrace the oft quoted reality of Samuel Beckett's *Worstward Ho*: "Ever tried. Ever failed. No matter. Try again. Fail again. Fail better."[38]

Pairing the Scenario Planning Framework with Quantitative Model Development

Kathleen Vazquez

The inevitable influence of climate change encourages the use of a resilience framework for analyzing social ecological systems such as the Tempisque-Bebedero basin. Ecologists and natural resource managers have been attempting to view and manage ecosystems with respect to resilience since the publication of Holling's seminal 1973 paper on the subject.[39] This focus on resilience, or a system's ability to return to some desired state after suffering a shock, has changed the way scientists look at natural systems, and more recently, human-dominated systems. Analytic tools that help quantify resilience are important in comparing the outcomes of policy and management decisions, potentially helping to avoid both ecological and economic regime shifts. Such tools however are either lacking or far from adequate for a complex social ecological system like the Tempisque basin. This section will explore dynamical systems models as a tool for quantitatively understanding resilience and tradeoffs in social ecological systems. Using an example from the literature, the model development process will be discussed. A framework for pairing elements of scenario planning with model development will then be presented for the Tempisque basin.

Dynamical Systems Models

Dynamical systems models are one option for better understanding tradeoffs and large-scale dynamics in social ecological systems. These models use differential equations to evaluate changes in key elements of the system over time. These key elements are the dynamical variables and must be chosen by the modeler. While the number of dynamical variables used is not fixed, there are advantages and disadvantages inherent in this choice. A dynamical model with one or two variables has the advantage of simplicity. Fewer equations means that stability analysis is nearly always possible, leading to concrete results about the equilibriums of the system. Too much simplicity can also be a disadvantage. Dynamical systems with fewer than three dynamical variables are unlikely to exhibit nonlinear behavior or regime shifts. This makes them more predictable, but uninformative for real systems that researchers suspect may exhibit regime shifting behavior. Including more than five dynamical equations opens the door for the inclusion of significant real-world complexity. However, stability analysis becomes impossible. For the Tempisque basin, an ideal dynamical systems model would have three dynamical variables. This allows for interesting behavior, potentially including regime shifts, which are of particular interest in this basin. It also allows for analytic stability analysis. This allows the model to be used to define resilience metrics. Boundaries of stability can be used as a quantitative measure of a systems ability to return to a desired state after a shock. To ensure an interesting, informative, and useful model, these dynamical variables should fit several criteria: They should be highly relevant to the system, represent reasonably well-understood processes, and should be sufficiently coupled as to produce interesting results. Once these dynamical variables are chosen, the processes governing their change over time must be established and mathematically operationalized. This requires pairing an understanding of the social ecological system with appropriate mathematical representations, such as existing hydrologic models or game theory approaches.

An Example of Model Development

Governance of common pool resources has been examined through a dynamical systems model, with interesting results. A summary of this existing model will serve to illustrate the development process. This work considers a natural resource that users can access through public infrastructure, which is maintained by public infrastructure providers.[40] An example of a common pool resource fitting this framework would be a lake used for fishing, accessed by docks maintained by a local government. If the docks are functioning, local users can use them to profit from the fishery. To understand more about this theoretical social ecological system, the framework is mathematically operationalized, with three dynamical variables and various decision variables and other parameters. Dynamical variables are selected to be the state of the infrastructure, the amount of the natural resource available, and the fraction of users choosing to access the resource for a profit. These three variables represent coupled processes within the theoretical system that are important to understanding potential tradeoffs. Decision variables included representations of taxes paid towards maintenance and prevalence of rent-seeking behavior or corruption. These represent variables that are not well defined and can be tuned to understand the implications of different potential governance scenarios. This model has been used to define quantitative measures of resilience, which are of use to policy makers looking to expand beyond optimization. [41]

There are several issues with this model development process. Relevance of the variables is a subjective distinction that will reflect the goals of research effort or the background of the researcher. While academic experts seek a comprehensive knowledge of a system before developing models, there is a disconnect between researchers and local stakeholders. When defining processes, a narrow academic perspective may omit important drivers of change that should be included as parameters. Decision variables, or tunable parameters that represent governance or climatic uncertainty, may also be difficult to identify without local knowledge in certain social ecological systems, such as a complex watershed like the Tempisque. To remedy this issue, a form of participatory modeling is presented here that uses elements from the scenario planning framework.

The Scenario Planning Framework

Scenario planning has been used to develop policies when there are large uncertainties within a system.[42] Conducting this exercise with stakeholders involves a structured exploration of possible future scenarios at the extremes of uncertainty. The goal is to develop different narratives to gain perspective and information in planning for the future. This methodology is useful in engaging stakeholders in identifying what aspects of the system are important to them collectively, but typically ends with the development of scenarios. These scenarios have been used to influence policy and management, and resulting scenarios have been input into existing models.[43] However, the process has not yet been linked directly to model development efforts. Scenario planning was conducted with stakeholders from the Tempisque basin from various sectors, including agricultural, academic, and government organizations. The general methodology is as follows, with details from the basin specific workshop included.

- A scope of the scenario planning was identified. Because interactions between human behavior and environmental outcomes are of interest, the scope of the scenario planning was defined to include environmental, water resource, agricultural, and livelihood changes in the Tempisque basin.
- All drivers of change within the scope were listed. This was done through a mix of interviews and online surveys. Stakeholders were asked to list 7-10 drivers of change for water resources, agriculture, and livelihoods, respectively. Some factors include water availability, governance, and population growth.
- Drivers were ranked by stakeholders for both relevance and uncertainty. Stakeholders were asked to choose from the combined list those drivers that they viewed as most important or relevant to the system, and most uncertain when thinking about the future. They were asked to provide 5 responses for most relevant and most uncertain, respectively, though some listed fewer or more.
- Axes were defined from highly relevant and uncertain drivers. Two axes were defined through discussion with stakeholders over the data collected on the many drivers of change. For each axis, two extremes were identified, with combinations of extremes forming the four quadrants.
- Scenarios were developed by groups of stakeholders. These quadrants are then expanded on, considering the other drivers listed in the second step. Stakeholders were encouraged to

create a narrative that included as many relevant drivers as possible to get a complete picture of how the scenario would unfold.

Scenario Planning and Development

This process can be tied to the model development process discussed previously. Data collected in steps two and three is shown in Figure 1, with values normalized for ease of comparison. This data provides a structured link between local stakeholder knowledge and concerns and academic researchers. From the model development discussion, the first goal is to define dynamical variables. For this, factors that are well understood and important to the system are needed. Drivers that stakeholders have listed as highly relevant, but not highly uncertain are prime candidates. From Figure 1, the second group of drivers including governance, natural resource management, water quality, population, and livelihood changes would be explored as options for dynamical variables. From these five options, the other requirements of dynamic variables should be explored to make the best selection. With regards to representing well understood processes, governance and natural resource management may prove too broad to model as a single process. Both include complex systems with many users making decisions on many policy scenarios. Water quality and population (including migration) are both narrower, and therefore more easily described. Changing livelihoods covered many possible areas in the scenario planning workshop. However, it might be informative to discuss it as the region's future as either an agricultural or touristic community.

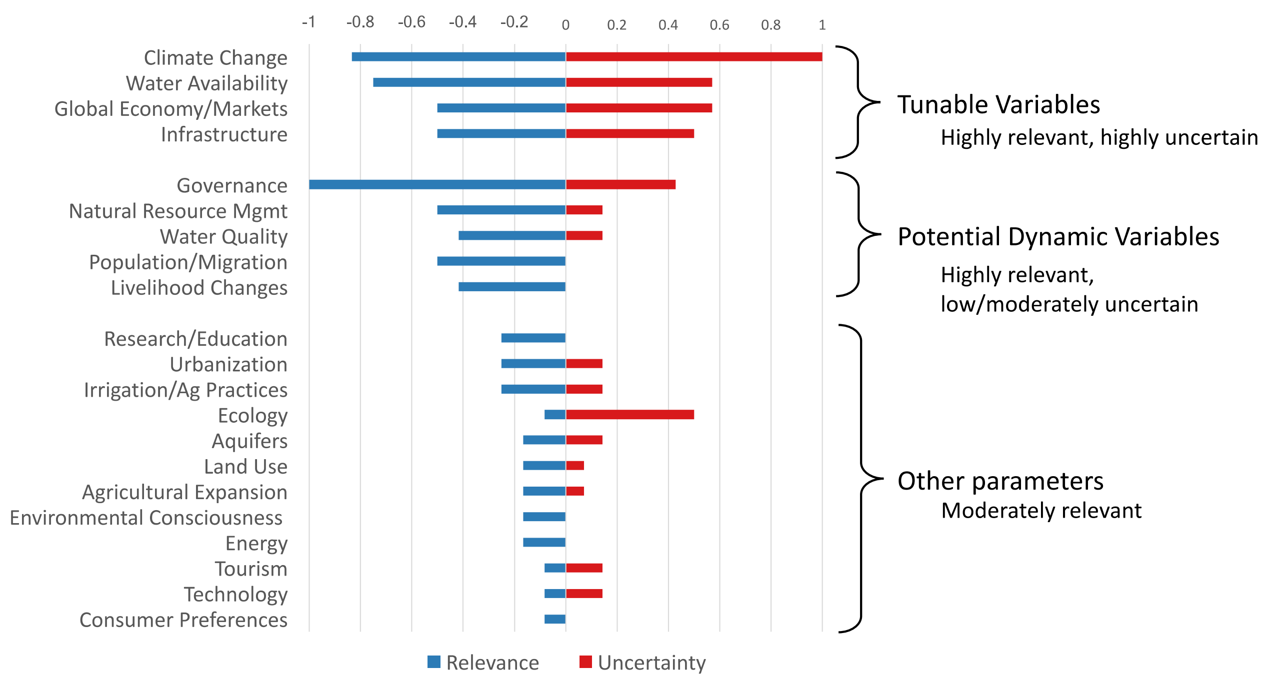

Figure 1: Data collected from scenario planning workshop, categorized for model development.

Tunable parameters should be system elements that are highly important, but not well understood. For these model elements, the first grouping of drivers from *Figure 1* are perfect candidates. These very uncertain elements of the Tempisque basin cannot be well described by simple mathematical processes. However, by incorporating them as tunable parameters, the system can be analyzed under different scenarios of climate change, water availability, or market fluctuations. This also sets up the model to be ideal for the modeling of the four scenarios developed by the stakeholders.

Remodeling the Configuration of Watershed Governance through Artificial Intelligence Software & Immerging Technology

Gabriel Perez

With the advent of the digital-age contemporary society now has access to ever evolving technology and information that can be utilized to address regional, national, and global environmental problems. However, in the field of watershed management, the US federal government, a majority of the US state governments, and multiple foreign governments have yet to restructure their watershed governance policy framework to incorporate the use of contemporary science, technologies, and understandings of the interrelatedness of ecosystems and the various variables that affect them. As a result, the world faces a global water crisis and the governance of watersheds is now more crucial than ever before. In order to appropriately manage the current governance of watersheds, the traditional environmental management scheme utilized by the US federal government, US state governments, and certain foreign governments needs to be re-conceptualized through adaptive management plans that continuously adjust the legal governance framework to incorporate current knowledge with contemporary technology, artificial intelligence computer systems, and up to date global information.

Contrasting the Establishment of Traditional Environmental Governance Frameworks with the Establishment of Adaptive Management Governance Frameworks

Watershed governance and management as it is contemporaneously understood did not develop until the middle of the 20th century. As was the case of a great deal of watersheds, the traditional model of environmental policy and planning was not very effective because it was narrow in geographic and jurisdictional scope. This narrowness of scope was a result of institutional norms focusing on administrative and political borders rather than adhering to natural geographical and hydrological boundaries, as well as a failure to address the complexity and connectivity of various variables that influence a watershed.[44] The failure to address the complexity of watershed governance stems from the very nature of the legal tradition because in order to create and enforce the law society must assume that the current knowledge of policy-makers is definitely the appropriate course to take, and as a result "complexity and uncertainty are sometimes arbitrarily dealt with by breaking complex systems down into seemingly manageable parts and then assuming that managing these parts addresses the entire social-ecological system."[45] These early aspects of the traditional model of environmental management allowed for "implementation gaps inhibiting action, particularly where information is hard to quantify".[46]

The formation of an ecological protection governance framework does not happen through a single process. In an instrument for the establishment of the restructured Global Environmental Facility (GEF), an international partnership created by the 1992 Rio Earth Summit, GEF distinguished "four main stages in the development of an environmental regime."[47] The first stage identifies the ecosystem at issue and ascertains potentially significant scientific uncertainties surrounding the problem.[48] The second stage centers on regime design by establishing advisory scientific bodies and creating a policy framework.[49] The third state comprises the actual implementation of the environmental management regime.[50] The final fourth stage entails an analytic evaluation of how effective the environmental management regime has been in affecting the ecosystem.[51] Although there are certain aspects of the various stages that overlap, the defining of four distinct stages of an environmental governance framework illustrates that there are unique areas in which algorithm modeling, artificial intelligence, and emerging information can be utilized to improve the legislation and regulations that comprise a watershed governance framework.

Utilizing Governing Body Restructuring and Artificial Intelligence to create Adaptive Management Watershed Governance Frameworks

As previous sections in this study have defined, adaptive management governance is defined as a way to embrace uncertainty by actively learning from policy implementations that are cyclically adjusted based on new findings.[52] Because adaptive management governance is a framework for pursuing a policy regime rather than a methodology, several different approaches and procedures can be utilized in order to create a governance scheme that is resilient to the uncertainties of the future. One such methodology, as previously discussed, is utilizing the local stakeholder input from scenario planning coupled with dynamic systems modeling to more accurately depict potential futures.

Restructuring the hierarchy of the governing bodies that manage a watershed is another methodology to achieve an adaptive management governance framework. As logic suggest, the success of watershed governance is impacted coordination and collaboration of the governing bodies. In GEF's stages of environmental policy framework development, the second stage is regime design. In the regime design stage, the treaty, conference of parties, or government establishes the institutional structure in the form of governing bodies tasked with "facilitating the subsequent adoption of more specific obligations, usually in the form of protocols."[53] Environmental conservation organizations that have been created by international treaties have traditionally utilized advisory scientific bodies to inform policy, protocols, and legislation. However, these advisory scientific bodies are impeded in their conservation efforts in the traditional model because "their function is as a rule limited to the evaluation of scientific research conducted outside of the treaty context and does not include the conduct of primary research."[54] As a result of not conducting primary research, advisory scientific bodies are hindered from being able to test the latest emerging hypothesizes and models, necessitating waiting for peer-review of these emerging hypothesizes and models from the larger scientific community.

Furthermore, in the traditional environmental governance framework advisory scientific bodies lack the ability to respond immediately to scientific developments because they do not have the ability directly to institute regulations, legislation, and protocols. In order to better bring the research of scientific bodies into the fore of watershed governance, "substantive decision-making is important for expanding the scope of the treaty obligations to respond to scientific developments."[55] Thus, establishing scientific bodies with the authority to legislate would establish a better adaptive management governance regime than the traditional model. Even if these scientific bodies are not granted sole decision-making power, by allowing advisory scientific bodies to have a direct power to create protocols and regulations the delayed gradualness of bureaucratic governance of the traditional model will give way to a much more streamlined adaptive management policy.

Another methodology to restructure watershed governance to be a more adaptive governance policy regime is to find a fixed place and usage for contemporary global information, technology, and artificial intelligence systems. Under the American Bar Association's Model Rule 1.1, attorneys have an ethical duty to keep up with changes in the law and legal practice, including the benefits of using technology.[56] In GEF's third stage, the implementation of watershed governance can be augmented significantly through the use of various legally defensible technological advances.

For the attorneys and policy-makers working in international, national, and regional watershed governance, emerging algorithmic software can significantly aid in the collection, review, and preservation of electronically stored information (ESI). A great deal of digital technology has already become commonplace in the legal profession generally, for example: the usage of website databases and hard drives to store ESI, the utilization of Cloud Storage as a backup drive to preserve digital data, and the usage of computer software to process information and provide the computer instructions on what to do with ESI, the usage of Boolean syntax operators to enhance search engine queries by retrieving documents utilizing words in specific combinations. However, in the last decade there have been groundbreaking technological advances in artificial intelligence software systems that are going to have a significant impact on watershed governance and environmental governance generally. Due to the cultural influence of science fiction, a large swath of the population envisions artificial intelligence as a robot with consciousness and autonomy. However, there are multiple definitions of artificial intelligence; and because humanity has yet to create cognizant machines, in legal governance a definition of artificial intelligence widely used is, "[artificial intelligence] is a sub-field of computer science. It can be broadly characterized as intelligence by machines and software. Intelligence refers to many types of abilities . . . It involves mechanisms, some that are fully discovered and understood by scientists and engineers, and some that are not."[57] By understanding artificial intelligence through this scope, various computational tasks done by algorithmic software are considered intelligence.

In terms of ESI and data review, Technology Assisted Review (TAR) has evolved through the use of predictive coding to software of artificial intelligence. The original TAR software utilizes sophisticated algorithms that enable a computer to predict and determine the relevance of ESI, based on training by a human reviewer.[58] The principle advantage of TAR is that it ranks documents in the collection allowing for proportionality cut-offs. The original TAR software has been augmented by Continuous Active Learning software, such as Catalyst's CAL. This software still utilizes predictive coding, however because CAL continuously learns with each responsive document that is added and ranked in the program, it does not require the assistance of expert human reviewers to create an original seed set to train the program.[59] Although in the legal profession this technology is currently almost exclusively utilized for discovery once anticipation of litigation is underway, once the research capacities provided by TAR & CAL are utilized by legislators and policy-makers it will produce remarkable benefits to watershed governance managing bodies; this artificially intelligent software has the capacity to sift through a litany of international treaties, international protocols, multi-national agreements, and national law at a fraction of the cost and time it would take an expert human reviewer working for the governing body to do manually. Thus, governing bodies are more efficiently able to assess issues and inform their policy decisions with better research.

A phenomenon known as the Internet of Things (IoT) has the capacity to significantly enhance adaptive management watershed governance through data collection. The IoT "is a rapidly expanding network of everyday web-connected and interconnected smart devices, buildings, vehicles, and other things that are embedded with sensors or microchips, including radio-frequency identification (RFID) chips, that enable them to collect, use, process, analyze, transmit, store, and share data."[60] In terms of water governance, items such as buoys and deck pillars can be connected to micro electro radio-wave systems or wireless internet networks to provide up to date data on changing water levels, pollutants present in the water, and water temperatures. The IoT network has straightforward applicability to GEF's third step of ecosystem governance creation, in that this artificial intelligence increases the efficiency of implementation by the watershed's governing body; however, the IoT can also be utilized for GEF's fourth step of governance creation, the analytic evaluation of how effective the environmental management regime has been in affecting the ecosystem. With more and more physical objects now having microchip sensors and internet data transition capabilities, the quantity and types of data that governing bodies can monitor remotely is going to continually increase. Due to the IoT's ease of acquiring data of a watershed, once enough data is compiled policy-makers can utilize the information gathered from the IoT to evaluate the dynamic variables of the watershed and create the most holistic watershed governance scheme.

Given the pace of the technological advancements in contemporary society, in the following decades there is going to be a significant increase in the availability of artificial intelligence systems. Although it is impossible for watershed governance managing bodies to continuously be up to date with the latest technology, the governing bodies need to make an effort through investigating and financing to incorporate these advances into their design, implementation, and analysis of their governance regime.

Conclusion

Examples of successful implementation of policy that has been created and evaluated based on models in an adaptive management regime include the Dutch, Danish, and Canadian models. Governments, like the state government for New Jersey, can look to these countries for influence on how they make use of preexisting models. The models need to be collaborative between all agencies that manage that type of eco system, they need to be accessible to both local and national officials as well as private sector scientists. Beyond the government backed models, statutes must be enacted that enforce compliance with adaptive management schemes that take models, among other resources, into account in both the beginning and end of a policy cycle.

In addition to the implementation of modeling, there are various other methodologies and practices that governing bodies should utilize to produce an adaptive management governance framework. Due to the complexity and uncertainty of several variables that can affect a watershed, governance regimes need configured to address the totality of an ecosystem's dynamics. The regulations and protocols of environmental governance regimes should be able to be quickly amended in order to be more adaptive to future ecological changes. Additionally, in order to best instill an adaptive management governance framework, the governing bodies must make an effort to utilize contemporary technology, artificial intelligence systems, and emerging information to forecast probable futures of the watershed under the proposed governance system. Policy-makers should employ these technologies and practices to direct the creation of their governance regime so that they avoid implementation gaps.

Adaptive management arose from a desire to promote resilient systems. When developing models to evaluate potential watershed management policy, tools that can quantitatively compare resilience are useful. There is a limit to models developed solely by academic researchers without the input of local stakeholder knowledge. The scenario planning framework provides much needed connection to local knowledge in the model development process. Recommendations for pairing scenario planning workshops are as follows:

- Stakeholder engagement in providing the drivers of change and ranking for relevance and uncertainty should be a primary focus of the workshop.
- Dynamic variables should be selected from the drivers which are of high relevance, and moderate-low uncertainty.
- When evaluating dynamic variable choices, narrative development by stakeholders should inform choosing those which are well understood and highly coupled.

Citations

[1] Michael Veale, Max Van Kleek & Reuben Binns, *Fairness and Accountability Design Needs for Algorithmic Support in High-Stakes Public Sector Decision-Making*, CHI '18 Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems 2 (2018).
[2] Fla. Stat. § 61.03 (2018).
[3] Science and Technology Committee, Algorithms in Decision Making, 2017-19, HC 351, at 7 (UK).
[4] Mason Marchildon, Thorsten Arnold, Steve Holysh & Rick Gerber, *A Guide for Actively Managing Watershed-Scale Numerical Models in Ontario*, Oak Ridges Moraine Groundwater Program 7 (2017).
[5] Matthew Knoblauch, *You Probably Shouldn't Build There: Watershed-Based Land Use Strategies for Mitigating Global Climate Change in New Jersey's Freshwater Systems*, 16 Sustainable Development Law & Policy 4, 7 (2017).
[6] Climate Modeling, UCAR Center for Science Education (2011), https://scied.ucar.edu/longcontent/climate-modeling.
[7] *Id.*
[8] *Id.*
[9] *Id.*
[10] Marchildon, Arnold, Holysh & Gerber, *supra* note 4, at 29.
[11] *Id.*
[12] Carl Folke, Thomas Hahn, Per Olsson & Jon Norberg, *Adaptive Governance of Social-Ecological Systems*, 15 Ann. Rev. Env't & Resources 441, 447 (2005).
[13] *Id.*
[14] Marchildon, Arnold, Holysh & Gerber, *supra* note 4, at 29.
[15] Olivia Odom Green et al., *Barriers and bridges to the integration of social–ecological resilience and law*, 13 Frontiers in Ecology & the Env't 332, 334 (2015).
[16] Marchildon, Arnold, Holysh & Gerber, *supra* note 4, at 10.
[17] *Id.*
[18] Xin He et al., *Designing a Hydrological Real-Time System for Surface Water and Groundwater in Denmark with Engagement of Stakeholders*, 30 Water Resources Management 1785, 1797 (2016).
[19] *Id.* at 1798.
[20] Marchildon, Arnold, Holysh & Gerber, *supra* note 4, at 10.
[21] Willem J. De Lange et al., *An operational, multi-scale, multi-model system for consensus-based, integrated water management and policy analysis: The Netherlands Hydrological Instrument*, 59 Envtl. Modelling & Software 98, 98 (2014).
[22] *Id.* at 99.
[23] *Id.* at 105.
[24] Marchildon, Arnold, Holysh & Gerber, *supra* note 4, at 10.
[25] Science and Technology Committee, *supra* note 3, at 14.
[26] *Id.* at 18.
[27] *Id.* at 9.
[28] Marchildon, Arnold, Holysh & Gerber, *supra* note 4, at 8.
[29] *Id.* at 9.
[30] *Id.*
[31] Alfred R. Light, *Tales of the Tamiami Trial: Implementing Adaptive Management in Everglades Restoration*, 22 J. Land Use & Envtl. L. 59, 83 (2006).
[32] Barbara A. Cosens, Lance Gunderson & Brian Chaffin, *The Adaptive Water Governance Project: Assessing Law, Resilience and Governance in Regional Socio-Ecological Water Systems Facing a Changing Climate*, 51 Idaho L. Rev. 1, 19 (2014).
[33] Lance H. Gunderson, Barbara Cosens & Ahjond S. Garmestani, *Adaptive governance of riverine and wetland ecosystem goods and services*, 183 J. of Envtl. Mgmt. 353, 357 (2016).
[34] Light, *supra* note 31, at 82-83.
[35] Knoblauch, *supra* note 5, at 7.
[36] Office of Air and Waste Management et al., EPA-450/3-74-056-c Hackensack Meadowlands Air Pollution Study - Emission Projection Methodology 1 (1973).
[37] Knoblauch, *supra* note 5, at 11.

[38] Samuel Beckett, WORSTWARD HO 7 (1983).
[39] C. S. Holling, *Resilience and Stability of Ecological Systems*, 4 ANN. REV. OF ECOLOGY & SYSTEMATICS (1973).
[40] Rachata Muneepeerakul & John M. Anderies, *Strategic behaviors and governance challenges in social-ecological systems*, 5 EARTHS FUTURE 865, 868 (2017).
[41] Mehran Homayounfar, Rachata Muneepeerakul & John M. Anderies, *How Robust is Your System Resilience?*, EARTH SYSTEM DYNAMICS DISCUSSIONS (2018), https://doi.org/10.5194/esd-2017-124.
[42] Garry D. Peterson, Graeme S. Cumming & Stephen R. Carpenter, *Scenario Planning: a Tool for Conservation in an Uncertain World*, 17 CONSERVATION BIOLOGY 358, 359 (2003).
[43] *Id.* at 360.
[44] Jeremy G. Carter & Iain White, *Journal of Environmental Management*, 113 Elsevier 228, 231 (2012) (problems with traditional models of environmental governance).
[45] Odom Green et al., *supra* note 15, at 332.
[46] Jeremy G. Carter & Iain White, *Journal of Environmental Management*, 113 Elsevier 228, 229-230 (2012) (traditional models of environmental governance).
[47] PIERRE-MARIE DUPUY & JORGE E. VIÑUALES, INTERNATIONAL ENVIRONMENTAL LAW 40-41 (Cambridge University Press, 1st ed. 2015).
[48] *Id.*
[49] *Id*.
[50] *Id*.
[51] *Id*. at 42.
[52] Carl Folke et al., *supra* note 12, at 447.
[53] PIERRE-MARIE DUPUY & JORGE E. VIÑUALES, *supra* note 47, at 42.
[54] Jorge E. Viñuales, *Legal Techniques for Dealing with Scientific Uncertainty in Environmental Law*, 43 Vand. J. Transnat'l L. 437 (2010).
[55] *Id*. at 455.
[56] MODEL RULES OF PROF'L CONDUCT r. 1.1 (AM. BAR ASS'N, 2017).
[57] William J. Connell, *Artificial Intelligence in the Legal Profession-What You Might Want to Know*, 66 R.I.B.J., 5 (May/June 2018) (defining artificial intelligence).
[58] Joel Henry & Michael Pasque, *Managing A Data Intensive Case: How to Find A Needle Without Drowning in A Haystack*, 72 J. Mo. B. 142, 144 (2016).
[59] SHIRA A. SCHEINDLIA et al., ELECTRONIC DISCOVERY AND DIGITAL EVIDENCE: CASES AND MATERIALS (West Academic Publishing, 1st ed. 2015).
[60] PLC US Law Department, Practice Notes: Practical Law Intellectual Property & Technology Thomson Reuters (2018)