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A Comprehensive Process for Stakeholder Identification and Engagement in Addressing Wicked Water Resources Problems

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Received: 15 February 2020; Accepted: 6 April 2020; Published: 14 April 2020



Abstract: Various sectors of stakeholders (urban, agricultural, policymakers, etc.) are frequently engaged in participatory research projects aimed at improving water resources' sustainability. However, a process for comprehensive and integrative identification, classification, and engagement of all types of water stakeholders for a region or river basin, especially in a transboundary context, is missing for water resources research projects. Our objective was to develop a systematic approach to identifying and classifying water stakeholders, and engage them in a discussion of water futures, as a foundation for a participatory modeling research project to address the wicked water resource problems of the Middle Rio Grande basin on the U.S./Mexico border. This part of the Rio Grande basin can be characterized as having limited and dwindling supplies of water, increasing demands for water from multiple sectors, and a segmented governance system spanning two U.S. states and two countries. These challenges are being exacerbated by climate change; a transitioning agriculture to more water demanding, high value crops; urbanization; and growing demand for environmental services. Moving forward, a core question for this region is **how can water be managed so that the three competing sectors—agricultural, urban, and environmental—can realize a sustainable future in this challenged water system?** We identified the major water-using sectors who represent competing demands as including agricultural, municipal, self-supplied industrial users, environmental, and a sector we labeled “social justice”, comprised of individuals who lack access to potable water, or who represent groups who advocate for access to water. We included stakeholders from both the U.S. and Mexico, which is seldom done, who share transboundary water resources in the region. We hosted a series of stakeholder dialogues and obtained results that identified and described their vision for the future of water; challenges to be overcome; and important research questions that could be addressed using participatory modeling approaches. Four broad themes common to multiple sectors emerged: (1) quantity, drought, and scarcity; (2) quality/salinization; (3) urbanization; and (4) conservation and sustainability. Each sector expressed distinctive views regarding the future of water. Agricultural stakeholders, in particular, had strong feelings of ownership of water rights as part of land ownership and a concomitant sense of threat to those water rights emanating from dwindling supplies and competing demands. The contribution of this work is a methodology for identifying, classifying, and engaging all types of stakeholders in the context of a research project, enabling us to compare and contrast views of different types of stakeholders. Heretofore, this has been accomplished in “bits and pieces”, but never comprehensively and holistically.

Keywords: participatory modeling; Rio Grande; stakeholder engagement; water futures; wicked problems

1. Introduction

The label “wicked” was first assigned to urban policy challenges by Rittel and Weber [1] and shortly thereafter applied to water resources planning and management by Liebman [2]. In the context of water resources, wicked problems can be characterized by the following statements: (1) they involve multiple definitions as to their nature; (2) they are the object of multiple and conflicting criteria for defining solutions; (3) the “solution” to one interested party is a “problem” for others; and (4) there are no obvious stopping rules that define when enough has been accomplished [3]. Gallagher [4] further demonstrated how the label applies to climate change and water resources management, because the problems are difficult to explain; unique; impossible to plainly define, often because they are the result of other indefinable problems; and have no one true solution.

The future of water resources management in the Middle Rio Grande basin, defined by the portion of the basin from Elephant Butte Reservoir in southern New Mexico to the “*Junta de los Rios*” (the convergence of the Rio Grande with the Rio Conchos in far west Texas), fits the definition of a wicked problem. This part of the Rio Grande basin can be characterized as having limited and dwindling supplies of water, increasing demands for water from multiple sectors, and a segmented governance system spanning two U.S. states and two countries [5]. On top of this, the region faces a number of drivers of change, including: (1) climate change that is impacting both (a) water supply, through reduced snowpack and timing of flows in the headwaters, and (b) demand, through increasing temperatures and greater evapotranspiration; (2) agricultural practices and trends, especially increasing production of high water demand crops and greater reliance on groundwater of marginal quality for irrigation; (3) urban growth, impacting water demand and quality (through wastewater discharges); and (4) growing demand for environmental services, such as riparian habitat and environmental flows [5–8]. In this mix of changing conditions, the prevailing water governance in the region was developed for the situation that existed about 100 years ago, and is characterized by rigid water institutions, weak participation, division by artificial borders, and quiet but protracted conflicts [5]. Moving forward, a core question for this region is **how can water be managed so that the three competing sectors—agricultural, urban, and environmental—can realize a sustainable future in this challenged water system?**

Freeman [3] identified four research challenges in addressing the wickedness of water problems: (1) the challenge of becoming more interdisciplinary; (2) the challenge of integrating two types of knowledge, scientific and local site-specific knowledge; (3) the challenge presented by multiple levels of analysis, in our case from global climate to binational agreements to federal governments to state and local entities to the individual citizen or water user; and (4) the challenge of individual rationality and common property resources, i.e., water is viewed and treated both as a property right and as a common resource property by various stakeholders, and at various points in space and time, resulting in a conflict between individual and community rationality. Although the characteristics of wicked water problems and the challenges in addressing them have been recognized for decades, only a fraction of the water resources literature blends social, technical, and scientific advances in order to more directly address the wickedness of water management problems [9], and even a smaller fraction attempts to engage a wide range of stakeholders, blending scientific and local site-specific knowledge [10]. We asked the question, “how can a participatory modeling approach that includes an interdisciplinary science team and engagement of a wide range of stakeholders be used to address the wickedness of the future of water in this very challenged desert river basin facing climate change and competing demands?” However, a process for the comprehensive identification, classification, and engagement of all types of water stakeholders for a region or river basin in a research project aimed at the future sustainability of water was missing.

Thus, our objective was to develop a systematic approach to identifying and classifying water stakeholders, and to engage them in a discussion of water futures as a foundation for a participatory modeling research project to address the wicked water resource problems of the Middle Rio Grande basin. The contribution of this work is a methodology for identifying, classifying, and engaging all

types of stakeholders in the context of a research project, enabling us to compare and contrast views of different types of stakeholders. Heretofore, this has been accomplished in “bits and pieces”, but never comprehensively and holistically. The improvement of this approach over other more segmented approaches is that it capitalizes on the “width” of stakeholder participation and the “depth” of their engagement as a motivating force for improvement and change. An important feature of our model for stakeholder engagement is that it inextricably and visibly crosses conventional boundaries. It is binational, multi-sectoral, and aims to unify surface and subsurface water.

2. Literature Review: Stakeholder Engagement

Farmer engagement in agricultural-related research is rooted in the pioneering work of Rhoades and Booth [11], who published the Farmer-Back-To-Farmer Model, a participatory research model in which applied research begins and ends with farmers, including problem identification, identifying potential solutions, research design, implementation, evaluation, and re-testing if necessary. Following their seminal work, participatory research methods found widespread adoption in agricultural research and international development, especially where technology dissemination or changes in farmer management are part of the goals of the research.

Participatory modeling combines stakeholder participation with computer-based modeling. Any form of stakeholder participation in the modeling process can be labelled as participatory modeling [12], ranging from only consultation to complete control and ownership of the modeling process by stakeholders. In its various forms, participatory modeling has recently emerged as an effective approach to water resources assessment, planning, and decision making [13–17].

Participatory modeling is particularly useful for evaluating long-term projections into the future, where direct observations are not possible and there is no experimental alternative to simulation models. The recent literature from the arid region of the southwestern U.S. advocates changing the timeframe of water management from immediate and isolated supply/demand variables to longer-term trajectories [18,19]. Participatory modeling could be particularly useful to evaluating uncertain water futures driven by climate change and urbanization, and to “adaptive change” approaches to water resources management that requires processes of continuous learning and modification [20], facilitated by dialogues around multi-participant, multi-objective models [21]. After all, wicked problems cannot be solved, but only managed.

A number of stakeholder participatory methods for water resources planning in the U.S., Europe, Mexico, and Southeast Asia have been described and evaluated by Megdal et al., [22]; Kallis et al., [23]; Robles-Morua et al., [17]; and Basco-Carrera [24], respectively. These range from approaches where stakeholders are actively engaged in model development and use (model development and mediated modeling), to approaches where stakeholders provide input and reaction, to model analyses conducted primarily by scientists (such as scenario testing and model output analysis). A limitation of many of these published studies is that stakeholder engagement is generally focused on certain groups that are dominated by professional water managers, such as national level government and other institutional decision makers [25,26]; local government and non-government organizations (NGOs) and local level water managers [27–29]; and political decision makers and policy makers [30]. Still others focus on water managers and users in certain sectors, such as urban stakeholders [31] or agricultural stakeholders [32]. Some are focused on the general public, both urban and rural [33,34]. They are also dominated by activities where the goal is improved approaches to water resources planning and management, and not where the main goal is participatory research.

However, despite the claims of integration of stakeholder participation made by approaches, such as Integrated Water Resources Management or Adaptive Management, real changes in the substance of decisions have “remained elusive” [10]. More often than not, planning processes and policy choices hardly reflect the diversity of input that inclusion of multiple actors affords [35,36]. In particular, social justice stakeholders, such as indigenous populations or, in our case, poor Hispanic populations who lack access to water, are generally marginalized in public discourse, and have little or

no political voice, are never heard as legitimate, or not included at all. The result is that management and policy decisions: (1) do not reflect local conditions and preferences; (2) mirror differentials in power that serve the interests of certain groups; (3) reflect the politics of who participates and by what rules; and (4) do not account for significant resource, skill, and cultural barriers to participation by some disadvantaged populations [10]. Thus, a systematic approach to identifying and classifying **all** water stakeholders and engaging them in a discussion of water futures as a foundation for a participatory modeling research project is missing.

We describe here our approach in accomplishing the task of identifying and engaging stakeholders as a first step in a research project based on participatory modeling, and report results that we obtained from stakeholders, including (1) their vision for the future of water in our region; (2) their views of challenges to be overcome; and (3) important research questions that we could address using participatory modeling approaches. We used this stakeholder knowledge base to inform and guide our participatory modeling approach, a process that is ongoing and that will be reported in detail in future articles.

3. Materials and Methods

3.1. Case Study Description

In 2015, we embarked upon a long-term, multi-institutional, interdisciplinary research project on water resources sustainability in the Middle Rio Grande basin, shown in Figure 1a. It is a highly managed system with very little riparian habitat, a network of irrigation canals diverting water to agriculture, a network of drains to return excess water to the river, and at least three significant municipalities with a combined population of over 2 million people (Las Cruces, New Mexico (NM), El Paso, Texas (TX), and Ciudad Juárez, Chihuahua, Mexico (CH)). The relevant aquifers in the project area are shown in Figure 1b (inside red rectangle). The primary sources of good quality water are the Mesilla and Hueco Bolsons, and the associated alluvial aquifer connected to the river. The deeper Hueco Bolson and large portions of the Mesilla Bolson are primarily “fossil” deposits of water with little or no recharge. Thus, drawdown represents withdrawals against current and future reserves [8]. This scenario is being repeated not only in other river basins of the southwestern U.S., but also in other arid and semi-arid regions of the world that are dependent primarily on a desert river basin and its associated aquifers to meet the needs of irrigated agriculture, as well as growing urban populations [37].

3.2. Theoretical Framework for Stakeholder Engagement

Our theoretical framework, illustrated in Figure 2, is a variation of the Farmer-Back-To-Farmer model [11], in which stakeholders are directly engaged in research or decision making processes, combined with recent participatory modeling research that relies on simulation models, exemplified by Robles-Morua et al. [17]. An important tenet of our approach is that stakeholders are involved in every step of the research process, shaping the process from the beginning. The organizational framework for identifying water resources stakeholders is foundational to the initiation of the participatory modeling research process. Thus, we place the identification and classification of stakeholders as a crucial first step in the larger framework of the research process. Our rationale for using this approach was that not only would we be able to provide science-based knowledge to stakeholders who are the “on the ground” managers of water resources in the region, but also that through the process, stakeholders would become more engaged and motivated to seek, test, and implement changes that would lead to more sustainable water resources management. This also draws on our team’s experience with highly successful stakeholder participatory approaches to water quality improvement [38] and participatory modeling [17]. We detail the steps taken to implement this theoretical framework in the following Section 3.3, Section 3.4, Section 3.5.

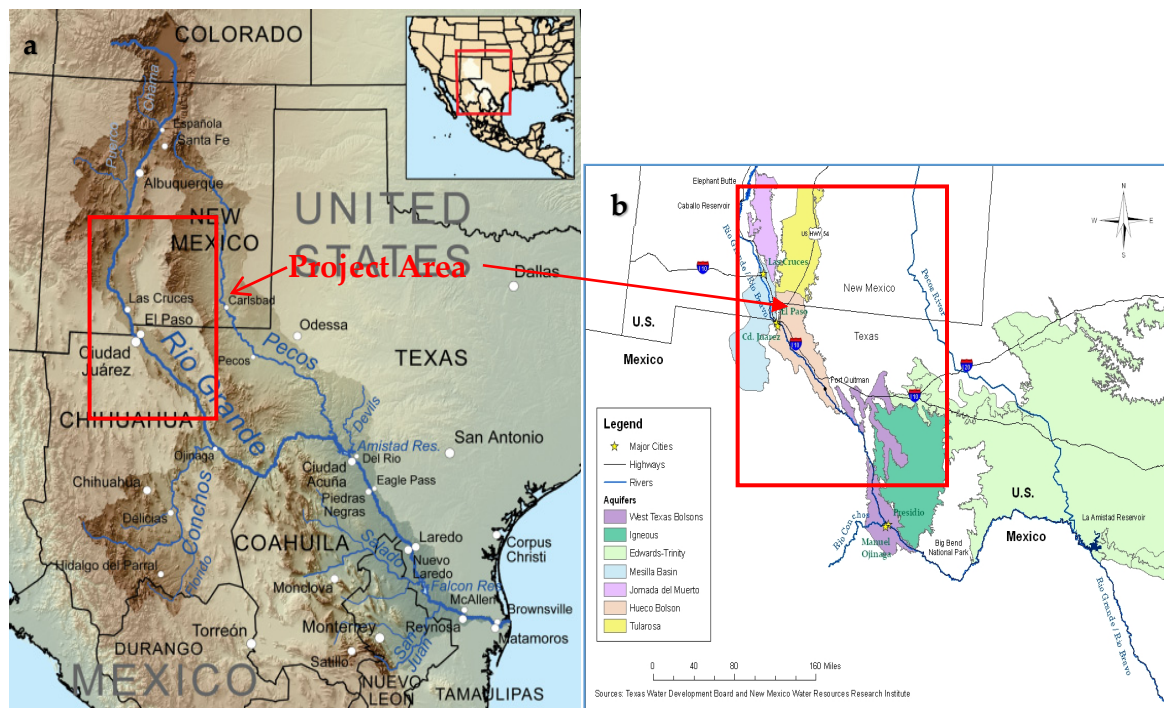


Figure 1. Water resources of the Paso del Norte region. (a) Rio Grande Basin showing the project area, the Middle Rio Grande; (b) Regional groundwater resources.

3.3. Stakeholder Identification and Classification

Stakeholders in water resources management include a complex array of individual and institutional users, suppliers and distributors, government agencies, non-government organizations, academic and research organizations, and technical service providers. The functional level of important stakeholders is summarized in Figure 2, but we refined this classification to a more detailed level in Figure 3. We identify the major water using sectors who represent competing demands to include: (1) agricultural, the biggest user, representing 80%–85% of consumptive use of surface water plus significant, but not well quantified, amounts of groundwater; (2) municipal, including El Paso TX, Ciudad Juárez CH, and Las Cruces NM, who rely primarily on groundwater, but in the case of El Paso, surface water also; (3) self-supplied industrial users (not connected to municipal suppliers); (4) environmental, supporting aquatic habitat, wildlife, riparian wetlands, etc., which currently represents a very small use, but for which there is a growing constituency; and (5) a sector we labeled “social justice”, comprised of communities who lack access to potable water or individuals who represent groups who advocate for affordable access to water, on behalf of disadvantaged communities. In the U.S./Mexico border region, there are many small unincorporated communities in rural areas that lack water and sanitation infrastructure on both sides of the border, designated as *colonias* in Texas and New Mexico. These communities have little or no political voice and are generally marginalized in water research or water resources planning projects. In order to achieve sustainable water resources management in the region, we believe that the inequities associated with inadequate water access, quality, and sanitation in the border region must be addressed.

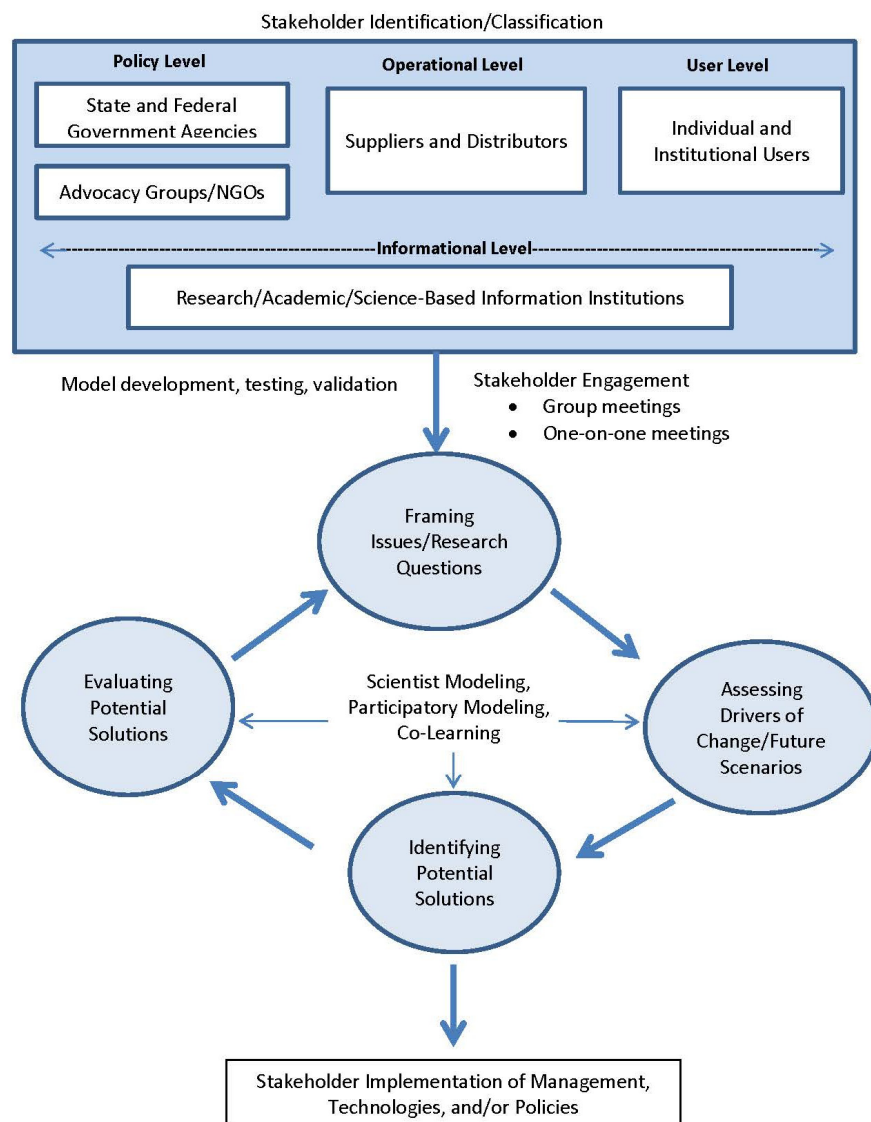


Figure 2. Theoretical framework for stakeholder identification and engagement in a participatory modeling process.

For each of these major sectors we further classified stakeholders into different types within each sector, based on their role in water use or water management. We also included a government sector, comprised of policy makers, regulators, and decision makers. We identified four main levels of stakeholders according to function (Figure 2): (1) user level, which is comprised of the direct users of water; (2) operational level, which is comprised of suppliers, distributors, and managers who are most active in supply of water to users; (3) policy and advocacy level, which is comprised of government agencies who are the policy makers and regulators, and NGOs who play an advocacy role that impacts policy; and (4) informational level, which is comprised of academic and research institutions, and science-based information providers (like extension). At the level of end-users (the most direct use) are individual, industrial, and institutional users of varying size. Among agricultural users in our region, size varies from 0.5 ha of irrigated pecans up to 1600 ha, with annual water use varying from 0.6–2 m of water on each ha. Residential users include large homes with swimming pools and irrigated landscaping to residents in *colonias* who might have very limited access to water through private providers or haulers. Institutional and industrial users also vary in size from small businesses, places of worship, or individual schools, to large industrial users and recreational users like golf courses,

sports fields, or parks. A range of suppliers and distributors provide water to these users, including the Bureau of Reclamation (who manage the reservoirs), irrigation districts, municipal utilities, smaller municipal utility distributors, rural community water systems, and small privately owned public water supplies. A plethora of state and federal agencies have varying degrees of influence on water supplies and use through policy, regulation, or conservation programs. A large number of non-government organizations advocate for their own interests in the agricultural, urban/industrial, and environmental sectors. Finally, a number of academic and research organizations, like universities and government agencies, also play an important role in providing science-based information to stakeholders.

All of these types of users were included in our engagement activities and project activities. Prior research and experience in the region [5] provided a basis for the identification and classification that we used in Figure 3. It was important to make the distinction between proximal water management organizations, such as utilities, and end users, such as residential households, and to include both. We also gave attention to the marginalized as well as the dominant users. Currently no surface water is allocated to ecosystems for environmental purposes, but we included environmental stakeholders nonetheless. Importantly, we also included stakeholders from both sides of the border (U.S. and Mexico), a necessity in our region of transboundary water resources, though seldom done.

3.4. Stakeholder Engagement: Vision, Challenges, and Research Questions

After identifying and classifying stakeholders, we hosted small group discussions to explore the future of water in the region. Since progress is often difficult in a large diverse group, we implemented an iterative process that includes small group meetings with representatives from single sectors (such as ag producers), and some larger mixed sector meetings. By organizing the meetings by sector, we sought to provide a relatively non-conflictive and trusting forum to begin our discussions, and to provide a better platform for marginalized groups to participate freely. Since we were embarking on a longer term (five-year) research project, we wanted to develop a relationship of mutual trust and respect with each group.

We hosted a total of ten stakeholder meetings with a total participation of 144 individuals. At the first meetings, we focused the discussion on stakeholders' vision of the future of water and the related challenges and research questions. We formulated a set of seven questions that guided the discourse:

1. Name, in one word, your biggest concern about the future of water in our region.
2. What questions would you like to ask about the future of water?
3. What future scenarios would you like to explore, both for water supply and water demand?
4. What issues or processes are important to consider in our models?
5. To help you think about (visualize) the future of water, what information (data, model predictions/output) would you want to know?
6. What time horizon concerns you?
7. Other issues/concerns?

Each meeting began with participants introducing themselves and naming their biggest concern about the future of water in our region, as an "ice breaker" and a means of identifying some commonalities, giving some import to frequently named concerns. This was followed by a brief overview of our project and then discussion of the questions listed above. We had two note-takers and we recorded each session to ensure that we captured all the output. The outputs from these discussions were evaluated for key themes by the two authors of this publication in terms of how different sectors valued water and the degree of agreement or differences in the vision of desired futures among sectors.

<u>Informational Level</u>	<u>Policy Level</u>	<u>Operational Level</u>	<u>User Level</u>
Research/Academic/Science-Based Information	Government Agencies/Regulators and Advocacy NGOs	Suppliers/Distributors	Individual Users
Universities State supported agricultural research & extension U.S. government research (i.e. USDA-ARS, USGS, USACE, NOAA, and others)	<u>USA Government</u> IBWC USDA-NRCS USDA-RDA USDI-BoR TX Department of Agriculture NM Department of Agriculture NM State Engineer TX Water Development Board BECC/NADB USEPA TCEQ <u>MX Government</u> CILA CEACH CONAGUA IMP BECC/NADB <u>NGOs</u> Environmental organizations Social justice organizations Environmental justice organizations Farm organizations Commodity-specific groups	Utilities Irrigation districts U.S. Bureau of Reclamation Municipal utility districts Privately owned public water systems	Farmers, small & large Residential users Small businesses Small institutional users Large Institutional Users Fort Bliss Industrial users Parks & golf courses Large institutions (like El Paso Independent School District)
<u>Identification of acronyms (alphabetical)</u> BECC/NADB – Border Environment Cooperation Commission/North American Development Bank; CEACH – Consejo Estatal Agropecuario de Chihuahua; CILA – Comisión Internacional de Límites y Aguas; CONAGUA – Comisión Nacional del Agua; IBWC – International Border and Water Commission; IMP – Instituto Municipal de Investigación y Planeación; NOAA – National Oceanic and Atmospheric Administration; USACE – United States Army Corps of Engineers; USDA-ARS – United States Department of Agriculture - Agricultural Research Service; USDA-NRCS - United States Department of Agriculture – Natural Resources Conservation Service; USDA-RDA - United States Department of Agriculture – Rural Development Agency; USDI-BoR – United States Department of Interior – Bureau of Reclamation; USEPA – United States Environmental Protection Agency; USGS – United States Geological Survey; TCEQ – Texas Commission on Environmental Quality			

Figure 3. Identification of relevant stakeholders for each functional level.

Residential consumers pose challenges for inclusion in group meetings of stakeholders, such as described above. There are hundreds of thousands of them in the region, with great geographic and social complexity, and their consumption patterns and decisions are mediated by utilities, who did participate in meetings described above. Public participatory meetings on water tend to attract activists, who are not very representative of the general population. To circumvent these challenges, we decided to use in-depth qualitative interviewing of a subset of individual consumers. We used an opportunity sample of 85 interviews of adult household decision makers in El Paso and Ciudad Juárez to collect some information about attitudes about drought, future water shortages, and policy and technological approaches for addressing water challenges in the future.

3.5. Model Validation/Verification

During the time that we were hosting the introductory stakeholder meetings, our modeling team was building, choosing, calibrating, and/or validating models to be used in our participatory research project. We chose a suite of models to be used that included: (1) a coarse level model, built by our team, that is not spatially explicit, but includes inputs, changes, and outputs from the main surface and ground water sources [39]; (2) a hydroeconomic optimization model built by our team [40]; (3) a web-based user interface with the hydroeconomic optimization model built by our team to provide a tool that stakeholders could use to evaluate future scenarios of their choosing [41]; and (4) the Soil and Water Assessment Tool (SWAT) plus a coupled SWAT-Modular Finite Difference Flow Model (MODFLOW) that is spatially explicit, and could be used to evaluate questions on a finer spatial scale [42,43]. We followed the initial stakeholder meetings with a series of meetings to present these models and their capabilities to the stakeholders, in order to build their confidence and trust in the results obtained from these models, and to make the user interface available to stakeholders with which to experiment on their own. We focused the verification session on historical data, where we could compare modeled results with direct observations. The relatively good agreement between the modeled results and direct observations (data not shown) for parameters such as stream flow and groundwater levels instilled stakeholder confidence in our models. We also shared with the stakeholders at this meeting the results from the first discussions.

These initial steps laid the foundation for subsequent participatory modeling approaches to developing and evaluating future scenarios, analyzing the drivers of change with stakeholders, and identifying and testing interventions. This process is ongoing in our project at present, and thus, the results will have to be presented in the future.

4. Results

4.1. Stakeholder Engagement: Diverse Participation

We achieved a reasonable representation of the diversity of views of different stakeholders across a wide spectrum of users, managers, decision-makers, influencers, and even the disenfranchised with respect to water, including environmental and social justice groups. Environmental stakeholders are often included in participatory management or modeling activities, but social justice stakeholders are seldom if ever included. We had stakeholder participation from every major stakeholder type in the organizational framework shown in Figure 2. Of course, the largest water users were more numerous in participation. Agriculture is the biggest user of water in our area, accounting for about 75% of water used, followed by urban uses, accounting for about 20% of all water used. Agricultural and urban users accounted for about 54% of the stakeholder participation in our study. Government stakeholders represented the next largest group, accounting for 31% of participation. Environmental and social justice groups comprised the remainder (15%). Government stakeholders have larger numbers of participation, stemming from the fact that for most, participating in such projects is one of their job responsibilities, while farmers and others must take time out from their major responsibilities in order to participate.

With respect to agricultural stakeholder participation, the possible range of important crops and the sizes of farms were well represented in our sample. An interesting result related to the demographics of the farmer participants was the timeframe of interest for projections into the future. The older farmers, especially >70 years old, said that the timeframe of interest was “today”. One farmer, age 89, said “yesterday”. In contrast, most of the farmers less than 70 years old expressed an interest in horizons of 20–50 or even 100 years. Many of the older farmers with smaller farms were anticipating retirement and selling their land in the near future. Most of the pecan farmers, who have a considerable capital investment in trees that can be productive over a period of 100 years, were interested in longer time horizons, and in passing their farms on to children and/or grandchildren. These differences in timeframes of interest had big impacts on how they saw the future and the challenges of the future, especially related to changing climate and competing demands for water.

4.2. Framing Issues and Identifying Research Questions: Commonalities

A summary of commonalities among stakeholders across sectors regarding the future of water in our region and the important research questions are presented in Table 1. Four broad themes common to multiple sectors emerged: (1) quantity/drought/scarcity; (2) quality/salinization; (3) urbanization; and (4) conservation/sustainability. These are discussed in more detail in the following paragraphs, including paraphrases of some of the rationales and discussion by stakeholders.

The strongest commonality among stakeholders were the concerns about prolonged drought, including how to predict it, plan for it, and manage in it. There are several implications for research underlying this concern and several related research questions were posed by stakeholders. First, the question of climate in the future and how it might impact the flows in the river is a question of high interest. Many stakeholders, especially those from agriculture but others as well, preferred not to use the term “climate change”, but preferred to talk about “prolonged drought” instead. All agreed that prolonged drought will force greater reliance on groundwater. A related question is the uncertainty about how much groundwater is available today. Since the major aquifers are transboundary and span two U.S. states and into Mexico, there is considerable uncertainty in exactly how much water is stored in these aquifers and how fast they are being depleted. Related to this uncertainty are the processes of groundwater recharge and the interaction of surface water with groundwater. A major question was “What are the limits to groundwater pumping?” Agricultural and urban stakeholders all had an interest in future water supplies and sources, including how to augment water supplies through importation, desalination, water reuse, storm water collection, aquifer recharge, and improving the efficiency of water capture in reservoirs. Farmers especially tended to focus on alternative water supplies as the answer to prolonged drought, and always focused on importation or reducing the use of water by others upstream, especially cities, but also other farmers. Farmers also tended to favor solutions that involved cities using more expensive sources of water, such as desalinated brackish water, which they could “better afford”, in order to leave more freshwater for agriculture. Concerns for water quality and increasing levels of salinity in both surface and groundwater are shared by agricultural, urban, and environmental stakeholders. Salinity has been increasing in the surface waters of the Rio Grande for several decades, due to a combination of natural geologic inputs, municipal wastewater discharges, and irrigation return flows, and exacerbated by changing climate [44]. Increasing reliance on groundwater during periods of prolonged drought also result in recharge of groundwater with increasing levels of salinity leached from agricultural soils, resulting in increasing levels of salinity in groundwater, especially the shallow groundwater. Buildup of salinity in agricultural soils can impact production negatively, especially with more sensitive crops like pecans and alfalfa, which are the most profitable crops in our region. Projections of salinity buildup in soils and its impact on crop yields are a major concern to agricultural producers in the region. As a result, they have a major interest in crop varieties with greater salt tolerance or even alternative crops that might have more salt tolerance.

Table 1. Summary of commonalities in stakeholder responses across sectors.

Question	Most Common Responses from Multiple Sectors
1. Summarize in one word your biggest concern about the future of water in our region.	Quantity Quality Drought Urbanization Conservation Sustainability Scarcity
2. What questions would you like to ask about the future of water?	Impacts of climate change? What will it take to get more conservation? Future water supplies and sources? Binational management? Value of water? What are the limits to pumping groundwater?
3. What future scenarios would you like to explore/evaluate?	Augmented supplies Transboundary/binational management
4. What issues or processes are important for us to consider in our models?	Salinization Surface/groundwater interactions
5. To visualize or think about the future of water, what information (data, model predictions, output) would you want to know?	Better weather information Medium and long-term climate projections Prediction of drought Surface/groundwater interactions
6. What time horizon interests you?	Varied widely with no consensus, but generally in the range of 20–50 years
7. Other issues/concerns?	Lack of public understanding of water issues and: value of agriculture, value of technology, value of ecosystem services, social justice

Land use change, especially urbanization, was a concern of all stakeholders. The growing urban population in Las Cruces, NM, El Paso, TX, and Ciudad Juárez, CH has several consequences with respect to land and water use in the region. One is the conversion of agricultural land to urban land uses through the process of urban development. Agricultural stakeholders in particular see this land use conversion in a negative light, due to the loss of farming as a way of life, regardless of the implications for water use. However, all stakeholders also see the loss of agricultural land to development as a conversion of water uses from agricultural to urban. There is some uncertainty about the net impact of this conversion on water use in aggregate in the region. For example, “smart growth” development could lead to less impermeable surfaces, less runoff, and greater capture of water where it falls. Also, the agricultural sector believes that as cities grow, it is incumbent on them to develop alternative water sources or technologies, which cities are better able to afford, and that draw on sources that are not in competition with their own, such as desalination of brackish groundwater.

Though water conservation might be a plus with respect to sustainable water resources management for the region, incentives are lacking for the major water users (agriculture and urban utilities) to implement conservation. For agriculture, water rights (both surface and groundwater in NM; groundwater in CH; and surface water in TX) are predicated on the principle of “use it or lose it”. Though farmers see conservation as a management tool under drought, in general, there are no mechanisms for carrying over unused water rights to a specific farm and no incentives for using less water. Unused water stored in Elephant Butte Reservoir goes into a general pool of stored water to be re-allocated in a future year. For water utilities, water conservation by urban users leads to less income for the utility, but at the same time, has to be part of their strategy to meet growing water demands. Thus, an important question for both agricultural and urban users is “what is it going to take, what incentives or policy changes will be required, to encourage water conservation?”

Though sustainability was a common interest among different sectors of stakeholders, it is viewed in different ways, producing what [10] describe as “ambiguity” in trying to frame a common problem.

Agricultural stakeholders are interested in the sustainability of farming as a way of life, as key to national food security, and as an important driver in the economic health of the region. The urban water providers see sustainability as being able to meet the future water needs of the region without depleting resources to the point of limiting economic growth. Environmental groups see it as sustaining the important ecosystems of the region. The social justice stakeholders see it as achieving access to water for all and keeping water affordable, in spite of increasingly expensive sources and technologies required to meet demands. All of these views comprise sustainable water resources management overall, and contributes to the complexity of the challenges.

A key component of sustainable water resources management for the non-agricultural stakeholders was the desire to consider binational water management in the long-term. This was most keenly expressed by the urban and government stakeholders, but also environmental stakeholders. Agricultural stakeholders in the U.S. have much more local autonomous control, compared to Mexico, and do not see any advantage for binational cooperation. Agricultural stakeholders in Mexico were much more interested in binational coordination, because their local interests are much less protected compared to the U.S.

4.3. Framing Issues and Identifying Research Questions: Divergent Views

The key stakeholder responses for different sectors are summarized in Table 2. Some key differences in stakeholder views by sector are elaborated and summarized in the following paragraphs.

Agricultural stakeholders expressed distinctive views regarding: (1) the value of water, (2) the strong desire for predictability, and (3) the sense of threat from competing demands and users. They expressed an interest in quantifying what they termed the “true value of water”, meaning the value of water in terms of agriculture’s contribution to the local economy and food security. The local economy includes the entire food chain, like value-added activities, plus the value of agriculture, as a business or industry, to the local economy. There is a strong sense among farmers that irrigated agriculture contributes substantially to the local economy and to national food security. “We feed the world”, was a common mantra repeated by agricultural stakeholders. In this regard, they feel under-appreciated by the general public.

Another unique research need expressed by the agricultural stakeholders is the desire for predictability. Farmers have strong management skills that, in many cases, have been shaped and honed over several generations of farming in this region. In this regard, farmers demonstrate a high degree of resilience. They believe that they can manage adequately through almost any situation if they know about it in advance. Uncertainty is one of their greatest “enemies”. Their chief concern is that they want to know how much water they can rely upon.

The urban/industrial stakeholders’ concerns were dominated by concerns for population growth, how future demands for water will be met, and at what cost. Among individual consumers, we found a universal concern about drought and future water shortages, but also lack of clarity about the policy and technological options put forward by utilities; and wide variation in actions at the household level to conserve water. Among utilities, there was concern for better education of the public so that they understand the challenges of meeting water demands and the costs of new technologies or long distance importation of water. Their belief is that understanding will generate support for the implementation of expensive technologies and rising costs of water. They were most interested in how the price of water will impact the behavior of consumers. Urban stakeholders are also more interested in binational cooperation and trying to achieve some form of binational management of not only water, but also of growth and development, and shared technologies, such as water reuse. They were the most willing to consider new or alternative policies, especially water conserving policies.

Table 2. Divergent stakeholder views by sector.

Short Question	Agriculture	Urban	Government	Environment	Social Justice
#1 - Word	Quantity Quality Drought Urbanization	Knowledge Education Understanding	Climate change	Climate change Ecosystems Habitat Wetlands	Access Supply
#2 - Questions about the future of water?	Urbanization Drought & its effect on groundwater Quality Limits of pumping Augmenting supply: importation, desalination, stormwater capture How to manage under scarcity	New policy approaches What is it going to take to conserve? Cost/behavior relationship Binational water management?	What do we have now? Optimal allocation of water Value of water/water footprint	Sources What will ensure consideration of environment? Value of water	Water quality Groundwater decline Future supplies Fracking impacts
#3- Future scenarios you would like to evaluate	Urbanization Alternative crops Value of water and economic impact on food/value chain Augmenting supply: desalination, importation, etc.	Prolonged drought Climate change Binational water treatment and expanded water reuse Binational economic impacts	Model droughts beyond the drought of record Management under scarcity Demand projections Limits to pecan production Strategies for no/limited water	How to connect water to ecotourism Define what is needed for environmental services	The limits to “digging deeper” Cost – how high? Uncontrolled growth
#4 - Issues or processes to be considered	Salinization Regional weather/climate	What is the sustainable water withdrawal rate?	What do we know already? Changes in water quality Value of ecotourism	Climate change Urbanization Benefits of natural systems Natural flows	
#5- To visualize future, what info do you need?	Management above Elephant Butte What are the supply limits Adaptability of crops to salinity Better assessment of groundwater Water demand by cities Recharge	What are the consequences of no action/no change Sustainable groundwater withdrawal rate	Impact of surface water on groundwater	No pecans scenario Impacts of urbanization	Current situation? Baseline Contaminants in groundwater Public health
#6 – Time horizon of interest?	Older farmers – now MX farmers – 5/15 All others 20/50/100	5/10/20/50	5/20/50	Short-term and 100 yrs	5/30/50

The government stakeholders were comprised of representatives from federal, state, and local government agencies. They were the only stakeholder group interested in evaluating the optimum allocation/re-allocation of water. They were interested in the value of water but from a different viewpoint from the agricultural and environmental stakeholders. They were interested in quantifying the “water footprint” for different activities in our economy. They were more willing than other groups to talk about “climate change” as a global process and to focus on the limits of groundwater use.

Environmental flows or allocations of water to environmental uses receive almost no consideration in the Middle Rio Grande basin. Environmental stakeholders posed a simple and direct question: “What will it take to get consideration of the environment in allocation of water?” Environmental stakeholders are particularly interested in the value of water for ecosystem services and the value of ecotourism if more water were allocated to environmental uses. They have questions about the impacts of both increasing urbanization and increasing production of high water use crops. Finally, environmental stakeholders are interested in the value of natural systems, i.e., riparian wetlands, for the beneficial treatment of water.

The greatest concern of the social justice stakeholders is access to water, or more correctly lack of access to water, especially good quality water. Many small rural communities, especially *colonias*, along the U.S./Mexico border, lack access to potable water. Many small rural communities lack the technical skills and capacity to manage small community water supplies, or to address water supply and water quality issues in small water systems. Another concern is the fact that groundwater levels in the region are falling. For rural residents with domestic wells, this represents a threat to water access if the water table falls below the water intake point of their wells.

5. Discussion

5.1. Sources of Tension and Conflict

5.1.1. Agriculture–Urban

Agricultural (ag) stakeholders consistently named urbanization as a problem, as a threat, and as a potential solution to their water scarcity. In discussions with ag stakeholders, the tension stems from a number of factors, including: (1) urbanization threatens the rural way of life by taking farmland out of production; (2) uncontrolled urban growth demands more and more water and results in designated uses for water transitioning from agriculture to urban; farmers generally want all the water managed by the irrigation districts to remain with agriculture; (3) ag stakeholders feel a direct threat as urbanization happens, and fear that cities will “take” their water rights; this is especially true in Mexico where the federal government does have the authority to take ag water rights and reassign them to the city; and (4) agricultural stakeholders think that large utilities could afford to rely on more desalination and thus use brackish water while saving more freshwater for their use. Urban stakeholders, especially water utilities, think that farmers are wasteful, could do more to use water efficiently, and could grow less water consumptive crops.

5.1.2. Environment–Agriculture–Urban

Environmental stakeholders have strong negative feelings about their inability to obtain water rights for environmental flows, and feel that it is the much larger water right holders, including ag and utilities, who keep them “locked out” of the market for water rights. These feelings come with a perception that farmers and utilities have disdain for environmental protection. Environmental stakeholders also blame agriculture and utilities for “polluting” streams and the groundwater with pesticides, fertilizers, and inadequately treated wastewater.

5.1.3. Social Justice–Agriculture–Urban

Small rural communities, especially *colonias* who lack access to water, feel that they have a right to water as a basic human right. They see that irrigators who are commonly large landowners with unfettered rights to pump water, especially in Texas, use as much water as they wish, depleting groundwater and lowering water tables, making it much more difficult for small rural communities to access affordable water through domestic wells.

These tensions and sources of conflict contribute to the wickedness of achieving sustainable water resources management in the Middle Rio Grande as discussed below.

5.2. *The Wicked Problem of Sustainable Water Resources Management in the Middle Rio Grande*

Using the perspectives of the wide range of stakeholders who participated in our meetings, we can characterize the wickedness of the challenges to sustainable water resources management in the Middle Rio Grande.

5.2.1. The Spiral of Climate Change, Prolonged Drought, Groundwater Depletion, and Salinization

Although the Rio Grande historically provided most of the irrigation water to support agriculture, annual releases from Elephant Butte Reservoir have been declining on the average over the past 20 years, due to less storage. The reduced storage is a result of warmer temperatures in the headwaters and reduced snowpack. Reduced surface water supplies have forced water users to rely more on groundwater, with the result of falling groundwater levels and, in many cases, use of more saline water for agriculture. The use of more saline water portends salinity buildup in agricultural soils, and possibly recharge of more saline water than what was withdrawn. The net result is dwindling water supplies of lesser quality, and more frequent periods of drought of longer duration. Predicting, planning, and managing for prolonged drought was the #1 concern of most stakeholders, both agricultural and urban. With warming trends projected to continue, identifying and quantifying the impact of future climate scenarios, including the depletion of groundwater reserves, is a prerequisite to planning and managing for prolonged drought. However, the agricultural stakeholders' answer to water scarcity from the river is pump more groundwater, and the answer to dropping water tables is to dig deeper wells. **This is a wicked problem because it is the object of multiple and conflicting criteria for defining solutions.**

5.2.2. Agricultural Intensification, Urbanization, and Conjunctive Management

While supplies are dwindling, demands for water are rising due to a number of factors, including warmer temperatures, expanding acreage of high consumption perennial crops (like pecan trees and alfalfa), urbanization, and increasing demands for environmental flows and other environmental-related uses of water. There is a significant acreage of perennial crops (and increasing) that afford very limited flexibility in fallowing or reducing water use in dry years. For example, pecan trees have to receive at least enough water to keep them alive every year; fallowing pecan tree orchards is not an option in extreme drought years. Keener competition for surface water is leading to greater extraction of groundwater. Long-term withdrawal of groundwater exceeds recharge, resulting in both alluvial and deeper groundwater decline, and deterioration of water quality from return flows of more saline water to the alluvial aquifer and brackish groundwater intrusion in the deeper aquifer. Although components of this system have been modeled, the connection of the surface and groundwater is poorly understood, and currently available models rarely broach holistic management strategies. Stakeholders are concerned about the limits of groundwater pumping and a better understanding of the interaction of surface and groundwater. In spite of these concerns, both agricultural and urban stakeholders' answer to increasing demand, in general, is to augment supplies through technology, management, or even importation, in spite of its high cost. However, the problem can also be defined by the need to reduce use, which is how many environmental and social justice stakeholders define the problem.

This is a wicked problem, because the problem has multiple definitions with no agreement on how it is defined or how it can be addressed.

5.2.3. The Complexity and Obsolescence of the Water Governance Framework

The water governance framework for this binational and multi-state region, which draws on common surface (the Rio Grande) and groundwater resources (Mesilla and Hueco Bolson aquifers), was developed over 100 years ago and is ill-equipped to address the dwindling supplies and growing demands described above. In particular, an agreement reached in 1905 with the U.S. Bureau of Reclamation gave all the water in Elephant Butte Reservoir to the Elephant Butte Irrigation District and the El Paso County Water Improvement District #1, leaving out any possibility for urban or environmental uses. A set of interstate compacts and international treaties governs allocations of surface water among the two nations and the two U.S. states, and these have not changed significantly over the past 75 years, although water use within each state and nation has drastically changed. Within each U.S. state, surface water is allocated according to the doctrine of prior appropriation, and in Mexico by the national government. Unlike surface water, there is no transboundary governance of groundwater. Mexico has centralized basin scale governance (but weakly implemented), Texas has “right of capture”, and New Mexico has centrally licensed (by the state) prior appropriation. Regulatory governance of surface and groundwater was established prior to the development of a hydrologic understanding of the connectivity between surface and groundwater, creating severe regulatory problems, as exemplified by numerous ongoing legal challenges and lawsuits currently within New Mexico and between Texas and New Mexico. Due to the fragmented and uneven jurisdictional boundaries, diverse sectoral uses, and weakly acknowledged surface/subsurface interaction, interested parties tend to conceptualize the water system in divided, non-integrated ways, and relatedly place blame on some other part of the system (other users or jurisdictional areas). **This is a wicked problem because the solution to one interested party is a problem for others.**

5.2.4. Land Ownership, Water rights, and Threats

An important concept emerged from the stakeholder meetings that was unique to the agricultural stakeholders: a readily apparent feeling of ownership of water rights as part of land ownership, coupled with the concomitant sense of threat to those water rights emanating from the current situation of dwindling supplies and competing demands. Farmers, more so in the U.S. than Mexico, feel a strong sense of ownership, stemming from at least three and as many as six generations of family members who: (1) descended from individuals who homesteaded land in Texas and New Mexico, (2) have lived on and farmed the same land, (3) were the beneficiaries of surface water allocated to them after the construction of Elephant Butte Reservoir, and (4) have played a significant role in the development of the region. At the same time, a common and very strong sentiment expressed was the sense of threat to agricultural water rights. The sources of these perceived threats are multiple and can be generally categorized into: (1) threats from changing climate, especially prolonged drought, that results in diminished supplies, (2) threats from competing demands by other users, and (3) threats from managers, regulators, and other decision-makers, represented mostly by state and federal government agencies. Commonly identified competing users include: (1) upstream users in general; (2) cities, especially Albuquerque and Las Cruces, NM, El Paso, TX, and Ciudad Juárez, CH; (3) environmental interests; (4) industrial interests, especially the oil and gas industry who recover oil and gas by fracking; and (5) urban/suburban residents who do not recognize the value of agriculture and its contribution to the food system. Many agricultural stakeholders told us “We are afraid _____ is going to take our water.” The blank can be filled in by a number of entities seen as threats, such as any of those named above plus any of several government agencies such as the U.S. Bureau of Reclamation (who manages the reservoirs), the State Engineer of NM, the “state”, and/or just “the government”. Besides direct threats to water rights, there are perceived threats to agriculture in general, including: (1) urbanization; (2) imported agricultural products, especially from Mexico, that compete with local production; and (3)

the loss of agriculture as a “rural lifestyle”. All of these factors converge to put farmers “on guard” against multiple threats and risks to not only their water use, but to their very way of life. **This is a wicked problem because the solution to one party is a problem for others.**

In summary, the region faces pressing wicked challenges stemming from: (1) changing climate and prolonged drought; (2) growing and competing demands, due to the production of high use perennial crops, growing population and urbanization, and the growing political voice of environmental advocates; (3) an outdated, complicated, multijurisdictional governance system that is ill-equipped to address the pressing challenges; and (4) strong feelings of tension and conflict, stemming from threats to water rights from other users and the proclivity to make “the other” responsible for actions to reduce use or conserve water. The Middle Rio Grande is not unique with respect to these wicked challenges among global desert river systems, which account for most of the world’s long-term groundwater declines [45,46]. Addressing the wicked problems and their associated transboundary conflicts require integrative thinking, considering surface and subsurface water jointly (conjunctive use), using dynamic scenarios of climate change and human water use, and utilizing basin scale integrated management. Furthermore, time is running out, due to groundwater depletion, to come up with a solution; there is lack of institutional authority to make decisions on how to proceed; and the same people who are trying to solve the problem are creating it, a common scenario in river basins facing wicked problems [4,47].

5.3. Stakeholder Engagement: Lessons Learned Regarding Best Practices and Pitfalls

Best practices for stakeholder engagement are well-known, especially in the context of water resources management and planning, and have been summarized by a number of authors [16,24,48]. We emphasize a few of these here as they relate, in general, to participatory research and, in particular, to our project.

- Relevant stakeholders need to be analyzed and represented systematically.
- Participation should be considered as early as possible and throughout the process.
- Clear objectives for stakeholder participation need to be established from the beginning, and the process should be transparent to all participants.
- At least some, if not all, modeling tools should be accessible and useable by all.
- Scientists should approach the project with humility.
- Stakeholders should be valued for their contributions.

From our experience, we add to this list the following that are not as well recognized in the literature.

5.3.1. Be Respectful of Stakeholders’ Views, Time, and Confidence/Trust

If you achieve wide participation, there is going to be a wide range of world views. Not everyone will accept “climate change” for example. Try to avoid judgments on the personal viewpoints of participants. A range of world views will likely be represented if stakeholder participation is very inclusive. This range of world views has to be respected. Avoid discussions of political views. Also it is not realistic to expect farmers or other businessmen or many private citizens to spend a whole day in a stakeholder meeting. Shorter meetings with small goals are more appropriate, and will be appreciated by the stakeholders.

5.3.2. Be Clear about Expectations

Being clear and realistic about expectations for the kinds of research results that are anticipated will build trust. Do not promise more than you can deliver. This will lead to frustration and a sense of wasted time on the part of the stakeholders.

5.3.3. Identify What Stakeholders Want to Get Out of It and Try to Deliver

In the case of research, there is usually some information that the stakeholders want; try to meet their expectations, even if what they want does not meet the standard of “publishable results”.

6. Conclusions

We found that our iterative, participatory approach with many relatively short meetings, was preferred by stakeholders as opposed to longer (full day) workshops. We propose this as the most reasonable approach to unraveling the wicked problems that we face, and attempting to address them with acceptable, implementable, and manageable solutions. Using what we learned from stakeholders in this foundational work, we have moved forward with an innovative participatory modeling approach to engage stakeholders in analyzing the drivers of change, developing and evaluating scenarios, and synthesizing meaningful outcomes from modeling results, work that continues to the present. By engaging directly in the research, we anticipated that stakeholders would become more effective agents of change [49]. With about one year remaining on our active project, this has not yet been borne out, though we still anticipate positive outcomes. Similar to Martinez-Santos et al. [50] and Beall et al. [51], we have used participatory approaches that include combinations of our team members and stakeholders to develop plausible scenarios, identify and test interventions, and will be attempting to arrive at acceptable and implementable solutions before the project ends.

Quoting Langsdale et al. [48], “Collaborative modeling changes the paradigm from ‘experts know best’ to ‘everyone knows a piece of the whole puzzle’, and decisions are value-laden, so everyone needs to participate to find the best solutions.” The goal is to ensure inclusive, quality participation, that “when conducted well ... increases knowledge about the system and leads to ... effectively balancing multiple interests” [48]. In describing his Farmer-Back-to-Farmer model, Rhoades said that “scientists know how plants grow, but farmers know how to grow plants ... both bodies of knowledge have value and are necessary” (1992, personal communication). Similarly, in our case, scientists have a reasonable scientific understanding of the processes influencing water supply and demand, but stakeholders actually contribute to and determine, in various and complex ways, its management and use. An important difference in values between scientists and farmers is the focus of farmers on profitability in the short-term and sustained livelihoods in the long-term, and the focus of scientists on credible, salient, and legitimate models in the short-term [52] and the quantity and quality of water resources in the long-term (as projected by their models). There is overlap in the long-term but not in the short-term, making short-term changes in behavior by either, a part of the wicked problem.

Brugnach and Ingram [10] also discuss the importance of different types of knowledge and the need to integrate them into what they call “knowledge co-production”. They offer a revised knowledge production process to better cope with ambiguity, one that is built on enlarging individual knowledge through social interactions. Their hypothesis is that in such a collaborative partnership, individual frames, objectives, and perspectives can be integrated to produce an agreement about what the problem is, the approaches to be used, and the desired outcomes. Their ideas about ambiguity were validated in part with actual stakeholders from a watershed in southern Italy [53], but their model has not been fully operationalized nor tested in a practical way in a collective decision-making process. For certain, such testing would depend on a process of identifying and engaging all sources of knowledge, all stakeholders, as a starting point, as we have done here.

While our participatory framework cannot eliminate or overcome the structural problems and jurisdictional conflicts that prevail currently, it can provide a channel for improved understanding, visioning “water resources futures,” and identifying and discussing solutions, perhaps resulting in the emergence of compromise and consensus on improved management. Thus, we conclude that participatory modeling holds great promise but an unproven “way forward” to realizing a sustainable water future in the region.

This region exemplifies an important category of wicked water sustainability challenges worldwide: it is an arid/semi-arid river basin relying on conjunctive use of surface water and regional groundwater

in order to sustain irrigated agriculture and urban growth. Significant areas of the western U.S. fall into this category, as do other intensively used desert river basins around the world, such as the Nile, Jordan, Tigris, Euphrates, and many more. Though it remains to be proven if such an approach will address the wickedness of water challenges exemplified by our region, the Middle Rio Grande basin is a compelling research site to explore solutions for long-term water sustainability for agriculture in relationship to urban and environmental uses. Our comprehensive approach to stakeholder engagement, we believe, is prerequisite to the search for workable solutions to wicked problems. Future research should focus on identifying and testing those workable solutions.

Author Contributions: All authors have read and agree to the published version of the manuscript. Conceptualization, W.L.H. and J.M.H.; Methodology, J.M.H.; Project administration, W.L.H.; Writing—original draft, W.L.H.; Writing—review and editing, J.M.H.

Funding: This work funded in part by the National Institute of Food and Agriculture, U.S. Department of Agriculture, grant number 2015-68007-23130.

Conflicts of Interest: The authors declare no conflict of interest.

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