

## Science Informed Water Management Policies

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### Abstract

Clearly policy makers should consider the impacts of any decisions they might make before making them. Science can provide estimates of various economic, ecologic, environmental, and even social impacts of alternative policies, impacts that determine how effective any particular policy will be. These impact estimates can be used to compare and evaluate alternative policies in the search for identifying the best one to implement. Among all scientists providing inputs to policy making processes are analysts who develop and apply models that provide these estimated impacts and, possibly, their probabilities of occurrence. But just producing them is not a guarantee that they will be considered by policy makers. This paper discusses ways scientists, including systems analysts, can effectively contribute to and inform those involved in making water management decisions. Brief descriptions of a variety of past and on-going water management policy making processes illustrate both some successes and failures of science informing policy.

**Keywords:** science, policy making, systems models, communication, case studies, water management

### 1. Introduction

The natural, economic, and social environment we live in today is changing, and at accelerating rates. We humans are simultaneously causing, adapting to, and attempting to manage, these changes. The impacts of a changing climate are now becoming increasingly obvious even to non-believers. In response to increasing public concern, more of our political leaders are finally becoming serious about doing something to reduce this increasing rate of change and its current and future adverse consequences. Evidence of these consequences is especially clear to water managers who must cope with more extreme and more frequent droughts and floods and water quality issues. New technologies are having a profound effect on almost every aspect of our lives. The science and technology that gave us the internet has changed when, how much, and how often, we communicate with each other, and access information, and even disinformation. Penetration of new technologies that took in the past a few decades is now taking less than 5 years. Within a few months the SARS-CoV-2 virus and its mutations changed major aspects of our social and economic lives – some of which will likely last long after all of us get vaccinated. More dams are being built to meet the increasing needs for water, to prevent floods, and to produce hydropower, among other purposes but they bring with them unexpected and unwanted problems. Public policy makers are expected to deliver solutions to these problems – solutions that work and are acceptable and sustainable. Sound scientific evidence can inform those responsible for establishing regulations and policies that address these management challenges. Acting on that evidence can only increase the likelihood that the resulting policy decisions will meet their objectives. [1].

Scientists are however not always ready to provide this needed information when policy makers want it. Scientists prefer to first inform and convince themselves as they work toward developing new knowledge and new technology needed to better address various issues. Much of this potentially useful science takes place in institutions where science is performed for science sake: aimed at better understanding our planet and what is happening in and on it, and why. Society needs this, and eventually we all will benefit from new knowledge and technology. But performing science for science's sake tends to lead scientists to talk to themselves as they cope to keep up with all the changes in their own disciplines, let alone others. Scientists can become entrenched in silos (ivory towers), challenged by their own problems, and very often isolated from, and not communicating with, the rest of society. All this, together with the explosion of data, including fake data, has sometimes resulted in a

distrust of science, scientists, and their contributions. Hence while there is a need to continue to support and encourage science for science's sake, there is also need to pay attention to how science can best inform those involved in creating policies that impact our individual and collective welfare, however measured. [2-7].

The focus of this paper is on the links between scientists and policy makers impacting the management of water. Informing policy makers is not the only reason that motivates scientists, but it is indeed an increasingly important one. This is evidenced by the growing interest and attention in professional scientific and engineering societies, such as the American Geophysical Union (AGU), the European Geosciences Union (EGU), the American Society of Civil Engineers (ASCE), the American Water Resources Association (AWRA), and the International Water Association (IWA), given to 'science for policy' topics at their conferences and publications. Producing science relevant for policy requires more than just presenting papers and writing journal articles, however. Collaboration between scientists and policy makers is key, and trust, good communication, and the ability to learn and adapt to each other's needs largely determine the extent scientists and their sciences are able to influence policy. Clearly both scientists and policy makers can do without each other's inputs, but almost certainly both the benefits derived from science and the effectiveness of policies chosen by policy makers will be the poorer for it.

## 2. Materials and Methods

There are a variety of factors that can influence how effective scientists may be in informing policy decisions. The following paragraphs discuss these factors and presents some examples illustrating the extent they impacted policy making in particular situations involving water management.

## 3. Results

### 3.1 Scientists and Policy Makers

For the purposes of this discussion, a policy maker is someone who determines policy. A scientist is someone who produces scientific data or evidence, sometimes in support of policy making, and other times just to better understand this world we live in and how parts of it function and interact. Performing science for knowledge and for informing policy can differ. Both are beneficial but conducting science for science sake is far less constrained than performing science aimed at informing a specific policy at a particular place and at a given time.

Scientists are trained to strive to discover or create new knowledge that is true, and can be verified by others. Policy makers however desire evidence from scientists that is good enough to allow an evaluation of alternative policies. It doesn't have to be new, nor does it have to be exhaustive. Good enough evidence rarely includes all available evidence. It is the evidence specifically relevant to, and in a form useable for, a particular policy decision at a particular place and time. It is likely to be evidence that comes from different research studies, and not necessarily just the latest ones. Scientific evidence produced several years ago may be more relevant and useful for policy than that produced last week. Neither is scientific novelty always a virtue when performing science to inform policy.



Figure 1. Storm runoff

Image courtesy of the U.S. Geological Survey, Wisconsin Water Science Center

Example 1. A wide variety of rainfall-runoff models are available for estimating the runoff from land areas. These range from the simplest empirical or data driven models (such as regression equations, neural networks, machine learning, and the Rational method that simply equates runoff to a constant fraction of the average rainfall intensity over a given area), to conceptual approaches based on simplified equations of hydrological process in lumped or distributed form (such as NWSRFS, XINANJIANG, HBV, TOPMODEL, HSPF, and VIC) to the more complex models (such as VELMA, MIKE-SHE, TOPKAPI, G2G and PIHM) that require detailed land surface and precipitation input data and have the potential of producing the most accurate runoff estimates. The particular water management policy issue being addressed, as well as the time and data available, may dictate which among this range of modeling approaches is the most appropriate. The best runoff estimates for informing a policy maker may come from the least accurate but most transparent model or the most complex and least transparent model, depending on the particular issue being addressed. [8].

### 3.2 *Science for Science vs. Science for Policy*

Scientists working in a policy making environment need to be clear when speaking as scientists, and when, as citizens or policy advisers, giving educated opinions. Scientists contributing to policy making debates have convictions and values just like everyone else. However, there is a difference between presenting scientific results and offering advice based on those convictions and values. Scientists cannot hide from the fact that they have opinions, but professional ethics requires that they make clear where their objective science ends and their normative opinions begin. Scientists should be advocates for the scientific evidence they produce, but opinions are not 'the voice of science' just because they are expressed by scientists. Disrespecting this distinction can degrade the trust people have in reputable scientific expertise.

The work of many scientists in academic or research institutions is largely driven by curiosity, rational analysis, and educated subjective judgements. They have ideas, they write proposals to obtain the funding needed to pursue those ideas, perform the research, and if successful, publish and repeat the cycle. Scientists working in a policy making environment, or for a policy making institution, have the same standards of integrity, openness, innovation, accountability and inclusiveness to maintain as the broader scientific community, but have some additional drivers and incentives as well. Those working in the policy environment, for example in The Institute of Water and Hydropower Research (IWHR) within The Ministry of Water Resources (MWR) in China, or in the US Army Corps of Engineers (USACE), the US Bureau of Reclamation (USBR), or the US Environmental Protection Agency (USEPA), to mention a few US federal agencies among many dealing with water, are mainly influenced by

their agency's policy agenda, its mission and authority, with some room for exploratory research. These agencies employ scientists who perform science, and make policy decisions as well. Science topics in these agencies are typically determined by existing or proposed regulatory requirements or by the needs to have social, ecological, economic, environmental impact estimates of proposed infrastructure project decisions. Research 'questions' needing answers from scientists serving in or for these agencies are often posed by legislators and regulators or policy makers who wish to know the immediate and longer term impacts of possible decisions they might make.

Similar conditions apply for consulting firms such as the Danish Hydraulics Institute (DHI) and Deltares that support (i.e., inform) policy making institutions. The National Research Council of the US National Academies and think-tanks such as RAND in the US and Europe, while not government agencies, are almost solely devoted to performing science that informs public policy issues, including those related to water management. The International Institute for Applied Systems Analysis in Austria provides a similar service: producing scientific knowledge useful for addressing regional and global policy issues. Water management has been among its main research areas since its founding in 1972.

### *3.3 Meeting the Science Needs of Policy Makers*

Policy is not dictated by science, or at least not by science alone. In addition to considering scientific evidence, policy makers also consider values, political relationships and concerns and a need to build majority coalitions. Policy makers must consider and work with the values and preferences and opinions of many including the public, other policy makers and scientists, and the regulatory/legal community. While scientific evidence is useful and relevant for developing policy solutions, science alone is not sufficient to replace politics just as politics is not needed to perform science. Yet scientists and their scientific inputs to policy can be more effective if scientists become aware of these other factors that policy makers need to consider. These factors may affect the usefulness of any science-based evidence or advice being offered as well as the how it is being offered.

Policy making is a complex and not-infrequently chaotic process that includes both scientific and normative dimensions. This leads to scientists and policy makers defining and viewing problems differently: one as something to solve technically just based on scientific data and methods, the other as a much more social process of negotiating solutions in an effort to find one that has majority support as well as being technically feasible. Policy makers need scientific evidence that will help them find the best consensus decision that is both technically and politically feasible. Thus their norms and values typically determine what scientific evidence is asked for and how they want it presented. For example, displaying Pareto frontiers identifying alternatives representing efficient tradeoffs among competing objectives may be interesting but not necessarily relevant to policy makers as might be other alternatives that are dominated (inefficient) but politically more acceptable based on values or reasons perhaps not even articulated. Values and concerns of policymakers are typically influenced by different types of evidence besides scientific data, including political and even religious ideologies, ethical principles, anecdotes and rumors, conspiracy theories, fake news and beliefs, disinformation, and so on. These concerns and beliefs can influence decision-making. There is no scientifically quantifiable right mix of all these inputs. As a result, there are no optimal policies, only ranges of satisfactory and unsatisfactory ones. Debates that take place in an open democracy over what policy to implement or what decision to make involve both scientific arguments and subjective judgements that cannot be combined and expressed as a benefit – cost optimization problem, as much as some of us might like. [9, 11].



Figure 2. Muskrats could benefit from a new water control regimen. Image: Wikimedia Commons

Example 2. A joint Canadian-US five-year 20-million-dollar study to identify improved operating policies for controlling the lake levels and river flows of the lower Great Lakes basin began over two decades ago. The study was undertaken for the International Joint Commission that oversees the management and operation of the Great Lakes. The lakes serve multiple users having multiple goals. These purposes include hydropower production, shipping, commercial fishing, recreational boating, shoreline protection and ecosystem enhancement. Ecosystem enhancement turned out to be in conflict with the others, especially shoreline preservation. Floodplain ecosystems benefit from some variation in water levels and flows, whereas shoreline owners would prefer low constant levels that cause less erosion. The higher and more constant the lake levels are, the better for the other purposes, as long as they are below flood stage. Furthermore, benefits derived from all the purposes but ecosystem enhancement could be expressed in monetary terms. But the main motivation for this study was to find operating policies that better protected, and in fact restored, wildlife habitat. Operating policies in force since the mid-1950s had not considered the welfare of wildlife such as muskrats, for example. At one point the US co-chair of the IJC requested a benefit-cost analysis that included all the purposes served by the Lower Great Lakes system, including ecological habitat restoration. He specifically wanted to know the dollar value of a muskrat since the conflict was between what shoreline owners wanted and what ecologists assumed muskrats (representing wetland habitats) wanted. The study ended without that benefit-cost analysis. He claimed later that not getting that analysis was one of the reasons no decision on a revised operating policy was made until some nine years after the study ended. [12].

### 3.3.1 Uncertainty

Scientists are used to dealing with uncertainty especially when dealing with nature and social-economic behavior, and accept it as part of the scientific process. Determining how best to manage water in large part involves determining how best to manage its uncertainties.

Policy makers are less comfortable with uncertainty and expect scientific knowledge to be 'more certain' than other sources. Predictive certainty is typically desired by legal systems as well (see for instance the definition of "predictive knowledge" in [13]). Policy makers know that uncertainty in the predicted impacts of a proposed policy can increase its chances of failure. Nevertheless, policy makers almost always are having to deal with uncertainties in the information they have and in the information they don't have, simply because it, like the future, is uncertain.

While policy makers have been accused of seeking 'one-handed science advisors' – scientists who will not say "on the one hand it could be 'A', but on the other hand it could be 'B'," policy makers seem to be increasingly asking for information related to the uncertainty of scientific evidence or conclusions, perhaps hoping to use that information to justify their ignoring the science they don't want to hear, instead of properly using it to select among expected impacts of alternative decisions.

When deciding among alternative policy options, policy makers are likely to be more interested in minimizing the probability of making a bad decision, whereas scientists tend to work toward maximizing the probability of being right or making a good decision. Policy makers are sensitive to the possible legal and political consequences of any new policies they might implement should they turn out poorly compared to the current situation.

Policy makers know implementing a new policy can involve risks. To a policy maker the risks of failure can exceed the awards of success. Stated another way, policy makers are often legally bound to minimize the probability of Type II errors – i.e., accepting an inferior alternative - even though that may increase the likelihood of Type I errors – i.e., rejecting the superior alternative. Scientists generally aim to maximize the probability of being right rather than minimize the probability of being wrong. The two objectives can lead to different decisions. [14, 15].





Figure 3. Tap water in a Flint hospital on Oct. 16, 2015.  
JOYCE ZHU / FLINTWATERSTUDY.ORG

Example 3. Seven years ago officials looking to save money switched the drinking water supply of Flint, Michigan, in the US, to a new source. Failure to treat the water properly caused lead to leach out from aging pipes into the drinking water of thousands of homes. The economic and health impacts resulting from the high levels of lead, and the legal impacts resulting from the attempt to cover up the crisis and its damaging evidence at all levels of government, are still being felt today. This still ongoing public health crisis highlights an example of environmental injustice and racism. Regretfully it is not the first of such cases in the US nor is it likely to be the last one. Ignoring science, even as it produces inconvenient truths, can be costly, but how much and to whom and when seems to make a difference.

### 3.3.2 Information Constraints

Policy making can become more difficult if being provided with too much knowledge and information. Having more information does not automatically lead to a faster or broader consensus or greater clarity. Policy makers often lack the time necessary to digest all the information they get and thus expect simple, clear inputs. Scientists must often eliminate the details of their research that may interest and motivate them and spend more time on preparing summaries of what they believe should interest and influence policy makers.

Too often the media tends to misrepresent the scientific consensus and focus on dissenting pieces of information, for the sake of a 'balanced approach' or by attracting attention to a conflict of ideas. Deliberate disinformation campaigns that produce false and carefully crafted messages can further confuse stakeholders and degrade the policy making process. [16, 17].



Figure 4. Transporting Pipes of the Great Man-made River in Libya.  
Wikipedia Commons

Example 4. During the planning and construction of Libya's Great Man-made River, several engineers convinced the New York Times newspaper, whose motto is 'all the news that is fit to print,' that instead of being one of pumping and transporting water through 4-meter diameter pipes from aquifers under the Sahara Desert to satisfy agricultural and domestic demands, the project was really for transporting troops and tanks in trucks and trains to where they could invade Libya's neighboring countries without being seen by satellites. This 'news' was published on the front page of the NYTimes, on December 2, 1997, and indeed it supported the popular notion that Libya's government was evil. [18].

### 3.3.3 Time Constraints

Just as policy makers are under time pressures that limits the amount of detailed scientific evidence they can consider as they debate policy options, scientists are often under time pressures to deliver their scientific evidence when policy makers can use it. A common cartoon image of a policy maker is someone facing urgent deadlines and demanding scientists submit all needed inputs yesterday.

For science to influence policy decisions, scientists must provide useful policy-relevant information before those decisions are made, or more accurately, before the debate on the impacts of alternative policies ends and their attention shifts to other issues or crises. This window of opportunity typically ends before all the needed scientific work is complete (let alone tested, validated, and peer reviewed). Debates over what to do about particular issues or problems are often crisis driven or driven by court-mandated timelines. The window of opportunity, within which scientists can usefully contribute, is finite and often quite short. This leads to decisions made based on incomplete information. Scientists working in or for policy making (including water management) institutions and consulting firms are used to this. Those working in a more academic research environment may not have to meet such tight schedules but do have other challenges such as finding, training students, and getting the research done before those participating in it graduate or the funding grant ends.

### 3.3.4 Time Horizons

As much as policy makers should consider long-term impacts of their decisions, especially if sustainability is among their objectives, they tend to favor short term goals given the limited time they have to gain the support they need to get re-elected. But decisions made to satisfy short-term objectives will have longer term impacts as well. In the words of Al Gore [19] *'the future whispers while the present shouts'*. Debates around issues such as many environmental and water management problems, climate change and social issues illustrate this bias toward the more certain present rather than the more uncertain future. The problems of biodiversity losses, sea level rise or acidification, the destruction of a river delta, and the potential of mass migration and destruction caused by extreme weather events might only be seen in the next decades.



Figure 5. Yemeni men relax in the shade chewing qat, a mild drug used by most Yemenis. Photograph: Cris Bouroncle/ theguardian.com

Example 5. Sana'a, the capital of Yemen, depends on an aquifer for its water. Years ago a groundwater modeling study showed that this aquifer would be depleted in a decade or two due to excessive withdrawals. Most of the groundwater withdrawals were being used for growing qat, a green-leaved plant that has been chewed for its stimulant effect for centuries. Asking Yemenis to restrict their chewing of qat would be similar to asking coffee drinkers to restrict their drinking of coffee. Finding a socially as well as economically acceptable solution to this water management problem proved to be difficult. When suggesting to policy makers that this issue be discussed in public in hopes of alerting the public to this issue and with their help identifying a suitable solution, they rejected the suggestion. "Why should we worry about this potential crisis? When it happens we may not even be alive."

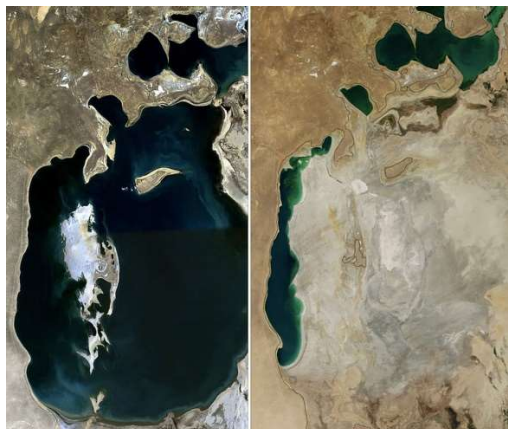


Figure 6. *Aral Sea, 1989 before (left) and 2014 after upstream water diversions.*  
wikipedia.org Creative Commons

Example 6. Little illustrates the possible long-term consequences of short-term decisions more than as does the drying of the Aral Sea in Southern Kazakhstan and Northern Uzbekistan and of lakes Sevan in Armenia Urmia in Iran, and Chad in Northern Central Africa to name just a few. In each case this depletion of lake water in large part has resulted from irrigation developments. In the short run increasing crop production and employment is beneficial. The long term consequences, now all too evident, range from unexpected climate feedbacks affecting the health and even lives of people in and out of those basins. The interesting question to ponder is whether or not policy makers that were promoting agricultural development knew these long-term impacts could occur, and if not, whether such scientific predictions would have changed their water allocation and management decisions. One cannot survive in the long-run if unable to in the short-run. Or, as they said in Yemen (Example 5): "Why should we worry about this potential crisis? When it happens we may not even be alive."

### 3.3.5 Complexity and Interconnectedness

In today's highly interconnected societies and economies, policymakers addressing and creating policies to manage one issue must consider the impacts of their decisions not only on the issue being addressed but also if and how those decisions may impact other aspects of society over time. We are now living in a many component system, hence taking a systems approach to managing it makes sense. A systems approach focuses on the performance of the system as a whole, not of each component separately. How one component of a system is designed and managed may impact the performance of one or more other components of that system or even of other systems. These possibilities are worth being identified and evaluated, ideally before policy decisions are made. Better to prevent major problems or crises than to deal with their consequences in spite of the fact that politicians, and indeed all of us, probably get more credit and fame from solving crises than from preventing them.

## 3.4 Communication



Making public policy is a balancing act between societal values, political priorities, competing interests and scientific knowledge. Nevertheless, scientists can impact policy by introducing good evidence and insuring the good use of that evidence during the policy making process. To do this, scientists need to be good communicators. Part of being good communicators is recognizing that many terms scientists use, such as the word model, can mean different things to others. Just within different scientific disciplines this language barrier can exist, and to perform interdisciplinary research one of the first steps is to learn the language of the other disciplines. Scientists attempting to communicate effectively to policy makers should be aware of this need to speak the language they understand.

What do policy makers expect from scientists? Ideally they would like definitive advice on what to do, what policy to choose, what action to take, backed up by scientific evidence supporting that position. However, science can by definition answer or address only analytical questions, not the normative ones. A push for decisive policy answers from scientists not only overlooks uncertainty but lies beyond the competence of pure scientists.

Furthermore, scientists working for policy can discover an 'inconvenient truth', i.e., results that are undesirable and therefore complicate a policy response, or force a politically sensitive conclusion. Such a situation causes two problems. One is the difficulty of communicating unexpected, disturbing results to the policymakers, thereby creating difficulties for them and possibly disrupting the relationship scientists have with them. The other is the dilemma of whether to publish such results, which can understandably be motivated by a sense of responsibility towards the public and the scientific community, as well as one's career as a scientist.

Even when they clearly distinguish facts from opinions, scientists involved in informing policy operate in a grey zone between informing and persuading. Scientists who present a range of relevant facts associated with different policy alternatives, adapting to what the policymakers want to know, but leaving the choice of solutions to them, are called 'honest brokers'. Honest brokers can offer opinions about the options if requested, but not as advocates. However, the idea of an 'honest broker' is often at odds with the demand by policymakers for evidence-informed recommendations. If given, scientists should make it clear they speak as an educated and informed person, not as a pure scientist. Scientists can opt to explain the weight of evidence for different policy goals and objectives, instead of giving general advice for action. [20, 21].

### *3.5 Science – Policy collaboration*

Knowing what to present and how and when is best learned through collaboration that generates a mutual understanding and trust between scientists and policy makers. Far less effective is the ad hoc scientific evidence delivered by parachute, either unsolicited, or in a rush when policymakers suddenly ask for evidence scientists may or may not have. This especially applies when a level of trust has not been developed between the scientists and their client policy makers. Good evidence comes from collaborative, continuous, long-term relationships with policy makers and their staffs throughout a policy making process. This is one reason why there is a tendency for policy making agencies to select the same consulting firms to provide the desired scientific evidence over time. To be relevant to, and imbedded in, policy making, scientists must build up that level of trust and be aware of, if not engaged with, the world outside of science that impacts policy making. This is the world, the so called policy ecosystem, in which alternative policies and stakeholder values are considered, debated and where choices are made. While science remains the most reliable and systematic way of gathering knowledge about this world, simple opinions and anecdotes are part of the policy ecosystem, and can influence final decisions. Yet policies chosen without sufficient supporting scientific evidence are likely to fall short of being as successful as they could be. The scale and inevitability of unintended consequences stemming from a non-evidence-informed decision can be too large to risk.

To bring science closer to meeting the particular needs of policy makers, scientists need to understand their information needs. However, these needs change depending on the particular issues being addressed. Hence the only way scientists can really be aware of what policy makers need is to work closely with them. This requires a transition from where scientists and policy makers are separated and in contact with each other only occasionally, to where they are working together more often in a more integrated environment. This transition is often difficult

to achieve, but often necessary if science is to become more successful in identifying and bringing politically feasible scientific evidence to the policy making process and in a timely manner. Maximizing the collaboration between scientists and policymakers, as well as others that impact the policy-making debates – experts, stakeholders, the media – is at the core of successful exchanges of information between scientists and policy makers.

Even though science may not be able to resolve the underlying value conflicts, it can help distinguish facts from values and thereby refocus policy making debates. This can be more easily achieved when scientists move from periodical advising to participating throughout the entire policy making process. It is up to both the scientists and policy makers to make that happen. Obviously for those individuals wearing both hats, mission accomplished! While reasons for advocating for the input of scientific knowledge in a policy making process seem obvious to scientists, there are no guarantees that a scientifically-informed solution will inevitably be successful. But given the complexities of today's water management issues, it seems being informed by science is worth a try.

Policymaking is not, as often assumed, a sequential, stepwise, deterministic process. Both the supply of and demand for scientific knowledge and evidence occur in the policy making process at seemingly random times. External events happen that influence policy makers' goals and constraints. With information and even deliberate disinformation overloads, it can become less clear what information is important and relevant, and when, and what, and who, to trust. Close collaboration among scientists and policymakers helps build and maintain the trust necessary for successful science – policy interactions. It also helps scientists focus on what science is relevant as opposed to what may not be. [22].



Figure 7. Aquatic Weeds hamper users of the Volta River at Kpong downstream of the Volta Dam.

Source: Solomon K. Nuwordu

Example 7. Where the science informing process failed to have an impact on policy making occurred in Ghana. The science was clear and convincing, it was just the wrong science. The African Development Bank funded a project involving the possible reoperation of the Akosombo Dam, also known as the Volta Dam. This hydroelectric dam on the Volta River in southeastern Ghana is operated by the Volta River Authority. Since the beginning of its operation in 1965, its regime of water discharges has degraded the ecosystem of the river and its floodplains and adversely impacted those living downstream of the dam. The aim of the project was to find an alternative operating policy that would restore the downstream ecosystems while still meeting electrical energy demands. The institution overseeing the project was the power authority. It had the authority to alter the dam's operating policy, but producing power and generating electricity was their main mission and objective. Here come these foreign scientists and modelers on relatively short visits to work with the authority and to help them obtain the data and develop the necessary impact models needed for establishing a reoperation policy. While spending considerable time with many of the impacted stakeholders as well as with the staff of the power authority during those visits to Ghana, the authority made it clear during each visit that ecosystem restoration was not their mission or interest. It might not have made any difference, but not being able to work closely and continuously with all involved in the project surely contributed to the failure to gain the level of trust and understanding needed to enable a successful reservoir reoperation result. [23].

### 3.6 The practice of integrating science and policy

Policy making processes involve debates about scientific evidence as well as values. A decision making framework where first scientific data are collected, next policy objectives are defined, then alternative policies that meet these objectives are identified, analyzed and evaluated, perhaps using some multiple-objective models to identify the efficient tradeoffs among the multiple objective values, and finally a choice that maximizes social welfare (or minimizes political risk) is made, rarely works in practice. For various reasons, this logical systematic framework does not represent the reality of most evidence-informed policy making. [24. 25].

One reason why evidence-informed policy making is different, and often more difficult, is the fact that policy problems not only have an analytical, scientific dimension but also a normative, value-based one. Policy makers need to find acceptable practical compromise solutions to problems or issues that meet the values held by all participants where there are no such solutions. These so called 'wicked' problems are hard to define, let alone solve, analytically. Thus inevitably their resolution is temporary and tentative and dependent on political judgements. As the saying goes, performing the hard sciences is easy, performing the soft sciences is hard. Participating in policy making is hard. [26].

This distinction between the scientific approach to discovery of knowledge and policy making does not make it impossible for scientists and policy makers to work together to better inform the policy making process and indeed the effectiveness of the policies themselves. But it is not always easy, as both scientists and policy makers might prefer to just focus on what they know how to do best, and speak their own jargon without having to learn the other's. The effectiveness of the chosen policies notwithstanding, policy decisions can certainly be made without being informed by scientists or their science. But both know the value of science informed policy making so it is worth making it work as well as it can and in a way that respects the values and concerns of policy makers, as well as of scientists.



Figure 8. Computer-based decision support system for managing water.  
www.suez.com

Example 8. Successful examples of effective on-going use of the systems approach to inform those managing water include the Mekong River Commission's Decision Support Framework (Mekong DSF), the Nile Basin Initiative's Decision Support System (NB DSS), and the flood forecasting model, FloRiAn, of the International Commission for the Protection of the Rhine (ICPR), the Corps' Water Management System (CWMS) used by the U.S. Army Corps of Engineers to support its regulation of river flows through reservoirs, locks, and other water control structures located throughout the US. Other water allocation models are being used to inform managers of the Senegal and Zambezi Rivers in Africa and the Euphrates and Tigris Rivers in the Middle East, the North-South water diversion project in China, and the designers and operators of the Great Man-made River systems in Libya. Another example of where the science informing process has succeeded in having an impact on policy making is in the operational management of Lake Como in Italy. Based on optimistic, standard and pessimistic predictive probability distributions of future lake volumes derived from historical data, satellite imagery, and climatological forecasts, a decision support tool identifies the corresponding most appropriate daily releases from the lake. This decision supporting tool has been in successful use since its installation in 1997. [27-29].

### 3.7 Characterizing Policy Issues

Some public policy issues are relatively simple to analyze and address. The scientific data are relatively certain, the behavior of the system in responses to various policies are relatively well understood, and given the policy objectives, the choice of the best policy is relatively obvious. But this is not typical for many issues, including those involving water management. Such cases are often characterized by uncertain facts, disputed or conflicting values, high stakes, and urgent time pressures. They are labeled as ‘wicked.’ Wicked policy problems are complex, meaning not easily analyzed or understood, interconnected with other systems, impacted by other issues, multidisciplinary in nature with many cultural and social aspects, contain conflicting objectives or goals among known stakeholders both of which are changing over time, and that, as a consequence, are not ‘solvable’ in a technical sense. They have no solution. Moreover, there are no criteria that enable one to prove that all feasible and reasonable policies to a wicked problem have been considered. This makes the policy making process challenging at best.

While classical scientific approaches cannot solve problems that have no solution, this doesn’t negate the value of scientific evidence that is relevant to those problems. Policy makers can still benefit from considering the analytical scientific evidence pertaining to policies that may favor or constrain them from achieving particular objectives or goals. At the same time policy makers need to reconcile conflicting values and objectives and also ensure that any chosen course of action is politically acceptable, which hopefully means acceptable to a majority, including the public. Good solutions are those that best reconcile all these considerations. Scientists can help with the technical or analytical part, but the rest falls to the policy makers.



Figure 9. Grand Ethiopian Renaissance Dam on the Blue Nile  
aawsat.com Asharq Al-Awsat

Example 9. The current conflict in the Nile River Basin between Egypt and Ethiopia over the filling of Ethiopia’s newly built Grand Ethiopian Renaissance Dam is perhaps one of the best examples of an international ‘wicked’ water management problem. So far, after a considerable number of modeling studies by just about every academic, consulting firm, NGO and agency or research institution that models water, and more modeling studies to check up on the results of other modeling studies, no solution is apparent in spite of negotiations that continue to take place at the highest government, and even international, levels. Egypt doesn’t want any increased risk of not having the flows it considers it is entitled to, and Ethiopia wants to fill the dam so as to produce hydropower to help meet the considerable demand for energy in their country and surrounding region. Water that is stored in the dam or that evaporates from the dam does not flow downstream to Egypt and that scientific fact for Egypt is unacceptable. All water allocation issues can turn into wicked ones that have no solutions when there is an unwillingness to compromise or think outside the box in order to enlarge the options for achieving an agreement.

Few would disagree that the public policy world of today can be volatile, uncertain, complex, and ambiguous. Solutions proposed to address problems or opportunities in this world, are often strongly contested. As a consequence, many policies developed to address problems in this world fail because of unforeseen side effects or difficulties in coordination and monitoring. Sustainable development issues related to water and the environment



are among those that policy makers must address whose outcomes are affected by this chaotic world. The challenge for scientists is therefore to generate meaningful (and useful) knowledge about the future by interpreting facts about current developments and use imagination about the possible future. [30].

In science, the process of *solving* a problem is identical with the process of *understanding* the nature of that problem. Scientific questions, especially those tackled by individual research projects, are typically narrow in scope. Science has a collective responsibility to collect, verify and synthesize research results, in pursuit of more and more coherent and complete knowledge. However, the scientific method cannot answer political or normative questions like 'what should be done about x'. Therefore, the process of interpreting science involves bridging the gap between producing scientific evidence and deciding what policies should be selected based on this evidence [31, 32].

To add to the challenges of policy making, science itself can not necessarily provide clear-cut options for addressing wicked policy problems. Wicked policy problems are found within interconnected multi-component systems and hence systems analysis methods can help provide scientific evidence useful to policy makers as they select policies for managing those systems. Reductionist approaches are useful for focusing on the parts of a system, i.e., parts of the economy, the environment and society. When it comes to understanding the complex dynamics resulting from the interaction of these parts, it is useful for both scientists and policy makers to shift their attention from the parts of the system to the system as a whole and the interactions among its components. Systems analysis methods permit taking a plurality of social values, perspectives and interests into account in a coherent and transparent manner.

### 3.8 Modeling Policy Issues

Systems analysis methods include a variety of modeling approaches that can be useful tools for informing policy makers. Models used to inform policy are built and solved to provide policymakers information that can help them develop insights into their problem situation and on which they can base, at least in part, their policy decisions. The usefulness of such 'policy modeling' is judged not by how accurately it reflects the real world, but by how well it is able to provide information that enables a policy maker to make knowledgeable choices among policy options – i.e., how well the modeling can help construct and defend an argument about the relative pros and cons of alternative policy options. A relatively crude model that can clearly demonstrate that alternative A performs better than alternative B under both favorable and unfavorable assumptions will probably lead to a better decision than a complex model that can perform only a detailed expected value estimation.

Policy models trade off rigor for relevance. In some cases, they are used for screening large numbers of alternative policy options, comparing the outcomes of the alternatives, and/or designing strategies consider a wide range of factors (e.g. technical, financial, social), but not a lot of detail about each factor. The outcomes are generally intended for comparative analysis (i.e., relative rankings), so approximate results are sufficient. They must provide sufficient information to map out the decision space – the ranges of values of the various input parameter values for which each of the various policy options would be preferred. [33].





Figure 10. Polluted Water flowing from a drain pipe into a small stream.

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Example 10. When in the 1970s the Clean Water Act and its Amendments were passed in the US, they required all point sources of wastewater to be treated using ‘best management practices’ (that generally results in secondary treatment that removes about 80% of CBOD) before being discharged into receiving surface water bodies. Model studies showed that considerable money could be saved by adopting cost effective policies, policies that met surface water quality standards at a minimum cost. In terms of infrastructure construction and operation costs, the CWA policy became an expensive national public works program. But politically, it was cheap. To enforce the CWA policy required monitoring only the quality of wastewater treatment plant effluents, an easier task than monitoring the quality of both wastewater effluents and receiving surface water bodies. Modelers who could identify more cost-effective wastewater treatment policies for particular watersheds and river basins did not have to defend their models, along with their assumed model parameter values, in court. Every potential polluter was treated equally. Investigations into which polluter upstream contributed to a water quality standard violation downstream, and by how much, were not necessary. Politically, the CWA policy was a much easier and politically less costly policy to implement. So much for the education of those scientists advocating cost-effectiveness.

The responsible use of policy models requires some level of understanding of their limitations as well as their strengths. Along with presenting the output of their analyses, modelers should make clear the assumptions underlying this output, margins of potential error and possible inconsistencies across different policy objectives. As useful as systems analysis models can be, they are still models, and all models depend on assumptions. The output of some types of models suggest the best policies to select given the assumptions but they don’t identify the best assumptions. Any model of a complex system is a simplification of that system and reflects only a subset of its possible representations. This implies that for any policy modelling exercise, there is a need to understand the information needs of all stakeholders. Knowing this may help determine the needed level of detail in models representing the real world system. But policy making processes are dynamic, and hence their information needs can change. Scientists developing and solving models need to be able to modify and adapt them as needed to meet those changing information needs. Models developed to inform policy makers can be viewed as learning tools to be used to facilitate the dialogue among policy makers, scientists and stakeholders. They can boost the effectiveness, consistency and transparency of policy making processes.



Figure 11. Increasing Algeria’s food security.

borgenproject.org [Creative Commons, Public Domain](#).

Example 11. A study for planning the infrastructure needed to increase the supply of irrigation water to parts of the Sahara Desert in Algeria, the system performance measures the government wanted considered were cost, reliability and the amount of water, the so-called yield. The task of the modelers was to identify alternatives that represented efficient tradeoffs among these three conflicting objectives. Upon presenting some results for one region of the country the response was to adopt an inferior solution, one that cost more, was less reliable and produced less yield than many other possible solutions. When asked why that

plan was chosen, the answer was that their chosen plan satisfied other objectives as well. Project objectives and their relative importance can change during a modeling, planning, and policy making process, especially as all involved learn more from the modeling and other sources about what is possible and hence what can be achieved.



Figure 12. Saving the Mekong with Floating Solar Power.

Photo: BayWa re rechargenews.com Public Domain

Example 12. In the Mekong, as in many other rivers in this world, hydroelectric dam builders are busy practicing their trade to meet increasing demands for energy. In one recent study the question being addressed was where to site and how to design and operate a series of dams to produce hydroelectric power. Framing the question in this manner leads one to identify dam sites and capacities and operating policies needed to meet specified energy targets. Framing the question to be how to produce more energy leads to a broader range of options including the consideration of solar panels. In the Lower Mekong solar power was shown to be a much less expensive option than building and operating more dams, and less damaging to the ecosystems and biodiversity of the river. This information had an impact on a decision not to build a particular dam that was planned, but for how long that decision will apply, who knows.

Science, as objective and value free as tries to be, cannot insulate itself from value judgements and decisions. Values enter the scientific process even in the framing of research questions and objects of study, in decisions about what gets funded, in the selection of data to be collected, and in the analytical methods to be used and scope of the analysis. Values also play a role in deciding what scientific evidence is deemed pertinent to be communicated, and how it is to be presented. Just how effective scientific evidence is in informing policy makers depends on just how much trust exists between scientists and policy makers. Trust in science increases if scientists are engaged and open with the people they want to inform and influence. [34].

#### 4. Discussion

Establishing policies for managing water typically involve dealing with individuals who have conflicting views on which policy decisions are best. Thus debates over how water should be managed take place in a politically driven policy making environment. In this environment many different factors influence policy makers and the decisions they make. Scientific data and recommendations based on those data are among them. Science and scientists have an important role in policy making, informing and guiding decisions on a wide range of water management issues. While scientific evidence is not the only input affecting policy decisions, it is an important one. The challenge of scientists involved in policy making processes is in determining how best to create and present scientific evidence so as to maximize its usefulness to policy makers. Scientific evidence can influence the ways that policy makers frame issues, address problems, consider solutions, and develop and implement policies. Policies defining how water is to be managed will affect people. Their impacts can be economic, environmental, ecological and social. Having predictions of these impacts before decisions are made helps policy makers make more informed decisions – decisions that are technically sound in that they work as expected, and that are as socially acceptable as possible. The purpose of this paper has been consider how scientists can effectively

contribute to this policy making process as they provide scientific evidence relevant to the issues and decisions being debated.

There is little doubt that science can and should inform water management policies. Managing water supplies and demands, and qualities, is becoming increasingly critical and more complex. The rapid evolution of information and communication technologies, and advances in social media and communication platforms, have substantially improved the public's ability to access information and influence policy makers. All this has increased the pressure on scientists and policy analysis to provide answers and solutions to pressing water management problems while also opening them up to closer surveillance and criticism. What used to be "private" debates between different scientific viewpoints over areas of uncertainty now have the potential to become public disputes that can be exploited by different stakeholders to confirm or deny entrenched positions. In other words, science is increasingly visible and, in some cases, increasingly vulnerable in policy making processes. Yet policy making needs science. Policy makers must make decisions even with inadequate and possibly conflicting data and even when there are no perfect solutions to the problems they are trying to address. Having objective high-quality scientific evidence pertaining to these problems can only improve the outcome. Providing high-quality evidence into policy making processes, at the right times and in the right amount of detail is challenging, but essential for effectively informing policy makers and improving policy decisions.

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Conflicts of Interest: The author declares no conflict of interest.

## References

1. Šucha, Vladimír, Marta Sienkiewicz (eds), 2020, Science for Policy Handbook, European Commission, Joint Research Centre (JRC), Brussels/Belgium, Elsevier, Amsterdam, Netherlands
2. Cairney, P., Heikkilä, T., Wood, M., 2019. Making Policy in a Complex World. Cambridge University Press, Cambridge
3. Craig, C., 2019. How Does Government Listen to Scientists? Palgrave Macmillan, London.
4. Gluckman, P., 2014. The art of science advice to government. *Nature* 507, 163–165.
5. Prewitt, K., Schwandt, T.A., Straf, M.L. (Eds.), 2012. Using Science as Evidence in Public Policy. The National Academies Press, Washington, D.C.
6. Langer, L., Tripney, J., Gough, D., 2016. The Science of Using Science: Researching the Use of Research Evidence in Decision-Making. EPPI-Centre, Social Science Research Unit, UCL Institute of Education, University College London, London.
7. Bell, S., Shaw, B., Boaz, A., 2011. Real-world approaches to assessing the impact of environmental research on policy. *Research Evaluation* 20 (3), 227–237.
8. Sitterson, Jan, Chris Knightes, Rajbir Parmar, Kurt Wolfe, Muluken Muche, Brian Avant, 2017, An Overview of Rainfall-Runoff Model Types EPA Report Number EPA/600/R-14/152 |, September, Office of Research and Development National Exposure Research Laboratory, Athens, Georgia
9. Arrow, K.J., Raynaud, H., 1986. Social Choice and Multicriterion Decision Making. M.I.T. Press, Cambridge.
10. Schultz, D., 2013. American Politics in the Age of Ignorance: Why Lawmakers Choose Belief over

Research. Palgrave Macmillan, New York.

11. <https://www.investopedia.com/terms/p/pareto-efficiency.asp>) Accessed 2/15/2021

12. IJC, 2006, Options for Managing Lake Ontario and St. Lawrence River Water Levels and Flows, Final Report by the International Lake Ontario - St. Lawrence River Study Board to the International Joint Commission, March 2006

13. Todini, E., (2014) - The Role of Predictive Uncertainty in the Operational Management of Reservoirs. In *Evolving Water Resources Systems: Understanding, Predicting and Managing Water–Society Interactions*, Proceedings of ICWRS2014, Bologna, Italy (IAHS Publ. 36X, 2014).

14. Newman, J., 2017. Debating the politics of evidence-based policy. *Public Administration* 95 (4), 1107–1112.

15. Parkhurst, J., 2016. *The Politics of Evidence: From Evidence-Based Policy to the Good Governance of Evidence*. Routledge, New York.

16. Boykoff, M.T., Boykoff, J.M., 2007. Climate change and journalistic norms: a case-study of US massmedia coverage. *Geoforum* 38 (6), 1190–1204.

17. Cook, J., van der Linden, S., Maibach, E., Lewandowsky, S., 2018. *The Consensus Handbook*  
 18. Bonner, Raymond, 1997, *Libya's Vast Desert Pipeline Could Be Conduit for Troops*, New York Times, December 2, 1997, Section A, Page 1  
<https://www.nytimes.com/1997/12/02/world/libya-s-vast-desert-pipeline-could-be-conduit-for-troops.html>

19. Gore, A., 1992. *Earth in the Balance: Ecology and the Human Spirit*. Houghton Mifflin, New York, NY

20. Pielke Jr., R., 2007. *The honest broker: making sense of science in policy and politics*. Cambridge University Press, Cambridge.

21. Parkhurst, J., 2016. *The Politics of Evidence: From Evidence-Based Policy to the Good Governance of Evidence*. Routledge, New York.

22. Rutjens, B.T., Sutton, R.M., van der Lee, R., 2018. Not all skepticism is equal: exploring the ideological antecedents of science acceptance and rejection. *Personality and Social Psychology Bulletin* 44 (3), 384–405.

23. Opgrand, Jeff, J, Paul V. Preckel, F.T. Sparrow, Gregory Thomas, Daniel P. Loucks, 2019, Restoring the natural flow regime of a large hydroelectric complex: Costs and considerations, *J. Energy*, Volume 190, 1 January 2020, <https://doi.org/10.1016/j.energy.2019.116260>  
 1626www.elsevier.com/locate/energyhttps://doi.org/10.1016/j.energy.2019.1162600360-5442/©2019 Elsevier Ltd, Energy,

24. Pielke Jr., R., 2007. *The honest broker: making sense of science in policy and politics*. Cambridge University Press, Cambridge.

25. Weible, C., Heikkila, T., deLeon, P., Sabatier, P., 2012. Understanding and influencing the policy process. *Policy Sciences* 45 (1), 1–21.
26. Damon, A., Lewis, J. (Eds.), 2015. *Making Public Policy Decisions: Expertise, Skills and Experience*. Routledge, London.
27. FAO, 2021 (expected), FAO sourcebook on hydro-economic modelling, in preparation.
28. Stakhiv, Eugene, Joe D. Manous, Jr, Gerald E. Galloway, Jr, 2020, The Mississippi River Flood of 2019: *Managing Mega-Flood Disasters*, paper for UN High Level Panel on Disaster Risk Reduction November
29. Todini, E., (2014) - The Role of Predictive Uncertainty in the Operational Management of Reservoirs. In *Evolving Water Resources Systems: Understanding, Predicting and Managing Water–Society Interactions*, Proceedings of ICWRS2014, Bologna, Italy (IAHS Publ. 36X, 2014).
30. Head, B., 2008. Wicked problems in public policy. *Public Policy* 3 (2), 101–118.
31. Douglas, H., 2009. *Science, Policy, and the Value-free Ideal*. Pittsburgh University Press, Pittsburgh.
32. Rittel, H.W.J., Webber, M.M., 1973. Dilemmas in a general theory of planning. *Policy Sciences* 4 (2), 155–169.
33. Walker, W. and Daalen, C. (2013). System Models for Policy Analysis. In *Public Policy Analysis: New Developments*, Thissen, Wil A. H., Walker, Warren E. (Eds.), Springer, Amsterdam, 10.1007/978-1-4614-4602-6\_7.
34. Oliver, K., Cairney, P., 2019. The dos and don'ts of influencing policy: a systematic review of advice to academics. *Palgrave Communications* 5, 21.