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A Philosophical Justification for a Novel Analysis-Supported, Stakeholder-Driven Participatory Process for Water Resources Planning and Decision Making

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Abstract: Two trends currently shape water resources planning and decision making: reliance on participatory stakeholder processes to evaluate water management options; and growing recognition that deterministic approaches to the evaluation of options may not be appropriate. These trends pose questions regarding the proper role of information, analysis, and expertise in the inherently social and political process of negotiating agreements and implementing interventions in the water sector. The question of how one might discover the best option in the face of deep uncertainty is compelling. The question of whether the best option even exists to be discovered is more vexing. While such existential questions are not common in the water management community, they are not new to political theory. This paper explores early classical writing related to issues of knowledge and governance as captured in the work of Plato and Aristotle; and then attempts to place a novel, analysis-supported, stakeholder-driven water resources planning and decision making practice within this philosophical discourse, making reference to current decision theory. Examples from the Andes and California, where this practice has been used to structure participation by key stakeholders in water management planning and decision-making, argue that when a sufficiently diverse group of stakeholders is engaged in the decision making process expecting the discovery of the perfect option may not be warranted. Simply discovering a consensus option may be more realistic. The argument touches upon the diversity of preferences, model credibility and the visualization of model output required to explore the implications of various management options across a broad range of inherently unknowable future conditions.

Keywords: scientific analysis; decision-support; classical views on knowledge and authority; designing participatory processes involving stakeholders

1. Introduction

The use of computer models to support the evaluation of water resources management options has grown steadily since the first hydrologic [1] and water resource computer modeling tools [2] were described in the 1960's and 1970's. In laying out their blueprint for a physically-based, digitally simulated hydrological response model, Freeze and Harlan echoed the developers of the Stanford Watershed Model [3] in claiming that *the ability to accurately predict behavior is a severe test of the adequacy of knowledge in any subject* [Emphasis added]. As part of a review and evaluation of multi-objective programming techniques in water resources Cohon and Marks paraphrase the assertion in Loucks and Dorfman [4] that these models *should be able to predict the outcome of the decision-making process* [Emphasis added]. These early pioneers in the field of water modeling were sanguine about the power of early computers to provide this predictive power, with Freeze and Harlan even conceding that their blueprint was more of an *artist's conception*. Nonetheless, the expectation was clear, as data quality and computing power improved; it would become increasingly possible to predict outcomes related to hydrology and water management and to use these predictions to identify the best possible course of action.

This expectation related to the power of rigorous analysis, common to modern science, is consistent with a line of thinking that came to prominence in Europe during the 18th Century Enlightenment. The Enlightenment ideal, which argued for a society based on reason instead of faith and doctrine, placing rational analysis in a favored position in terms of identifying the best course for social and political evolution, emerged following more than a century of thought on the proper balance between reason and faith. In 1615, Galileo wrote in a letter to the Grand Duchess Christina of Tuscany that *nothing ... which necessary demonstrations prove to us, ought to be called in question ... upon the testimony of biblical passages which may have some different meaning beneath their words* [5]. In his work *Pensées*, published in 1670, Pascal opined that *the supreme function of reason is to show man that some things are beyond reason* [6]. In 1693, following the 1687 publication of his landmark Principia, Newton wrote in a letter to Richard Bently that *gravity may put the planets into motion, but without the divine Power, it could never put them into such a circulating motion as they have about the Sun* [7].

By the 18th Century, however, this search for a holistic balance between reason and faith faded in the face of the predominance of reason and analysis. The Scottish philosopher David Hume [8] went so far as to suggest that *there is no question of importance whose decision is not comprised in the science of man; and there is none, which can be decided with certainty, before we become acquainted with that science*. Hume would likely have included the complex water management decisions confronting society today amongst his *questions of importance*. In the decades since the publication of the early work on hydrologic and water resources computer modeling, the water management community has worked diligently to capitalize on improved data availability and computing power. This has been done in order to assess whether a particular bit of infrastructure should be built (e.g., [9]), operating rule, encoded (e.g., [10]), policy, promulgated (e.g., [11]), or behavior, incentivized (e.g., [12]), based on the application of ever more sophisticated models and analysis.

Yet in the face of this growing sophistication within the water resources practice, and the continued aspiration that better data and computing power can uniquely identify the rational water management choice, two important trends conspire to complicate matters. The first relates to the increasing reliance on participatory stakeholder processes as a forum for evaluating water management options and selecting the appropriate course of action. This trend was launched in the United States by the passage of the National Environmental Policy Act, signed into law by President Nixon in 1970, which increased the influence of stakeholders in environmental policymaking [13]. Similar laws exist elsewhere in the world. The second trend relates to the growing recognition that earlier deterministic analytical approaches to this evaluation of options may no longer be appropriate in the face of future uncertainty. For example, the weakness of the assumption of hydrologic stationarity in the face of climate change, an assumption that has underpinned most water modeling work carried out since the 1970s, has been well documented [14].

The convergence of these two trends poses questions as to the proper role of data, information, analysis, and expertise in the inherently complex social and political process of negotiating water resources management agreements and implementing water resources management interventions.

The authors have encountered this convergence while working in Bolivia on the Pilot Program on Climate Resilience (PPCR) and in California working on Integrated Regional Water Management (IRWM) planning. In response, it has proven useful to look back before the Enlightenment, to the origins of the western philosophical tradition in ancient Greece, and to re-discover that still important conversations on the proper role of knowledge and expertise within systems of governance and authority took place over 2000 years ago, conversations notable for the absence of consideration of faith. This paper argues that these conversations offer insights regarding the proper design of analysis supported, stakeholder driven, participatory water resources management planning, and decision-making processes.

2. A Conversation during an Athenian Drought

An article about the evolving mythical and metaphorical power of the weather in literature [15] states the obvious, we all talk about the weather, and we always have. As such, it is not impossible to imagine that two leading minds of the western philosophical tradition would have discussed the drought conditions effecting Athens around 360 BC. At that time, Plato, 67 and the leader of his own academy, and Aristotle, 24 and studying with him, were engaged in a dialogue about the proper role of the state, and coming to somewhat different conclusions. Looking back on this dialogue from the perspective of the Renaissance, Rafael, in his fresco the School of Athens (Figure 1), depicted Plato gesturing towards the sky where presumably some divine truth about society could be discovered while Aristotle gestures towards the ground where mortals walk. Assuming Rafael captured them discussing the Athenian drought of 360 BC, what might we expect them to be saying to each other?

Figure 1. View of the central portion of the Raphael's *School of Athens* painted between 1509 and 1511 in the Vatican's Apostolic Place, depicting a supposed conversation between Plato (left) and Aristotle (right). (Stanza della Segnatura, Palazzi Pontifici, Vatican).

Before imagining such a hypothetical exchange, some context. Writings by a contemporary of Plato and Aristotle, Demosthenes, from 361 BC, observes that his *land not only produces no crops, but that year, as you all know, the water even dried up in wells, so that not a vegetable grew in the garden* (Polykles 61) and in 357 BC, he found that *there was a universal shortage of grain* (Leptines 33), chronicling that around 360 BC Athens, with its Mediterranean climate, was indeed gripped by a severe drought. Archeological evidence [16] suggests that by 360 BC Athens had become increasingly reliant on private rainwater catchment cisterns. This water management strategy stood in stark contrast to earlier expenditures by pre-democracy autocrats, even "tyrants", in more centralized water management arrangements, most notably the 7.5 km long aqueduct constructed during the reign of Peisistratos, also known as the Tyrant of Athens, who ruled from 546 BC to 527 BC. The Peisistratos Aqueduct conveyed water from springs in the foothills of the Hymottos Mountains to a point near the Acropolis and was comprised of both tunnels hewn from the solid rock and intricate terra cotta pipelines. It is one of antiquity's early examples of hydraulic engineering [17]. Against this backdrop, a possible conversation in Plato's Academy:

Plato: Things are getting worse, the wells are drying up, crops are failing, and conflicts over access to the cisterns still holding water are increasing. Something needs to be done.

Aristotle: Might I suspect that you favor some bold, ambitious plan?

Plato: Of course. You recall how Peisistratos responded to earlier water shortages by constructing his aqueduct that filled the fountains of the Acropolis. Why are we not considering similar responses today?

Aristotle: Because he was only able to achieve such a system by imposing severe taxes on his subjects. Surely you are not proposing that we sacrifice our Athenian democracy simply to increase water supplies. You must know that the empowered citizens of today's Athens are loathe to fund such autocratic endeavors.

Plato: But such ambitious responses need not be autocratic. Even though the citizens are fixed in the shadows[1], so to speak, ignorant of the real options to manage current water shortages, I am confident that someone driven by the quest for the pure drought management option[2] could identify the correct response that would truly benefit the polis.

Aristotle: It sounds like you would consider the role of Officer of the Fountains to be one fit for your ideal Philosopher-King[3].

Plato: I would, and that seems to be consistent with the way our democracy is heading. I have seen your notes for your pending treatise on the Athenian Democracy where you document how the position of Officer of the Fountains is no longer filled by lot[4].

Aristotle: Indeed, but as much as we cannot let a small group of recalcitrant citizens, based on self-interest alone, reject any collective action to respond to the drought, we must also avoid the temptation to cede all authority to a small group of the elite. You know my views on the importance of a strong middle-class[5]. That group must ultimately arbitrate the merits of any response to the current drought.

Plato: That sounds to me like a recipe for paralysis. Surely something as important as the management of water during these dry times warrants ceding control to those with the knowledge and experience to discover the correct course of action[6].

Aristotle: I am not sure that the Officer of the Fountains alone could identify such a correct course of action when each citizen brings to the decision his or her own desires and passions. Better to engage the polis in the process of deliberating on what to do. Such a process might not yield the universally perfect drought response, but it might yield something that could practically be implemented[7]. In addition, there is the issue of uncertainty surrounding this decision. How do we know if the drought will persist or the rains return?

Plato: Uncertainty is indeed tricky. While some would accuse me of being an absolutist in my pursuit for the truth, be it in terms of the proper drought response or any other issue confronting the polis, I am cognizant of my unfortunate friend Socrates who recognized the wisdom of acknowledging what he did not know[8].

Aristotle: It seems then that perhaps you should be willing to ascribe similar wisdom regarding the unknown and uncertain to the Officer of the Fountain. Adhering to an absolute version of the true drought response is not reasonable[9]. Can you defer to the deliberations of the middle class?

Plato: I cannot. The issue of how to navigate the current drought is simply too important to the survival of the polis to be left to the middle class. I adhere to my conviction that in this case the Officer of the Fountain must indeed by granted the authority of a Philosopher-King. Given the gravity of the situation and import of our response, it would seem that we are not of a like mind as to how best to respond.

Aristotle: So it seems. Let us hope it rains soon, and if it does not let us hope that our political deliberation, in whatever from it takes, leads to a decision. Doing nothing does not seem like a viable option.

[1]In the Allegory of the Cave (Republic, VII 514 a, 2 to 517 a, 7) Plato wrote of individuals chained in a cave, convinced that the shadows on the wall in front of them are reality. He goes on to speculate how someone freed from the cave would come to see both (i) the real world, *he would be able to view the things themselves, the beings, instead of the dim reflections* and (ii) his or her responsibility to those remaining in the cave because *If he again recalled his first dwelling, and the "knowing" that passes as the norm there, and the people with whom he once was chained, don't you think he would consider himself lucky and, by contrast, feel sorry for them?* [2]In his Theory of Forms, Plato (Republic 477a-478e) asserts that there is a difference between knowledge (*epistémé*) and *doxa*, translated as opinion. *Knowledge is infallible—you cannot know what is false. Opinion, however, can be mistaken. So opinion cannot be knowledge*. As Plato applies the Theory of Forms to all things and ideas, he would argue that knowledge about the perfect drought response existed to be discovered. [3]Plato (Republic V.473c11-d6) asserts that those with the ability to distinguish between knowledge and opinion should be endowed with authority because *unless philosophers become kings or those whom we now call kings and rulers philosophize and there is a conjunction of political power and philosophy there can be no cessation of evils*. While there is some debate as to whether Plato felt that all decision should be under the purview of his Philosopher-King, or simply the constitutional decisions, he does make reference to laws and institutions, which are related to the implementation of a constitution, stating that *knowledge of what justice is, which requires knowledge of the definition of its essence (form), will in some cases improve judgments about how far possible or actual laws or institutions are just* (Republic VI.484cd, VII.520cd). Major water management decisions would seem to be one such case. [4]From Aristotle (Athenaion Politeia, 43.1) we learn that among the leadership positions on the Athenian Democracy, *the Officer of Fountains was one of the few that were elected by vote whereas most other officers were chosen by lot; so important was this position within the governance system of classical Athens*. As such, the citizens of the Athenian Democracy seemed to have already identified the need for a "professional" class of water managers. [5]Aristotle (Politics 1296b-1297a 4.12) argues that a large and strong middle class is essential to the stability of a democracy as a stabilizing force against the conflict between the autocratic elite and the disgruntled masses. He writes that the *lawgiver in his constitution must always take in the middle class* and that *everywhere it is the arbitrator that is most trusted, and the man in the middle is an arbitrator*. The assumption here is that Plato would not agree that this middle class possessed the sort of training that he ascribed to his Philosopher-King. [6]Plato (Republic, Book 6, lines 487d-488e), describing the state of affairs aboard a ship at sea, writes that sailors *have no idea that the true navigator must study the seasons of the year, the sky, the stars, the winds and all the other subjects appropriate to his profession if he is to be really fit to control a ship*. The inference is that the true captain is in a better position to steer the "Ship of State". [7]Aristotle who wrote that sensation, reason and desire all contribute to action, stressed the difference between scientific knowledge and practical wisdom. Of the latter he wrote (Nicomachean Ethic, Book VI) it is *concerned with things human and things about which it is possible to deliberate; for we say this is above all the work of the man of practical wisdom, to deliberate well. Nor is practical wisdom concerned with universals only-it must also recognize the particulars; for it is practical, and practice is concerned with particulars*. This suggests that unlike Plato, Aristotle would not expect that a perfect, context independent, drought response to be available to be discovered. [8]In his recounting of the trial of his mentor (Apology 21d), Plato suggested that in describing one of his accusers Socrates said *I am wiser than this man; for neither of us really knows anything fine and good, but this man thinks he knows something when he does not, whereas I, as I do not know anything, do not think I do either. I seem, then, in just this little thing to be wiser than this man at any rate, that <u>what I do not know I do not think I know either</u>*. [9]Aristotle (Nicomachean Ethic, Book I) acknowledged uncertainty in the setting of public policy by stating that *we must therefore be content if, in dealing with subjects and starting from premises thus uncertain, we succeed in presenting a broad outline of the truth: when our subjects and our premises are merely generalities, it is enough if we arrive at generally valid conclusions for it is the mark of an educated mind to expect that amount of exactness in each kind which the nature of the particular subject admits.*

History records that in 346 BC, and again in 333 BC, Kephisodoros of Hagnous and Pytheas of Alopeke, respectively, were named in decrees commending their efforts as Officers of the Fountains to restore the public water system of Athens. The archeological evidence also points to increased investment in public water supply in the third quarter of the 4th Century BC [16]. As such, it seems that the citizens of Athens did take collective action in response to the drought of 360 BC. We can only imagine the conversations between the Officers of the Fountains and the citizens of Athens that took place in the Agora in more than a decade between 360 and 346 BC, leading to this apparent change in water policy. One can surmise, however, that they may have been contentious.

3. Implications for Water Management for the 21st Century

This hypothetical dialogue is offered in order to suggest that, as in antiquity, the current efforts by a group of water management professionals to convince, through analysis, the wider body politic that a particular course of action is in its collective best interest, is rooted in a longstanding philosophical debate. Thanks to the early pioneers in the field of water modeling, today's water management professionals have access to powerful tools as they seek to discover the best water management option in the face of uncertainty related to climate change, demography, economic development, and regulatory reform. New approaches to decision making under uncertainty based on rigorous analysis [18,19] have been proposed to assist in this effort. However, the fundamental question of whether the "perfect" option, the Platonic form, even exists to be discovered remains, motivating new questions as to the proper role of data and analysis in the creation of knowledge (epistemology from Plato's reference to *episteme*) that will guide society towards more sustainable patterns of water use and conservation as pressure on this vital resource grows.

This paper will argue that the proper response to these questions lies not in rejecting either the view of Plato, with his focus on the quest for the perfect form, or that of Aristotle, with his recognition of the importance of human desires in shaping decisions, but in their integration. Based on that argument, this paper reports on an attempt to translate recent academic work on decision making under uncertainty into a structured, analysis-supported, stakeholder-driven participatory process focused on river basin planning and management that includes the sustained participation of the full spectrum of stakeholders in a river basin and not simply interactions between the decision makers themselves. The process has been designed to facilitate negotiations amongst water managers and stakeholders holding distinct opinions as to the definition of a successful outcome, analogous to Plato's Philosopher-Kings" and Aristotle's "middle-class", respectively, leading, hopefully, to broad and stable agreements.

In presenting this process, the authors acknowledge that there is a rich literature pertaining to the use of participatory processes in water management, including literature on the use of models to inform these processes. Vionov et al. [20], presented the current state of the practice of modeling with stakeholders, identifying seven components of potential stakeholder participation in the environmental modeling process. Basco-Carrera et al. [21] proposed a framework for distinguishing between participatory and collaborative modeling in water resources management. Halbe et al. [22] propose a framework for initiating, designing, and institutionalizing participatory modeling in water resources management. The work presented here might reasonably be considered a single case within the general frameworks that these papers propose. What distinguishes this approach is the bottom up manner in which it has been developed and improved based on our experience as water modelers, trained to aspire to the Platonic role of Philosopher-King, yet working with stakeholders as members of the Aristotelian middle class, in a number of diverse settings over a number of years. While the approach may conform with more general frameworks, it is distinguished by its intentional design references to philosophical discourse.

It could be argued that the initial seeds of this approach were sown during the same period of time as the origins of water modeling. A recent review of the seminal psychological research related to decision making [23] referenced experiments conducted in the 1970s where individual subjects refused to apply accepted axioms from rational choice theory while playing games of chance, even after these axioms were fully explained to them [24]. Extrapolating these findings into the broader realm of decision-making, Slovic suggested that:

> *An analysis which fails to appreciate the concern for regret and ambiguity is likely to violate the decision maker's preferences. Therefore we must work to devise methods for incorporating such psychological variables into the decision analysis, despite the aesthetic and practical complications that will arise when utilities and preferences are context-dependent.* [Emphasis added]

This conclusion, backed up by volumes of subsequent research in the fields of psychology and behavioral economics, suggests that no single "right" answer will be independently discovered by every player confronting the same game of chance, as suggested by the rational choice model. Gintis [25], demonstrated that counter to rational choice theory, when facing individual decisions game players are variably more averse to loss than attracted to gain, with some individuals placing greater value on what they possess than on what they could acquire. In public goods games, where freeriding is the rational choice, Lopes [26], reported that participants demonstrated notions of fairness, cooperation, reciprocity, and social pressure that led to non-rational decisions. Finally, Henrich et al. [27] found that the degree of pre-existing social cohesion and market integration within a group of players of a public good game largely explained the degree of cooperation expressed.

Slovic's conclusion that the distinct preferences that individuals bring to a decision-making challenge will uniquely shape their notion of the correct course of action, has been repeatedly confirmed. The conclusion strongly evokes Aristotle's suggestion that in addition to reason, sensation and desire also contribute to action. The challenge is to create an intentional space for this sensation and desire in the water management decision-making process, which heretofore has been structured more along technical and analytical lines. Moreover, the suggestion that the degree of social cohesion contributes to higher levels of cooperation implies that a process that actually contributes to the creations of such cohesion can better harmonize the distinct sensations and desires of individual stakeholders. The practice described in this paper has been structured so that the distinct preferences held by individual stakeholders in a particular river basin remain the central focus, with each stakeholder taking responsibility for articulating and defending his or her own interests or values, as the group collectively seeks to define a mutually acceptable course of action.

This focus is consistent with the conclusions of the National Research Council [28], which in a useful review of models of decision-making, draws a distinction between the more common "predict-then-act" framework and an alternative "analysis with deliberation" approach. As its name implies, the first framework imagines a sequential progression of gathering information, using this information to construct knowledge, leading to decisions. This is how Plato imagined the path towards knowledge in his Theory of Forms. The second approach imagines a more iterative process, which begins with the stakeholders and decision makers participating in a joint problem formulation based on their particular preferences that guides data gathering and analytical design. This analysis will produce intermediate results that are collectively reviewed by these same participants leading to new cycles of data gathering and analysis, and ultimately to a decision. Aristotle's model of the deliberating middle class corresponds well with this approach.

As part of a research program on the "analysis with deliberation" approach, researchers at the RAND Corporation proposed a decision-making model called Robust Decision Making (RDM) that attempts to formalize this approach (Figure 2). A novel problem formulation framework referred to as XLRM initiates the iterative process. In the XLRM framework, a decision making challenge is divided into four component parts. The first corresponds to uncertain e**x**ogenous (X) factors that are outside the control of stakeholders and decision makers but which have the potential to influence outcomes (e.g., climate change, population growth). The second component relates to the **l**evers (L) or options that decision makers can implement in order to improve outcomes (e.g., new infrastructure, new regulations), with the option of maintaining the current system configuration (Business as Usual) always being considered. The R in the framework corresponds to the analytical tools deployed to **r**elate the articulated uncertainties to the identified management options so that values of stakeholder specific **m**etrics (M) of performance used to evaluate and compare potential outcomes can be produced. These different performance metrics can be equated to the different human sensations and desires that Aristotle referred to in the Nocomachean Ethic and the context-dependent preferences that Slovic discovered during his research on the validity of rational choice theory.

It is worth noting, however, that the iterative process shown in Figure 2 and described in Lempert et al [18] suggests that the "analysis with deliberation" approach will ultimately lead to the identification of the "Robust Strategy", which is one that will perform "well" over a range of possible future conditions. This strategy is presumably discovered by moving through a series of steps focused on case generation, scenario discovery, and tradeoff analysis leading to the identification of the robust approach. There are, however, several potential pathways that the analysis can follow after the XLRM participatory scoping has been completed which do not lead directly to the robust strategy. These include:

1. Returning to the XLRM scoping exercise after determining that the performance of the identified strategies is too poor.
2. Returning to the XLRM scoping exercise after determining that the vulnerabilities of the identified strategies are too high.
3. Returning to the XLRM scoping exercise after determining that the tradeoffs among the identified strategies are too extreme.

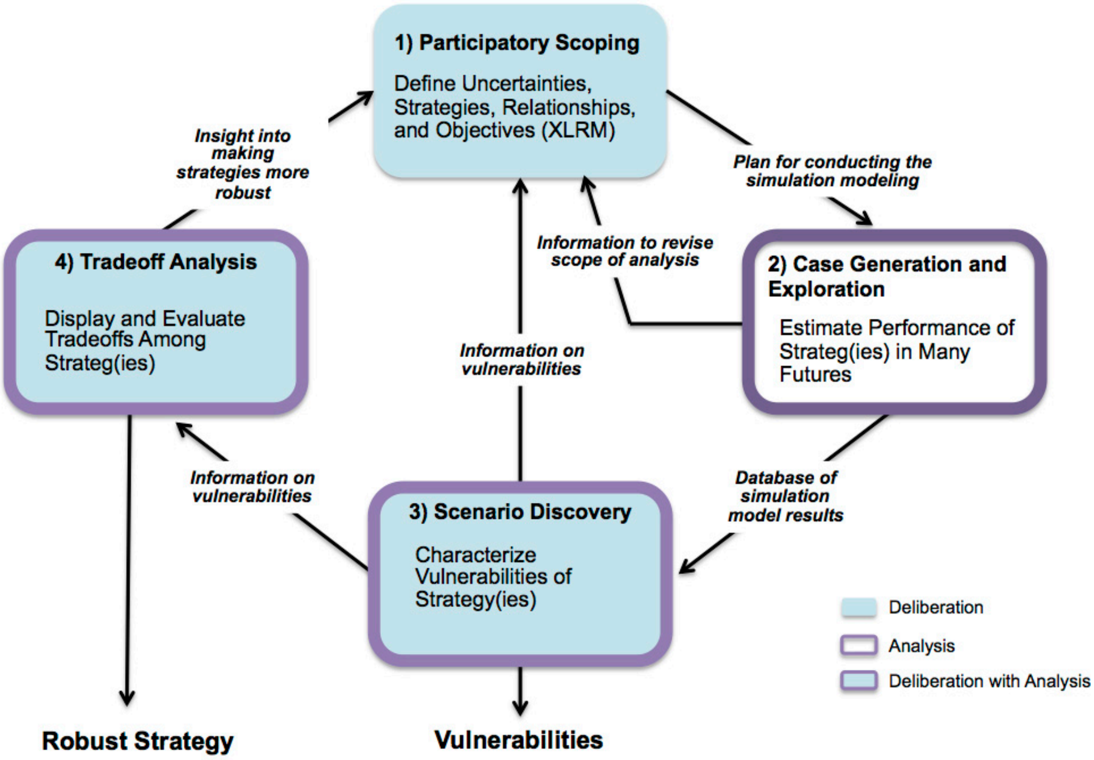

Figure 2. The Robust Decision Making framework, an example of the Analysis with Deliberation Approach to decision making under uncertainty. [18].

The figure is not explicit, however, in defining what constitutes a too poor performance, a too high vulnerability, or a too extreme tradeoff. In fact, in many applications of RDM in the water sector [29,30], efforts have been made to inform the definition of these thresholds through some algorithmic procedure. When taken to the extreme, this would render the process defined in Figure 2 a more complex version of predict-then-act, in effect reducing efforts to reconcile the different desires and preferences held by the stakeholders to simply add another deterministic step in an analytical procedure.

The participatory process described in this paper, referred to as the Robust Decision Support (RDS) practice attempts to operationalize the process described in Figure 2 while avoiding the inclination towards the Platonic inherent in overly algorithmic assignment of thresholds of performance, vulnerability, and tradeoff. Here is it important to be clear that the proposed RDS practice fully adopts the analytical framework within RDM (Figure 2), with its rigorous combination of uncertainties and strategies within model runs designed to produce values of a range of performance metrics. What is novel is the manner in which this analytical framework is embedded within a broadly subscribed participatory process, where the participating stakeholders, not algorithms, drive the decision to return to the participatory scoping step. These decisions are made based on the desires of individual or groups of stakeholders involved in a particular river basin planning exercise, desires that Slovic showed may have little relation to rational choice. While RDS should be considered a derivative of

RDM, it is distinct in how it understands the motivations of individual stakeholders within a decision making process, and the importance it places on these distinct motivations.

While developing the RDS practice in the context of water management planning and decision making, the authors have spent five years working in collaboration with water management stakeholders and decision makers in Latin America, the United States, Southeast Asia, and Africa in order to test, refine, and formalize this analysis-supported participatory process. In developing this practice, the research team sought to recognize the unique preferences of each stakeholder engaged a decision-making process. The result is a formal process for accompanying stakeholders and decision makers through a series of modules, as shown in Figure 3.

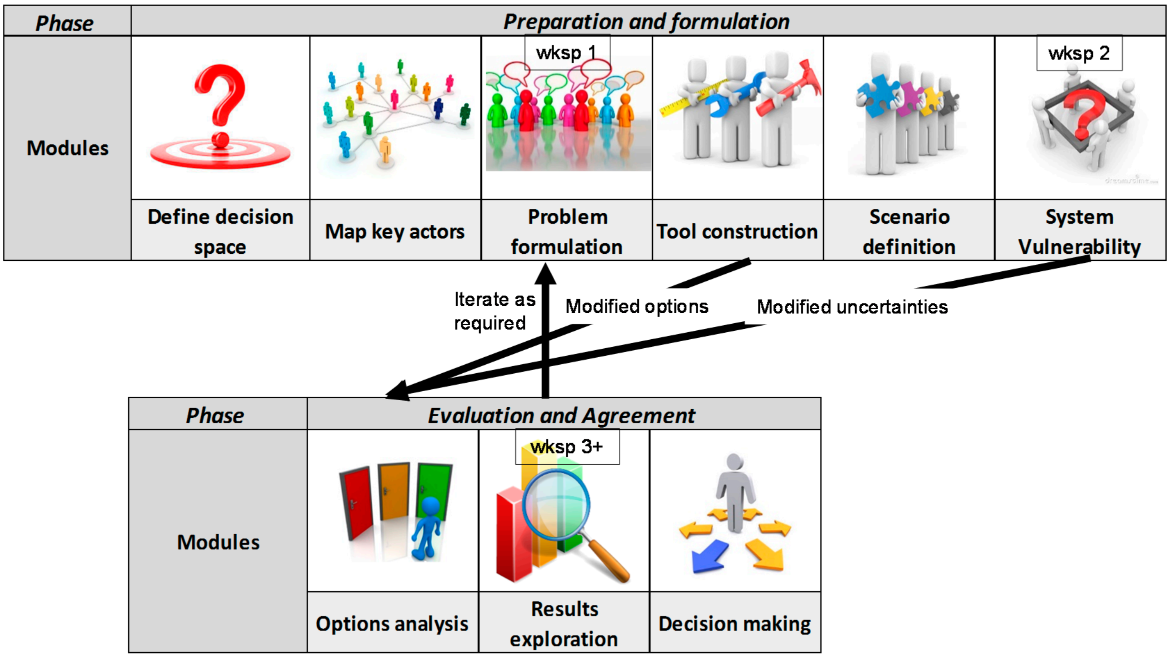

Figure 3. Steps within the Robust Decision Support (RDS) practice designed to lead stakeholders representing different water management constituencies though a process of highly participatory negotiations beginning with a problem formulation and culminating with a joint commitment to implement a consensus program of action. Potential iterative loops back to the initial problem formulation can follow model results exploration. Adjustments in the assumed future uncertainties will require a new system vulnerability assessment, while adjustments to the management options under consideration can be accommodated without generating a new vulnerability baseline. The timing of stakeholder workshops within the process is indicated.

More complete descriptions of each of modules, in Figure 3, which are implemented in two phase Preparation and Formulation followed by Evaluation and Agreement, are included below, including some justification for their inclusion in the RDS practice in terms of managing stakeholder dynamics.

1. Define decision space. River basin management decisions do not typically take place in a vacuum, rather they emerge from a legacy of prior discussions and decisions. In this step, a thorough review of past reports and plans, as well as interviews with key decision makers, are used to document what broadly defines the decision space, focusing on the legal, regulatory, political, or financial factors that motivate the decision-making process. If there are no such motivating factors present, it may be hard to initiate the RDS practice.
2. Map key actors. Once the motivating factors for a decision are understood, the next step involves administering a survey designed to identify which stakeholders should be invited and encouraged to participate in the RDS process, and to define the sorts of information, experiences,

and perspectives they will bring to the process. The results are used to produce a map of social networks that highlight potential conflicts and coalitions, as well as a plan to encourage the contribution of information and insights to the process.

3. Problem formulation. Once the key stakeholders are convened, a workshop is held to develop a first version of the XLRM matrix framing the decision making challenge. This workshop begins with a session designed to articulate key planning uncertainties, many of which are not contentious. All interest groups, for example, can usually agree that climate change is an uncertainty that has the potential to impact outcomes related to any individual stakeholder desire. This exercise serves to create common purpose amongst disparate stakeholders. The next session focuses on the particular strategies that each stakeholder favors in order to improve outcomes. This discussion can be quite contentious as many stakeholders strongly oppose strategies being offered by others, so no judgement can be cast on any particular strategy suggested at this point. This exercise serves to encourage respect amongst the stakeholders. The final session is the most important, as it focuses on the definition of the distinct metrics of performance that each stakeholder will use to evaluate the outcome of each strategy identified, their own preferred strategy as well as those offered by others. These metrics should be independent of any particular strategy, leaving open the possibility that a strategy proposed by one stakeholder might actually improve outcomes in terms of the metrics defined by another. This is the basis of tradeoff analysis and compromise.
4. Tool construction. Once the problem formulation is complete, work can begin to assemble the analytical tools (R) required to capture the articulated uncertainties (X), represent the identified management options (L), and produce the desired metrics of performance (M). In this step, it is important to assure that the analytical tool responds fully to the stakeholder-driven problem formulation. Failure to do so will degrade the creditability of the tool itself while success will further the commitment to knowledge co-creation amongst the participants. This is critical in order to avoid the model as a "black box" outcome that can lead to all too common and unproductive model critiques that divert attention from the real task of balancing the distinct values held by each stakeholder.
5. Scenario definition. Once an acceptable analytical tool is developed, a set of scenarios based on the articulated planning uncertainties must be defined in order to construct an ensemble of model runs spanning possible future conditions. This entails defining plausible future ranges for each uncertainty, and here the stakeholders must be involved. The goal is to define endmembers that the stakeholders feel would both stress the system and be easily handled, and to then populate the intervening space with a series of discrete intermediate assumptions. The ensemble of scenarios is constructed by implementing a full combinatorial sorting of each discrete condition associated with each articulated uncertainty.
6. System vulnerability. Once an ensemble of scenarios is constructed it is run supposing that current management regimes are maintained. This Business as Usual case is critical to the RDS practice as it allows for an assessment of the baseline vulnerability of the current system in the face of the articulated uncertainties. In fact, the second stakeholder workshop in the RDS practice involves exploring the modeled values for the stakeholder-defined metrics of performance for each member of the scenario ensemble under current management in order to co-create an assessment of the potential vulnerability of the existing system. The discussion of stakeholder preferences in the absence of any analysis of the performance of any particular management options is critical in order to avoid the case where each constituency locks on to the strategy that will produce the best outcome with respect to their particular metric of performance, typically the one they suggested. This workshop also includes the definition of performance thresholds for each stakeholder preference corresponding to the minimum acceptable and maximum aspiration levels.

7. Option analysis. Only once the vulnerability assessment is complete, and the sideboards of "could live with" and "would love to have" thresholds are defined for each stakeholder's individual desires, is the ensemble run again to include representations of the current formulation of the stakeholder-proposed management options.
8. Results exploration. When only the Business as Usual case is run, the model ensemble contains a single run for each scenario constructed, each run producing model output associated with each stakeholder-defined metric of performance. The model output database produced from option analysis doubles in size with each proposed management strategy considered. As such, the use of innovative, interactive data visualization tools to explore the outcome space defined by the desired metrics of performance for each combination of articulated uncertainties and identified management options is critical to the success of the RDS practice. This exploration is carried out in close collaboration with key stakeholders in order to promote the creation of shared knowledge and insights about the system and potential outcomes that allow the discussion to focus on the particular values held by each participant and not of the merits of the analytical tools themselves.
9. Decision support. Based on the shared insights developed through the participatory exploration of the ensemble model output database, the performance of specific management options can be evaluated relative to the Business as Usual base case and to each other. Using the model results related to metrics of performance of particular interest to each stakeholder, the participants can decide to either reformulate the problem (refine uncertainties, and/or modify existing or propose new management options), leading to the reformulation of the XLRM matrix and the initiation of a new analytical cycle. Eventually, if the process is successful, broad acceptance of a preferred set of options is achieved. Experience with the RDS practice suggests that, following the vulnerability assessment step, it is useful to first configure the set of model runs to represent in isolation the distinct management options suggested by each stakeholder. The results typically suggest that while the strategy will improve outcomes in terms of the particular metrics of performance proposed by that stakeholder, it will have negligible or negative impacts on the metrics of performance proposed by the other. This typically leads to a negotiation focused on defining integrated programs of action that combine key features of several of the distinct strategies originally offered by the participants. The subsequent evaluation of the ensemble output associated with these integrated programs typically leads to the definition of a preferred program of action.

The entire process, from the initial definition of the decision space to the identification of the preferred integrated program of actions can take anywhere from 9 to 18 months to complete and requires stakeholder participation in up to five all-day workshops. The RDS practice should not be viewed as a quick effort that will miraculously lead to the identification of the perfect management option. The goal is not to create a common vision of what constitutes the true best outcome, rather, the RDS practice is a sustained effort to create a stable agreement between disparate parties, each of whom expresses and advocates for his or her own desired outcome within a process that fosters social cohesion.

We cannot know exactly what conversations took place in the Athenian Agora between the height of the 360 BC drought and the recognition of the Kephisodoros of Hagnous in 346 BC for his efforts to restore the fountains of Athens. Nonetheless it is clear that the process leading to the restoration of the fountains took years to complete. The great contribution of the early pioneers in the development of hydrologic and water resources model is that they provided the tools required to accelerate the complex social and political process leading to improved policy setting and decision-making around water resources. A decision that took more than a decade to reach in Ancient Athens can now be completed in a little more than a year.

4. Implementing the RDS Practice in the Andes

Water managers across the tropical Andean Region must plan for an uncertain future prompted by climate change [31]. These changes are already being felt in high elevations. The glaciated area of Peru's Cordillera Blanca—which represents 35% of all glaciers in the country—have retreated from 728 km^2 in 1960 to 536 km^2 in 2003 [32]. In Bolivia's Cordillera Real, the glaciated area shrank 43% by volume between 1963 and 2006 [33]. Colombia has lost more than 50% of its glaciers, with only six glacier capped mountains remaining as of 2012 [34]. Also vulnerable to climatic changes are the Andean páramos (high altitude moorlands) and bofedales (high altitude marshes), which with their high infiltration and soil moisture storage capacities provide crucial water production for downstream users, particularly during low flow periods. The unique biodiversity of páramos and bofedales underscores their fragility, with climate change compromising their ability to supply water [35], as well as reducing their total area [36]. For the 40 million people that depend directly on Andean ecosystems (glaciers, páramos, and bofedales) for their water resources [37], such changes can have far-reaching consequences, creating water management challenges in terms of meeting urban and agricultural demands, capturing hydropower generation potential, and preserving important ecosystems.

One Andean region where these consequences are already being felt is the La Paz/El Alto Region of Bolivia (Figure 4). These neighboring cities possess very different histories and geographies that have translated in to very different levels of water service provision. The historical city of La Paz lies in a canyon to which several glaciated watersheds drain providing the city with reasonable levels of water supply, albeit one at risk to future retreat and disappearance of these glaciers. El Alto situated on the western edge of La Paz lies atop a 4000 meter high altiplano that drains to Lake Titicaca. Only one watershed draining the Cordillera Real has been tapped to provide water to El Alto, complemented by a groundwater pumping plant in the southern part of the city. The water quality in the Tuni watershed is also threatened by contamination associated with relic mining activity. While the two cities are actually served by the same water utility, the residents of El Alto typically rely heavily on water procured from private tanker trucks that ply the streets of the city. Based on its own analysis, the utility developed ambitious plans for increased water sharing between La Paz and El Alto and expansion of the El Alto capture zone far to the north. These plans encountered extreme skepticism and strong resistance from both the City of La Paz and existing irrigators in the targeted watersheds.

In 2012, in order to build trust and resolve the conflict between the stakeholders in La Paz and in rural areas to the north of El Alto, the Ministry of the Environment and Water convened a focal group of key stakeholders and decision makers to plan for new water management investments in the region. Over the course of a year, these stakeholders participated in an RDS process, beginning with the problem formulation workshop that produced the XLRM matrix shown in Table 1. Two of the articulated uncertainties merit further explanation. To a large extent, the current government in Bolivia draws its political power from indigenous communities, which are more present in rural areas and in El Alto than in historic La Paz. There was an interest in exploring the implications of a possible shift away from the current policy related to historical water rights in La Paz and/or the lower priority assigned to agricultural water use as against potable supply. Also, the uncertainty related to further expansion of irrigated areas had a particular local character as it was tied strongly to a global quinoa boom that was underway when the problem formulation was completed. In total, the definition of the five dimension of planning uncertainty resulted in the definition of an ensemble of 192 different future scenarios.

Using a widely available water resources systems model [38] as an analytical engine, a model of the pertinent region of the Cordillera Real was constructed and calibrated to simulate glacier evolution, bofedal dynamics, and rainfall-runoff hydrology in existing and potential source watersheds. The current urban and agricultural demand and supply systems were also represented, along with several strategies to expand the urban water supply system to several watersheds to the north along the Cordillera Real and to invest in watershed protection. To explore the six identified strategies across the full range of articulated uncertainties required an ensemble of 1152 WEAP model runs (192 future scenarios × 6 management strategies), each producing a time series output for each of the metrics of performance. The challenge of exploring the large database of model output associated with such an ensemble is to develop a shared conceptual model amongst the RDS participants regarding the interpretation of results associated with each unique combination of scenario and strategy. It is in the development of this shared conceptual model that advanced data exploration and visualization tools proved particularly useful. Forni et al. [2016] reports on how advanced visualization was used in Bolivia to guide the RDS participants in the construction of a shared conceptual model and in the extraction of shared insights and knowledge from the ensemble of model output.

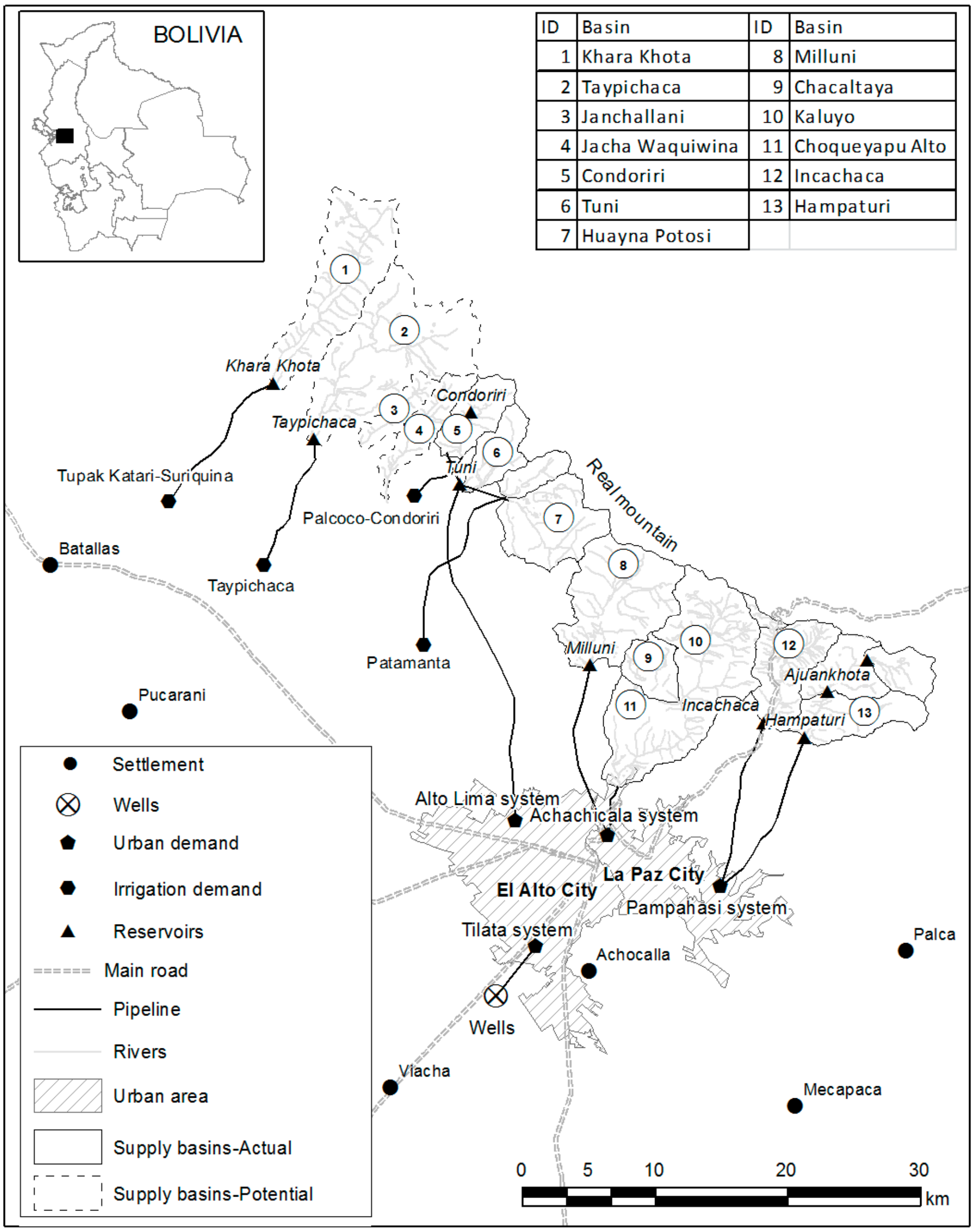

Figure 4. The La Paz/El Alto Region of Bolivia depicting current sources of water supply for La Paz and El Alto (solid outlines), along with potential new source watersheds (dashed outlines), existing reservoirs (triangles), conveyance facilities (solid lines), and points of urban (hexagons) and agricultural (pentagons) demand. The wellfield (circular cross hatch) providing water to El Alto is also shown. (Data source: Ministry of Environment and Water).

Table 1. Initial XLRM problem formulation matrix developed by a focal group of stakeholders representing various constituencies convened by the Bolivian Ministry of the Environment and Water during a one-day problem formulation workshop held in La Paz, Bolivia.

X (Exogenous Factors/Uncertainties)	L (Levers/Management Strategies)
Climate change and variability Population growth Increased per capita demand Changes in water allocation priority Expanded agricultural production.	Current system 3 new urban system expansion plans Conservation of bofedales Reduced urban distribution losses Reduced agricultural distribution losses
R (Relationships/Model)	**M (Metrics of Performance)**
Cordillera Real Model (in WEAP)	Urban water demand satisfaction Agricultural water demand satisfaction Total system losses Reservoir storage levels

At this point it is sufficient to say that once this shared model was available it became increasingly easy to add additional layers of complexity to the data visualizations, without overwhelming the participants in the process. In spite of the complexity of the system, the RDS participants were able to grasp the implications of the information presented, co-creating knowledge about the performance of the system under various future scenarios and management strategies. At the end of the 9-month process a consensus was reached that the capture zone for the El Alto water supply system should be extended north to include new watersheds, but only in combination with investments to improve the performance of existing irrigation systems in these watershed. This decision was subsequently refined through engineering design and costing and submitted to the PPCR for funding. By 2018, the realization of these new investments was nearing completion.

5. Implementing the RDS Practice in California

California has one of the most complex engineered water resource systems in the world. More than a century of water resources development has deeply impacted the environment. Most of California's historical wetlands are gone, water quality is impaired, habitats for salmonid fish are severely reduced, and close to 90% of riparian woodlands have been lost [39]. Much of this development occurred over the 20th century, from a combination of local, state, and federal infrastructure projects that invariably sourced water from a distance after local sources failed to keep up with demand. Since the 1970's, environmental demands have come to the forefront, and state and federal government's role has shifted a bit, from supporting infrastructure development, to protecting environmental needs [40]. Nonetheless, today, close to 80% of human water use in California is for irrigated agriculture, supporting a 40+ billion dollar industry and making California, especially the Central Valley, a globally important agricultural producer [41].

In California, the RDS practice has been applied to support local efforts to complete an Integrated Regional Water Management (IRWM) planning process in order to propose specific projects for financial support from the State of California. In Yuba County (Figure 5), at the downstream end of the Yuba River basin, which originates upstream in the Sierra Nevada, a stakeholder group representing municipal water supply, irrigation, hydropower, flood management, and environmental interests worked together over a period of 18 months to define the uncertainties, objectives and management options required to create an XLRM problem formulation matrix and to explore the potential performance of various management options contained within the Yuba County Integrated Regional Water Management Plan. To support the analysis a model was calibrated to represent the hydrology of the Yuba River Basin and the North and South Sub-Basins of the Yuba County Groundwater Aquifer. Within this hydrologic context, the operations of the major hydropower, flood control, and water supply infrastructure in the basin were simulated along with the allocation of water to meet municipal, irrigation, and ecological water needs.

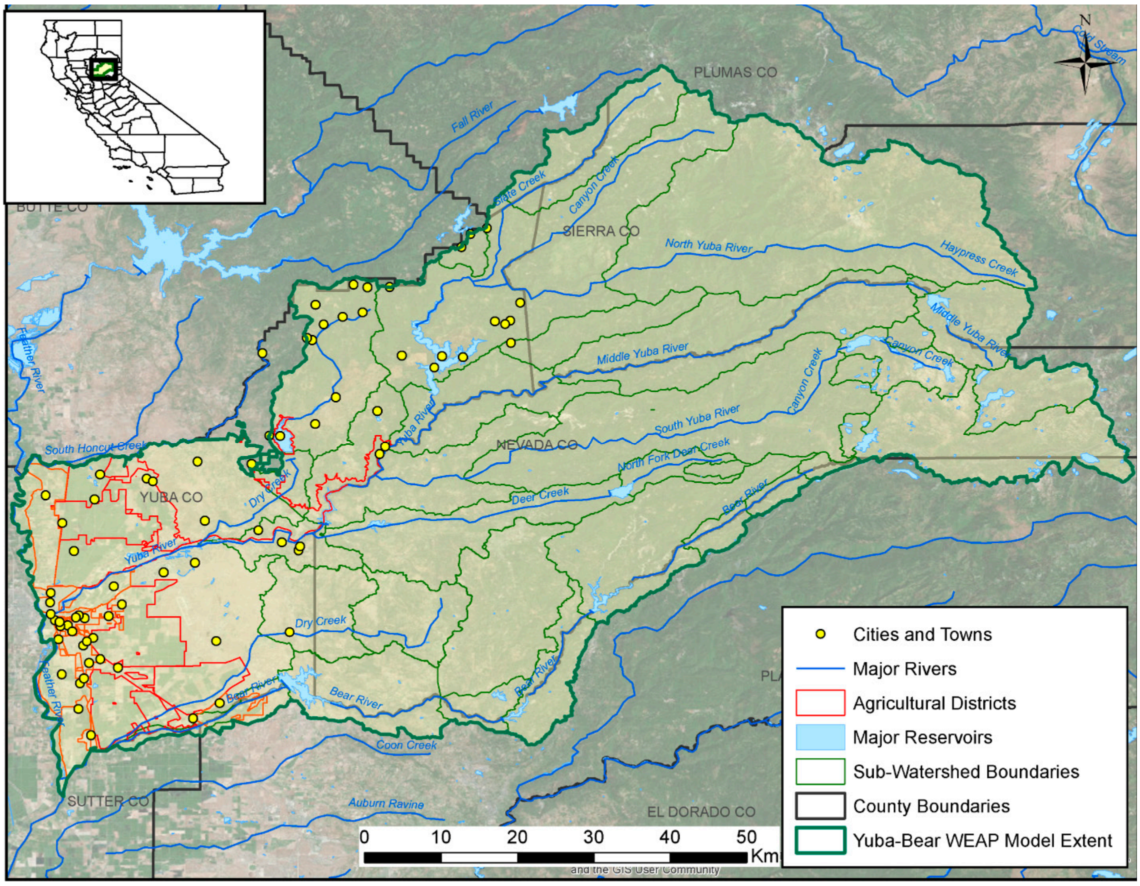

Figure 5. The Yuba River Watershed in Northern California, depicting the source water region in the Sierra Nevada as well as the water management infrastructure located within Yuba County in the western portion of the watershed. Red dashed lines show the position of irrigation districts with access to some portion of the flow in the Yuba River Watershed, yellow dots show the location of population centers where drinking water is supplied by a public utility. (Data source: California Spatial Information Library).

The final XLRM matrix, co-created over several rounds of ensemble analysis, is shown in Table 2. It contains two dimensions of planning uncertainty, climate change, and regulatory reform associated with current efforts to update the Bay-Delta Water Quality Control Plan that contemplate requiring the tributaries in the Sacramento and San Joaquin River Basin to constantly contribute a percentage of their full natural flow to ensure the health of the Bay Delta system. Four climate projections of critical interest were formulated based on the concerns articulated by the stakeholders. Two corresponded to end members extracted from the IPCC database (hot-dry and warm-wet) and two were constructed to contain climate attributes of particular concern to stakeholders (repeating extended drought and dry-fall/wet spring). Two Delta regulation futures were also formulated, the first corresponding to the current regulatory regime and the second representing a 50% of full natural flow contribution to Delta health, meaning that in the final round of analysis, a total of eight future scenarios were ultimately explored.

Table 2. Final XLRM problem formulation matrix developed by a focal group of stakeholders representing various constituencies convened by the Yuba County Water Agency in Marysville, California. The initial problem formulation contained two additional dimensions of uncertainty associated with hydropower relicensing and land use change, but these were eliminated from consideration due to the discovery of their relatively small impact, relative to climate change and the eventual Delta regulatory regime, on the vulnerability of the system.

X (Exogenous Factors/Uncertainties)	L (Levers/Management Strategies)
Climate change Delta regulations	Current system 12 Yuba IRWMP projects
R (Relationships/Model)	**M (Metrics of Performance)**
Yuba Model (in WEAP)	Ecological Water supply Hydropower Flood safety

As in the case of Bolivia, a widely available water resource systems model was used as the primary analytical engine to produce values for the metrics of performance and innovative data visualization techniques [42] were used to create a shared conceptual model of the results of the ensemble analysis. The RDS analysis showed that the Yuba system is highly vulnerable in a drought scenario, combined with a new 50% of full natural flow Delta regulatory regime. The analysis of strategies, drawn from the IRWM plan, showed that most of the individual strategies proposed did not broadly reduce the regional vulnerabilities of the system as it relates to the metrics of performance posited by the full spectrum of stakeholders. In particular, urban conservation projects, while helping local constituencies, would not significantly decrease system level vulnerabilities because of the very small proportion of total water used by the non-agricultural sector. In this setting standalone urban water management actions, while helping to improve overall water use awareness, cannot produce broad benefits. However, an ambitious combination of multiple discrete strategies—a portfolio of infrastructure and river restoration action—could create positive cross-sectoral regional impact. Based on this exercise in negotiation, the participants in the Yuba RDS process were able to prioritize and combine discrete actions into a package for which they have sought financial support from the State of California. While there is no guarantee that this application will prove successful, it does represent the sort of integrated package of broadly supported actions that the IRWM planning process was intended to promote, but which has proved elusive over California's decade-long experiment with Integrated Regional Water Management Planning [43].

6. Discussion and Potential Limitations

Beginning with the work in Bolivia, and continuing through the work in California, the research team has continued to refine the RDS practice based on feedback from participants. This has produced the current design of the RDS practice shown in Figure 3. One current feature of the practice, which was implemented in California but which was not undertaken in Bolivia, is the discrete step of assessing the vulnerability of the current system, and defining threshold values for the user specific performance metrics associated with the "would love to see" and "could live with" criteria prior to actually presenting any results associated with the performance of a particular strategy. In Bolivia, the results for the base case were simply presented along with the results associated with the strategies. It has become clear that taking the time to develop a baseline system vulnerability assessment and to define performance thresholds before evaluating the implications of strategies is an effective way to diffuse potential conflicts that typically surround strategies. This is particularly true for strategies related to new infrastructure, as it focuses the discussion where it should be, on the distinct set of values that each stakeholder brings to negotiation, values which must be broadly addressed by any proposed water management intervention, including new infrastructure investments.

Another feature of later RDS efforts has been subsequent sets of ensemble model runs that combine features of individual strategy options into integration programs of action. In Bolivia, the exploration of performance focused only on the proposed strategies in isolation. Fortunately the stakeholders were able to extract from this analysis the broad outlines of an integrated program that became the kernel of eventual engineering design and costing work. This effort was complicated somewhat, however, by issues related to timing and scale that could have been resolved as part of the RDS work had additional rounds of analysis been completed. In the Yuba case, and in all other current RDS efforts, these additional rounds have proved very useful in creating a consensus around not only the timing of specific actions but also around more coordinated operating rules associated with these interventions.

Nonetheless, it is safe to say that in all venues where the RDS practice has been deployed the experience has been positively received. Table 3 contains some written impressions of the process from both the Bolivia and California cases. In general, the experience suggests that the co-creation of knowledge is an effective way to diffuse distrust between various stakeholder constituencies that often characterize water resource planning and decision-making process. This co-creation process begins with the joint problem formulation, with its open statement of stakeholder-specific values and preferences, continues with the joint vetting and validation of the modeling tools that will be used to inform the process, and culminates in an open discussion of mutually acceptable tradeoffs and compromises. The entire process is facilitated by the ability to dynamically explore the implications of various management options using powerful data visualization tools, which is both empowering for the RDS participants, and, based on feedback provided following workshops, enjoyable. In addition to helping the participants deliberate on the relative merits of each individual strategy proposal, the RDS process itself seems to build the social cohesion that can lead to increased levels of cooperation.

Table 3. Some observations on the utility of the RDS practice from a survey of participants following the completion of the exercise in both La Paz/El Alto, Bolivia and Yuba County, California.

Survey Questions	Responses from Bolivia Case Study	Responses from Yuba Case Study
Was the exercise useful?	Yes	Yes
How was it useful in extracting valuable information?	- Direct comparison of the considered alternatives. - Recollection and organization of basin data. - Discovery of new research areas and monitoring improvements needed for reliable future databases. - Democratization of information by reaching a wider audience, not just modelers.	The visualization platform was invaluable to our group's efforts to evaluate the complex quantitative data produced during the RDS ensemble analysis. It helped move us from being overwhelmed to comprehension and gave important insights regarding future conditions and the efficacy of various water management projects.
How was the visualization useful in your future management design?	- To establish the magnitude of the operation that needed to be done in order to guarantee water supply for the cities of El Alto and La Paz in the next 30 years. - The study demonstrated that small interventions in the basin would not bring about the desired levels in the short term and were vulnerable to climate change.	The visualization platform was transformative to our water planning process. We initially started down the well-worn path of traditional water management planning. Following established guidelines, we seemed bound to write yet another formulaic plan that would define desired outcomes for our region and then propose, rank, and elicit funding for the subset of projects that appeared most likely to help achieve our desired outcomes. The visualization techniques allowed us to move beyond conventional wisdom and recognize that the projects included in our plan would likely not get us to where we needed to be as a region. Based on this experience, our group plans to fund a project that would internalize these techniques to our formal planning process.

That said, there are potential drawbacks associated with the RDS practice that need to be considered and compensated for, if possible.

1. The process is time-consuming, with experience suggesting that the entire process can take anywhere between 9 and 18 months to complete, depending on data availability and system complexity. Participants need to be aware of the time commitment from the outset.
2. In addition to being time consuming, the RDS practice requires the sustained participation of the stakeholders in the process. Each workshop is designed to continue the construction of the shared conceptual model that allows the complex data visualizations to be understood and useful. The process is severely hampered by the representatives of the various stakeholder constituencies dropping in or out. This risk should be made clear at the outset.
3. There is no guarantee that a consensus preferred program of action that emerges from the RDS process will be optimal in the classic sense of the word as the strategies that are considered are limited by the imagination and creativity of the participants. That said, if the participants each maintain their own value-specific definitions of what constitutes a successful outcome, and agree to a common preferred program of action, there is a high likelihood that it will at least avoid being Pareto sub-optimal.
4. Only human beings can directly participate in the RDS process, so the environment will always be a silent party to the negotiations. If the interests of the environment are not being actively defended in the RDS process, there is a risk that the consensus preferred program of actions will not be environmentally sustainable. This is why the active participation of environmental organizations in the RDS process is vital.
5. There is always the possibility that some stakeholder or stakeholder constituency will emerge at the end of the process, claiming that they were not involved in the development of the consensus preferred program of action and that they are not in favor of its implementation. Avoiding this eventuality is the reason why the decisions space definition and key actor mapping steps must be taken seriously.
6. There always exists the possibility that the participating stakeholders will not be able or define a consensus preferred program of action. While this has yet to occur in any of the roughly ten RDS exercises the research team has implemented in California, Latin America, Africa, and Asia, were it to occur there might be a temptation to characterize the decision space as a wicked problem [44]. Wicked problems generally require authoritarian responses, although it could be argued that a failed RDS process would aid in discovering that requirement, making the eventual implementation of a decision by fiat more politically acceptable.

Recognizing these potential limitations, and making plans to address them early in the RDS process will greatly improve the usefulness and potential success of the investment of time and talent required to actually implement what is a powerful negotiation technique. It must be acknowledged, however, that the RDS practice has not been applied in a context of institutionalized power imbalance, such as a caste system. It would be interesting to see if the RDS practice would prove successful in such a setting.

7. Conclusions

While there is a long heritage of participatory process design in the water resources planning and management space as well as other public policy arenas [45–47], the experiences reported upon from Bolivia and California suggest that the RDS practice should be considered to be a particularly effective approach. One potential explanation for its effectiveness might be found by looking again at the Allegory of the Cave referenced in the hypothetical dialogue between Plato and Aristotle. Plato actually concludes the allegory by posing the following question.

Now if once again, along with those who had remained shackled there, the freed person had to engage in the business of asserting and maintaining opinions about the shadows . . . would he not be exposed to ridicule down there?

It is almost as if Plato recognized the impossible task of his Philosopher-King in a democratic context where decisions cannot easily be imposed by fiat. Even if the expert believed that these opinions about the shadows held by the enchained, Aristotle's desires and sensations, were wrong, he or she would have no way to change them. Slovic discovered this too when even after explaining the axioms of rational choice theory to the participants in his study, he could not get them to uniformly apply them. The great insight of Aristotle was to recognize the importance of practical wisdom associated with deliberation within a particular decision-making or policy-setting context. The RDS practice attempts to capitalize on this insight, not by allowing the shadows alone to dictate, but by bringing the monumental contributions of the early pioneers in the field of water modeling to bear in an attempt to reduce the fuzziness of the flickering shadows. While many other factors beyond good models and effective negotiations determine success, some problems are indeed wicked, thanks to the early water modeling pioneers, and the countless contributions of the water management community over the decades; these tools allow us to do more when confronting a drought or any other water management challenge than simply pray for rain.

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