

Quenching Our Thirst for Future Knowledge: Participatory Scenario Construction and
Sustainable Water Governance in a Desert City

by

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ABSTRACT

Transformational sustainability science demands that stakeholders and researchers consider the needs and values of future generations in pursuit of solutions to sustainability problems. This dissertation research focuses on the real-world problem of unsustainable water governance in the Phoenix region of Central Arizona. A sustainability transition in the local water system is necessary to overcome sustainability challenges and scenarios can be used to explore plausible and desirable futures to inform a transition, but this requires some methodological refinements. This dissertation refines scenario methodology to generate water governance scenarios for metropolitan Phoenix that: (i) feature enhanced stakeholder participation; (ii) incorporate normative values and preferences; (iii) focus on governance actors and their activities; and (iv) meet an expanded set of quality criteria.

The first study in the dissertation analyzes and evaluates participatory climate change scenarios to provide recommendations for the construction and use of scenarios that advance climate adaptation and mitigation efforts. The second study proposes and tests a set of plausibility indications to substantiate or evaluate claims that scenarios and future projections could become reality, helping to establish the legitimacy of radically different or transformative scenarios among an extended peer community. The case study of water governance begins with the third study, which includes a current state analysis and sustainability appraisal of the Phoenix-area water system. This is followed by a fourth study which surveys Phoenix-area water decision-makers to better understand water-related preferences for use in scenario construction. The fifth and final study applies a multi-method approach to construct future scenarios of water governance in

metropolitan Phoenix in 2030 using stakeholder preferences, among other normative frames, and testing systemic impacts with WaterSim, a dynamic simulation model of water in the region.

The scenarios are boundary objects around which stakeholders can weigh tradeoffs, set priorities and reflect on impacts of water-related activities, broadening policy dialogues around water governance in central Arizona. Together the five studies advance transformational sustainability research by refining methods to engage stakeholders in crafting futures that define how individuals and institutions should operate in transformed and sustainable systems.

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CHAPTER 1

Introduction

1. Background

If, as the saying goes, we do not inherit the earth from our ancestors but borrow it from our children, how do we ensure the earth we return to them is not damaged? Even further, how do we pass down a world that is just, equitable and safe, for all future generations? This is the central challenge of sustainability, and since its introduction to the world stage with the 1987 Brundtland Report, sustainability has evolved and spread to different knowledge communities (WCED 1987; Redclift 2005). As part of the growing movement, sustainability science emerged in the late 1990's to galvanize the scientific enterprise in service of sustainability goals (Lele & Norgaard 1996; Holling et al. 1998; Clark et al. 2001; Kates et al. 2001; Clark & Dickson 2003; Wiek et al. 2012). Despite the enthusiastic adoption of sustainability in scientific and international development spheres, the urgent problems facing humans and ecosystems are under-addressed. Critical planetary life support systems – like freshwater, biodiversity, and soil nutrients – are reaching, and in some cases surpassing, critical thresholds beyond which recovery may be impossible (Rockström et al. 2009). In the case of freshwater, particular types of knowledge are needed to inform transitions in urban water systems, which face the compounding threats of population growth, urbanization, and climate change. Such urgent problems demand that sustainability science generate solution-oriented knowledge (Clark and Dickson, 2003; van Kerkhoff and Lebel 2006; Wiek et al., 2012; Miller et al., in press), while explicating the values that define problems and solutions. To do so

requires a scientific enterprise that is guided by morals and aims for transformation (Bäckstrand 2003; Crow, 2012; Miller 2013).

Science in the 21st century, given the scale and complexity of problems facing humanity, needs to be leveraged in service of real-world problem solving, not simply knowledge generation. This dissertation research emerged from and is situated within the real-world problem of unsustainable water governance in Phoenix, Arizona. The guiding research questions are:

- (1) How can anticipatory and normative knowledge be generated (and combined) to inform sustainability transitions and how can this be applied to the Phoenix-metropolitan water system?
- (2) What are different, plausible, and desirable water governance regimes for the Phoenix region, what are their impacts, how can they inform governance that contributes to a sustainability transition in the local water system and what are the implications for other systems and other regions?

Located in the Sonoran Desert, the Phoenix metropolitan area provides a good case study for generating anticipatory and normative knowledge that can inform a sustainability transition. The region faces a number of water-related challenges and many have called for fundamental changes to the water system to achieve comprehensive sustainability (Larson et al. 2009; Gleick 2010, Larson et al. 2013).

In response to this real-world problem, research methods were selected, combined and adapted to ultimately explore different water governance regimes to inform sustainability transition activities; based on and complementary to frameworks developed to support sustainable water governance efforts (Wiek and Larson, 2012). The selected

methods are integrative, systemic, and participatory, in the vein of post-normal science and mode-2 knowledge production. In line with a transformational conception of sustainability science (Wiek et al., 2012; Wiek et al., 2014), this dissertation has the explicit goal of generating scientific results that are credible, legitimate, and salient to an extended peer community, and relevant for decision-making (Futowicz and Ravetz 1993; Ravetz 2004, 2006).

2. Research Gap

“It is always wise to look ahead but difficult to look farther than you can see” (Winston Churchill, February 18, 1945) summarizes well a fundamental dilemma in sustainability science and in this dissertation. Efforts aimed at informing and designing a sustainable future must do so without full knowledge of what the future will look like or what future generations will want or need. To cope with “the problem of the future” researchers employ a range of anticipatory methods from the highly technical and dynamic to the qualitative and literary, which span the ladder of participation from the expert-driven to the citizen-empowering (Arnstein 1969; Swart et al. 2004; Bishop et al. 2005; Withycombe 2010; Wiek et al., 2014). Across this spectrum, managing and reducing uncertainty to inform decision-making is a priority (Morita et al. 2000; Swart et al 2004). However, designing and implementing a sustainability transition, while aided by reduced uncertainty, requires constructing a research agenda that can co-generate anticipatory and normative knowledge with stakeholders in order to *guide decision-making* toward a *collaboratively-defined, sustainable future* (Sarewitz 2004; Robinson et al. 2011; Wiek and Iwaniec, 2013). This dissertation research aims to construct such a research agenda to inform sustainable water governance in the Phoenix-region, but also

to provide a refined participatory scenario methodology for use in other cities and in other systems (i.e. food, transportation, energy).

Scenarios are a common form of anticipatory knowledge in sustainability science and are generally conceived as stories about the future told in narratives, pictures, visualizations, systems diagrams, and numbers, among others. Among the most prominent sustainability-related scenarios are those of the International Panel on Climate Change (IPCC), which depict changes to the global climate under different emissions and more recently representative concentration pathways (Nakicenovic 2000; Moss et al. 2010). However, within the sustainability field there are also scenarios of food (Kendall and Pimentel 1994; Kitchell et al. 2000; Rosegrant et al. 2002), energy (Goldemberg et al. 1987; Hopkins 2008; Kowalski et al. 2009) and water (Raskin et al. 1996; Xu et al. 2002; Gallopin and Rijsberman 2000; Lienert and Truffer 2006), to name a few. Despite the ubiquity of scenario construction activities, many of the problems they purport to mitigate persist unabated. Common deficits in scenario methods and outcomes inhibit their efficacy in problem-solving efforts. These deficits include methods which:

- (1) Fail to embed scenario construction within a broader set of problem-solving activities (Wiek et al. 2014);
- (2) Do not sufficiently take into account the function of scenarios (e.g. in transition or policy-making processes) as part of the research design (Wiek et al. 2006) ;
- (3) Limit participation from stakeholders who will use scenarios, making the results less salient and relevant outside academia (Loibl and Walz, 2010);

and scenario outcomes, which:

- (4) construct plausible futures (as opposed to probable futures) without providing evaluative criteria for plausibility or considering to whom they are plausible (Wiek et al., 2013);
- (5) are too narrowly focused and therefore ignore and marginalize critical uncertainties that could have dramatic consequences (Van Notten et al. 2005);
- (6) are not sufficiently normative and ignore important facets of human behavior like values, preferences and norms (Swart et al. 2004; Wiek and Iwaniec, 2013);
- (7) are too dynamic and complex – despite more accurately reflecting the natural world (this is disputed) – stakeholders who are supposed to use them cannot understand how they work and therefore do not trust them (Sarewitz 2004);
- (8) present too many scenarios making it difficult for stakeholders to attach significance to any one scenario, rendering the scenarios less instructive for decision making (Girod et al. 2009).

This dissertation aims to address these deficits by: (i) providing recommendations and evidence for participatory scenario construction; (ii) defining common indications of plausibility to construct and evaluate scenarios (iii) creating governance scenarios, as part of a larger transition-oriented research agenda, that reflect different water governance regimes, closely linked to decision-makers and decisions that can affect change in the Phoenix-region, and which provide insights for other systems and regions.

The refined scenario methodology is put into practice through a case study constructing plausible futures of water governance for the Phoenix region considered desirable under different normative frames. There have been many other scenario studies

in Phoenix and water experts have used scenarios to test policy options and anticipate changes to water quantity and quality, for example, but the tool has been underutilized with regard to water governance (Alcamo et al. 1997; Varela-Ortega et al. 1998; Vorosmarty et al. 2000; Liniert et al. 2006; Liu et al. 2008; Mahmoud et al. 2009; Gober et al. 2011). Re-conceptualizing water governance is critical, as facilitating a sustainability transition will require new approaches to water governance (Gober et al. 2010, Quay 2010; Wiek and Larson, 2012). Traditional governance regimes, which are expert-driven, involve complex bureaucracies, and depend on technocratic solutions to water challenges are criticized as ill-equipped to prepare for and respond to a range of climate change impacts (Glieck 2003, Pahl-Wostl 2007, 2009). They often suffer from path dependence and lack the proper institutional incentives to consider or implement transformational change (Dietz et al. 2003; Lienert et al. 2006; Pahl-Wostl 2007).

This dissertation research builds on Wiek and Larson's (2012) framework for sustainable water governance, which is: (i) systemic, accounting for the full complexity of water systems, challenges, and strategies (Lach et al. 2005; Reed and Kasprzyk 2009); (ii) actor-oriented, focused on who does what with water and how such activities and relationships contribute to water system problems and solutions (Lubell et al. 2008; Braden et al. 2009); (iii) transparent and value-laden, explicating values of local stakeholders and negotiating value conflicts (Ostrom 2009); and (iv) committed to comprehensive sustainability, in which a full suite of sustainability principles (e.g. Gibson 2005; Larson et al. 2013) are taken into account (Kallis et al. 2006; Pahl-Wostl 2009; Huitema et al. 2009; Wiek and Larson 2012; White et al. in press). The refined scenario approach allows researchers and stakeholders to explore and evaluate the

impacts of different governance regimes, as well as redefine individual and institutional roles and responsibilities in a sustainability transition or sustainable water system (Pahl-Wostl 2009; Huitema et al. 2009; Wiek and Larson 2012; White et al. submitted).

3. Research Design and Methods

To inform sustainable water governance in the Phoenix metropolitan area and contribute to refining anticipatory and normative methods in sustainability science this dissertation research is divided into two parts: a methodological refining of participatory scenario construction (Chapters 2-3) and an application of these refinements through a case study (Chapters 4-6). Several frameworks have been proposed that guide the selection, combination, and adaptation of methods to generate solution-oriented knowledge (Wiek and Lang 2012). This dissertation research follows the Sustainability Research and Problem Solving Framework (Wiek and Lang 2012) and includes three types of research methods that each generates distinct knowledge types critical for informing a sustainability transition generally and in the Phoenix-area water system in particular:

- 1) *Descriptive-analytical methods* including current state analysis (Chapter 4) and system analysis (Chapter 6) to generate knowledge about the current state and functioning of the water system in Central Arizona;
- 2) *Anticipatory methods* including participatory scenario construction to generate future-oriented knowledge about how current water system problems might evolve and how different governance regimes might impact the functioning of the water system, particularly under different climate scenarios (Chapter 2, 3, & 6);

3) *Normative methods* including sustainability appraisal (Chapter 4) and a stakeholder survey (Chapter 5) to appraise the sustainability of the current water system and future governance regimes and to incorporate stakeholder preferences into the construction of the scenarios, respectively (Chapter 6).

The combination of descriptive-analytical, anticipatory, and normative knowledge is essential for informing a sustainability transition for the water system in the Phoenix area and the methodological innovations described in this dissertation are an important contribution to the sustainability field. While the research lays an important foundation for future strategic and policy-related activities it does not generate instructional or strategic knowledge. Future research activities will build on this dissertation research to generate these knowledge types, particularly related to planning and managing a sustainability transition in the Phoenix-area water system. Figure 1 depicts the link between the Sustainability Research and Problem Solving framework and the five dissertation studies.

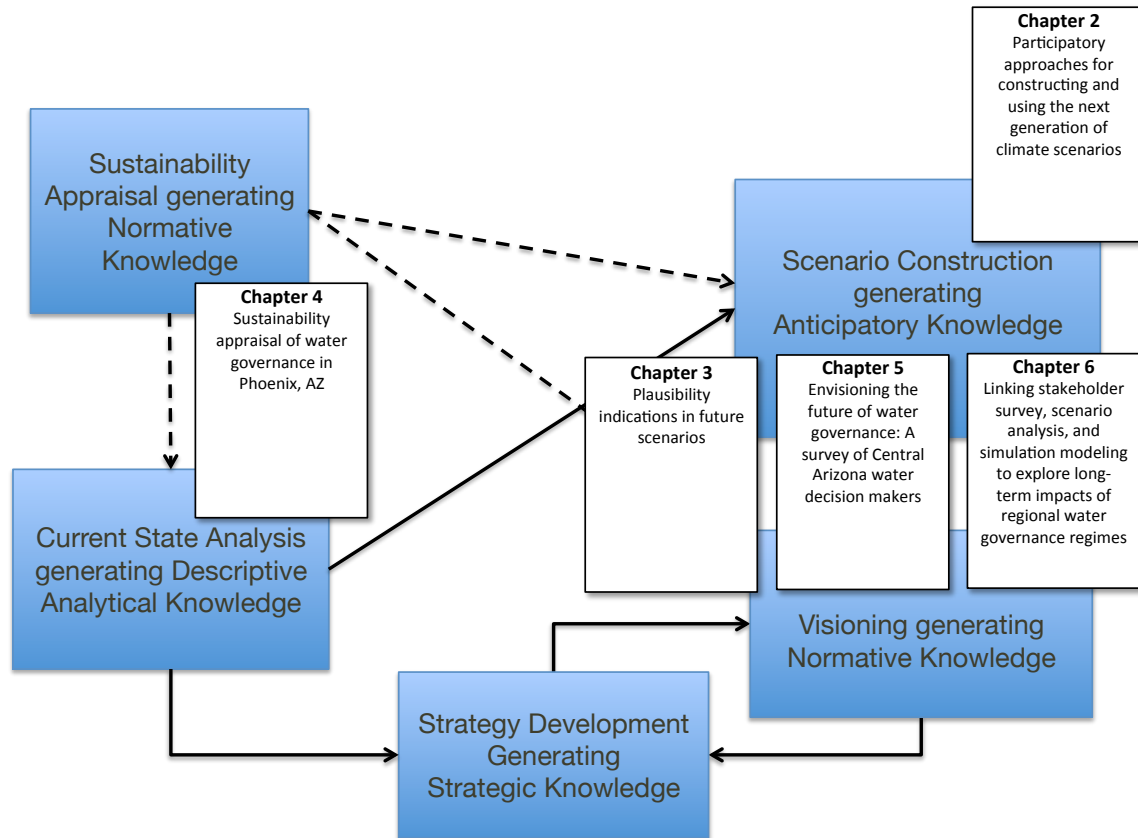


Figure 1. Five dissertation studies (Chapters 2-6) mapped onto the Sustainability Research and Problem Solving Framework (Wiek and Lang, in press).

Among the five studies, the first two refine scenario methodology by investigating participatory scenario construction and use (Chapter 2) and defining plausibility indications for use in scenario construction and evaluation activities (Chapter 3). The last three studies together constitute a case study of sustainable water governance in the Phoenix-metropolitan area beginning first with a current state analysis and sustainability appraisal of the Phoenix-area water system (Chapter 4), moving to stakeholder survey of value-based normative preferences about future water governance, and concluding with a scenario study generating future scenarios of water governance in the Phoenix-region in

2030 (Chapters 2-6). Figure 2 depicts the organizational structure for the dissertation, including key outputs from each study that act as inputs to other studies.

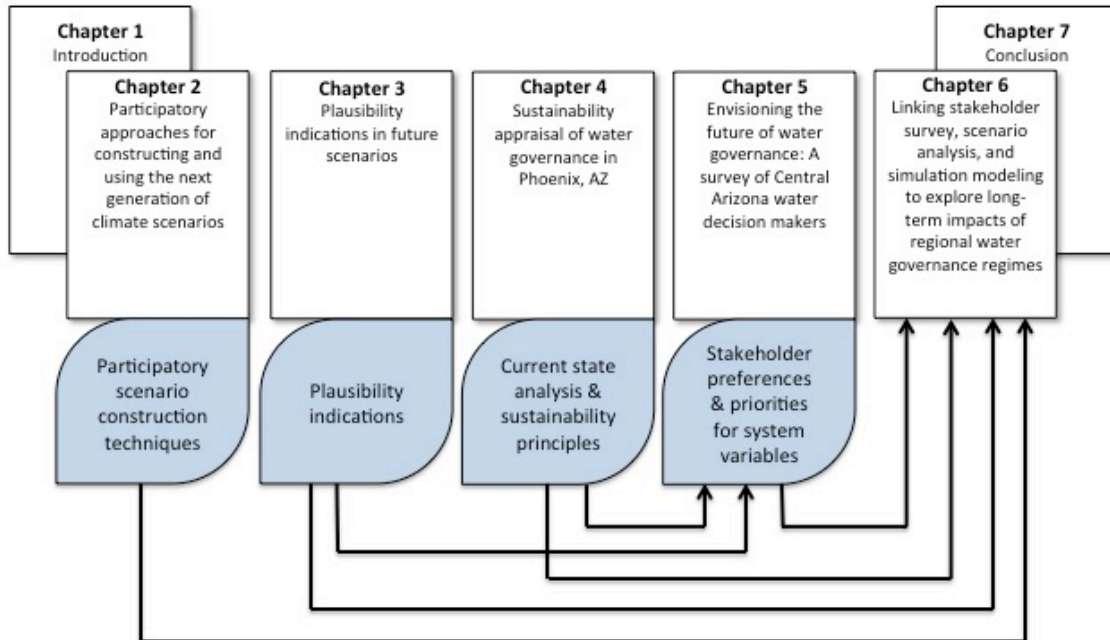


Figure 2. Dissertation structure including key products from each chapter and links to other chapters.

Study 1 (Chapter 2): Participatory approaches for constructing and using the next generation of climate scenarios

The dissertation research begins with Chapter 2, a literature review and evaluation of participatory approaches for constructing and using climate change and other scenarios to answer the question: How can climate scenarios be generated and used in participatory settings to increase the legitimacy, saliency, and relevancy of climate information? The research community is currently preparing the next generation of scenarios for climate change research and assessment, which will inform the Fifth Assessment Report of the IPCC. Previous IPCC assessment reports and their different usages were based on expert-

driven scenario processes. Over the last decade, numerous climate change scenario studies have employed participatory approaches and engaged a broad spectrum of stakeholders in the construction and use of climate change scenarios. Thus, it is both timely and necessary to explore the potential contributions of participatory scenario approaches to creating and using climate change scenarios. This study first proposes an analytical-evaluative framework that conceptualizes all critical components of participatory scenario studies through a synthesis of the pertinent literature. Based on this framework, six exemplary participatory climate change scenario studies are reviewed. Results include a qualitative summative evaluation, highlighting strengths and weaknesses of the reviewed scenario studies and approaches, and institutional recommendations to support participatory processes for constructing and using climate change scenarios. Insights from this first study are used to construct a scenario study in Chapters 4-6 to construct and explore water governance scenarios for the Phoenix region with stakeholders.

Study 2 (Chapter 3): Plausibility indications in future scenarios

Following the study of participatory scenario construction, Chapter 3 further refines scenario methodology by proposing and testing plausibility indications in future scenarios to answer the question: What is plausibility and how can it be applied pragmatically to construct and evaluate plausible future scenarios? Quality criteria for generating future-oriented knowledge and future scenarios are different from those developed for knowledge about past and current events. Such quality criteria can be defined relative to the intended function of the knowledge. Plausibility has emerged as a central quality criterion of scenarios that allows exploring the future with credibility and

saliency. But what exactly is plausibility vis-à-vis probability, consistency, and desirability? And how can plausibility be evaluated and constructed in scenarios? Sufficient plausibility, in this study, refers to scenarios that hold enough evidence to be considered ‘occurable’. Specifications for plausibility were derived from literature and workshops on future studies, plausibility, future-oriented knowledge, and scenario construction. Results include a set of plausibility indications for use in constructing and evaluating plausible future scenarios, illustrated with scenarios constructed for Phoenix, Arizona. Insights from this study are used in Chapters 5 to construct plausible, normative future statements for evaluation by stakeholders and in Chapter 6 to select plausible future scenarios of water governance. Elaborating the structure of plausibility in a pragmatic way supports scholars and practitioners of scenario construction.

Study 3 (Chapter 4): Sustainability appraisal of water governance in Phoenix, AZ

The case study begins with Chapter 4, a current state analysis and sustainability appraisal of the Phoenix-area water system. The sustainability appraisal of the current governance regime is presented based on an actor-oriented current state analysis to answer the question: who does what with water and why in the Phoenix-region, and how do these activities interact with hydro-ecological systems and man-made infrastructure, and how sustainable are these activities and interactions? Broadly applicable to other areas, the systems approach to sustainable water governance overcomes prevailing limitations to research and management by: employing a comprehensive and integrative perspective on water systems; highlighting the activities, intentions, and rules that govern various actors, along with the values and goals driving decisions; and, establishing a holistic set of principles for social-ecological system integrity and interconnectivity,

resource efficiency and maintenance, livelihood sufficiency and opportunity, civility and democratic governance, intra- and inter-generational equity, and finally, precaution and adaptive capacity. This study also contributes to reforming and innovating governance regimes by illuminating how these principles are being met, or not, in the study area. Results indicate that what is most needed in metropolitan Phoenix is enhanced attention to ecosystem functions and resource maintenance as well as social equity and public engagement in water governance. Insights from this study are used to construct future scenarios of water governance for Phoenix that will allow stakeholders to explore different governance regimes to address critical challenges.

Study 4 (Chapter 5): Envisioning the future of water governance: A survey of Central Arizona water decision makers

The case study continues with Chapter 5, in which a survey of local decision makers who impact water resources is conducted to determine value-based normative preferences about the future of water in the Phoenix region. Survey answers the question: What do central Arizona water decision makers envision as desirable for the water system in terms of supply, delivery, demand, outflow, and crosscutting activities? This reflects the water system as conceptualized in the current state analysis from the previous chapter. Principle components analysis is used to identify patterns underlying responses about preferences for each domain of the system and correlation analysis is used to evaluate associations between themes across the domains. The results reveal two distinct visions for water in central Arizona – one in which water experts and policy makers pursue supply augmentation to serve metropolitan development, and another in which broadened public engagement is used in conjunction with policy tools to reduce water

consumption, restore ecosystem services, and limit metropolitan expansion. The results of this survey inform the development of a set of normative scenarios in the next chapter for use in exploratory modeling and anticipatory governance activities.

Study 5 (Chapter 6): Linking stakeholder survey, scenario analysis, and simulation modeling to explore long-term impacts of regional water governance regimes

This final study brings together the previous four chapters to construct a small set of *normative signature* scenarios for water *governance* in Phoenix in 2030, – answering the question: What are different, plausible and desirable (under different normative frames) governance arrangements for water resources in the Phoenix region? A participatory, mixed-methods approach was used to construct these scenarios as distinctly different, coherent, plausible, and desirable. In particular, the water system analysis (from Chapter 4) and the stakeholder preference survey (from Chapter 5) are integrated into a qualitative scenario analysis to create water governance scenarios, which were then run through WaterSim, a dynamic water model of the Phoenix area, to test their performance under different climatic conditions. Results include four scenarios: *Technical Management for Megapolitan Development; Citizen Councils Pursue Comprehensive Water Sustainability; Experts Manage Limited Water for Unlimited Growth; and Collaborative Governance Makes Local Water Security a Priority*. The scenarios bring together the preceding four studies to help stakeholders explore different ways water could and should be governed and with what consequences to guide informed policy-making.

4. Value Proposition

This dissertation presents a novel approach to scenario construction focused on generating governance scenarios that can inform sustainability transitions. By answering the first overarching research question – How can anticipatory and normative knowledge be generated (and combined) to inform sustainability transitions generally, and in the particular case of the Phoenix-area water system? This research innovates classical scenario methodology and addresses the deficits in scenario construction outlined in the introduction. This research provides evidenced-based frameworks for constructing *plausible* future scenarios *with stakeholders* for use in participatory settings. The mixed-method approach to scenario construction provides researchers with a means to explicitly incorporate stakeholder values and preferences into dynamic modeling and generate results that are both comprehensive and comprehensible to broader audiences.

The case study incorporates insights from the first two studies to answer the second guiding research question – What are the impacts of different governance regimes on water system sustainability in the Phoenix region and how does this inform the design of water governance regimes that can facilitate sustainability transitions? Each chapter of the case study is explicitly structured with the goal of generating knowledge that will make water *governance* in the Phoenix region more *sustainable*. The scenarios themselves point to future challenges related to water availability and the necessity for both supply and demand based approaches if Arizona experiences the harshest of plausible climate impacts. There are ample measures that could be taken to increase water sustainability in Phoenix, which have varying degrees of plausibility and desirability to different stakeholder groups. To use these scenarios to their fullest intent and generate

strategic knowledge, further stakeholder engagement activities need to be constructed that can engage decision makers and the public in defining a sustainable governance regime for the Phoenix region to facilitate a sustainability transition in the water system.

The governance-based approach applied throughout the case study is critical for informing sustainability transitions. While descriptive-analytical and anticipatory research are common in the water resources field, this dissertation employs a comprehensive approach focused on water governance that attempts to capture the richness of the water system and the activities of important actors. With an eye toward transition, the focus on who is doing what with water is critical as the scenarios help redefine individual and institutional roles that will contribute – or not – to the future sustainability of the water system. Results highlight important contradictions in and challenges for concepts of desirability, sustainability, plausibility, and security, as they relate to water governance and use in the Phoenix region now and in the future. These insights have implications for the governance of complex social-ecological-technical systems beyond the Southwest.

5. Resources

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CHAPTER 2

Participatory Approaches for Constructing and Using Climate Change Scenarios

Abstract

The research community is finalizing the next generation of scenarios for climate change research and assessment, which informs the Fifth Assessment Report of the IPCC.

Previous IPCC assessment reports and their different usages were based on expert-driven scenario processes. Over the last decade, numerous climate change scenario studies have employed participatory approaches and engaged a broad spectrum of stakeholders in the construction and use of climate change scenarios. Thus, it is both timely and necessary to explore the potential contributions of participatory scenario approaches to creating and using climate change scenarios. This article first proposes an analytical-evaluative framework that conceptualizes critical components of participatory scenario studies through a synthesis of the pertinent literature. Based on this framework, we then review six exemplary participatory climate change scenario studies. We provide a qualitative summative evaluation, highlighting strengths and weaknesses of the reviewed scenario studies and approaches. The article concludes with institutional recommendations to support participatory processes for constructing and using climate change scenarios.

1. Benefits and Costs of Participatory Scenario Studies

In September 2007, IPCC experts convened to develop a plan “Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies” (Moss et al., 2008). Their recommendations were endorsed by the IPCC, which in 2008 invited the scientific community to develop this new generation of scenarios. Unlike previous scenario processes that informed the IPCC assessment reports and were conducted sequentially, the experts proposed a “parallel approach” to “provide better integration, consistency, and consideration of feedbacks [between radiative forcing, socio-economic, emissions, and climate scenarios], and more time to assess impacts and responses” (Moss et al., 2008, p. 3). In response, the community completed “representative concentration pathways” (RCPs) which provide a starting point for subsequent construction and use of socio-economic and emissions, climate, impact, and response scenarios (Moss et al., 2010; Van Vuuren et al., 2011). In addition, progress has been made towards completing a global set of ‘shared socio-economic pathways’ (SSPs) with detailed narratives and quantification of challenges to adaptation and mitigation (Kriegler et al., 2012).

The scenario studies that informed IPCC assessment reports one (1990) through four (2007) were commissioned and approved by the IPCC, with experts developing the scenarios. Prominent examples are the emission scenarios, based on inputs from scientists in 1990 and later on input from scientists and governmental representatives in 1992 and 2000 (Girod et al., 2009). The current parallel approach could potentially explore different socioeconomic futures that consistent with the RCPs to respond more effectively to user needs. However, it continues to be an expert-driven process.

Since the last comprehensive emission scenarios were published in 2000 (Nakicenovic and Swart, 2000), numerous peer-reviewed studies have employed participatory approaches and engaged a spectrum of stakeholders in the construction and use of climate change scenarios. There is emerging agreement that such participatory approaches are valuable for understanding and interpreting implications and local impacts of climate change and informing mitigation and adaptation policies and actions (Berkhout et al., 2002; Pahl-Wostl, 2002; Baker et al., 2004; Moser and Luers, 2008; Mahmoud et al., 2009; Larsen and Gunnarsson-Östling, 2009; Tschakert and Dietrich, 2010; Girod et al., 2009; Salter et al., 2009; Shaw et al., 2009; Salter et al., 2010; Vervoort et al., 2010; Robinson et al., 2011; Sheppard et al., 2011).

Arguments in favor of participatory approaches in scenario processes include (Tab. 1):

1. Participatory approaches allow *sharing of expert information* on drivers, effects, and impacts of climate change, and response options, across different stakeholder groups, thereby building anticipatory competence and adaptive capacity among publics and decision makers (Kok et al., 2006; van Kerkoff and Lebel, 2006; Salter et al. 2009; Robinson et al., 2011). This increases the scientific *credibility* (accuracy and evidence) of the generated scenarios (Cash et al., 2003).
2. Participatory approaches allow *integration of local knowledge from non-academic communities* (Loibl and Walz, 2010). This increases the salience (relevance to decision makers) of the generated scenarios (Cash et al., 2003). Larsen and Gunnarsson-Östling (2009) argue that the integration of best available knowledge is *necessary* for enabling society to tackle the complex challenge of climate

change. Others argue that participatory approaches and knowledge integration are advantageous when research budgets are limited (assuming expertise to conduct participatory processes) (Vervoort et al., 2010). Still others contend that in democratic systems local stakeholders have the right to demand that their knowledge be included in decision-making processes of public relevance (Fiorino, 1989).

3. Participatory scenario creation and interpretation that build on local knowledge and discussion can provide a *richer picture of how climate impacts and responses play out in practice, and also the opportunity to connect climate change in to actual decision-making at a local scale*. There is growing recognition of the importance of municipal and local scale governance on climate issues (Bulkeley and Betsill, 2003). Eliciting local knowledge can provide a better understanding of the multiple forces or stresses unrelated to climate change for which little data exists. Such stresses are often crucial for understanding potential impacts, opportunities, and constraints on implementation of adaptation and mitigation measures. Engaging local stakeholders increases scenario saliency and therefore use (Cash et al. 2003).
4. Participatory approaches help clarify *differences in perspectives and build agreement* across stakeholder groups. Numerous scholars argue that deliberation among stakeholders is *necessary*, as the future is inherently open and malleable (Swart et al., 2004; Brewer, 2007). If well executed, this can build trust and collaborative expertise (Swart et al., 2004). Trust and expertise reduce friction and tension while enhancing the willingness to collaborate, coordinate, and realize

synergies. This increases the legitimacy (transparency and fairness) of the scenario process (Cash et al., 2003).

5. Participatory approaches can *build acceptance and ownership* of climate change, its impacts, and adaptation and mitigation options, among different stakeholder groups (Walz et al., 2007; Patel et al., 2007; Bizikova et al., 2010). Ownership can *increase stakeholder motivation and accountability*, enhancing the chance that adaptation and mitigation options get implemented (Patel et al., 2007; Talwar et al., 2011).

The reviewed benefits presented above apply Cash et al.'s (2003) differentiation of credibility, salience, and legitimacy of knowledge claims, while adding the feature of accountability (Talwar et al., 2011). The reviewed benefits align with Fiorino's (1989) differentiation of normative, substantive, and instrumental reasons for public participation (c.f. Stirling, 2006). The first three benefits above (capacity building; integration of local knowledge; tangibility) correspond to substantive reasons for participation (increasing the breadth and depth of the information informing the decision-making process). The second benefit above (integration of local knowledge) also corresponds to normative reasons for participation (engaging all legitimate constituencies in the decision-making process). And the last two benefits above (4. & 5.) correspond to instrumental reasons for participation (sustaining or restoring public trust in the decision-making process).

However, participatory processes do not inevitably lead to sound scenarios. They are not a remedy that guarantees quality scenario work. And if participatory processes are carefully designed, they usually come with significant additional costs compared to

expert-driven scenario processes (Kok et al. 2006a; 2006b). Literature draws attention to the following costs associated with participatory approaches in scenario processes (Tab. 1):

- *Additional time and financial resources* are needed to support the collaborative processes. In most cases, participatory scenario processes include additional research steps (e.g., stakeholder mapping and analysis). In some cases, it might be advantageous to design a staged process beginning with more homogeneous stakeholder groups (e.g., related to sectoral scenarios) and proceeding at later stages to collaborative activities across various stakeholder groups (Stauffacher et al., 2008; Withycombe Keeler et al., in prep).
- *Additional expertise* is required for conducting high quality participatory scenario processes. This includes anticipatory competence, skills in elicitation, facilitation, and mediation for stimulating out-of-the-box thinking and discussions as well as mapping, confronting, and reconciling diverging perspectives (Baker et al., 2004; van den Hove, 2006). Additional experts (e.g., professional facilitators) might be required to compensate for limited capacities or expertise.
- Participation that truly engages stakeholders leads to a *shift in control* toward stakeholders and away from experts (Talwar et al., 2011). It is critical to acknowledge a mutual dependence between climate scientists and stakeholders when constructing and using climate change scenarios. When scientists do not share control over the scenario process, they cannot reasonably expect stakeholders to feel accountable and take action based on the generated results. Conversely, stakeholders who are not willing to put actions behind credible and

salient scenario results cannot expect researchers to share control over the scenario process. This mutual shift of sharing rights and responsibilities within the scenario process requires those involved devising and following new principles of collaboration.

- Since most participatory processes are local, resources are required to downscale climate scenarios to the local level. Fortunately, such downscaled scenarios are increasingly available (Shaw et al., 2009). In return, the results of participatory scenario processes speak directly to local and perhaps regional or national contexts. They cannot easily be aggregated to higher scales of decision-making.

Table 1

Overview of Benefits and Costs Associated with Participatory Approaches

Benefits	Costs
Sharing of expert information increases credibility of the climate change scenarios and builds capacity across stakeholder groups (from experts to stakeholders)	Additional time and financial resources required to support the participatory processes
Integration of knowledge from non-academic communities increases salience of the climate change scenarios (from stakeholders to experts)	Additional expertise required for conducting high quality participatory scenario processes (elicitation, facilitation, etc.)
A richer picture of the local social, economic, and institutional dimensions of response and impact scenarios and ability to consider multiple stresses increases salience of the climate change scenarios (tangible and iconic)	Shift of control over scenario process and results (balance of influence and accountability)
Clarifying differences of perspectives and building agreement (trust) across stakeholder groups increases legitimacy of the scenario process (mutual learning and joint research)	Additional research and costs associated with downscaling climate scenarios to local context, as well as aggregating local results to larger scales
Building acceptance and ownership of climate change challenges as well as response options across stakeholder groups increases accountability for implementation	

Note. Benefits and costs do not correspond in this table.

Whether participation in scenario processes actually realizes the indicated benefits and outweighs the associated costs requires empirical evaluation. Such evaluative studies are still rare. The available studies are for the most part: not focused on climate change scenarios; individual case studies rather than comparative studies; based largely on self-reflection or document analysis rather than interviews and in-vivo observations; and

provide descriptive rather than evaluative insights (Pahl-Wostl, 2002; Shackley and Deanwood, 2003; Wiek et al., 2006; Salter et al., 2010; van Asselt et al., 2010). A recent external comparative evaluation of four scenario studies (conducted over multiple years in different regions of the US) suggests that participatory scenario processes that engaged stakeholders more frequently, intensely, and reflexively yield greater ownership, satisfaction, and usability of the generated scenarios (Wiek et al., 2012). Despite these favorable indications, this and similar studies on participatory approaches caution against simply advocating for “participation” (as it is often done) (Newig and Fritsch, 2009); instead, the *function, type, and quality* of participation are likely decisive factors of success or failure for the scenario process (Stauffacher et al., 2008; Talwar et al., 2011). Given the increased use and demonstrated efficacy of participatory scenario approaches, it is timely and appropriate to review and assess these activities to inform the next generation of climate change scenarios. This requires a transparent analytical framework and evaluative criteria derived from the literature. In this article, we provide a *methodological* literature review of selected participatory scenario studies and approaches, focusing primarily on those approaches *related to climate change scenarios*. For the conceptual part of the article, we expand this focus to the broader body of literature on participatory research approaches and participatory scenarios processes in general.

Our goal is to ultimately build a *functional typology* of participatory processes for constructing and using climate change scenarios. This typology would allow researchers and decision-makers to learn about strengths and weaknesses of available approaches and to choose the participatory approach that matches their goals and expectations.

The remainder of this article is structured as follows: the development of an analytical-evaluative framework (section 2); a review of selected participatory climate change scenario studies published in refereed journals between 2002 and 2011 (section 3.1); and a summative evaluation of their strengths and weaknesses (section 3.2). The article concludes with recommendations on how to carry out meaningful participatory processes for constructing and using the next generation of climate change scenarios.

2. Analytical-Evaluative Framework

A participatory process is not a random sequence of steps but purposefully designed activities. The quality of the process depends on a variety of aspects, including resources, planning, and expertise, similar to traditional research methods, but also willingness to share responsibility and acknowledge accountability (Talwar et al., 2011; Wiek et al., 2014). The literature offers many approaches with varying levels of quality. We propose a two-part framework: (i) for comparing key elements of participatory approaches across different climate change scenario studies, and (ii) to conduct a criteria-based, summative evaluation of these approaches.

2.1. Analytical framework

For the purpose of this review, we propose a pragmatic framework for analyzing and comparing participatory approaches in climate change scenario studies. The term “pragmatic” deliberately emphasizes the *practice* of participation. There are numerous scenario typologies (Van Notten et al., 2003; Biggs et al., 2007), but few focus on methodological issues, and even fewer on participatory approaches (van Asselt and Rijkens-Klomp, 2002; Wiek et al., 2006; Salter et al., 2010). While those few are

removed from the actual practice of participation, our framework remains close to the design and process of participatory scenario construction.

We start with a series of definitions to create common ground for the subsequent sections (Nakicenovic and Swart, 2000; Girod et al., 2009; Mahmoud et al., 2009; Moss et al., 2010). “*Climate change scenarios*” are here defined as *diverse representations of climate change in the future (i.e., future states as well as the developments leading up to these future states)*. There are four distinct features that characterize any given set of climate change scenarios:

- (i) The component of the climate-human system addressed:
 - a. *Pathways scenarios* on socioeconomic drivers (greenhouse gas emissions and their anthropogenic sources, such as technologies and activities (land-use changes), and root causes, like motives, rules, etc.) of climate change
 - b. *Climate system scenarios* on atmospheric composition and climatic phenomena (atmospheric concentration of greenhouse gases, variability of precipitation, temperature, etc.)
 - c. *Impact and vulnerability scenarios* on direct impacts (e.g., melting ice and sea level rise) and indirect impacts (e.g., soil erosion or migration) of climate change
 - d. *Mitigation and adaptation scenarios* on responses to address climate change
 - e. Combinations of a.-d. (e.g., RCPs, SSPs)
- (ii) The specific spatial scale (from local to global)
- (iii) The time scale (reference year or period)

“Climate change scenario studies” are the full range of quantitative and qualitative research that construct or use climate change scenarios. “Participatory processes for climate change scenario studies” are collaborative activities that involve a variety of stakeholders. “Stakeholders” are individuals or groups with interest (a “stake”) in the scenario process and/or its outcome; in the case of climate change scenarios these are representatives from government, business, media, research and education, non-governmental organizations, and citizens.

Based on these definitions, we propose a set of core components that characterize a generic participatory process for climate change scenario studies (Fig. 1). The process is structured into three sections:

- (i) The *framing*, with goal setting and participant selection
- (ii) The *core*, with the participatory activity (or activities)
- (iii) The *effects*, resulting from the framing and the participatory activity; we differentiate two types of effects: outputs (e.g., products) and outcomes (e.g., decisions taken that are informed by the scenarios)

Put simply, we are interested in: the purpose of participation (why), who is involved (who), in what kind of activity (how), and with what effects (to what end) (cf. Krutli et al., 2010). Each section features a variety of components. Sections (i) and (ii) require several choices in designing the participatory process, which shape the resulting effects in section (iii).

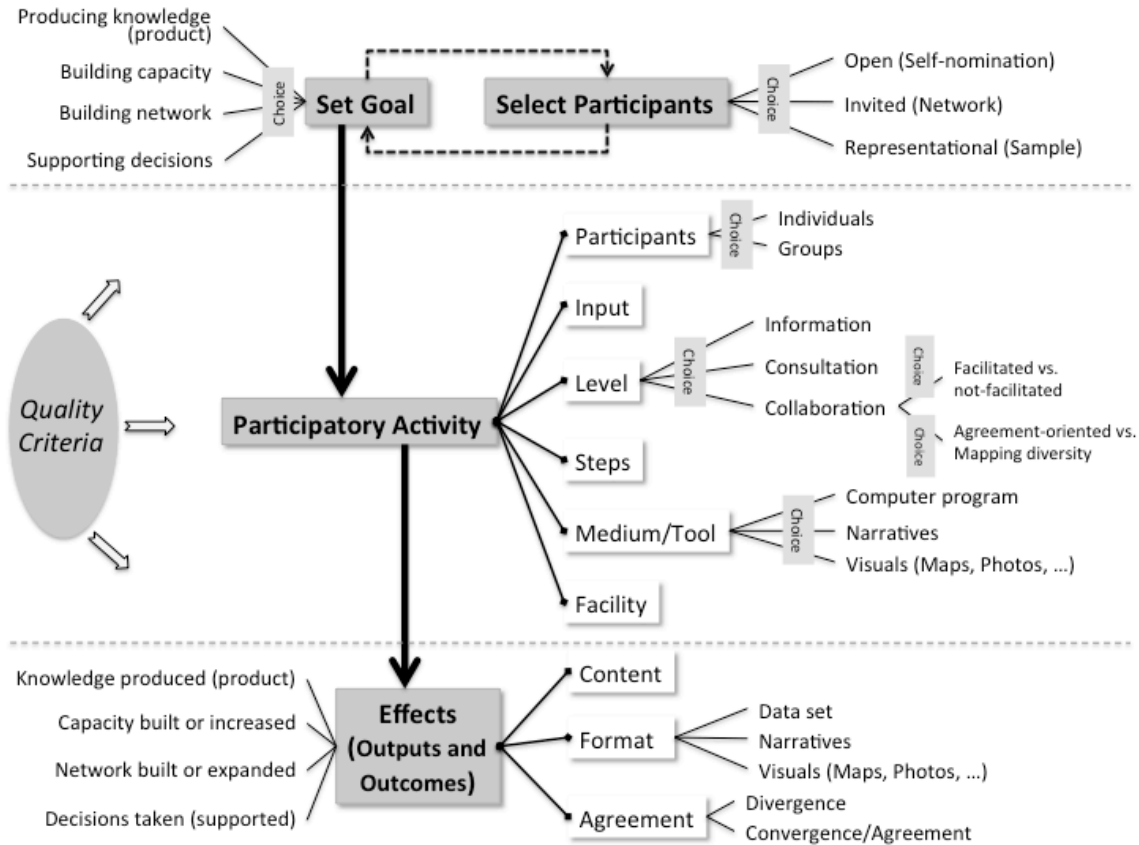


Figure 3. Analytical framework of a generic participatory scenario process (with selected choices in the framing and design of the participatory process).

Framing Phase. Either stakeholders, researchers, or both set goals for the participatory scenario process and determine who to invite to participate. Participating stakeholders may be selected through an open invitation, existing professional or social networks, or representative sampling. A traditional categorization differentiates stakeholders into representatives from government, business, research and education, non-governmental organizations, citizens, and so forth. In addition, Wiek et al. (2006) suggest distinguishing between different agents, depending on whether they are involved in the framing phase, or in the core phase, or in both. The processes of goal setting and inviting participants can be iterative or sequential. In the iterative case, newly recruited

participants might reshape previously defined goals. Goals can be differentiated in various ways (Wiek et al., 2006; Larsen and Gunnarsson-Östling, 2009). We use here the framework developed by Wiek et al. (2014) and differentiate between goals related to the product of the scenario study (knowledge produced = output) and the aspired subsequent benefits (outcomes), such as: building or increasing capacity, building or expanding stakeholder networks, and supporting (informing) decisions or changing behavior (Godet, 2000; Harries, 2003; Chermack, 2004; O'Brien, 2004; Mietzner and Reger, 2005; Wiek et al., 2006; Burt and Chermack, 2008; Salter et al., 2010; Antle et al., 2014).

Core Phase. Here, the participatory activity or process takes place (Fig. 1). There are several components to consider when designing a participatory scenario activity, first, who is involved, if they are engaged as individuals or groups, and what the inputs for the activity are (e.g., storylines of global emission scenarios). The next component is the sequence of steps, specifying what the participants actually do (e.g., filling in an impact matrix, drawing expected flooding zones on a map, or discussing the cost of different mitigation measures). Closely related to the steps of the activity is the level of engagement, which describes the degree to which participants determine the process and products of the scenario study. A common scale of engagement levels ranges from *information* (experts communicating to stakeholders) and *consultation* (experts eliciting from stakeholders), to *collaboration* (mutual interaction, co-production) (Arnstein, 1969; Wiek, 2007). Standardized forms of engagement that correspond to these three categories are, for instance, *expert hearings/input* (information), *stakeholder focus groups* (consultation), and *workshops* (collaboration). The level of engagement can change over the course of the activity—even from step to step (Stauffacher et al., 2008). On the

highest level of engagement, i.e., collaboration, participation takes many forms (and includes many choices), including whether to facilitate collaboration, and whether collaboration is diversity- and/or agreement-oriented (van de Kerkhof, 2006). Finally, the activity can engage participants through various media, including computer programs (e.g., GB-Quest [Robinson et al 2011; Carmichael et al, 2004]), films, or audio. It can also engage them with various formats, including narratives and visuals. Recently, many have questioned the assumption that knowledge primarily drives decisions on climate change, and instead explored affective and experiential aspects as critical drivers of behavioral change (Sheppard, 2005; Antle et al., 2014). As a result, visuals are a new scenario component developed and used to illustrate, for instance, climate impacts and response options (Shaw et al., 2009). Several studies suggest that visually contextualizing climate change impacts on the local level better links understanding of climate change impacts to behavioral change and action (Nicholson-Cole, 2005). Computer technology has brought about a new type of participation through participatory *tools*—first and foremost, interactive and immersive *visualizations* (Salter et al., 2009). Two prominent participatory tools applied to climate change scenarios (with more or less sophisticated visual components) are (i) *simulation tools* that build stakeholder capacity for systems thinking related to climate change drivers, impacts, and responses (e.g., Quest: Robinson, et al 2011; Carmichael et al 2004) and (ii) *gaming tools* that engage stakeholders with climate change scenarios in entertaining and competitive settings (Salter et al., 2010; Vervoort et al., 2010; Antle et al., 2014). *Participatory tools* can be integrated in participatory processes, yet, they can also function as stand-alone applications, for instance, as *web-based* or *kiosk* applications (e.g., Haas Lyons et al., 2014). In those

cases, they primarily engage individuals and without direct person-to-person interaction. In the majority of cases, participatory tools have educational goals but they can also be used as consultative devices (for instance, feeding a database of stakeholder preferences). Advantages of participatory tools compared to participatory processes are: standardized presentation of information, accessibility, instant feedback, and low/no cost usage. Downsides include relatively high development costs, and lack of in-depth exploration, deliberation, and adaptability to stakeholder interests. There are temporary and permanent *participatory facilities* developed to engage stakeholders climate change scenario construction and use. Museum exhibitions, like “Rising Currents” in the Museum of Modern Art in New York (2010), provide temporary opportunities for stakeholders to explore climate impacts and response options. Compared to participatory tools, museum settings have the advantage of alternative forms of information presentation, including large installations, dioramas, multi-media, experiential settings, etc. They also provide the flexibility to combine different forms of participatory tools and processes. Recently, “decision theaters” emerged as a particular type of participatory facility, the majority of which were designed to support climate change decision-making (White et al., 2010). Decision theaters are physical spaces in which participatory processes occur and virtual spaces for decision support and research, which use participatory tools, particularly visualizations. (Edsall and Larson 2006). They also offer a research laboratory (control, documentation, etc.). But there are disadvantages including limited accessibility, high maintenance cost, and required technical expertise. Permanent decision theaters are in operation or under construction at Arizona State University, the University of British

Columbia (Canada), Linköping University (Sweden), and Huazhong University (China). An international research network among the decision theaters has been initiated.

Effects. Participatory activities generates outputs and outcomes. Corresponding to the framing phase, outputs are tangible and immediate products, while outcomes include built or increased capacity; built or expanded stakeholder networks; and decision support (Wiek et al., 2014). The content component of the outputs (products) can occur in various formats (e.g., data sets, narratives/reports, visuals/audios). Depending on the design of the participatory activities, the content can represent a spectrum of diverging/different perspectives, converging/agreeing perspectives, or both.

2.2. Evaluative guidelines

Based on the literature, a set of quality criteria and good practices can be linked to the key components of participatory scenario processes (Fig. 1), which allow for transparent evaluation of completed scenario studies. Their primary intent, however, is to inform the *design* of participatory processes in climate change scenario studies (or to evaluate ongoing participatory scenario studies).

Framing Phase – Stakeholder Selection. In the initial phase of a participatory scenario process, stakeholder participants are selected. The selection should be a transparent process in which stakeholders are aware of the reason they were selected, their role(s) in the process, expectations (time, input, travel, etc.), and any incentives for participating (Robinson and Tansey, 2006; Wiek et al. 2014). For climate change, the range of stakeholders, i.e., those who have a “stake” in the issue, is broad, including government officials, representatives of business, media, experts, and members of the public (Kok et al., 2007; Biggs et al., 2007; Evans et al., 2008). A quality criterion in

selection is the elicitation and explication of the specific “stakes” the participants have in the issues of climate change (Pahl-Wostl, 2002; Keskitalo, 2004). This increases transparency and enables identifying gaps in the spectrum of involved stakeholders. Recent studies on participation recommends extending established social networks (“the usual suspects”) when recruiting participants to avoid overrepresentation of certain groups and viewpoints (Webb et al., 2009). Recruitment of participants and ensuring diverse representation is more feasible at smaller than larger scales (Biggs et al., 2007). Studies have shown, however, that it is possible to successfully engage stakeholders in scenario processes at the national and international scale (Kok et al., 2007; Salter et al., 2010). In scenario processes that cut across scales, stakeholder representation from multiple scales is critical as in alternative futures “winners” and “losers” often occur at different scales (Kok et al., 2007). In sum, the selection of stakeholders needs to be well crafted and is best based on stakeholder mapping and analysis, prior to or accompanying the selection process (Keskitalo, 2004).

Framing Phase – Goal Setting. The initial goal of the scenario study is set by the group initiating the study and the selection of participants. A basic quality criterion is that the goal of the study reflects and specifies both outputs and outcomes. Another quality criterion is that the goal definition ought to be open as selected participants might join the process later and ask to changed the set goal. Though this approach may take more time, it helps ensure ownership of the scenario process and its effects by the participants. This also enables study teams to better tailor the outputs to the needs and decision-making contexts of those involved and thus increases the likelihood that the outputs will be used and outcomes will be generated beyond the project duration (Wiek et al., 2006; Talwar et

al., 2011; Wiek et al., 2014). The goal of the scenario study, in addition to being defined in consultation with stakeholders, should be realistic and equally beneficial for all participants, with consideration of both scientific knowledge and the real-world context (Pereira et al., 2007). The initial framing of the project is critically important as it sets the tone for the participatory process – the effects of which will be subject to a broad set of evaluative criteria.

Core Phase. The participatory process should go beyond consultation and allow a high degree of interaction and collaboration between participants and those facilitating the process (O'Brien, 2004; Chermack, 2006; Talwar et al., 2011). In this way, stakeholder and expert participants contribute their knowledge, perspectives, values, and preferences on what constitutes a coherent, plausible, desirable or undesirable future. Participants involved in the process will likely have different knowledge, perspectives, values, and preferences. Collaborative interaction challenges the assumptions of both expert and stakeholder participants through exposure to a variety of motives, perspectives, and agendas (Kok et al., 2007). A well-facilitated participatory scenario process will elicit the spectrum of participant perspectives and insights without letting any individual or sub-group “capture” the process to serve their personal agenda (Van de Kerkhof, 2006). In other words, participatory scenario processes should be *legitimate*, not favoring any singular political agenda and accurately reflecting the inputs of the stakeholders who participated (Shoemaker, 1993; Pereira et al., 2007). Ensuring legitimacy is closely related to the transparency of the participatory process, indicating how different perspectives and expertise are integrated, or not, over the course of the process. Collaboration in the construction as well as in the use of scenarios allows for

stakeholders to coordinate efforts and share information across relevant decision-making scales (Biggs et al., 2007). This linking across scales is particularly important in the construction and use of participatory climate change scenarios where processes and outcomes take place on multiple scales and thus require knowledge of the different scales and the interaction between them (Biggs et al., 2007). Participatory scenario processes that bring together a diversity of stakeholders in collaborative settings (e.g. workshops or focus groups) can capitalize on different expertises, generating scenarios that better capture such complexities (Kok et al. 2006).

This type of intense collaboration can be both time consuming and expensive, so it is critical to determine where in the core phase it is most important that stakeholders be intensely involved. It may neither be practical nor feasible to maintain a high level of stakeholder participation in every step of the scenario process. Many participatory scenario exercises (Baker et al., 2004; Kok et al., 2006; Shaw et al., 2009; Loibl and Walz, 2010) are characterized by iterations of intense stakeholder collaboration (typically in workshop settings) where input data is produced, followed by expert-driven construction of models or 3D representations using the input data, followed again by intense stakeholder collaboration where the outcomes of the expert-driven step(s) are vetted. This is particularly relevant for quantitative scenario approaches, which often limit the number and types of interactions possible with lay stakeholders. Alternatively, the scenario generation engine may itself be designed as a participatory tool, allowing the stakeholders to be part of the process of scenario construction (Robinson, et al, 2011, Carmichael et al, 2004). In a successful scenario process time and money can be saved by reserving intense collaboration for critical steps, such as the production of input variables,

the generation of scenario storylines, the interpretation and assessment of scenarios, or the development of strategy options. If done transparently, this interaction between stakeholder- and expert-driven activities can empower stakeholders while maintaining a high quality of the scenario process.

Effects. A successful participatory scenario process yields tangible and less tangible effects, which are subject to an expanded set of evaluative criteria. Though outputs (i.e., the scenarios) should be scientifically *credible*, additional criteria for evaluating outputs and outcomes produced in participatory scenario settings apply (Cash et al., 2003; Pereira et al., 2007, Talwar et al., 2011). Girod et al. (2009) highlight the challenge of balancing different quality criteria without significantly compromising any of them (bounded trade-offs). Preferably, the scenarios ought to be endorsed by the participants and decision makers, which speaks to the salience of the outputs. The strongest endorsement, however, is whether or not the scenarios are at least consulted and considered in the subsequent decision-making processes. This is critically important for participatory climate change scenarios which aim to not only generate knowledge about the effects of carbon emissions on global biogeochemical cycles and climatic phenomena but also to be useful for decision-makers at varying scales in the development of adaptation and mitigation strategies. In addition, participatory scenario processes would ideally yield additional outcomes such as built or increased capacity, as well as built or expanded networks in support of decision-making processes to combat climate change (Shaw et al., 2009).

Table 2

Overview of Evaluative Guidelines for Participatory Scenario Processes

Aspect	Evaluative Guideline
Participant Selection	Participant selection should be transparent regarding roles, expectations, and incentives for participation. Participant selection should include the spectrum of stakeholders from the range of “stakes” in climate change (e.g., including children, stakeholders affected by climate change, and representation across multiple scales)
Goal Setting	Goals should include both outputs and outcomes. Goals should be open to influence from stakeholder perspectives and needs. Goals should be formulated with consideration of scientific knowledge and real-world context.
Participatory Activity	The activities should allow for a high degree of interaction between and among stakeholders, experts and facilitators. The activities should challenge assumptions of stakeholder and expert participants. The activities should maximize resources and stakeholder input by reserving intense collaboration for the most critical steps. The process should be transparent, documenting how knowledge from stakeholders and experts was integrated, or not, over the course of the process.
Effects	Outputs (i.e., the scenarios) should be scientifically credible. Outputs should be salient and meaningful to stakeholder, in form and content, and should be endorsed by them. Outcomes should include built or increased capacity; built or expanded networks; decisions taken to combat climate change.

3. Case Studies

We collected peer-reviewed scenario studies that: (i) used participatory processes; (ii) included climate change as a core theme; (iii) were published between 2002 and 2011. To capture the diversity of such studies, we selected exemplary studies based on being different from studies that were already included. In all, six exemplary studies were

analyzed in detail: Berkhout et al. (2002), Shackley and Deanwood (2003), Kok et al. (2006), Shaw et al. (2009), Loibl and Walz (2010), Bryan et al. (2011) represent a diverse set of illustrative examples of how participatory scenario studies engage scientists and stakeholders in the development or use of climate change scenarios to anticipate local climate change impacts and explore response options. It is important to note that this selection is a small sample from the ongoing activities. Apart from studies led by university researchers, a number of U.S. Federal Agencies, such as the National Park Service, are experimenting with participatory scenario processes related to climate change. An extensive list of participatory scenario studies on climate change issues is made available in the online supplementary material.

3.1 Comparison of participatory climate change scenario studies

Berkhout et al. (2002) present results from the Non-Climate Futures Study, which constructed four *impact scenarios* of possible socio-economic effects of climate change in the United Kingdom in 2020, 2050, and 2080. They were generated to *increase capacity* for impact assessments and *inform decision-making* related to climate change. The research engaged participants from *government, business, and non-governmental organizations* in *consultation* through interviews and *collaboration* through workshops and ‘bilateral and group contacts’. Participants were engaged in the selection of scenario axes and identification of key factors that determine future changes; the analysis of the scenario matrix; and provided feedback on scenario results. Research outputs included *four impact scenarios* of socio-economic impacts of climate change on the UK in the form of *narratives* (storylines) and *data* (indicators). Outcomes from the process included increased understanding of regional socio-economic impacts of climate change and

networks developed among participants. The study outputs were provided to stakeholders for private use, but yielded limited subsequent outcomes.

Shackley and Deanwood (2003) present four socio-economic development pathway scenarios in East Anglia and North West regions of England for 2050 for use in climate change impact assessments. Three workshops engaged participants from local government, businesses and NGOs and members of the public in *collaboration*. A scenario axis-like technique adapted from Berkhout et al. 2002 was used to identify storylines based on participant discussions and input from experts on regional plans and existing scenario studies. Storylines were modeled by researchers who generated map visualizations, data tables, and descriptions of the scenarios, which were presented to participants. Feedback from participants motivated the development of a fifth, planners' scenario for year 2020 developed in collaboration with participants. By using stakeholder input to generate the scenarios and incorporating feedback to generate a new scenario, the participatory approach had the outcome of *increasing the legitimacy of scenarios* among participants.

Kok et al. (2006b) present research to develop three combined pathway-impact scenarios of land use and degradation resulting from climate change in the Northern Mediterranean to 2030. Participants from businesses, NGOs, local, regional and national government as well as members of the public including media, psychologists, farmers and so-called “free-thinkers” were engaged in three, facilitated workshops. The scenario construction was participant-driven, with researchers observing the process and trained facilitators synthesizing working group results. Participants first defined scenarios of the present which illuminated important system features; then developing local storylines for

three Mediterranean scenarios presented by researchers; participants then refined those storylines by specifying short-term and long term trends associated with each scenario; and finally participants identified desirable elements of the scenarios and reason-backward to previously discussed trends. The intense stakeholder engagement yielded a number of outputs, including *increased understanding* of climate impacts among participants, *networks developed* between participants and researchers for future collaboration, *mutual learning* between and among participants and researchers, and *decision support* for local policymakers related to climate change adaptation.

Shaw et al. (2009) developed four integrated impact-adaptation scenarios of climate change for the municipality of Delta (Metro Vancouver, Canada) in 2020, 2050, and 2100. The study consisted of three main phases: expert participants collaborated with the research team to synthesize global scenarios of climate change in narrative and pictograph form; these were downscaled by expert and lay participants in workshops to determine local impacts and adaptation/mitigation options; finally, the research team generated visualizations of local climate change which were vetted in broader participant workshops. The study *built capacity* for climate change adaptation and mitigation among participants from Delta, confirmed by a pre-post study to document participant experiences.

Loibl and Walz (2010) created two *impact scenarios* depicting climate change and land use change in the Montafon region of alpine Austria in 2030. Local members of the public were engaged through workshops to identify critical issues for regional development stemming from climate and land-use changes, create system diagrams of climate change and local impacts, and create initial best-case and worst-case scenarios for

the Montafon region. Experts used agent-based models to simulate land-use and climate change impacts, generating 3D maps of two scenarios for Montafon in 2030, one “wishful” and one “dreadful.” A follow participant workshop was held to develop response strategies to the scenarios as *decision support*. Participants *built capacity* in systems thinking and *increased their understanding* of climate impacts on the region. Bryan et al. (2011) generated *four adaptation scenarios*, which explore the impacts of environmental policies in light of climate change impacts in the Mallee region of southern Australia for an unspecified timeframe. Participants were *consulted* to help define environmental objectives and prioritize policy options. A collaborative workshop was held to develop an initial set of four scenarios with participants and specify policy options for alternative futures. Researchers modeled scenarios and policies, generating GIS maps and quantitative indicators of policy performance for each of the four scenarios. Participants *built capacity* for visualizing the impacts of different environmental policy options, resulting in *decision support* related to natural resource management in the Mallee region.

Table 3

Selected participatory climate change scenario studies published in refereed journals

2002 – 2011

		Berkhout et al. (2002)	Shackley and Deanwood (2003)	Kok et al. (2006b)
Framing	Goal	<i>Impact scenarios</i> (4 scenarios of socio-economic impacts from climate change in the UK for 2020, 2050, and 2080)	<i>Pathway scenarios</i> (4 socio-economic development pathways in two English regions to 2050)	<i>Pathway-Impact scenarios</i> (3 scenario storylines to 2030 of local climate change impacts)
	Aspired Outcomes	<i>Increased capacity</i> (improved impact assessment) <i>Decision support</i> (in response to impacts)	Not specified	<i>Decision support</i> (for multi-scale policy efforts)
	Selection of Participants	Not specified	<i>Open selection</i> (anyone willing to participate)	<i>Targeted selection</i> (desired participants with diverse interests, expertise, ages, occupations)
Core Phase	Participants (P)	Representatives from: <i>Government</i> (national and regional) <i>Business</i> <i>NGOs</i>	Representatives from: <i>Government</i> (regional planning) <i>Business</i> <i>NGOs and non-profits</i> (mostly environmental NGOs)	<i>Members of the public</i> Representatives from: <i>Government</i> (local, regional, national) <i>Business</i> (Agriculture, tourism) <i>NGOs</i>
	Input	UK Climate Scenarios IPCC Emission Scenarios Natural Resources and Environment Panel of UK Foresight Programme futures research	UKCIP SES Report Spatial Development Scenarios Plans and guidance for North West and East Anglia regions	MedAction Scenarios (Kok et al. 2006a)
	Level and Form of Participation	<i>Consultation</i> (Interviews) <i>Collaboration</i> (Workshops and working groups)	<i>Consultation</i> (Workshop - Steps 1-2,4) <i>Collaboration</i> (Workshop, Step 3b)	<i>Collaboration</i> (Facilitated workshops Steps 1-4)
	Steps (Activities)	<i>Selecting Scenario Inputs:</i> 1. Identify scenario axes and key factors that determine future change 2. Create and discuss scenario matrix (<i>Participatory</i>) <i>Generate Scenarios:</i> 3. Interpret scenario matrix - (<i>Participatory</i>) <i>Interpretation and Visualization:</i> 4. Produce quantitative indicators and storylines for scenarios (According to the research team, each step engaged participants)	<i>Selecting Scenario Inputs:</i> 1. Review and interpret existing reports and studies (<i>Participatory</i>) 2. Review and discuss possible futures along scenario axes (<i>Participatory</i>) <i>Generate Scenarios:</i> 3. Generate Scenarios 3b. Develop scenario to 2020 relevant for planners (<i>Participatory</i>) <i>Interpretation and Visualization:</i> 4. Review and critique scenarios (<i>Participatory</i>)	<i>Selecting Scenario Inputs:</i> 1. Develop stories of the present and main scenario factors (<i>Participatory</i>) <i>Generating Scenarios:</i> 2. Develop local storylines for 3 Mediterranean scenarios (Participant engagement) 3. Specify major current trends for each scenario (<i>Participatory</i>) <i>Interpretation and Visualization:</i> 4. Backcasting from future scenarios and identification of desirable scenario aspects (<i>Participatory</i>)
	Medium/Material	Data Visuals (Cognitive maps)	Visuals (Cognitive maps) Narratives (Storylines)	Visuals (collages with Post-Its) Narratives
Effects	Output	<i>Four impact scenarios</i> (of possible socio-economic impacts of climate change in the UK (p. 16))	<i>Four impact scenarios</i> (for each of the two regions for three illustrative issues Spatially explicit maps of two of the scenarios)	<i>Three combined impact-pathway scenarios</i> (exploring local impacts of climate scenarios) <i>Scenario appraisal</i> (participants identified desirable features of scenarios)
	Format	Data (indicators) Narratives (storylines) (p. 16)	Data (tables) Visualizations (maps)	Narratives Visualizations (collages, flow charts, videos)
	Agreement	Not specified	Not specified	Not specified
	Outcomes	<i>Increased understanding</i> (of climate impacts among participants) <i>Networks developed</i> (among participants)	<i>Increased legitimacy of scenario results</i> (to participants)	<i>Increased understanding</i> (of local climate impacts among participants) <i>Networks developed</i> (for collaboration among researchers and participants) <i>Decision support</i> (for local policymakers) <i>Mutual learning</i> (between and among participants and researchers)

		Shaw et al. (2009)	Loibl and Walz (2010)	Bryan et al. (2011)
Framing	Goal	<i>Impact-Adaptation scenarios</i> (4 scenarios of impacts and adaptation options for the Delta municipality in 2020, 2050, and 2100)	<i>Impact scenarios</i> (2 scenarios of climate impacts on Alpine landscape in 2030)	<i>Adaptation scenarios</i> (4 scenarios based policies and environmental objectives)
	Aspired Outcomes	<i>Increased capacity</i> (for climate change adaptation)	<i>Decision support</i> (for building robust strategies for regional development under climate change)	<i>Decision support</i> (policy-making in response to climate change)
	Selection of Participants	Not specified	<i>Open selection</i> (All local organization that work across municipalities. Snowball sampling from key stakeholders)	Not specified
Core Phase	Participants (P)	<i>Members of the public</i> Representatives from: <i>Government</i> (local, regional) <i>Business</i> <i>NGOs</i>	<i>Members of the public</i>	<i>Members of the public</i>
	Input	IPCC SRES scenarios Millennium Ecosystem Assessment scenarios Global Scenario Group scenarios	Expert knowledge on effects of climate change on the region and socio-economic and demographic changes that might result	Regional plans (15) Natural resource management objectives
	Level and Form of Participation	<i>Consultation</i> (Interviews - Step 1) <i>Collaboration</i> (Workshops - Steps 2,4)	<i>Collaboration</i> (Workshops - Steps 1-3,4)	<i>Consultation</i> (Steps 1-2, form not specified) <i>Collaboration</i> (Workshop to define future scenarios - Step 3)
	Steps (Activities)	<i>Selecting Scenario Inputs:</i> 1. Synthesize global scenarios, specify key drivers and impacts of climate change (<i>Participatory - with experts</i>) 2. Specify local impacts and adaptation/mitigation options (<i>Participatory</i>) <i>Generate Scenarios and Interpret and Visualize Results:</i> 3. Visualize climate change impacts/responses in Delta 4. Review visualizations (<i>Participatory</i>)	<i>Selecting Scenario Inputs:</i> 1. Discuss trends and possible climate impacts on Montafon, identify issues for regional development. (<i>Participatory</i>) 2. Create visual systems model of climate impacts on regional development (<i>Participatory</i>) <i>Generate Scenarios:</i> 3. Generate qualitative scenarios (<i>Participatory</i>) 4. Model of regional development alternatives <i>Visualization and Interpretation:</i> 5. Scenario assessment and strategy development (<i>Participatory</i>)	<i>Selecting Scenario Inputs:</i> 1. Identify environmental objections and natural resource management actions (<i>Participatory</i>) 2. Define spatial prioritization of policy options (<i>Participatory</i>) <i>Generate Scenarios:</i> 3. Define future scenarios (<i>Participatory</i>) <i>Visualization and Interpretation:</i> 4. Modeling the spatial distribution of costs and benefits of NRM actions 5. Specify alternative landscape futures with combinations of policy options (<i>Participatory</i>) 6. Quantify impacts of range of landscape futures across indicators
	Medium/Material	Visuals (Pictographs) Narratives	Visuals (causal loop diagrams) Narratives (positive and negative trends)	N/A
Effects	Output	<i>Four Combined Impact-Adaptation Scenarios</i> (for Delta in 2020, 2050, 2100 that include response options)	<i>Two scenarios of climate impacts</i> (landscape change and population growth)	<i>Four adaptation scenarios</i> (depicting spatial distribution of environmental objectives based on policy options)
	Format	<i>Visualizations</i> (3D computer visualizations and supporting material)	<i>Data</i> (key scenario features, positive and negative) <i>Visualizations</i> (3D maps of landscape change and population density in the region; conceptual system diagrams)	<i>Data</i> (quantified impacts on key indicators) <i>Visualizations</i> (GIS Maps)
	Agreement	Not specified	Consensus, diversity mapping	Not specified
	Outcomes	<i>Increased legitimacy of scenario results</i> (local climate impacts and response options) <i>Capacity built</i> (for flood management and climate change response) <i>Decision support</i> (for adaptation and mitigation options in Delta)	<i>Capacity built</i> (for systems thinking and anticipation) <i>Decision support</i> (for strategies to adapt/mitigate climate and development impacts in Alpine regions)	<i>Capacity built</i> (to visualize and convey impacts of different management options) <i>Decision support</i> (related to costs, benefits, and impacts of environmental policies)

3.2 Summative evaluation

Framing Phase. Stakeholder engagement in the reviewed scenarios ranged from unilateral consultation involving small numbers of expert stakeholders (Berkhout et al. 2002; Bryan et al. 2011) to intense and iterative collaboration with diverse expert and lay stakeholders (Kok et al. 2006b; Loibl and Walz 2010). Participant selection varied across groups and depended on the needs and priorities of the research team, including: broadening the idea space (Kok et al. 2006b); ensuring participation among impacted stakeholders (Shackley and Deanwood 2003); or the need for specific expertise (Berkhout et al. 2002; Shaw et al. 2009). While participant selection did not directly impact research results, it was motivated by the broader goals of the study. Those studies that made outcome goals explicit involved more stakeholders more intensely and reported more outcomes, such as decision support, increased capacity for a variety of adaptation and mitigation activities, and increased knowledge of climate impacts (Kok et al. 2006b; Shaw et al. 2009; Loibl and Walz 2010). This is likely because the participatory processes were structured and intended to generate additional outcomes beyond enhancing the scenarios.

Core Phase. Participation in core research activities varied across studies but all others made clear that stakeholder insights were critical to the core research phase. While some studies sought to build participatory processes from the ground up (Kok et al. 2006b) others affixed participatory activities to traditional scenario development processes (Shaw et al. 2009). Most projects used an iterative approach to stakeholder engagement, eliciting stakeholder input through interviews or workshops, conducting expert modeling and feeding back results in further workshops (Bryan et al. 2011; Loibl

and Walz 2010; Shackley and Deanwood 2003; Shaw et al. 2009). Kok et al. (2006) brought previously developed scenarios to stakeholders and the rest of the process was stakeholder-driven. Shackley and Deanwood (2003) began with consultative engagement but when stakeholders indicated that scenarios lacked saliency for decision making the research team collaborated with stakeholders to produce another, more salient scenario. This is an excellent example of the need for flexibility in participatory scenario processes to accommodate stakeholder insights. The specificity of reporting on the participatory process and results increases with the intensity of the collaboration. The reviewed studies indicate that strong participatory scenario development processes have core research activities structured to reflect their intended functions. For example, Kok et al. (2006) sought to improve local and regional responses to climate change impacts therefore they developed a stakeholder-centric process heavily focused on local knowledge. Across the studies a variety of media was used to engage stakeholders and integrate their input during engagement activities. The use of cognitive maps was associated with an increase in stakeholder capacity for systems thinking and/or understanding of climate impacts. In reviewing the core research phases of these participatory scenario studies it is evident that stakeholders can be involved in generating all types of scenarios at all phases in the research process including selecting scenario inputs, generating scenarios, and interpreting scenario results.

Effects. Results from the studies were presented in a variety of ways including narratives, maps, visual diagrams, computer simulations and quantitative indicators. The diverse and non-traditional media contribute to the saliency of the outcomes. However, only Kok et al. (2006) provided a stakeholder feedback survey in the report. The survey

indicated that stakeholders were largely happy with the process. Further confirmation of the saliency of the other projects is difficult given the lack of information. By all accounts the outcomes appear legitimate and were published in peer-reviewed journals, vetting their credibility, validity and reliability. In addition, most studies reported that the participatory processes increased communication and mutual learning between and among stakeholders and experts (Bryan et al. 2011; Loibl and Walz 2010; Shackley and Deanwood 2003; Shaw et al. 2009; Kok et al. 2006). Shaw et al. (2009) reported an increased intent to support adaptation and mitigation strategies resulting from the collaboration.

4. Discussion

In the climate change and sustainability discourses there is a need to determine how to conduct research that is more impactful. There are many claims that scenario studies need to be participatory in order to increase their impact. Participatory scenario studies were analyzed and evaluated because we believe that participation increases the efficacy of scenarios and scenario construction for decision-making. Nearly all studies claim that stakeholder engagement yielded some output related to increased capacity and decision support. Immediately following research activities such claims can be difficult to evaluate, however pre/post surveys such as that conducted by Kok and colleagues (2006b) could help determine the impact of participatory scenario construction.

Across the studies research results included broader outcomes in addition to the scenario outputs. This alone gives strong support to including stakeholders in the construction of climate scenarios as scenarios constructed without engaging stakeholders and published in scientific journals are not likely to yield any broader outcomes. There is

a need for stakeholder engagement in climate scenario studies from both the supply side (generating knowledge) and the demand side (using knowledge). On the supply side, as evidenced by some of the studies reviewed (Kok et al. 2006b, Bryan et al. 2011; Loibl and Walz 2010), stakeholders are important suppliers of local knowledge relevant for considering future impacts and possible responses. On the demand side, stakeholders will need to act in anticipation of or in response to climate impacts therefore require climate information that is directly relevant to their lives, as with Shaw et al. (2009) and Berkhout et al. (2002). While it might have been possible to generate similar scenarios without stakeholders, doing so could undermine the legitimacy of the results, anger residents (as with the Greenpeace scenarios in Spain) and might overlook critical impacts important to local stakeholders. The reviewed scenarios indicate clearly that additional benefits come from engaging stakeholders and while in the short term this may be difficult to observe, its certain the outcomes could not be generated *without* stakeholder engagement.

The results of the empirical comparison show that researchers tend to restrict the pool of potential stakeholders and often do not allow stakeholders to define the goals of their studies. While the justification for such tactics is clear – limited resources and funding for specific research objectives – the persistence of such approaches constitutes an instrumentalization of stakeholders to serve research priorities. Its possible that researcher and stakeholder interests align, but this cannot be known unless stakeholder interests are solicited before research objectives are imposed. To overcome this deficit stakeholders need to be involved in defining the goals of the research – or even further upstream in determining funding priorities through participatory budgeting, for example.

In addition to underserving stakeholders, by limiting stakeholder engagement in defining the broader research goals and process, its possible that critical insights and new perspectives are not captured – a disservice to the research.

5. Recommendations

We outline three recommendations for the National Climate Assessment or other national and international organizations coordinating climate change research. First, define and promote a framework for comparing participatory scenario processes, a prerequisite for making progress on participatory scenario processes. Such a framework allows research groups around the world to coordinate their efforts and utilize existing expertise and institutional capacity. The analytical-evaluative framework introduced and applied above could fulfill this role as it allows for transparently describing, comparing, and assessing the key components of participatory climate change scenario studies. This framework can be applied retrospectively but also and more importantly for designing participatory scenario studies.

Second, create an accessible repository of participatory scenario studies, including information on the scalability and transferability of different participatory scenario processes. Such a repository would, if updated regularly, provide state-of-the-art information to teams interested in creating or using climate change scenarios, and would facilitate comparative research. This repository would include a set of exemplary studies that display the use of diverse participatory processes, tools, and facilities. The set of exemplary studies should also include scenarios derived from different socio-economic drivers, emissions, impacts, and responses. A website could be the public-facing version

of the repository and would provide social networking functions and facilitate collaboration among researchers.

Finally, organize coaching and training workshops to help researchers and stakeholders develop competencies in conducting participatory scenario processes. In the long term, such efforts allow developing tools, resources, and capacity for scenario activities and real-world impact.

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7. Resources

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CHAPTER 3

Plausibility Indications in Future Scenarios

Abstract

Quality criteria for generating future-oriented knowledge and future scenarios are different from those developed for knowledge about past and current events. Such quality criteria can be defined relative to the intended function of the knowledge. Plausibility has emerged as a central quality criterion of scenarios that allows exploring the future with credibility and saliency. But what exactly is plausibility vis-à-vis probability, consistency, and desirability? And how can plausibility be evaluated and constructed in scenarios? Sufficient plausibility, in this article, refers to scenarios that hold enough evidence to be considered ‘occurable’. This might have been the underlying idea of scenarios all along without being explicitly elaborated in a pragmatic concept or methodology. Here, we operationalize plausibility in scenarios through a set of plausibility indications and illustrate the proposal with scenarios constructed for Phoenix, Arizona. The article operationalizes the concept of plausibility in scenarios to support scholars and practitioners alike.

1. Background and Purpose

Future scenarios, or consistent stories about possible future states or pathways, have been used with increasing frequency over the last 50 years to consider how systems too complex to predict might evolve over time (Swart et al., 2004). In this capacity, scenarios are constructed for different time frames (e.g., in 10 years, or in 1,000 years), for different spatial scales (e.g., neighborhoods, or the world), for different systems (e.g., nanotechnology innovation, or water management), and for different purposes (e.g. to provide inputs for modeling and simulation, or to build capacity among decision makers) (Wiek et al., 2006). Constructing scenarios has become a prominent way to generate future-oriented (anticipatory) knowledge.

Unlike knowledge about past events or observable phenomena in the present, knowledge about the future is ‘non-verifiable’ in the conventional sense (Pereira et al., 2007). Yet, anticipatory knowledge can be evaluated for its subjective probability, or the estimated likelihood that the given future will occur. It is important to recognize the function and rationale behind such predictive knowledge – it is mainly used to prepare strategies for one or few future states that are deemed most likely to occur (Armstrong, 2006). Scenarios often address complex issues and systems with numerous interacting elements and non-linear dynamics, for which probability values are difficult to determine (Miller, 2007). Perhaps more importantly, even if these scenarios could be assessed for probability, this could be an irrelevant criterion if their function is not to predict events (Robinson, 2003). Their function could be preparation for a variety of future states, including some that have low probabilities. Also, when it comes to complex and urgent problems, such as those addressed in sustainability science, the predictive capacity of

scientific information may be of limited use if immediate decisions need to be made before science can deliver robust predictions.

Thus, two additional quality criteria for future-oriented knowledge were suggested, in particular considering the relevance of future knowledge that aims to invent and influence rather than predict the future (Brewer, 2007). First, a prominent concept suggests that scenarios ought to be consistent, preferably not holding internal conflicts, which could undermine coherent planning and decision-making (Scholz and Tietje, 2002; Tietje, 2005; Wiek et al., 2006). This criterion has been developed in different concepts and methodologies such as morphological analysis (Ritchey, 2006), cross-impact balance analysis (Weimer-Jehle, 2006), and formative scenario analysis (Scholz and Tietje, 2002; Wiek et al., 2009). It is based on the general idea of compatibility – consistent scenarios are those in which all future projections ‘fit to each other’ (independent of whether they are more or less likely to occur). Second, scenarios can also be evaluated against or constructed by employing the normative criteria of desirability (or undesirability). Desirability can be determined through structured assessments, subject to explicit subcriteria, or intuitively, e.g., through stakeholder input as to which scenarios, or aspects thereof, are desirable and why (Nijkamp and Vreeker, 2000; Sheate et al., 2008). Visioning, as the construction of desirable future states (visions), has emerged in different fields from urban planning to technology studies and sustainability science over the last decade (Shipley, 2002; Wright, 2010; Wiek and Iwaniec, in press). Desirability is a powerful feature of future-oriented thinking and can be employed using methods such as normative scenario construction or backcasting to create direction for action (Robinson, 2003; Swart et al., 2004). The function and rationale of such normative scenarios is quite

different from the ones mentioned above; here, the function is less preparation than actively pursuing a future that is deemed most desirable. It is important to note that all quality criteria are assessed under current patterns of reasoning; and these patterns might change over time.

Plausibility as a quality criterion has been discussed since the criterion of probability was put forward (e.g., Schoemaker, 1995); some even argue that there is little difference between the two (Tversky and Kahneman, 1973; Morgan and Keith, 2008). So far, the literature remains ambivalent and opaque as to what exactly plausibility entails compared to the described features of probability, consistency, and desirability of scenarios (e.g., Gausemeier et al., 1998). Even less clear is how one can evaluate the plausibility of scenarios and construct plausible scenarios. This article begins by proposing a pragmatic concept of plausibility criteria, separated from, yet connected to, the other criteria mentioned above, through a set of plausibility indications. We then illustrate the proposal with a case study on scenarios constructed for the city of Phoenix, Arizona. The article concludes by discussing how the pragmatic concept can be used by scholars and practitioners alike. The plausibility indications proposed in this article are intended for use in constructing and evaluating scenarios. Plausibility claims should be evaluated in similar ways as probability scores for predictive scenarios. Outside academia, providing arguments for the plausibility of improbable scenarios is important for establishing legitimacy with decision-makers. The plausibility indications provide a line of argument for why improbable scenarios can nevertheless be plausible and therefore worthy of consideration.

2. Plausibility and Probability

In November 2009, an international conference on plausibility was held at Arizona State University, sponsored by the Consortium for Science, Policy and Outcomes (Selin and Wiek, 2009). Scholars in future studies and futurists discussed a variety of plausibility concepts and applications of plausibility in practice, particularly in scenario studies. Definitions of plausibility have ranged from the abstract and immeasurable, ‘having intuitive logic’, to the narrow and measurable, “how far we go into the tails of the distribution” (Breuer et al., 2009). On the intuitive side of the spectrum plausibility is a breaking free from the epistemic confines of probabilistic future thinking (without necessarily disregarding it). Here, the space opened by plausibility is one of creativity and exploration, while scientific rigor is ensured through other quality criteria. On the positivist side, plausibility is a moderate extension of probability – an exploration of the standard deviation to accommodate the uncertainty inherent in ever more complex and sophisticated models of the future.

Despite continued controversy over the ties (or lack thereof) between plausibility and probability of scenarios, the relatedness of these concepts is evident in habitual language use. Dictionaries appeal to terms such as ‘reasonable’, ‘probable’, or ‘believable’ to define plausible, while probable is defined by phrases such as “likely to be or become true or real” and “likely to be the case or to happen” (Merriam Webster Dictionary). While some scholars argue for a rigid distinction, for instance, between scenarios and forecasts (Wilkinson, 2009; Ramírez et al., 2010), others see a productive relationship between plausibility and probability of scenarios (Millett, 2009). Morgan and Keith (2008, p.196), for example, assert: “The literature on scenarios often aims to make

a sharp distinction between scenarios and forecasts or projections; for example, it is asserted that scenarios are judged by their ‘feasibility’ or ‘plausibility’ rather than their likelihood. We cannot find any sensible interpretation of these terms other than as synonyms for relative subjective probability. Absent a supernatural ability to foresee the future, what could be meant by a statement that one scenario is feasible and another infeasible but that the first is (subjectively) more probable than the second?”

Following this proposal, scenario plausibility is correlated with scenario probability, however, without being identical. In other words, if a scenario is deemed highly probable, it follows that the scenario will also be considered highly plausible. However, in reverse, plausibility does not require the explicit assignment of probabilities. In fact, the rationale of plausibility is quite different from the one developed for probability, as outlined above. In both cases, the function is getting prepared for the future, but plausibility is not primarily focused on only the future states deemed most likely to occur; instead, plausibility seeks to prepare for a variety of future states that are considered ‘occurable’ (could happen), explicitly including some that are not the most likely ones. For example, the 2011 overthrow of Hosni Mubarak’s regime in Egypt could have been considered plausible, though improbable, prior to the actual event. A sufficient level of plausibility could have been established by meeting several of the plausibility indications identified in the following section, most prominently, that similar events have occurred in the past under comparable circumstances (plausibility indication 1). Though this is a retrospective evaluation of plausibility, the downfall of Mubarak’s regime was plausible prior to the time it occurred because it satisfied this indication then.

Probabilistic futures are given probability values for the purpose of determining the likeliness of occurrence. This works best for simple systems, with short time horizons, where there is ample opportunity for feedback and iteration to improve the accuracy of the predictions (Sarewitz and Pielke, 1999; Armstrong, 2006). On the contrary, plausible futures often strive for the opposite – to explore futures which are improbable (or unlikely) but could still occur (Mahmoud, 2009) and where predictive capacity is limited due to high uncertainty from systemic and temporal complexity (Swart et al., 2004). Some situations warrant an approach that considers a range of plausible scenarios while others require narrow predictions. There is a place for both probability and plausibility in future studies and the two can be complimentary. For example, Superstorm Sandy hit the East Coast of the USA in October 2012 causing an estimated \$50 billion in damages (Cuomo, 2012). Probability-based weather forecasts predicted a few days in advance where the storm would hit, wind speeds, rainfall totals, and storm surge, with a great deal of accuracy. Before the storm made landfall, officials directed human and financial resources to those areas predicted to be worst hit. A range of plausible futures for Sandy’s path would have made this early preparation and timely response difficult. However, emergency response to Sandy was swift and effective because the Federal Emergency Management Agency (FEMA) was ready for such an improbable storm. After the experiences with Hurricane Katrina, FEMA began workshops with federal, state, local, and business actors to develop scenarios and response strategies to a range of improbable but plausible future scenarios. The report “Crisis Response and Disaster Resilience 2030: Forging Strategic Action in an Age of Uncertainty” was published in 2010. An event such as Sandy could not be considered in

long-term future scenarios if those scenarios were evaluated for their probability – because the likelihood of such a storm is far too low. However, in disaster preparedness, future scenarios need to consider response capacity for a range of plausible but improbable futures in order to have in place all mechanisms necessary for effective response when disaster strikes.

3. Plausibility Indications

We propose a pragmatic definition of plausibility that builds on the futurist quote, “the future is already here — it’s just not very evenly distributed” (Emery, 1977).

Plausible scenarios are composed of elements that are to a sufficient degree grounded in what we consider ‘real’. In other words, sufficient plausibility is the quality of a scenario to hold enough evidence to be qualified as ‘occurable’, i.e., to become real, to happen.

Following the reference above, an initial indication for plausibility is if a future scenario is based on elements that are already ‘here’, even if not everywhere (‘not very evenly distributed’). This approach has been operationalised in scenario construction and forecasting, for instance through ‘structured analogies’ (Armstrong, 2006). A similar concept has been developed for future visions, i.e., desirable or normative future states, by Wright (2010) and adopted by Wiek and Iwaniec (2013).

Following this basic idea, we can initially differentiate three indications of plausibility:

1. The scenario or scenario element occurred in the past. For example, lush gardens in South Phoenix, Arizona from the late 1800s are now discussed as future scenarios for South Phoenix and other parts of the city. This plausibility indication requires that similar systemic circumstances exist between the past in

- which the scenario or element occurred and the present or future into which it is being projected.
2. The scenario or scenario element is currently present; yet, it occurs at a different location (somewhere in the world). In order to indicate plausibility, however, reasonable transferability needs to be demonstrated. For instance, the cycling culture in some Dutch cities provides the base for plausible future scenarios, as there are striking similarities to some US cities (e.g., previous car dependency), which are currently widely overlooked (Miller, 2011). This plausibility indication requires that similar systemic circumstances exist between the different location and the location into which the scenario or scenario element is being projected.
 3. The scenario or scenario element is supported by a proof of concept. For example, many technology scenarios are not yet realised, but pre-tested through concepts, prototypes, and other forms of initial evidence before they are deployed or distributed. This plausibility indication has been operationalised, for instance, in the concept of ‘The Seven Horizons’, that indicates stages of development, from early speculation through theoretical and applied research to on-market applications (<http://www.sevenhorizons.org>).

These three categories of plausibility indications can further be differentiated and ordered from the minimum threshold for plausibility to maximum evidence of plausibility:

1. the scenario or scenario element is theoretically ‘occurable’ as evidenced by early warnings, soft signals (review process), or theoretical insight;
2. the scenario or scenario element has occurred in the past under different framing conditions (social, economic, cultural, environmental circumstances);

3. the scenario or scenario element currently occurs elsewhere in the world, under different framing conditions;
4. the scenario or scenario element currently occurs elsewhere in the world, in a location with similar framing conditions;
5. the scenario or scenario element has occurred in the past (at the same location), under comparable or similar framing conditions;
6. the scenario or scenario element does currently exist at the same location (trend extrapolation).

In order to assess the plausibility of future scenarios, the individual scenario elements are evaluated against these six indications. The plausibility appraisal provides information on:

1. the plausibility of the individual elements
2. to what degree each element contributes to the plausibility of the entire scenario
3. the plausibility of the scenario in totality.

Those scenarios deemed highly plausible have the majority of their elements meeting Plausibility Indication 6, with no element failing to meet the minimum plausibility threshold (Indication 1). For spatially explicit scenarios, such as that presented in the case study below, it is necessary for most scenario elements to reach at least Plausibility Indication 4 as similar system conditions are necessary for transferability of scenario elements across space and time. If any scenario contains one or more elements that do not meet the minimum indication (1), the entire scenario is considered implausible. To conduct the plausibility appraisal the following resources are needed:

- the elements that make up each scenario

- information on the origin of each scenario element
- information on historical cases and present cases.

In addition, the original consistency analysis for each of the scenarios is needed, because it allows aggregating from the plausibility appraisal of individual scenario elements to the plausibility of the entire scenario. While all consistent scenarios are not plausible, in order to be plausible a scenario must be consistent. A consistent scenario is one in which all scenario elements ‘fit together’ (Tietje, 2005), and the occurrence of any scenario element does not make impossible the occurrence of any other element. If a consistency analysis was not performed during the scenario construction, a retrospective consistency analysis can be completed prior to the plausibility appraisal (Schweizer and Kriegler, 2012).

4. Case Study: Plausibility Appraisal of Scenarios for Phoenix in 2050

In order to illustrate the plausibility appraisal proposed above, we apply the set of plausibility indications to scenarios that were developed for Phoenix, Arizona in 2050 (Thompson et al., 2012; Wiek et al., 2012). These scenarios are supposed to represent three distinctly different and plausible futures of Phoenix, in which no specific effort is made to achieve the sustainability vision that was developed by stakeholders and researchers in tandem with the scenarios (Wiek et al., 2012). Two of the authors (A.W., L.W.K.) were investigators on the project. We present below a plausibility self-assessment that utilises the information available to the investigators, allowing for an exemplary application of the plausibility indications.

The scenarios were constructed as part of a multi-year long research and teaching project at the School of Sustainability at Arizona State University (internally funded).

The purpose of the scenarios was to inform the update of the General Plan for the City of Phoenix, the overarching planning document that is updated every 10 years. For more details on the study consult: Thompson et al. (2012) and Wiek et al. (2012). The study applied an advanced form of the formative scenario analysis methodology (Scholz and Tietje, 2002; Tietje, 2005; Wiek et al., 2006, 2009). The construction process included:

1. criteria-based selection of variables
2. development of future projections, primarily based on existing trend and scenario studies (see next paragraph)
3. consistency analysis to ensure internal compatibility among future projections
4. scenario selection based on consistency and diversity indices, in particular, contrast to the sustainability vision 5 scenario interpretation, narrative construction, and visualization.

The scenarios were based on variables and projections derived from existing future studies on the Phoenix metropolitan area or aspects thereof. The selection focused on those variables deemed critical to stakeholders in the development of the sustainability vision. Variables from the vision were included even if they did not have corresponding variables in existing future studies. The study was based on the (contestable) assumption that the future knowledge landscape, represented in existing scenario studies and future-oriented public discourses, lends plausibility to the scenarios.

For illustrative purposes a single scenario, of the three, was selected for the plausibility appraisal below. Future projections were appraised for their compliance with the six plausibility indications introduced above. Table 1 summarizes the plausibility of all future projections that were used in the Phoenix scenario study, while Table 2

summarizes the plausibility of only those future projections that were included in one of the resulting future scenarios – the Phoenix Overwhelmed scenario.

Table 4

Plausibility Appraisal of all Future Projections in the Phoenix Scenario Study

Indicator	Future Projection	Theoretically Occurable	Occurred in past - different conditions	Occurs elsewhere - different conditions	Occurs elsewhere - similar conditions	Occurred in past - similar conditions	Trend extrapolation
Educational attainment	Decline						
Educational attainment	Constant						
Educational attainment	High levels						
Electricity production by	Renewable sources 15%						
Electricity production by	Solar and wind 100%						
Intergovernmental relations	Some inter-city cooperation						
Intergovernmental relations	Strong inter-city cooperation						
Citizen satisfaction and trust	Stable						
Citizen satisfaction and trust	Improved						
Citizen satisfaction and trust	Decreased						
Cityscape	Expansion slows; urban growth downtown						
Cityscape	Expansion slows; urban growth distributed						
Cityscape	Expansion slows; urban growth in distributed cores						
Cityscape	Expansion continues and density remains constant						
Access to suitable employment	High income/skill jobs increase; low income/skill						
Access to suitable employment	Job accessibility remains constant						
Access to suitable employment	High income/skill jobs decrease; low income/skill						
Public engagement	Increase						
Public engagement	Constant						
Public engagement	Decrease						
Neighborhood Social Cohesion	Pockets of social cohesion with high issue variance						
Neighborhood Social Cohesion	Wide-spread social cohesion with high issue						
Neighborhood Social Cohesion	Wide-spread social cohesion with low issue						
Urban trees and shade	Constant						
Urban trees and shade	Increase						
Walkability	Increase						

Table 4 continued

Plausibility Appraisal of all Future Projections in the Phoenix Scenario Study

Indicator	Future Projection	Theoretically Occurable	Occurred in past - different conditions	Occurs elsewhere - different conditions	Occurs elsewhere - similar conditions	Occurred in past - similar conditions	Trend extrapolation
Walkability	Constant						
Walkability	Decrease						
UHI	UHI stabilizes						
UHI	UHI (high increased) by 3-5 degrees F						
Sustainability in City Government	High priority						
Sustainability in City Government	Low priority						
Transportation	Travel miles increase, most by car						
Transportation	Travel miles increase most by mass transit						
Transportation	Travel miles decrease						
Population size and age	3.8 million; 12% over 65						
Population size and age	2.8 million; 16% over 65						
Racial and ethnic relations	High integration						
Racial and ethnic relations	Limited integration						
Waste	Recycling rate at 40%; some composting						
Waste	Recycling rate at 20%; landfill management						
Waste	Recycling rate at 20%; landfill management not						
Water consumption	Rationing of groundwater						
Water consumption	No rationing of groundwater						
Business-scape	Small and medium businesses thrive; new big						
Business-scape	Small and medium businesses thrive; no new						
Business-scape	Small and medium businesses struggle; no						

Table 5

Plausibility Appraisal of the Phoenix Overwhelmed Scenario

Future Projection	Theoretically Occurable	Occurred in past - different conditions	Occurs elsewhere - different conditions	Occurs elsewhere - similar conditions	Occurred in past - similar conditions	Trend extrapolation
Educational attainment - Decline						
Renewable energy - 15%						
Inter-city cooperation - Some						
Satisfaction and Trust - Decrease						
Development - Constant						
Jobs - High income/skill jobs decrease; low income/skill jobs increase						
Public engagement - Decrease						
Social Cohesion - Some with high issue variance						
Tree and shade - Constant						
Walkability - Decrease						
UHI - Increased 3-5 degrees F						
Sustainability - High priority						
Travel miles - increase with car and mass transit						
Population - 3.8 million; 12% over 65						
Racial and ethnic intergration - Limited						
Waste - 20% recycled, landfill not adequate						
Water - No rationing of groundwater						
Business-scape - Small and medium struggle; big business ok						

For this appraisal we have considered that the scenario was initially selected because of its high consistency values, according to a consistency analysis conducted in the original study. Therefore, the future projections appraised here, if plausible individually, are also plausible in the scenario context. The Scenario Phoenix Overwhelmed describes a future state in which living conditions in the City of Phoenix have deteriorated significantly in 2050, compared to the current conditions in 2010.

Projections in this scenario exhibit varying degrees of plausibility (Table 2). For example, the scenario projects that the urban heat island will increase by 3– 5 degrees by 2050. This is a trend extrapolated from observed temperature increases in Phoenix since the 1970s and therefore meets the highest plausibility indication (6). The scenario also projects that sustainability is a high priority in planning and policy-making at the City of Phoenix. While this has not been the case in Phoenix it has been the case in number of comparable cities in the USA over the last couple of years, including Denver, Colorado and Austin, Texas; therefore, this projection meets Plausibility Indication 4 (occurs elsewhere under similar conditions). Based on the appraisal, this scenario is deemed highly plausible with each of the projections at least meeting Plausibility Indication 4, and half the projections meeting Plausibility Indication 6.

5. Discussion and Conclusions

This article introduces a pragmatic concept of scenario plausibility, separated from, yet connected to, the criteria of probability, consistency, and desirability, through a set of plausibility indications. Each criterion either fulfills a somewhat different function, or is based on a somewhat different rationale. For instance, while probability and plausibility both aim at providing information that helps us to prepare for an uncertain future (multiple future states), probability suggests focusing on the few future states that are most likely to occur, while plausibility suggests to explore a broader range of future states that are deemed ‘occurable’ (even if not very likely). Whether probability, consistency and desirability are necessary or sufficient conditions for plausibility warrants further discussion.

As stated above, highly probable scenarios are considered plausible. Yet, less probable scenarios can still be plausible if they are theoretically ‘occurable’ (the minimum indication introduced above). So, high probability seems to be a sufficient (highly probable scenarios are plausible), yet not a necessary condition for plausible scenarios (some plausible scenarios are not highly probable).

As also indicated above, plausible scenarios are considered consistent (internal inconsistencies would make a scenario implausible). Thus, consistency is necessary for plausibility (all plausible scenarios need to be consistent). Yet, consistency is not a sufficient condition for plausibility (consistent scenarios can be implausible). This has two reasons: first, consistency does not predicate ‘empirical evidence’ (how grounded a scenario is in reality, as defined through the plausibility indications above); second, if applied to complex systems, consistency analysis might not capture all factors relevant for influencing future outcomes, which is an inescapable problem for scenario studies of open (not closed) systems (Rotmans and Dowlatabadi, 1998). Finally, desirability is neither necessary nor sufficient for plausibility, but it might still be an indirect positive indicator for plausibility. The reason is that stakeholders and decision makers are more likely to strive to realize a desired future (Wiek and Iwaniec, in press); yet, this cannot be taken for granted.

We have illustrated the proposed plausibility concept with a case study on scenarios constructed for the city of Phoenix, Arizona. We can derive several insights from this initial appraisal. First, the assumption that an existing future knowledge landscape, represented in existing scenario studies, lends plausibility to scenarios to be constructed is indeed contestable. The plausibility appraisal highlights several scenario

elements (future projections) of low plausibility. However, this does not suggest these elements should be excluded, as plausibility does not follow a similar logic like probability. It suffices for an element to be considered if it is plausible, even if the plausibility indication is low (1 or 2). In fact, these might be some of the elements that are of particular interest to be included in a scenario, as wild cards, for example (Van Notten et al., 2005). Second, the application demonstrates that a great deal of contextual information is necessary to determine the level of plausibility for each element of a scenario. Finally, the study illustrates a transparent scheme to represent plausibility indications in scenarios; thereby, it provides a way forward to facilitate redesign of scenarios from the perspective of plausibility, similar to re-analysis of scenario consistency as developed by Schweizer and Kriegler (2012).

While the article charts a way forward to utilize the promising yet vague idea of plausibility in scenarios by means of a pragmatic concept, future research is needed along several trajectories: First, there is the need for further shaping and operationalizing the proposed concept, linking it to similar methods such as structured analogies, and also developing it into a full methodology with clear (participatory) procedures and mechanisms for review. Second, more and in-depth empirical applications are required to demonstrate the applicability of the concept to a variety of cases (spatially-explicit ones and not spatially-explicit ones). Following Armstrong (2006), as with any future-oriented research method, there is the need to thoroughly evaluate the proposed plausibility concept and provide empirical evidence that the results are ‘better’ with respect to the defined function than when using other approaches. And finally, the concept needs to be tested not only for appraising plausibility in existing scenario studies, but also for

constructively designing plausibility in scenarios, as part of an extended scenario construction methodology.

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7. Resources

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Notes

1 To clarify, examples of subjective, or Bayesian, probability judgments include betting odds for the performance of teams in sporting events or projected winners for elections. This can be contrasted with frequentist, or classical, probability, which is the likelihood of something like a fair die roll (i.e., something that can be observed given enough repeated events). For further discussion, see Chapter 4 of Morgan and Henrion (1990).

CHAPTER 4

A Comprehensive Sustainability Appraisal of the Water System in Phoenix, Arizona

Abstract

In Phoenix, Arizona and other metropolitan areas, water governance challenges include variable climate conditions, growing demands, and continued groundwater overdraft. Based on an actor-oriented examination of who does what with water and why, along with how people interact with hydro-ecological systems and man-made infrastructure, we present a sustainability appraisal of water governance for the Phoenix region. Broadly applicable to other areas, our systems approach to sustainable water governance overcomes prevailing limitations to research and management by: employing a comprehensive and integrative perspective on water systems; highlighting the activities, intentions, and rules that govern various actors, along with the values and goals driving decisions; and, establishing a holistic set of principles for social-ecological system integrity and interconnectivity, resource efficiency and maintenance, livelihood sufficiency and opportunity, civility and democratic governance, intra- and inter-generational equity, and finally, precaution and adaptive capacity. This study also contributes to reforming and innovating governance regimes by illuminating how these principles are being met, or not, in the study area. What is most needed in metropolitan Phoenix is enhanced attention to ecosystem functions and resource maintenance as well as social equity and public engagement in water governance. Overall, key recommendations entail: addressing interconnections across hydrologic units and sub-systems (e.g., land and water), increasing decentralized initiatives for multiple purposes

(e.g., ecological and societal benefits of green infrastructure), incorporating justice goals into decisions (e.g., fair allocations and involvement), and building capacity through collaborations and social learning with diverse interests (e.g., scientists, policymakers, and the broader public).

1. Introduction

Research on water resource governance has been limited in scope, synthesis, and integration both broadly and in our study region of Phoenix. Although numerous studies have been conducted in Arizona and the Phoenix area, for instance, they focus on particular segments of the water system (e.g., infrastructure; Pulwarty et al., 2005), components of governance (e.g., water conflicts; Bolin et al., 2008), or elements of sustainability (e.g., safe yield; Gober et al., 2010). Few studies address the entire water governance regime with a comprehensive, actor-oriented perspective (Wiek and Larson, 2012). Yet such studies provide an overall account of the sustainability of water governance regimes, thereby promoting innovation and reform (Quay, 2010). To address these gaps and aims, our holistic appraisal poses the following questions in metropolitan Phoenix:

1. How and why do various actors use, impact, and otherwise interact with hydro-ecological and technological systems in carrying out water governance activities?
2. How does the current water governance regime adhere, or not, to a comprehensive set of sustainability principles?

We focus on Phoenix, Arizona because of the challenges faced by this region, which are similar to other arid and growing cities. In addition, much research has been conducted on specific water issues in the area, thereby allowing a synthesis of previous research in our comprehensive appraisal. Boundary work across the science and policy spheres is also underway in the area, and thus, our appraisal advances collaborative decision-making and the regional dialogue on sustainability. Though we examine metropolitan Phoenix in particular, the approach is applicable to other regions around the

world, especially urban and urbanizing ones. Finally, the framework we employ can facilitate comparative assessments across regions.

Building upon proposals to integrate actor-oriented perspectives with system dynamics (Binder et al., 2004), we apply a recently developed framework for evaluating sustainable water governance (Wiek and Larson, 2012). The holistic approach focuses on what people do with water and why. We especially consider the people affecting and affected by the water system, who in turn are responsible for its viability and integrity as *governance actors* (Ludwig, 2001; Ostrom, 2009). Beyond considering socio-political dynamics, our analytical and normative goals involve 1) examining interactions between actors and biophysical and technological systems, and 2) assessing water governance sustainability with an integrated set of principles.

The Wiek and Larson (2012) framework extends Ostrom's (see 2011 review) institutional framework and the broader social–ecological systems approach by focusing on various actors and action situations, including the social rules governing decisions and their interactions with biophysical resources. The approach adds to Ostrom (2011) and other actor-oriented frameworks (e.g., Pahl-Wostl et al., 2010) in that we detail the major interacting activities (or action situations) involved with water decisions specifically (i.e., supplying, distributing, using, and discharging water, along with activities that cut across those activities). The framework also follows Pahl-Wostl et al. (2010) by focusing on actions, rules (institutions), and social–ecological–technological interactions. Although the approach could be coupled with transitions frameworks (e.g., Brown et al., 2009) as well, we focus primarily on how water-specific actors and activities intersect with ‘layered’ biophysical and technological resources. Uniquely, our holistic approach

outlines assorted water resource activities and decisions in relation to an integrated set of sustainability principles drawn from Integrated Water Resource Management (IWRM) and similar work (e.g., Mitchell, 2005, 2006).

Given our actor-oriented approach, we define *sustainable* water governance as *the decision processes of stakeholders who influence and are impacted by activities involving water supplies, deliveries, uses, and outflows in ways that ensure a sufficient and equitable level of social and economic welfare without compromising the viability and integrity of supporting hydro-ecosystems now and into the future* (Wiek and Larson, 2012). This definition draws on broader views of governance as a wide range of social, political, economic and administrative interactions (Pahl-Wostl et al., 2010), inclusive of actors in both the public and private sectors (Peters and Pierre, 1998; Stoker, 1998). Due to space limitations, we cannot fully detail all the complexities and challenges associated with the numerous issues, actors, goals, and rules of urban water governance. Instead, the goal is a broad-based, qualitative synthesis and appraisal that informs actions and interventions to transform the Phoenix-area water system toward sustainability *as a whole*. Aligned with this purpose, we first establish the integrated, systems framework, and second, describe the general principles used to assess water resource sustainability (see Wiek and Larson, 2012 for more details on the general approach). Next, we synthesize the water governance activities and system dynamics in metropolitan Phoenix and then explain the extent to which the region is meeting (or not) the principles employed in this appraisal. We conclude with discussing recommendations and challenges to sustainable water governance.

2. Conceptual Approach

The first part of our framework explains water systems by focusing on key governance activities, relevant actors and institutions (at the core of the social system), and how they interface with biophysical and technological systems. The second part outlines an integrated set of water principles.

2.1. Integrated analysis of regional water governance systems

The systems approach centers on what people are doing with water, in addition to how water is circulating through the social–ecological–technological system (Pahl-Wostl et al., 2010). Applied to a particular system or place, these “doings” broadly include supplying and extracting, treating and distributing, using and conserving, and reusing and discharging water, plus cross-cutting activities spanning them (e.g., planning). In applying the framework, the following considerations are delineated: 1) the scope or scale of the system (i.e., boundaries); 2) core water resource decision domains (i.e., activities), and 3) how the associated actors affect and are effected by social institutions as well as the hydro-ecological and technological systems (i.e., cause–effect structure; Wiek and Larson, 2012).

First, the *Boundaries of the Regional Water System* must be defined. Regional water systems can be delineated in different ways geographically, focusing on biophysical units (e.g. ecosystems or watersheds) or social ones (e.g. local and state to federal and international territories). Regardless of the scope, cross-scale interactions are critical considerations for any sustainability appraisal (Pahl-Wostl et al., 2010). In our appraisal, we focus on the greater Phoenix area since this is the primary scale at which water is hydrologically and legally connected (Jacobs and Holway, 2004). Throughout this paper,

references to Phoenix encompass the entire metropolitan region including numerous municipalities, tribal lands, farmland and relatively rural areas, unless “The City of...” denotes a particular municipal government. Additional studies might delineate watersheds, political units, or other scales in their analyses, depending on the specific intent and other logistics.

Second, the *Activity Domains* outline the basic aspects of what people do with water. These activities reflect a broad understanding of major water resource decision arenas (e.g., supplies versus demands) and input from stakeholders (see Methods section, plus Wiek and Larson, 2012). With an input–output oriented view on how water flows through the system, we distinguish among interconnected but distinctive sectors of activities:

- i) *Supplies*: how water is obtained, stored, allocated, diverted and managed technologically, institutionally, and otherwise from various sources.
- ii) *Deliveries*: how water is distributed, treated, and delivered to end users through engineered and natural infrastructure as well as social institutions.
- iii) *Demands*: how people consume and conserve water for various purposes among households, businesses, and governments, in addition to ecosystems.
- iv) *Outflows*: how water and sewage is transported, treated, and dealt with after use, including immediate reuse (as effluent, or treated wastewater), groundwater recharge, or discharge back into the hydro-ecological system.
- v) *Cross-cutting*: how policy and administration, research and assessment, and civic participation and advocacy span and influence the above activity domains. Although cross-cutting activities pertain to all four domains, this category is important for

representing activities that span arenas and address system interconnections, as recommended for integrated water management (Mitchell, 2005, 2006).

Finally, *the Systemic Cause–Effect Structure* details the actors and drivers of activities, along with their outcomes and interactions with various components of the water system (Kallis et al., 2006). Building on Ostrom (2011) and Pahl-Wostl et al. (2010), the assessment provides information on *actors and their guiding intentions and rules*. For each activity, we identify the individual and group actors (private and public) involved in water resource decision making to understand how they interact with (i.e., influence or are impacted by) other actors and institutions (social system), hydrological resources and ecosystems (ecological system), and human infrastructure (technological system) (i.e., as *system interfaces*; Pahl-Wostl, 2007; Pahl-Wostl et al., 2010). Each the social, ecological, and technological sub-systems constitutes a distinctive ‘layer’ in water systems. A fourth layer—*perturbations*—is also critical since actors must cope with stressors to the system (Fig. 1; Wiek and Larson, 2012).

- a. *Social Actors*. Various individuals and organizations undertake activities and make decisions about how water is supplied, distributed, used and treated throughout water systems. Depending on societal goals and rules, government and non-government entities build, use, alter, manage and otherwise impact infrastructure while influencing earth system processes and ecosystem dynamics. Both networks of actors and societal institutions potentially facilitate and constrain activities (Pahl-Wostl, 2002; Pahl-Wostl et al., 2010). Guided by particular intentions or barriers (including perturbations; see below), both formal and informal institutions—respectively including *codified* rules, laws, policies,

- and mandates as well as *unwritten* social norms, expectations, and customs—must be considered in determining peoples' actions and interactions across system components (Mitchell, 2005; Ostrom, 2011).
- b. *Ecological Resources*. Water activities rely on and impact the natural environment, including the basic elements of earth systems. The physical water resources on which life depends interact within and across these spheres based on: hydrological dynamics involving surface and underground water; terrestrial processes pertaining to soils and land use/cover; ecosystem dynamics encompassing vegetation and wildlife; and climatic processes including drought and environmental change, among other system interactions (Wiek and Larson, 2012).
 - c. *Technological Infrastructure*. Water activities involve creating and maintaining man-made infrastructure and facilities, including: extraction and retention facilities (e.g., dams) for supplying water; canals, pipes, and pumps for distributing water; human infrastructure (e.g., pools, fountains, low-flow appliances) affecting water demands; and the treatment facilities involved with cleaning water and managing outflows (Wiek and Larson, 2012). Considering the transition from a “water supply city” to a “water sensitive city” (Brown et al., 2009), human-built infrastructure encompasses traditional ‘gray’ elements (e.g., dams and canals) as well as ‘green’ ones (e.g., created wetlands and retention ponds).
 - d. *Perturbations* influence actors and activities as potential stressors or disturbances to the system, or as barriers or constraints to particular decisions (Wiek and

Larson, 2012). Critical perturbations involve climate and other environmental changes, along with shifts in growth and migration as well as modifications in regulations or policies governing regional decisions (Gober et al., 2011; Overpeck and Udall, 2008).

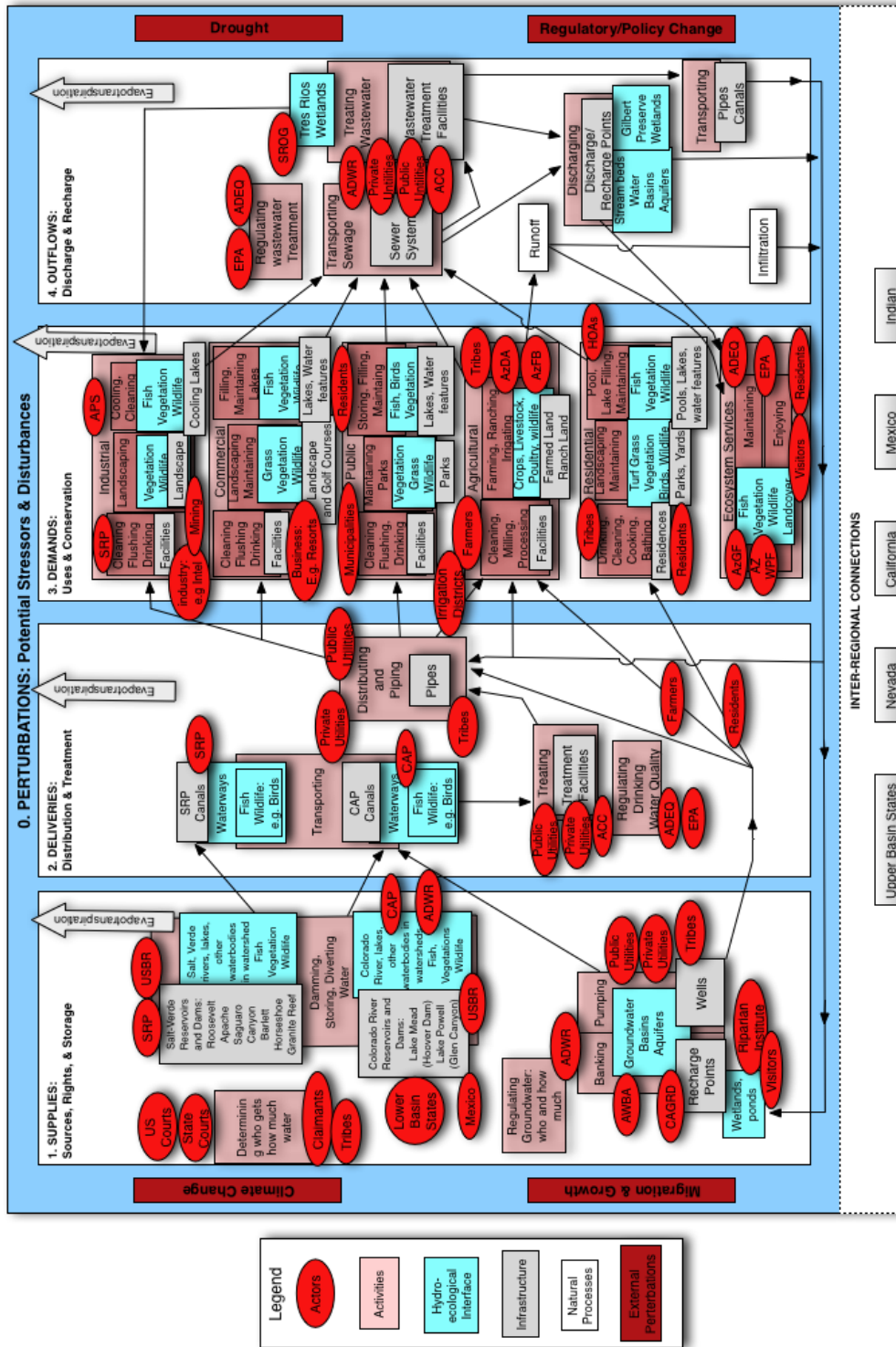


Figure 4. Water governance information system. Organized by activity domains, the diagram highlights key actors in red circles along with intersecting hydrological and ecological resources in blue boxes and human infrastructure in gray boxes. More specific key activities are denoted by gerunds in tan boxes, and arrows imply pathways and interconnections between various water resource activities and supporting natural or technological processes.

The information gathered on system dynamics can be represented in a layered manner, wherein the interfaces are the intersecting layers on which actors and activities depend (Fig. 4), and which in turn are affected or altered by them (Wiek and Larson, 2012).

2.2. Sustainability principles for water governance

The appraisal is based on a set of principles for water governance (Table 1), which were derived from literature on integrated water management (e.g., Mitchell, 2005, 2006; Brown et al., 2009; Pahl-Wostl et al., 2010) and sustainability broadly (e.g., especially Gibson, 2006; Ostrom, 2009). Seven principles—each with more precise specifications, or sub-principles—were compiled through iterative discussions among the research team, interviews with experts (see below), and applications to this and other cases (Wiek and Larson, 2012). While each principle is distinctive, they do overlap and affect each other due to intersecting system elements operating in the face of multiple criteria.

1. The principle of *social–ecological system integrity* demands balancing anthropocentric needs and uses of water with those of ecosystems (Gibson, 2006; Mitchell, 2006) by: maintaining or restoring minimum stream flows for wildlife and riparian areas; preserving or enhancing the quality of water through pollution prevention and mitigation; ensuring aquifers are not taxed to points of instability (e.g. land subsidence); and, recognizing and coordinating resource uses and impacts within hydrologic units such as watersheds and groundwater basins (Mitchell, 2005).
2. The principle of *resource efficiency and maintenance* stresses getting the greatest benefit from using as little water as possible while minimizing excessive uses (efficiency) and avoiding irreversible actions or outcomes (maintenance) (Gibson, 2006). This involves: reducing water use through technological and behavior change;

recycling water by reusing gray water or treated wastewater; eliminating water losses from leaky infrastructure or evaporation; and not extracting groundwater at rates that exceed recharge (Gleick, 2002; Jacobs and Holway, 2004).

3. The principle of *livelihood sufficiency and opportunity* ensures fair access to a sufficient quantity and quality of water for: basic livelihood needs for drinking, eating, and sanitation; recreation and enjoyment for broader personal and societal well-being; and, economic activities that depend on water (Gibson, 2006). Of course, in the face of tradeoffs, hard decision must be made across decision and outcomes (Mitchell, 2006).
4. The principle of *civil engagement and democratic governance* calls for participation and collaboration among all relevant and interested stakeholders. This entails: considering the interests, needs, and perspectives of local actors who affect or are effected by water resource decisions (Ostrom, 2009); engaging diverse stakeholders through various stages of decision making, from problem formulation and goal setting through to implementation, assessment, and adaptive changes; and establishing collaborative decision processes among entities who share resources or live in the same region (Larson and Lach, 2010). Ultimately, such participatory decision making leads to social learning and the co-production of knowledge, both of which are central to transforming society toward sustainability (White et al., 2008; Pahl-Wostl et al., 2010).
5. The principle of *inter-generational and intra-generational equity* safeguards equitable access to a sufficient quantity and quality of water for current and future residents (WCED, 1987; Gibson, 2006) by: guaranteeing all residents have access to

safe water for basic needs; ensuring a fair distribution of benefits and costs among various stakeholders; facilitating fair involvement in decision making based on diverse representation (Larson and Lach, 2010); and, providing representation for future generations. The latter could be achieved through the use of delegates, as proposed and approved during the Rio+20 Conference in June 2012.

6. The principle of *interconnectivity from local to global scales* ensures the allocation and management of resources across hydrologic basins, which encompass the land area within which water flows and is interconnected as it moves downhill to an outlet such as the sea (Mitchell, 2005). This principle entails: minimizing negative impacts on actors and activities including those downstream; planning across political jurisdictions that are hydrologically interconnected within river and groundwater basins (Pahl-Wostl et al., 2010); and, considering and coordinating activities and impacts across local to broader scales of interaction (Ostrom, 2011).
7. The principle of *precaution and adaptability* calls for anticipating potential problems as well as mitigating and responding to them (Gibson, 2006) by: studying and understanding perturbations and possible impacts; lessening the stressors or effects of changes to the system; and, facilitating adaptations now and in the future through capacity building, policy making, behavior change, and other mechanisms for coping with systems changes and stressors (Pahl-Wostl, 2007).

3. Appraisal Methods

Data and evidence for the analysis of water governance in Phoenix (Phase 1) and the sustainability appraisal (Phase 2) was gathered primarily from published literature and policy documents, along with expert interviews. We interviewed seven stakeholders

with substantial knowledge of the water system in the Phoenix region to critique and validate our approach and assessment. The informants were purposively selected to represent diverse interests involved with boundary activities at the Decision Center for a Desert City (DCDC): two academics (one social and one ecological scientist); three ‘policymakers’ or managers (one each focused on the provision and quality of water and state policies), and two additional interests (one local environmental interest and one lawyer who deals with land development).

Interviews lasted approximately an hour, during which time student research assistants took notes about 1) the structure and perceived challenges for regional water governance, and 2) how the sustainability principles have or have not been met. Upon sharing the principles and our working systems diagram (Fig. 1) with informants, the anonymous professionals also suggested how to revise the appraisal to include the whole array of actors, activities, and interactions. This integrative, stakeholder process helped to validate the appraisal.

Altogether, we synthesized the literature and interview notes to understand the actors, rules, and system dynamics into a visual diagram (Fig. 1) accompanied by the following narrative (see also Appendix A). We now explain the major governance activities and actors across the water system interfaces of metropolitan Phoenix.

Although we cannot provide intensive details on particular issues, we aim for an overall appraisal of how people and social organizations supply, treat, distribute, use, discharge and plan for water resources in the greater region.

4. Water Governance in Metropolitan Phoenix

A myriad of actors and institutions determine how water is used, managed, and treated as it flows through the social–ecological–technological system, ultimately resulting in various impacts and tradeoffs within and beyond the region. Below, we briefly detail ‘who does what with water’ to offer a holistic, actor-oriented view of water governance—organized by the five activity domains—for the sustainability appraisal that follows.

4.1. Water supplies

The Phoenix region has four primary sources of water: local rivers in the Salt-Verde watersheds, water from the Colorado River, groundwater, and effluent (Fig. 5). Each source is governed by different actors and institutions, as described below.

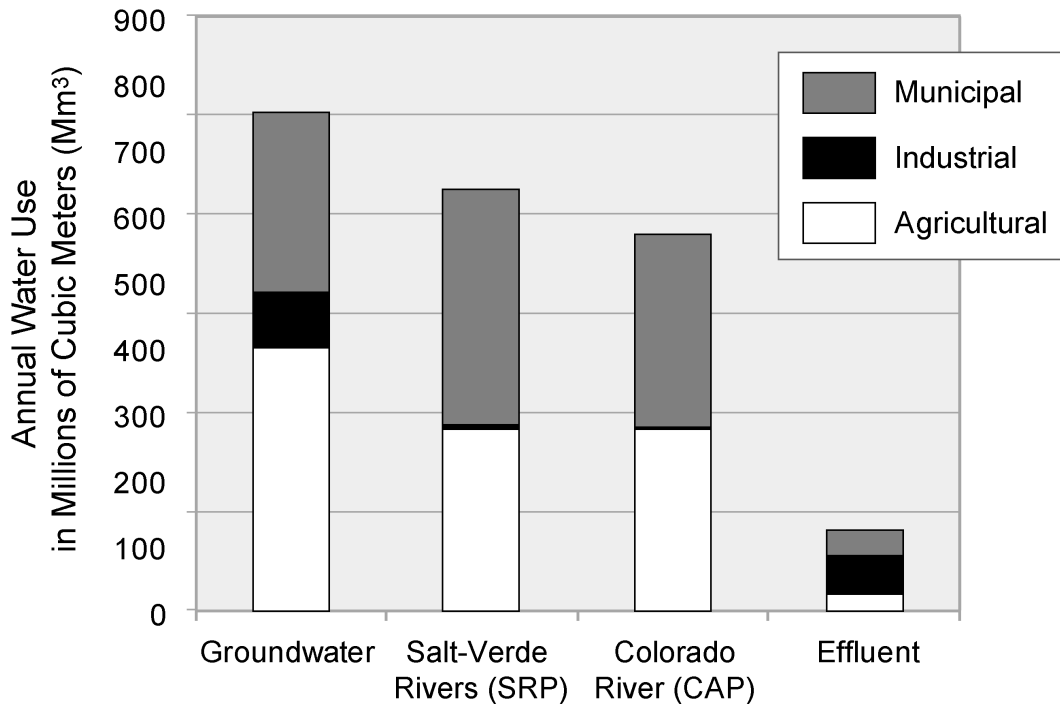


Figure 5. Average annual water usage by source and sector for the Phoenix Active Management Area 2001–2005 (ADWR, 2010).

4.1.1. Salt-Verde River water

Rights to surface water are granted based on the ‘first in time, first in right’ principle, which means early settlers and settlements have senior rights over junior users who lose their allocations first during shortages. Despite Native Americans being ‘first in time,’ early rights were largely granted to agricultural settlers. Thus, local Native tribes have had to demand and negotiate their water rights. Under the 1908 Winters Doctrine, the law guarantees tribes enough water to meet the needs of reservations. Yet negotiations can take decades, and identifying water sources for allocations can be controversial (Smith and Colby, 2007). In the Phoenix region, the Gila River Community gained rights to 806.1 million cubic meters (m³) (653,500 acre-feet, or af) of water through a 2004 settlement, while the Salt River Pima-Maricopa tribe gained 151 million m³ (122,400 af) in 1988 and the Fort McDowell tribe gained 44.8 million m³ (36,350 af) in 1990. Despite such rights to local rivers such as the Gila, most tribal settlements are honored with water from the Central Arizona Project (see more on the Colorado River below).

Adjudication and legal procedures continue to clarify water allocations while disputes continue to erupt over rights. Recently, for example, the Salt River Project (SRP)—which has senior rights to this water source over tribes and others—has contested groundwater pumping of the Big Chino aquifer in the Verde Valley, upstream of Phoenix, where groundwater is thought to feed the Salt-Verde Rivers downstream (Bolin et al., 2008).

To cope with another critical uncertainty, specifically high intra- and inter-annual variability in stream flows, the 1902 U.S. Water Reclamation Act funded the creation of

the Roosevelt Dam and Reservoir to store up to 2.0 billion m³ (1.7 million af) of water (SRP, 2011). Although dams are owned and overseen by the U.S. Bureau of Reclamation (USBR) nation-wide, the Salt River Project is a combined private–public initiative responsible for managing seven dams and reservoirs along the Salt-Verde Rivers, which have a total capacity of 2.9 billion m³ (2.3 million af). SRP operates and maintains this storage infrastructure, along with 250 groundwater wells. They also administer the timing and delivery of nearly 1.2 billion m³ (1 million af) of water to homes and businesses in their service area, which includes ten municipalities that receive water and five more that receive electricity (SRP, 2011).

As local rivers have been diverted for human uses, expansive areas of irrigated lawns and over 650 man-made lakes and ponds have replaced narrow zones of riparian vegetation (Larson et al., 2005). Downstream of the regional dams, the Salt and Verde channels remain dry for much of the year. Changes to local hydrology have led to degraded ecosystems and endangered species, with ten species in Maricopa County designated as such by the U.S. Fish and Wildlife Service (USFWS, 2011) under the Endangered Species Act. Imperiled species include four types of fish and birds reliant on aquatic habitat. To comply with this and other federal laws such as the Migratory Bird Treaty Act, SRP undertakes activities such as an Avian Protection Program while permitting employees to take actions for preserving, rescuing, or moving birds, nests, and eggs.

4.1.2. Colorado River water

Beyond local watersheds, the Central Arizona Project (CAP) diverts and pumps water from the relatively distant Colorado River. Based on the Boulder Canyon Project

Act of 1928, Arizona's allotment is 3.6 billion m³ (2.8 million af), an amount less than California's 5.4 billion m³ (4.4 maf) but much more than Nevada's 0.4 billion m³ (0.3 maf) (August and Gammage, 2007). For 25 years after this agreement, Arizona fought to secure its water, which unless diverted would flow downstream to California. Because of the 'use it or lose it' principle of prior appropriation law, the state sought to acquire its full allocation in advance of actual needs by creating the Arizona Water Banking Authority (AWBA, 2007). AWBA diverts water to underground savings facilities where water is stored for future use. AWBA also stores water for Nevada, in addition to providing water for tribal settlements. In 2010, AWBA recharged 261.1 million m³ (211,712 af) including 23.4 million m³ (19,000 af) for Nevada. From 1996 to 2010, the Authority transported and stored a total of 4.6 billion m³ (3.8 million af), which would have otherwise gone 'unutilized' by the state (AWBA, 2010).

As a political compromise to secure funding for the CAP canal that now transports Colorado River water 541 km from the western border of the state to central Arizona, the state consented to junior rights, which means Arizona is the first to be cut-off in times of drought or shortages in the basin (USBR, 2010). Since the total 20.2 billion m³ (16.4 million af) of water estimated during negotiations in the 1920s was based on data from the wettest century over the past 500–1200 years, the river is over-allocated and likely to experience shortages in the future (Hirt et al., 2008). On August 13, 2010, Lake Mead was at 331.3 m (m, or 1087 feet), the lowest level since 1956 and only 3.7 m (12 ft) above the 327.7 m (1075 ft) trigger point established by a 2007 shortage-sharing agreement among the states. Shortage allocations for Arizona would amount to 2.8–3.1 billion m³ (2.5 million af), or more than a 10% cut. In early 2011, however, the Bureau of

Reclamation sent 14.3 billion m³ (11.6 maf) of water from upstream Lake Powell to Mead, raising the water levels to 9.1 m (30 ft) above the “danger zone” (McKinnon, 2011).

In anticipation of reduced flows and allotments, water managers' tradition of augmenting supplies (Gleick, 2002) currently prevails through Project ADD—Acquisition, Delivery, and Development—Water, an initiative by the Central Arizona Project to secure more resources (CAP, 2007). The ‘Drop 2’ reservoir was initiated by inter-state negotiations over shortage-sharing in the Basin. With substantial funding from Nevada, the new reservoir is being built at the border with Mexico to increase storage downstream of Lake Mead in the U.S. This reservoir also ensures ‘excess’ water does not flow into Mexico—that is, beyond the 1.9 billion m³ (1.5 million af) allocated to the nation according to a treaty signed in 1944. Another international agreement in 1973 established salinity standards since water quality is greatly diminished due to diversions and evaporative losses as the river flows downstream through the desert. Shortly thereafter in 1974, the U.S. authorized the Yuma Desalting Plant (YDP) with the intent of removing salt before delivery to Mexico (Judkins and Larson, 2010).

Before the YDP was built in 1992, agricultural drainage from Arizona was directed via a bypass canal to the Cienega de Santa Clara, thus creating a biologically diverse wetland ecosystem with thriving birds and wildlife (Judkins and Larson, 2010). Although operating the YDP was initially unnecessary because of a wet period, states including Arizona started looking to the desalting plant as an additional water supply when a long-term drought began around the turn of the century. In response to disputes over depriving this wetland ecosystem of water by operating the plant, U.S. stakeholders

developed a collaborative working group to pursue agreeable resolutions to this conflict. CAP officials led the workgroup process, which only involved US interests while excluding Mexico from the discussions, but the group did develop recommended solutions to this conflict (see Judkins and Larson, 2010 for details).

4.1.3. Groundwater

Increasing reliance on the Colorado River in the late 1900s has allowed the state to wean itself off non-renewable ‘fossil’ aquifers to some degree, but groundwater still represents 39% of supplies for the region (Fig. 2). From historic to present, groundwater pumping has led to the drawdown of water tables as well as land subsidence and fissures (ADWR, 2010). Arizona adopted the 1980 Groundwater Management Act (GMA) to address overdraft problems in exchange for federal funding of the CAP canal, but this happened only after a political ultimatum under President Carter (see Connell, 1982; Hirt et al., 2008 for historic reviews).

The primary goal of the GMA in the greater Phoenix area is safe yield by 2025 (Connell, 1982), which mandates that groundwater only be withdrawn at rates that are replenished (Jacobs and Holway, 2004). The Arizona Department of Water Resources (ADWR) was established to oversee implementation of the GMA over a series of five planning stages. Thirty years later, however, overdraft remains a problem due to how the GMA has been implemented and loopholes that have developed since then (for details, see Hirt et al., 2008; Maguire, 2007). In 2005, groundwater withdrawals amounted to 1.0 billion m³ (813,000 af), with 29.7 million m³ (24,100 af) of natural recharge and 136.1 million m³ (110,303 af) of artificial recharge leading to 837.0 million m³ (678,597 af) of overdraft (ADWR, 2010). Meanwhile, funding for ADWR has been substantially cut by

the state in the face of declining budgets and a lack of political will to support the agency (Larson et al., 2009a). From 2009 to 2011, resources declined from 236 to 98 employees and from \$21.6 to \$7.1 million (AMWUA, 2010).

Although the GMA and associated institutions are far too complex to detail here (for more information, see Colby and Jacobs, 2007; Jacobs and Holway, 2004), a few provisions are noteworthy. First, the GMA provides a structure for permitting and monitoring groundwater usage while requiring entities to report pumping, with the exception of small wells withdrawing less than 132.5 L per (35 gallons) per minute (Hirt et al., 2008). Second, despite heavy involvement of farming interests (along with urban and mining) in drafting the GMA (Connell, 1982), the policy stipulates ‘no new irrigation’ for agriculture, though each sector has demand management programs (see the demand section below). Finally, the GMA requires new subdivisions in the Phoenix area to demonstrate a 100-year Assured Water Supply (AWS), mostly using renewable sources but with recharge and recovery programs to allow pumping in return for replenishment (Jacobs and Holway, 2004).

Since the AWS rule posed a hindrance to development in areas without access to surface water, the state formed the Central Arizona Groundwater Replenishment District (CAGRDR) in 1993 (August and Gammage, 2007). For a fee written into home mortgages, the CAGRDR acquires water—typically from the Colorado River—to replenish extracted groundwater. Replenishment is not required at the place of use, even though recharge elsewhere might not compensate for the local hydrologic effects of withdrawals. Although these efforts neglect physical realities, the East Valley Water Forum (EVWF)—a consortium of water providers who share a groundwater basin—collectively

models groundwater flows in order to understand how pumping in one location will alter water levels in other areas.

4.1.4. Effluent

Finally, water providers use treated wastewater, or effluent, to recharge groundwater, in addition to supplying non-potable water to irrigate golf courses, parks, and farms (Jacobs and Holway, 2004). Currently about 5% of regional supplies, effluent is also used as a coolant for power generation and industrial activities. The mixture of sources in effluent creates a fuzzy area of water law, giving rise to a dispute and ultimately a court case in the 1980s (Colby and Jacobs, 2007). The ruling declared that effluent is the property of the entity who treats the wastewater, but if or when discharged, ownership of the resource is lost and the water rights revert back to the alternative laws for surface or underground water. This may clarify the legalities of reusing treated wastewater, which is on the rise. Yet the ‘yuck factor’ and other barriers (discussed below) may limit its use generally (Russell and Lux, 2009).

Although the technology exists to clean wastewater to drinking water safety, pollutants plague some water sources and may render their use hazardous and/or their treatment expensive. The treatment and delivery of water is the focus of the next section.

4.2. Water deliveries

Water from various sources is distributed through a network of eight canals totaling 2092 km (1300 miles) (Gooch et al., 2007), with connections to aboveground ditches and underground pipes for direct irrigation purposes and for potable uses through treatment plants. Pumping and distributing water throughout the region requires 2.8

million MWh annually, which amounts to nearly 4% of Arizona's total energy use (UAWRRC, 2010).

Maintained by SRP and CAP, the concrete, open-air canals have traditionally been managed as functional conduits of water, with residents and businesses turning their backs to these man-made waterways. In recent years, attention has turned to beautifying and embracing the canals as amenities. The Canalscape project is one example wherein university professors and students worked with SRP and stakeholders to re-envision the canals as centerpieces of mixed-use development and leisure activities (Ellin, 2010). Municipalities such as Phoenix, Tempe, and Scottsdale have also developed paths, lights, and vegetation to improve canals locally as recreational corridors and, to a lesser extent, wildlife habitat.

Over 100 public (municipal) and private (for-profit) providers deliver water to customers (Bolin et al., 2010). Some non-potable water is delivered untreated for industrial uses and for residential and agricultural irrigation, but most water is treated at one of 97 drinking water plants (ADWR, 2009). Water treatment must comply with the US Safe Drinking Water Act, which sets the maximum contamination levels (MCL) for “primary” pollutants—microorganisms, organic and inorganic chemicals, radionuclides, disinfectants and related byproducts—that negatively affect public health. The U.S. EPA establishes the safe limits while also recommending guidelines for “secondary” contaminants, which result in aesthetic or cosmetic problems such as bad taste or tooth decay.

At the state level, the Arizona Department of Environmental Quality (ADEQ) oversees compliance with regulatory standards for 87 primary contaminants and 15

secondary pollutants (ADEQ, 2010b). When MCLs exceed federal limits, ADEQ develops remediation strategies (Smith and Graf, 2007). Locally, water providers must provide the public with information on contaminant levels in drinking water, which is typically done with periodic water quality reports mailed in customers' bills.

Salinity, especially in surface water, can affect the taste of water and it is also hard on treatment systems. Nutrients and endocrine-disruptors also are ongoing pollution concerns that are not currently mitigated through treatment technologies. The region also struggles with arsenic, which naturally occurs in soils (Welch et al., 2000). Recent increases in federal arsenic standards have created treatment difficulties for some water providers and regulators in central Arizona (UACE, 2005). Higher standards mean higher treatment costs.

Industrial activities have polluted water in Phoenix so much so that multiple groundwater plumes have been designated Superfund sites. In the 1980s, for instance, Trichloroethylene (TCE)—a chlorinated solvent used for cleaning metal parts and circuit boards that has toxic, ozone-depleting, and carcinogenic characteristics—and other volatile organic compounds (VOCs) were released into the groundwater at several industrial facilities in Phoenix. With multiple parties potentially responsible for several pollutants, the contaminated groundwater and bedrock extend well beyond the release sites despite various legal agreements, scientific assessments, and treatment efforts (ADEQ, 2010a). While some water has been contained or treated, some contaminants still pose health risks to well users or nearby neighborhoods, such as exposure to VOCs (released through vapor degassing) as polluted water is brought to the surface and transported for non-potable uses via open-air canals. In 2009, the U.S. Environmental

Protection Agency (USEPA) and Arizona Department of Environmental Quality (ADEQ) released a community involvement plan to structure the process for eliciting concerns and input over this Motorola Superfund site (EPA, 2009). Working with industrial polluters (e.g., Freescale, Honeywell) and citizen advocates, the EPA leads the ongoing remediation projects (USEPA, 2009). In other Superfund cases, some entities must sue and continue to push the responsible parties for compensation under the Superfund Act.

4.3. Water demands

Agriculture has historically used the majority of water region-wide, primarily through the production of water-intensive cotton, cattle, and citrus, which have long dominated the Arizona economy. Down from 57% in 1985, agricultural uses now represent 33% of regional water demands, with Native American reservations using 10%, and large industrial users 7% (Fig. 3). At 50%, municipal uses by households, businesses, and the public sector (e.g., for parks and schools) now lead water demands. Residential and outdoor uses are paramount; within the City of Phoenix, for example, households consume two-thirds of water, mostly for watering landscapes.

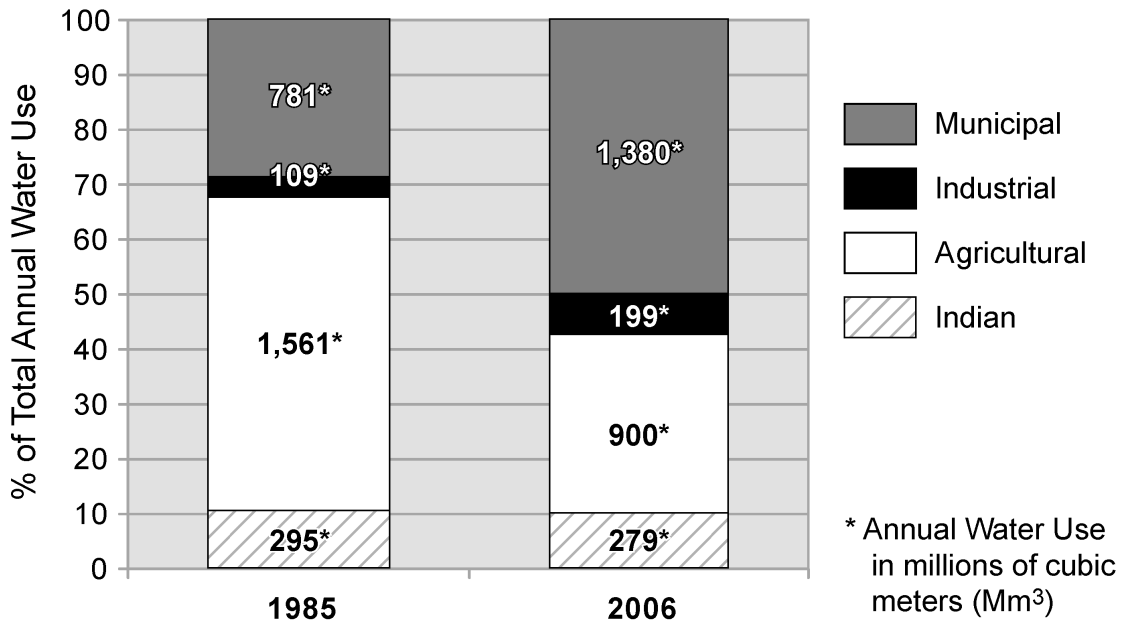


Figure 6. Water demands per year by sector 1985 and 2006 (ADWR, 2010).

Lawns, pools, and large lots contribute most to consumption levels in Phoenix neighborhoods, along with household size (Wentz and Gober, 2007). Largely as a result of the region's lush 'oasis' landscapes, which have been promoted with historical slogans such as 'do away with the desert,' water use rates are high compared to climatically similar areas, with a rate of 871 L (230 gallons) *per capita daily* (LPCD, or Gallons PCD) in Phoenix relative to 651 LPCD (172 GPCD) in Tucson (Larson et al., 2009a).

Water-intensive commercial users include carwashes, water parks, plant nurseries, and golf courses, although the latter increasingly use effluent to irrigate turfgrass. The largest industrial consumers in the Phoenix area produce electricity (e.g., Arizona Public Service or APS) and electronic chips (e.g., Intel), among other goods. Industrial users often use effluent, as with cooling at SRP's Kyrene Electric Generator Station. At APS's Palo Verde Nuclear Generator, for instance, over 90.8 million m³ (24 billion gallons, or 73,613

af) of wastewater were used in 2009 to produce energy which is largely exported to California (SWEET, 2009).

Regarding demand management overall, the GMA specified conservation targets and programs for three sectors (Jacobs and Holway, 2004). First, ADWR sets allotments for farmers (with more than about 4 ha, or 10 acres) based on the historic crops grown and assumptions about irrigation efficiency (Paul, 2010). Second, industrial limits apply for those using more than 12,335 m³ (10 af) of water, depending on the best available technologies for conservation. Third, municipal standards require ‘reasonable reductions’ in water use over time for providers delivering more than 308,370 m³ (250 af).

Despite these policies, recent evidence indicates gross failures in achieving significant reductions in water demands (Larson et al., 2009a). For example, the state backed away from enforcing municipal water-use standards (as measured by Gallons Per Capita Daily) in the face of local resistance. As water providers contested regulatory standards, which some failed to meet, ADWR eventually created an alternative program that rewards conservation efforts (e.g., outreach, incentives) while no longer mandating actual reductions in water-use rates.

Finally, environmental demands constitute resources used to maintain vegetation and ecosystems as well as water ‘lost’ to evaporation. So far, the Phoenix region has not allocated water to in-stream flows (McKinnon, 2009). Some localized, small-scale projects dedicate water to maintain habitat, as with the Rio Salado project in central Phoenix, where shallow groundwater is being pumped by the City to maintain wetlands and native riparian vegetation in the river channel, which also receives stormwater flows. Funded largely by the U.S. Army Corps of Engineers (USACE), the project enhances

redevelopment opportunities in an old industrial area that has historically turned its back to the river channel. The project also facilitates recreation and wildlife habitat, with an Audubon Center on site to support activities.

In the arid desert, evaporative losses from pools, lakes, and canals are high. Tempe Town Lake, which was created by damming the Rio Salado channel with water from the Colorado River and other sources, loses 1.7 million m³ (1338 af) annually to evaporation (City of Tempe, 2011). Transpiration, or the release of water by plants, represents another environmental loss. Yet when water is used on lawns and other vegetation, local cooling can occur along with energy savings for air conditioning. In other words, a tradeoff exists between heat mitigation and water conservation in landscaping (Gober et al., 2010).

4.4. Outflows

Once used outdoors, water flows back into the hydrologic system via evaporation, runoff into local water bodies, and infiltration into soils and aquifers. Some water is also carried through underground pipes to one of the 92 wastewater treatment plants, which are typically separate from drinking water plants and whose discharges are regulated by the U.S. Clean Water Act (ADWR, 2010). In the City of Phoenix, about 30–40% of all water deliveries flow through the sewer system after usage. At wastewater plants, water is then treated through physical, chemical, and biological processes before being discharged. In general, treated wastewater faces three potential fates—discharge into surface water or river channels, recharge into groundwater basins, or direct use for non-potable purposes, thereby completing the cycle of water back into the system to maintain supplies or meet demands (Fig. 1).

While wastewater treatment often relies on engineered (gray) technology, biological (green) approaches include the use of vegetated wetlands to filter water and remove pollutants. The Tres Rios project at the 91st Street Treatment Plant, which is run by a Sub-Regional Operative Group (SROG), is one example where after basic mechanical treatment, wastewater is filtered through wetlands to ensure the water discharged into the stream channel meets federal standards overseen by the U.S. EPA and ADEQ (similar to drinking water regulations, though stemming from the Clean Water Act) (City of Phoenix, 2011b). This project treats wastewater at lower costs than plant upgrades would have been. The wetlands also provide habitat as well as recreational and educational benefits for bird-watchers, students, researchers, and others. With similar features and the goal of reusing 100% of the town's effluent, the City of Gilbert's Riparian Preserve is about 45 ha (110 acres) with seven recharge wetlands that allow treated wastewater to percolate into aquifers while also serving wildlife and recreational purposes (USFWS, 2011).

4.5. Perturbations and cross-cutting activities

In the Phoenix area and elsewhere, critical perturbations include: climate variability and change, regulatory or policy changes, population growth and urban development. Drought conditions, for example, lower surface water supplies while also increasing demands (Balling and Goodrich, 2007). Human-induced climate changes are also expected to result in greater aridity and lower surface water flows in the southwest. In the Colorado Basin, climate change models for the 2010–2100 period suggest a temperature increase of 1.2–4.4 °C leading to runoff reductions of up to 11%, with all scenarios showing a decline in water flows to the lower basin (Christensen and

Lettenmeier, 2006). For the local Salt-Verde Rivers, the modeled effects of various climate change scenarios into 2050 illustrate a range of uncertain outcomes, with the likelihood of lower runoff in the SRP watershed (Ellis et al., 2008).

Climate conditions affect water physically, in addition to potentially triggering shortages imposed by the shortage-sharing agreement for the Colorado River. Additional institutional stressors include regulatory changes such as the federal increase in arsenic standards. Shifting market conditions can also impose stress on the regional water system, as with the current economic recession and mortgage crisis, which have hit the Phoenix area hard given the central role of land development in the regional economy (Larson et al., 2009a and Larson et al., 2009b). Declining funds due to political and economic factors may therefore thwart initiatives—especially government ones—to help anticipate, mitigate, or adapt to changes.

While large municipalities such as the City of Phoenix (2011a) have conducted water resource assessments and have several plans in place, including a Climate Action Plan, smaller towns often lack the resources for anticipatory activities (Larson et al., 2012). The City of Phoenix has also developed a drought-contingency plan with trigger points for adaptive actions, but participation has been limited to the city council, water suppliers, and special interests (Quay, 2010). Overall, drought planning has increased over the last decade as the region has faced a long-term drought.

In-migration and growth increase water demands, though the exact effects of urbanization depend on the type and form of development. From 1970 to 2010, the region grew from one million to about four million people (Hirt et al., 2008). Urban development has led to rising temperatures due to the Urban Heat Island (UHI) effect,

which has increased water demands (Guhathakurta and Gober, 2007). Nighttime summer temperatures have risen 4–10 °F in central Phoenix, where a 1° increase in daily lows amounts to an average monthly increase of 1098 L (290 gallons) consumed per single-family unit. While research has helped inform understanding of these dynamics—especially as Arizona State University's Decision Center for a Desert City (ASU DCDC; see <http://dcdc.asu.edu.ezproxy1.lib.asu.edu/>), collaborative initiatives such as the Phoenix's UHI task force (which involves municipal officials and other stakeholders) also help to mitigate and cope with the urban heat island.

Funded by the National Science Foundation, DCDC has served as a “boundary organization” since 2004 to facilitate science-policy research and collaborative events to support water resource decision making under climatic uncertainty (White et al., 2008). Working with local stakeholders, ASU researchers conduct interdisciplinary research on climatic variability and uncertainties; urban dynamics, and tradeoffs; and adaptation and governance decisions (as largely synthesized above). DCDC has also created “WaterSim,” an interactive simulation model that examines how alternative climate conditions, rates of population growth, and policy choices interact to impact future water supply and demand conditions (Gober et al., 2011). Together, past and ongoing DCDC activities have strengthened understanding of the regional water system among researchers and decision-makers, especially water providers and resource managers/planners who work for local to federal government agencies or other entities (Crona and Parker, 2012). Although these collaborations have led to cross-sector and cross-jurisdictional interactions, some stakeholders have not yet been very involved.

5. Sustainability Appraisal of Water Governance in Phoenix

Based on the examination of water governance activities above, we now apply the sustainability principles presented earlier (see also the Appendix A) to summarize the successes and challenges of the Phoenix water system.

5.1. *Social–ecological system integrity*

Diversion of water from streams and riparian areas—largely for human uses—has diminished the ecological integrity of aquatic ecosystems in the Phoenix area, where streams and riparian ‘ribbons of green’ have been transformed into reservoirs, lakes, and expansive blankets of turfgrass and other irrigated landscapes. Damming and diverting water have left streams dry and species endangered. Select local projects, especially to treat wastewater or recharge groundwater, have created new wetlands and habitat areas to support birds and other wildlife while also providing recreation and other opportunities. Although restoration projects could further enhance ecological integrity, such efforts have been limited and institutional arrangements (e.g., over-allocated rivers, effluent laws, anthropocentric customs) currently constrain such activities. Moreover, created and restored habitat areas may not function the same as natural ones.

Though aquifers are being recharged to some degree, overdraft still taxes groundwater. From 1980 to 2000, overdraft was cut in half; but between 1995 and 2025, ADWR expects overdraft to increase by 30% at the “current use” trends from 444.1 to 581.1 million m³ (or 360,019 to 471,085 af) (Hirt et al., 2008). As aquifer drawdown continues, problems such as pollution and land subsidence will heighten.

While some contaminated water poses little risk, other polluted resources (e.g., Superfund sites) harm people and the environment (Foley et al., 2012). Although

emerging approaches to biological (e.g., wetland filtration) or technological (e.g., nanotechnology filtration) treatment hold promise for improving water quality, future challenges include making treatment cost-effective (especially for meeting raised arsenic standards). Another barrier to improving water quality results from the lag time in identifying contaminants and then developing treatments.

Rising attention to the interactions and tradeoffs across environmental sub-systems, along with associated collaborations, is promising for maintaining social-ecological integrity. Positive steps include regional management under the GMA for the Phoenix 'Active Management Area' (AMA), which corresponds to groundwater basin boundaries of the greater region (Jacobs and Holway, 2004). Whether these increases in awareness will lead to change has yet to be seen, but other aspects of interconnectivity are discussed further in Section 5.6.

5.2. Resource efficiency and maintenance

As noted above, the integrity of aquifers is threatened by continued overdraft. Achieving the legislative mandate for safe yield by 2025 is now highly unlikely due declining state support and loopholes in implementing the GMA (Hirt et al., 2008). A recent USGS (Tillman et al., 2011) study found that most of the 1300 wells tested across Arizona indicate aquifer levels are dropping. Maintaining water tables and flows will be increasingly difficult over time as supplies dwindle and demands rise. Region-wide, the geographic mismatch between groundwater withdrawals and recharge sites especially threatens local resources where pumping is occurring but recharge is not.

Though water demands have been reduced somewhat, regulatory targets for municipal conservation in the Phoenix area have been abandoned by the state and water-

use rates remain relatively high (Larson et al., 2009a). Political resistance and lifestyle changes present barriers to enhanced efficiency. In addition, cheap water prices and the ‘lose it or use it’ principle of prior appropriation law reinforce flagrant water uses while thwarting conservation and the preservation of in-stream flows. Ultimately, these practices and rules harm both resource maintenance and ecosystem integrity.

Conservation gains have been greatest in newly developed areas with low water-use landscapes (e.g., without grass) as well as efficient fixtures and appliances. But lush landscapes, pools, and other factors still place high demands on water (Wentz and Gober, 2007). The efficiency of new infrastructure is critical for reducing water use, but so is retrofitting older areas (e.g., upgrades to leaky and aging canals, pipes, and other storage and conveyance infrastructure). High evaporation rates in open-water systems (e.g., pools, canals) further represent intervention points for minimizing atmospheric losses in such a warm, dry region.

Progress in the efficiency of water use has been made with the increased use of effluent for recharge and some direct uses (e.g., landscaping, industrial processing). Recharge projects like the Gilbert Preserve serve the dual purpose of reserving water for future use and preserving ecosystem functions. However, the use of treated wastewater is constrained by perceptions that lead customers to reject its use (Russell and Lux, 2009), in addition to regulations, salinity problems, and the centralized nature and downstream location of treatment infrastructure. These factors also explain why the use of gray water (e.g., dirty dishwater or laundry water) and other decentralized modes of capturing and utilizing water are not widespread across the region.

5.3. Livelihood sufficiency and opportunity

The basic needs of Phoenix-area residents are being met overall through the widespread provision of treated drinking water and adequate sanitation systems. Still, some residents are exposed to detrimental pollutants, especially due to untreated water and contaminated aquifers (see associated inequities below).

Regarding societal enjoyment, some localized projects provide water resources for birding, learning, and other forms of recreation around canals, ponds, lakes, wetlands, and some riparian areas. The creation of man-made lakes and the redevelopment of canals as amenities and transit corridor also provide recreational opportunities (e.g., walking, biking, boating, fishing), rather than simply functioning to store or distribute water. Yet these projects are relatively new and few, resulting in uneven access to such amenities.

As for economic livelihoods, agriculture has been somewhat marginalized with a ‘no new irrigation’ clause, thereby privileging municipal and industrial uses. Some communities have even drawn high water-use industries, specifically microchip processors (e.g., Intel in Chandler) that consume resources and also contribute to toxic emissions (Bolin et al., 2000). Such water-reliant industries may mean jobs and economic growth in the near term, but greater economic losses may result from water shortages into the future (e.g., compared to fallowing irrigated farmland during shortages).

5.4. Civil engagement and democratic governance

Power in water governance is largely centralized among a few agencies such as SRP and CAP, along with other water providers and managers. The minimal involvement of select interests (e.g., water providers) in decision processes (e.g., development of

regional plans) marginalizes some interests while potentially leading to detrimental outcomes (e.g., erosion of conservation policies). With respect to continuous involvement, the Groundwater Act does structure planning periods that require adaptive consideration of implementation successes and failures over time. Yet participation among the broader public is limited (e.g., to short ‘comment periods’). While environmental and other interests have also been largely absent from regional deliberations over the GMA and its implementation, Mexico has been excluded from some Colorado Basin deliberations.

Led by the EPA and DEQ, the decontamination efforts at the Motorola Superfund site demonstrates an explicit lack of democratic governance. For over two decades, the community—which includes some of the poorest neighborhoods in Phoenix—has confronted flaws in stakeholder representation and involvement, access to comprehensible information, resources for legal and expert advice, effective remediation strategies, and negotiations of adequate compensation (Foley et al., 2012). Although the EPA established a community engagement process in 2009, increased government involvement has only served to further deepen the community's frustration and mistrust. Although participatory decision making is weak overall, collaboration appears to be rising (see Interconnectivity Section). DCDC, in particular, has fostered science-policy deliberations since 2005, although not among a wide range of interests. Thus, deliberative governance is improving somewhat, but certain interests tend to be excluded, especially those outside of formal decision arenas in the U.S. government. Who participates in decision making has equity implications, as described next.

5.5. Inter- and intra-generational equity

While residents broadly have access to sufficient water, some areas lack secure, long-term access to resources given both contaminated aquifers and dependence on single sources (e.g., non-renewable groundwater). Newer areas along the metropolitan fringe are especially at risk, since older and more centrally located areas have greater access to diversified sources (Bolin et al., 2010). Rural areas and private landowners dependent on untreated groundwater are also particularly vulnerable to pollution (Madrid, 2010). Further, low-income neighborhoods are most exposed to contaminants and least equipped to demand effective remediation (e.g., in Superfund decisions; Foley et al., 2012). In negotiating the 1980 GMA, municipal, mining, and agricultural interests were well represented, but environmental and others perspectives were not (Connell, 1982). While urban and industrial interests have ultimately been favored over agricultural users by state policies and economic imperatives, Native American rights have been historically neglected. Adjudication processes have started to remedy this issue through legal negotiations with tribes (e.g., Gila River), through power asymmetries may perpetuate inequalities into the future for the tribes as well as Mexico or other marginalized actors. Mexico is perhaps the biggest loser in the Colorado Basin, since they receive limited, low-quality water as the downstream user. Regarding equity of representation, Mexican interests have also been excluded from some collaborative processes as U.S. interests have worked among themselves.

Finally, future generations receive no formal representation in governance, and explicit consideration of future residents is limited. The 100-year timeframe for “Assured Water Supply” provisions only applies a few generations out, for example, and loopholes

allow development where water could become scarce or eventually depleted (Hirt et al., 2008). As a whole, inequitable uses, impacts, and involvement occur across upstream and downstream entities of river basins, different areas within the region, and current and future generations.

5.6. Interconnectivity across scales and sectors

Although some coordinated decision making within hydrologic units is happening through negotiated treaties (e.g., with Mexico for Colorado River) and regional workgroups (e.g., East Valley Water Forum), consideration of upstream–downstream interconnections is lacking for the Colorado Basin (e.g., since downstream users such as Mexico have been excluded from workgroups) and the Salt-Verde Watershed (e.g., where hydrologic connections between surface and groundwater have been ignored until recently). With ongoing conflicts raising attention to hydrologic interconnections among political jurisdictions (e.g., Big Chino aquifer in Verde Valley), water professionals increasingly call for conjunctive management and basin-wide institutions for effective governance (Colby and Jacobs, 2007). However, the legal separation of water rights laws constrains integrated governance in Phoenix and elsewhere, as does the fragmentation of local water providers and multiple bureaucratic agencies across towns and government levels (e.g., separate missions and planning for water, land, and energy resources at varying scales).

Improved communications and capacity-building across municipalities as well as state and federal governments could help local communities as they adapt to changes and cope with stressors on water systems, especially in the face of perturbations, constraints, and tradeoffs. Of particular importance are: the water–energy nexus (e.g., given the

energy costs of pumping, treating, transporting water; Scott and Pasqualetti, 2010) and the water-land use/cover intersection (e.g., given the implications of land use/cover and irrigation on water use/conservation versus heat mitigation; Gober et al., 2012). Even more complex sectoral interconnectivity—for example, relationships among land, water, energy and climate—should be considered among researchers and policymakers in planning for sustainability.

Attention to interactions and collaborations across scales and sub-systems has increased in recent years, specifically activities led by ASU's DCDC. Yet integrated planning is still limited (e.g., across the land–water sectors; Larson et al., 2012) and some disconnected activities threaten certain risks (e.g., groundwater replenishment removed from the point of withdrawals). The regional group studying groundwater flows (EVWF) could help coordinate pumping to minimize risks, but ultimately the decision to pump depends upon territorial jurisdictions and political will.

5.7. Precaution, mitigation, and adaptability

Academics, consultants, government agencies, and others have conducted numerous studies in the Phoenix area to anticipate the effects of climate conditions on supplies and demands (e.g., Ellis et al., 2008; Balling and Gober, 2007). DCDC-affiliated activities have: expanded knowledge of climatic and land use/cover changes on water supplies and demands (e.g., Balling and Goodrich, 2007; Ellis et al., 2008); identified interactions and tradeoffs between water, energy, and land planning (e.g., Gober et al., 2012; Guhathakurta and Gober, 2007), and examined how individuals and groups make decisions about water (e.g., Larson et al., 2009b; White et al., 2008). Meanwhile, few studies and events addressed ecological impacts and ecosystem functions, and little

intervention research has been conducted to critically assess public involvement in decision making. These gaps may exacerbate ecosystem degradation and injustices in water governance. Yet, overall, DCDC activities have advanced anticipatory understanding and social learning across scientists and policymakers (e.g., through modeling and cross-sectoral events such as land–water planning workshops).

Insufficient resources and inabilities to conduct assessments, develop plans, or participate in activities limits adaptive capacity, especially in smaller towns with fewer staff and less money (Larson et al., 2012). Inadequate data and limited knowledge—for instance, about small wells exempt from reporting—also inhibit monitoring and adaptations to change. Meanwhile, political resistance and popular assumptions among policymakers (e.g., ‘there will be water’; Holway et al., 2006) thwart transformative research as well as certain mitigation and adaptation strategies (e.g., demand management). A pro-growth culture and cheap water rates prevent related management and adaptation strategies as well, while making it difficult to pursue research on sensitive topics (e.g., incorporating higher prices in DCDC's model). Overall, the customs of water managers—which emphasize centralized, technocratic strategies and supply augmentation (Lach et al., 2005; Larson et al., 2009b)—block or diminish adaptation mechanisms (e.g., harvesting rainwater or restricting demands). Open dialogue and trust building can aid discussions about such controversial matters, especially since political–economic forces present significant barriers to mitigating and adapting to water scarcity.

Given the relatively inefficient water-use rates and the lack of water dedicated to aquatic ecosystem functions in the Phoenix area, there is room to explore stronger conservation initiatives in the region. In fact, many residents seem more supportive of

conservation efforts (e.g., water pricing and bans) than policymakers have suggested, indicating that public support may exist for more stringent efforts (Larson et al., 2009b). Into the future, lifestyle changes—including reduced water consumption—will be necessary for continued growth regardless of climate conditions (Gober and Kirkwood, 2010). Managing demands through people's choices will be particularly essential since water use is more sensitive to land use/cover conditions than climate (Gober et al., 2012), in part due to human management of technology (Balling and Gober, 2007).

While ‘doing more with less’ or ‘doing the same with less’ are central to efficiently using finite water supplies and adapting to urban-environmental change, too much efficiency may lead to “demand hardening” wherein squeezing more water out of current uses reduces flexibility and adaptive capacity (at least in the short term; Larson et al., 2012). Thus, we recommend managing demands for efficiency while avoiding complete hardening for long-term sustainability. In Phoenix, this could mean halting some farmland development while making the remaining agricultural activities more efficient—that is, to reduce demands in the near term while reserving irrigation water as a flexible adaptation strategy (i.e., through water transfers) during times of need (e.g., temporary or extreme shortages).

6. Discussion and Recommendations

The Phoenix region faces various water resource challenges including high consumption rates, degraded ecosystems and habitats, inequities in outcomes and involvement, and fragmented decision making. From irrigating agriculture to increasingly urban lifestyles, anthropocentric and economic uses of water for residents and businesses have trumped biocentric uses for preserving aquatic ecosystems and wildlife. Meanwhile,

a warmer, drier climate and degraded water quality threaten finite water supplies, which will require increased demand management into the future (Gleick, 2002; Gober and Kirkwood, 2010). Collectively, these issues present a range of choices and tradeoffs involving multiple actors: supply versus demand management, centralized (top-down) versus decentralized (bottom-up) governance, and ‘gray’ versus ‘green’ technologies (Mitchell, 2006; Pahl-Wostl et al., 2010). In pursuit of sustainable water governance, there are no one-size-fits-all options. We therefore suggest a number of alternatives among diverse actors in order to achieve multiple objectives and address tradeoffs in an integrated, coordinated fashion.

One critical need is to enhance the integrity of degraded ecosystems. The Phoenix region currently has some isolated projects to restore or protect ecological functions (e.g., habitat and biodiversity) while primarily serving other purposes (e.g., water treatment and recharge). The development of such green infrastructure (e.g., wetlands and ponds) can enhance the ecological value of water for wildlife, help to clean water and replenish water supplies, and provide societal benefits such as recreation and enjoyment. Although local municipalities may pursue such projects, citizens and non-profit organizations (e.g., local ‘friends of’ groups or those such as Audubon Society) increasingly play key roles in governance (Stoker, 1998; Peters and Pierre, 1998). Non-governmental groups can garner support and help to manage green infrastructure, especially in instances where resources are limited or partnerships are formed across public and private actors.

Dedicating water and managing resources for ecological purposes could also create a ‘buffer’ against shortages, such that water might be shifted from ecosystems (e.g., dedicated stream flows) to essential uses to protect livelihoods during times of

scarcity. As agricultural land is developed in favor of ‘higher’ economic uses, losses or hardships during water shortages will likely increase since the flexibility to transfer water from low- to high-value uses will diminish (Larson et al., 2012). Reconsidering the future of agriculture in the study region and elsewhere could therefore transform the region toward sustainability as an adaptation mechanism (at least temporarily or in the short-term), while potentially providing still other benefits (e.g., local food production that could minimize greenhouse gas emissions and preserve open spaces between urban and undeveloped lands). Finally, one other option for managing water uses and tradeoffs—while avoiding demand hardening—may be to carefully irrigate landscapes to achieve greater efficiency as well as heat mitigation and other purposes, including the adaptive capacity to move water from outdoors to indoors during times of shortages. However, flagrant or wasteful uses of water should be eliminated for resource maintenance and social–ecological integrity as well as equity of use and access.

With high outdoor water uses, drought-tolerant landscaping, shared pools, and other ways to reduce such demands are imperative in the Phoenix region. While some progress has been made in this area, especially in new developments, attention to older area with lush landscapes and outdated, leaky infrastructure (e.g., pipes, fixtures) is imperative to conserve water in residential and other areas. Investments to minimize water losses from canals are another option, particularly as facilities age and become less efficient. Decentralized initiatives such as gray-water reuse or rainwater harvesting can further improve efficiency while helping to avoid costly supply-augmentation strategies. Although awareness and adoption of such strategies is rising (especially in other places

such as nearby Tucson), barriers must be overcome including the dominant centralized infrastructure and lawsuits concerning the right to capture water under surface water law. Institutional constraints present barriers to changes in management—that is, toward “soft path” approaches (Gleick, 2002) involving decentralized strategies such as conservation and green infrastructure. These barriers encompass the informal norms and customs embedded in water managers and government planners, who are formally governed by jurisdiction-based missions and activities that are too narrow and fragmented to address the complexities of regional water systems (Larson et al., 2012). The centralized, technocratic, and supply-oriented culture of water managers will be hard to change given long-engrained traditions embedded in professional mindsets and organizations (Lach et al., 2005). Although organizational change tends to be slow, collaborative initiatives and deliberative dialogue can facilitate change through social learning (Pahl-Wostl et al., 2010). Transformations are particularly needed in terms of integrated planning across water sources, societal sectors, and biophysical units of relevance for maintaining social–ecological integrity and resource systems. Attention to the interconnections across places and sectors (e.g., land–water and water–energy) will enhance resource maintenance while addressing tradeoffs (e.g., water conservation versus heat mitigation and energy use) and minimizing inequitable outcomes (e.g., vulnerabilities to heat or pollution) (Mitchell, 2005; Larson et al., 2012).

Despite cultural and political constraints surrounding the largely centralized nature of water management, increased participation is needed for sustainable water governance in metropolitan Phoenix and elsewhere, including the involvement of marginalized groups (e.g., low-income neighborhoods, Native Americans, and

representatives from Mexico). Deliberative processes can facilitate fair participation and outcomes in decision making while potentially bolstering political support and actions (Larson and Lach, 2010). However, given weak political will and leadership to implement and enforce rigorous decisions and policies, participation is likely to remain limited, especially in the absence of public resistance or actions that challenge the status quo. Non-governmental and non-profit entities (including universities) may therefore play leadership roles in pursuit of sustainability and social learning across diverse actors (Pahl-Wostl et al., 2010).

Although useful, our appraisal is limited by a number of factors including the available data and studies for various components of water system dynamics. Future research can build on this appraisal to address these limitations. In doing so, studies might focus on developing in-depth appraisals where information is lacking (e.g., ecosystems and participatory governance). Scholars, policymakers, and still other stakeholders might also develop indicators (or metrics) to quantify and monitor how well various (sub)principles are being met (e.g., per-capita demand as a metric for water use efficiency or established minimum flows for habitat integrity). Deliberative discussions about how to proceed in the future could also bolster such appraisals and the participatory nature of research, which we will continue to pursue collaboratively by developing and exploring scenarios at DCDC.

7. Conclusions

Our appraisal of water governance in Phoenix offers insights and recommendations for transforming this arid metropolitan system toward sustainability. Although the region is doing well in some respects, several problems and stressors

threaten communities and ecosystems. Key steps toward sustainability encompass: conservation advances for enhanced efficiency as well as groundwater recharge and effluent reuse programs to maintain resources and ecological integrity; multi-purpose green infrastructure projects that provide wildlife habitat and enrich livelihoods while also potentially recharging aquifers or filtering pollutants; enhanced participatory governance and decision making on current challenges and future possibilities; and, increasing attention to groundwater–surface water interactions, water–energy tradeoffs, and integrated land–water planning.

These lessons apply widely to diverse areas since water systems must be governed holistically considering multiple objectives and tradeoffs, degraded water quality and ecosystems, and rising demands and resource costs, among other challenges. Not only can other areas learn from this study, but the Phoenix area can also learn from other places (e.g., Colorado's in-stream flow policies, California and Singapore's water-reuse efforts, or Australia's water conservation and drought planning experiences). In the face of dwindling supplies and environmental change, building adaptive capacity through collaborative research and participatory decision making is critical for sustainable water governance that is effective, efficient, and equitable in Phoenix and elsewhere. Applied within and across regions, moreover, our framework can assist with holistic, interdisciplinary assessments to advance sustainability.

An actor-oriented, systems approach to water sustainability must consider who is doing what with water, coupled with the goals, rules and implications of those activities and their interactions with natural and engineered infrastructure. Not only is this comprehensive approach useful for synthesizing research and conducting comparative

appraisal; it also provides a framework for innovating water systems through the co-production of knowledge and adaptive learning, both of which are essential for anticipating and coping with perturbations and environmental change. Future assessments employing deliberative processes will benefit from such an approach by synthesizing and improving understanding of water systems from multiple perspectives and with an eye toward the future.

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9. Resources

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CHAPTER 5

Envisioning the Future of Water Governance:

A Survey of Central Arizona Water Decision Makers

Abstract

The future of the American West depends on sustainable water resource governance. A variety of uncertainties associated with limited freshwater supplies, population growth, land use change, drought, and climate change impacts present significant challenges. To inform decision making, managers are adopting new techniques such as scenario planning to understand how water resources might change and what practices can support economic, environmental, and social sustainability. Scenario planning can be informed by understanding the normative future preferences of a variety of stakeholders, including decision makers, who influence water governance. This paper presents a survey of central Arizona decision makers to understand their visions for a desirable future for the water system in terms of supply, delivery, demand, outflow, and crosscutting activities. Principle components analysis is used to identify patterns underlying responses about preferences for each domain of the system and correlation analysis is used to evaluate associations between themes across the domains. The results reveal two distinct visions for water in central Arizona – one in which water experts and policy makers pursue supply augmentation to serve metropolitan development, and another in which broadened public engagement is used in conjunction with policy tools to reduce water consumption, restore ecosystem services, and limit metropolitan expansion. The results of this survey will inform the development of a set of normative scenarios for use in exploratory modeling and anticipatory governance activities.

1. Introduction

Water sustainability is vital to the future of the American West. As the Western Water Policy Review Advisory Committee (1998) stated, “Water defines the West, and our use of it will define the West of the 21st Century” (p. xxxi). Water governance is particularly important to urban sustainability in places such as the metropolitan Phoenix area, a sprawling desert metropolis of more than four million inhabitants situated in central Arizona. Effective water governance is essential to ensure continued social wellbeing and economic prosperity in the region while preserving and restoring vital ecosystems. For example, the Colorado River and its tributaries provide a range of ecosystem services, contributing to municipal water supplies for nearly 40 million people in seven western states, irrigating millions of acres of farmland, generating thousands of megawatts of electrical capacity for the region, and providing critical habitat for threatened and endangered species (Bureau of Reclamation, 2012). Multiple factors, however, threaten the future vitality of the Colorado River Basin, including inherent surface water variability, record droughts, rapid population growth, urbanization, land use change, and climate change impacts.

The region will very likely become warmer and drier in the coming century, reducing the average flows of available surface water (National Research Council, 2007). There is evidence that this transition is already underway (Seeger et al., 2007) and that the warming, droughts, reduced snowpack, and decreased river flows are consistent with anthropocentric climate change and may be occurring faster than predicted by prior assessments (Overpeck and Udall, 2010). A major study led by the Bureau of Reclamation (2012) projects that, without new interventions, a long-term and structural

supply-demand imbalance of up to 3.9 billion m³ (3.2 million acre feet) is possible by 2060 in the Colorado River Basin. Meanwhile, climate scientists have warned that future climate conditions in the region will be non-stationary (Millie et al., 2008), meaning that they will operate outside the long-term historical range of variability. Future water resource planning in the region has to cope with several challenges: the unreliability of historical trend extrapolations; a range of other uncertainties associated with environmental, social, and scientific processes; as well as increasing competition for water between residential, industrial, agricultural, and environmental uses (Gober and Kirkwood, 2010).

Scientific knowledge and modeling are critical to understanding the socio-ecological dynamics of water systems. Yet, it is increasingly accepted that too much attention has been focused on representing uncertainties, and too little attention on building capacity to make decisions under uncertainty (Gober, 2013). As Trenberth (2010) noted, while our knowledge of systems and the sophistication of models increases, so does our understanding of factors and feedback mechanisms we did not previously incorporate. This can have the paradoxical effect of *increasing rather than reducing* uncertainties. Dealing with these uncertainties challenges existing water management institutions, which have been guided by conservative norms and incremental decision-making rather than innovation and transformative solutions (Lach, Ingram, and Rayner, 2005; Rayner, Lach, and Ingram, 2005). Arizona water managers, for instance, recognize the significance of climate change, but struggle with how to deal with climate uncertainties as they lack relevant information at time and spatial scales compatible with

their conventional planning practice (Jacobs, Garfin, and Buizer, 2009; White, Corley, and White, 2008).

Scholars have called for water management institutions to undergo a transformative shift toward a new paradigm (Gleick, 2003; Gober et al., 2010; Pahl-Wostl, 2002). While recommendations vary, scholars commonly call for a transition away from centralized, regulatory, predict-and-plan, engineering-dominated water management models. Proposed alternatives are distributed and participatory water governance regimes that seek to manage multiple uncertainties by incorporating stakeholders' values and preferences, using exploratory scientific modeling, anticipating multiple plausible futures (scenario planning), implementing evidence-supported policies, adapting to changing conditions, and fostering social learning (Hering and Ingold, 2012; Pahl-Wostl et al., 2007).

Such emerging approaches recast decision making under uncertainty in terms of “anticipatory governance” (Barben et al., 2007; Guston, 2008; Quay, 2010), which employs participatory modeling and scenario planning to promote resilience, flexibility, and adaptive capacity. This is in contrast to conventional water planning and policymaking, which focuses on existing problems, predicting a specific future, incorporating uncertainty derived from a historic range of variability, and planning to optimize the water system under that prediction based on expert recommendations (Adams et al., 2003). Anticipatory approaches are particularly powerful when incorporating stakeholders' values and preferences because decision making is guided by normative references (Robinson, 2003). To ensure that such normative scenarios or visions are well justified, however, it is critical to apply principles of sustainability,

justice, or resilience (Swart, Raskin, and Robinson, 2004; Wiek and Iwaniec, 2013). There is a growing body of research describing approaches for envisioning sustainable water futures to inform anticipatory governance and scenario planning activities (Beniston, Stoffel, and Hill, 2011; Schneider and Rist, 2013). Common to these approaches is the use of normative references to anticipate visions, assess their plausibility and desirability, and provide evidence for decisions necessary to achieve the desirable visions and avoid undesirable ones. By explicitly incorporating stakeholder values and preferences into scenario planning, these approaches can improve the utility of scenarios for policymaking and collective action (Kemp, Parto, and Gibson, 2005; Thompson et al., 2012). It is important to note that stakeholders' values and preferences might not always align among each other; they might also conflict with principles of sustainability, justice, resilience, or other generic normative frameworks (Wiek and Iwaniec, 2013). This is why participatory decision-making and governance requires deliberation and negotiation (Guston, 2008; Van Den Hove, 2006).

Prior research has documented current knowledge, risk perceptions, and preferences of water managers and other stakeholders in central Arizona (Larson, Ibes, and White, 2011; Larson et al., 2009; Larson et al., 2011; White, Corley, and White, 2008). We lack sufficient knowledge, however, about stakeholders' normative preferences about what the water system and its governance *should* look like in the future. Understanding these normative perspectives is important because the actors and institutions working in local and regional water management contexts will be the ones responsible for implementing any reforms to the governance regime. This knowledge is a useful input for the development of normative future scenarios to envision desirable

futures as well as for exploratory future scenarios to develop “what ifs” resulting from normative scenarios (Schneider and Rist, 2013).

To address this need, this article presents a survey of water decision makers in central Arizona describing their evaluations of the *desirability of plausible future states and processes in the water system*. Our study analyzes decision makers’ future preferences across multiple domains of the water system, contributing to a systems approach for analyzing water governance that integrates ecological, engineering, and, especially, actor-oriented perspectives (Wiek and Larson, 2012). Decision makers were defined in this study as individuals who affect water governance and use on an aggregated scale – beyond individual choice – and who have relevant institutional affiliations, decision making authority, and represent diverse perspectives on water. The results of the study are intended to inform the development of value-based normative future scenarios of water governance in central Arizona for use in exploratory modeling and scenario planning processes.

First, we review literature on stakeholder perceptions of water governance in central Arizona. We then present the conceptual systems framework for analyzing water governance, which guided the development of the survey. This is followed by the description of the survey research method and presentation of the results. We conclude with a discussion of the implications of this work for water resources planning and management in central Arizona and beyond.

2. Stakeholder Perceptions of Water Governance in Central Arizona

A number of recent studies have examined the current values, attitudes, and policy preferences across diverse samples and stakeholder groups involved in water

resource planning and management in central Arizona (Bausch et al., 2013; Jacobs, Garfin, and Buizer, 2009; Keller, Kirkwood, and Jones, 2010; Larson, Ibes, and White, 2011; Larson et al., 2009; Larson et al., 2011; White, Corley, and White, 2008; White et al., 2010). This work provides an important foundation for our study by delineating the actors and institutions engaged in water decision-making and their current perceptions of water sustainability problems and attitudes about potential solutions. As mentioned previously, however, this body of research has not specifically addressed the long-term future preferences of water decision makers.

In a series of studies, Larson and colleagues (Larson, Ibes, and White, 2011; Larson et al., 2009; Larson et al., 2011) examined affective concerns about water risks, cognitive perceptions about the causes of water shortages, and conative attitudes (or behavioral intent) toward specific approaches for water resource management. This work identified significant dimensions along which perspectives vary, in addition to areas of divergent and convergent views among stakeholders based on their personal interests, demographic profiles, professional roles, and other factors. One study found that concerns about water risks varied between groups of academic scientists, water policy professionals, and the public, depending in part on the scale and type of risks involved (Larson et al., 2009). For instance, while the sufficiency of water supplies was of concern across all groups, water policy professionals worried the most about cost, system performance, and political factors such as impacting and regulating consumer behaviors. In the same study, water policy experts were less concerned about regional water use rates than both residents and academic scientists, posing a potential constraint on regulating demand as a means of conservation. Findings from this study demonstrated the

supply-side orientation of water managers given their relatively strong support for acquiring more water to address shortages. By comparison, academic scientists stressed managing demands through price-based and regulatory approaches. Such divergences in resource concerns reflect areas of potential conflicts in decision making as well as potential constraints to collaboration.

Keller, Kirkwood, and Jones (2010) surveyed central Arizona water stakeholders' about their value-focused decision making to determine their current and short-term future (six months to five years) evaluation concerns and priorities. Respondents evaluated a hierarchy of concerns and provided weights for the importance each category. The final categories and weights, across the full sample (n=45), where weights ranged from 0 to 1 included: sufficiency of water supplies (.32), impacts on the natural/biophysical environment (.16), health and safety (.15), financial and technical requirements (.12), political impacts and governance (.12), central Arizona socio-economic impacts (.08), and indirect external impacts (.05). Comparing stakeholder groups, sufficiency of water supplies was the highest average weighted category except for among environmentalists. Not surprisingly, the private sector was more concerned about economic impacts, and environmental groups cared about environmental impacts of decisions.

While current perceptions of water resource challenges present a “push factor” for decision making, visions can be a strong “pull factor.” Visions – consisting of normative future preferences – can serve to orient decision making and prioritize strategic activities (Robinson, 2003). While there is some convergence in stakeholder concern regarding sufficiency of water supplies in central Arizona, there is divergence in perceptions of how

best to address supply issues and other challenges (Larson et al., 2009; Keller, Kirkwood, and Jones, 2010). There has yet to be a study that analyzes what stakeholders see as desirable resolutions to current (and future) water resource challenges. This survey examines the normative future preferences of key decision makers across the water system in central Arizona to understand what visions are guiding current and planned future activities.

3. A Systems Framework for Analyzing Water Governance

This study was guided by an integrative conceptual framework (Wiek and Larson, 2012) of sustainable water governance, which has been developed in part to facilitate syntheses of information on the actors and rules (social system), human infrastructure (technological system), and hydrologic and ecological resources and processes (biophysical system) relevant for sustainable water governance. This framework is focused on the seemingly straightforward question, “who does what with water?” This interdisciplinary approach builds on research by the likes of Ostrom (2009), Pahl-Wostl (2007), and others to guide institutional governance analysis. The framework outlines a core set of water management activities and a holistic set of principles for water sustainability (Larson, Wiek, and Withycombe Keeler, 2013; Wiek and Larson, 2012). Largely following Gibson’s (2006) sustainability assessment approach and Pahl-Wostl’s (2007) insights on social-hydrologic systems, the sustainability principles include social-ecological system integrity and interconnectivity, resource efficiency and maintenance, livelihood sufficiency and opportunity, civility and democratic governance, intra- and inter-generational equity, and, lastly, precaution and adaptive capacity.

Informed by this framework, we seek to understand the normative future preferences of the actors overseeing the major activities involved with water decisions. Consequently, the survey was constructed to assess water decision makers' preferences for the future of the water system across five major categories of: a) supplying, b) distributing, c) using, and d) discharging water, along with e) activities that cut across these actions.

4. Research Method

In this study, we employed a cross-sectional survey design with data collected via an online questionnaire emailed to water decision makers in the greater Phoenix area. Methodologists have identified several advantages of email and online data collection for survey research including response speed, cost efficiency, precise tracking, heightened response quality, and more candid responses (Sheehan, 2001). Our approach is consistent with related research on, for instance, land managers' perceptions of climate adaptation (Archie et al., 2012) and environmental experts' perceptions of water security (Larson, Wiek, and Withycombe Keeler, 2013). We employed a non-probability, stratified, purposeful sampling strategy to collect data from decision-makers who influence water governance in central Arizona. We created the initial sampling frame from a database of approximately 400 water resource decision makers engaged with a university-based research center focused on water sustainability and climate adaptation in central Arizona. Following Wiek and Larson's (2012) water governance framework, we then stratified the sampling frame to identify individuals who make organizational-level decisions about how water is supplied, distributed, used, discharged, and governed in central Arizona.

Since the focus of this study is on stakeholders directly involved in water management decision making, we did not collect data from residential end users.

We used SurveyMonkey for data collection and, to enhance response rates, sent six emails to potential respondents over a three-month period from June – September 2012. We invited 352 potential respondents to participate in the study. Of that total, 30 email addresses were returned as undeliverable, 10 respondents opted out, and 106 participants completed the questionnaire. The final effective response rate was 32%, which is consistent with norms and expectations for survey studies with online data collection (Sheehan, 2001). The survey respondents represented central Arizona water resource decision makers from planning and management, agricultural, and environmental interests. Most were male (64%) and the group was highly educated, with 90% having achieved a bachelor's degree or higher level of education and 16% having earned a PhD.

The questionnaire included six parts. One section requested information on participants' background, including educational attainment, professional responsibilities, and demographics. The core of the questionnaire included five, multi-item, Likert-type questions focused on the future of the water system in terms of: a) supply, b) delivery, c) demand, d) outflow, and e) crosscutting activities. Each section included a series of normative statements intended to capture plausible future *processes and outcomes* for water governance and use in the greater Phoenix area. We developed the original statements for this research guided by the following criteria:

- Statements should be plausible. Plausibility here implies that enough evidence exists for each event or pathway that they can be considered

realizable. To meet the criteria of plausibility individual statements should, at minimum, not violate any physical laws and, at maximum, be extrapolated from current trends or ongoing activities (Wiek et al., 2013).

- Statements should describe future processes and outcomes for each phase of the water system as described by Wiek and Larson (2012). The statements should describe both what the system looks like (e.g., the physical landscape or water use by industry) and how the system operates (e.g., formal and informal rules about water).
- Statements should represent a spectrum of both future processes and outcomes. There should be a balance between statements reflecting current pathways and statements describing a transformed future, while still meeting plausibility criteria (Wiek et al., 2013).
- Statements should be relevant to the survey respondents. They should be salient to the priorities and concerns of decision makers.

Respondents rated the desirability of the statements on a five-point, Likert-type response scale (1=Very Desirable to 5=Very Undesirable). We pretested the survey with a small set of water decision makers not included in the full study and revised the instrument to improve the relevance and clarity of the items based on the results of the pilot test.

5. Analysis

To reduce the number of items and identify underlying components that explain the pattern of correlation within the observed items, we conducted principal components analysis (PCA) for each substantive multi-item question on the survey (i.e., supply, delivery, demand, outflow, and crosscutting activities). We used PCA to form

uncorrelated linear combinations of the observed variables and Varimax rotation to simplify interpretation of the components. In the initial extraction, we used the Kaiser criterion to retain factors with Eigenvalues greater than 1.0, examined scree plots to look for a distinct “elbow,” and considered total variance explained. Individual items were retained if the loading was >0.50 for a single component and the item did not cross-load on multiple components in the rotated matrix. We gave components meaningful labels reflecting the contributing items, paying attention to the items that had the highest component loadings, and then computed composite scores for each component as mean values of the items comprising the component. We then calculated bivariate correlations between the components. The PCA results are presented first, including the final accepted solution for each domain of the water system with labeled components and sample items being those with the highest component loadings. This is followed by the correlation analysis.

6. Results

6.1 Future of Water Supply

For the future of water supply in central Arizona, a two-component solution emerged from the PCA, which explained 40.70% of the total variance (see Table 1). We labeled the first component “Groundwater conservation and demand management.” This component explained 23.0% of the variance and included seven items with a reliability of $\alpha=.79$. The items with the highest component loadings included, “Safe yield (the long-term balance of groundwater withdrawals with recharged water) should be the central principle of water managers” and “Groundwater should be replaced where it was originally removed.” We labeled the second component “Supply augmentation for

metropolitan development.” This component explained 17.7% of the variance and included five items with a reliability of $\alpha=.67$. Sample items include “New water supplies should be sought to allow continued growth and development” and “De-salted water should be a source of water for the greater Phoenix area to meet growing demands.” Examining the mean values for the new composite variables representing the two components, we found that central Arizona water decision makers rated “Groundwater conservation and demand management” as desirable to very desirable ($M=1.79$, $SD=.60$) for the future of the water supply system. The mean value for “Supply augmentation for metropolitan development” ($M=3.19$, $SD=.80$) indicates that respondents found this approach to be slightly undesirable for the future of water supplies and governance.

6.2 Future of Water Delivery

For the future of water delivery in central Arizona, a two-component solution emerged from the PCA, which explained 41.14% of the total variance. We labeled the first component “Efficient infrastructure and reuse.” This component explained 22.52% of the variance and included four items and had a reliability of $\alpha=.70$. Sample items included: “The canals and delivery system should be upgraded to reduce water losses” and “Water managers should develop infrastructure to deliver reclaimed water to residents for outdoor landscaping.” We labeled the second component “Multi-purpose delivery infrastructure.” This component explained 19.62% of the variance and included two items with a reliability of $\alpha=.64$. The items were “Throughout the greater Phoenix area, canals should be lined with shade trees and walking paths for recreation” and “Mixed-use development should occur along canals in the greater Phoenix area.” Examining the mean values for the variables created from the components, we found that

respondents rated both approaches as desirable for the future of the water delivery system.

6.3 Future of Water Demand

For the future of water demand in central Arizona, a three-component solution emerged from the PCA, which explained 45.77% of the total variance. We labeled the first component “Cross-sector water conservation.” This component explained 22.69% of the variance and included 11 items with a reliability of $\alpha=.86$. Sample items included: “Industry should be required to reduce their water use to meet specific conservation targets,” “Cities should be required by the state to achieve aggressive water conservation targets,” and “Farmers should be required to reduce their water use to meet specific conservation targets.” We labeled the second component “Water use for residential and economic development.” This component explained 11.93% of the variance and included seven items with a reliability of $\alpha=.70$. Sample items included, “Irrigated farmland should be maintained as a buffer so that water can be transferred to municipal uses during droughts” and “Water should be used to develop Phoenix as the ‘golf course capital of the world.’” The third component, labeled “Water use for environmental and social justice,” explained 11.15% of the variance and included three items with a reliability of $\alpha=.67$. Sample items included, “No species in the greater Phoenix area should be endangered” and “If unable to afford water, residents should receive free water to meet their basic human needs.” Examining the mean values for the new composite variables representing the two components, we found that central Arizona water decision makers rated cross-sector water conservation ($M=2.55$, $SD=.86$) and water use for environmental and social justice ($M=2.49$, $SD=.67$) as desirable, whereas water use for

residential and economic development ($M=3.46$, $SD=.70$) was rated as slightly undesirable overall.

6.4 Future of Water Outflows

For the future of water outflows, the PCA produced a single component, which included three items that explained 67.4% of the variance and had a reliability of $\alpha=.68$. We labeled this component “Effluent for ecosystem services” and sample items included “Effluent (treated wastewater) should be dedicated to maintaining water in habitat areas for wildlife” and “Wetlands should be created and managed to treat wastewater while providing other benefits to the public.” Examining the mean values for the new composite variable representing the components reveals that water decision makers rated this as desirable to very desirable.

6.5 Future of Crosscutting Activities

For the future of crosscutting activities, the PCA produced a two-component solution that explained 58.5% of the total variance. We labeled the first component “Multi-stakeholder cross-sector planning.” This component explained 36.4% of the variance and included seven items. Sample items included “A watershed council for the Salt and Verde Rivers should be established to make water resource decisions” and “Groundwater basin councils should be established to make decisions about groundwater management.” We labeled the second component “Democratization of decision making.” This component explained 22.1% of the variance and included two items “Local stakeholders and residents should be actively engaged in water resource decisions in the greater Phoenix area” and “Policymakers should consult with the broader public to make water resource decisions.” Examining the mean values for the new composite variables

representing the components reveals that water decision makers rated both components as desirable.

6.6 Correlation Analysis

The results of correlation analysis are presented in Table 2. Examining the correlation matrix, and considering Cohen's (1988) conventions to interpret effect size, we identified large and statistically significant ($p < .01$) bivariate correlations ($< .50$) between components. The results show that the groundwater conservation and demand management component (future of water demand) exhibits large correlations with cross-sector water conservation (future of water supply), water use for environmental and social justice (future of water delivery), and multi-stakeholder cross-sector planning (future of crosscutting activities). In contrast, the supply augmentation for metropolitan development component (future of water supply) is strongly correlated with water use for residential and economic development (future of water demand). The efficient infrastructure and reuse component (future of water delivery) exhibits large correlations with cross-sector water conservation (future of water demand) and multi-stakeholder cross-sector planning (future of crosscutting activities). Cross-sector water conservation (future of water demand) is strongly correlated with multi-stakeholder cross-sector planning (future of crosscutting activities). Finally, water use for environmental and social justice (future of water demand) is strongly correlated with multi-stakeholder cross-sector planning (future of crosscutting activities).

Table 6

Principle Component Analysis Results

Watery System Domain Component label	Number of items	M	SD	α	Variance explained
Water Supply					
Groundwater conservation and demand management	7	1.79	.60	.79	23.00%
Supply augmentation for metropolitan development	5	3.19	.80	.67	17.70%
Water Delivery					
Efficient infrastructure and reuse	4	2.23	.80	.70	22.52%
Multi-purpose delivery infrastructure	2	2.22	.95	.64	19.62%
Water Demand					
Cross-sector water conservation	11	2.55	.82	.86	22.69%
Water use for residential and economic development	7	3.48	.66	.70	11.93%
Water use for environmental and social justice	3	2.59	.97	.67	11.15%
Water Outflows					
Effluent for ecosystem services	3	1.93	.76	.68	67.35%
Cross-cutting activities					
Multi-stakeholder cross-sector planning	7	1.96	.71	.85	36.40%
Democratization of decision making	2	2.02	.89	.84	22.11%

Table 7.

Correlation Matrix for Components

	1	2	3	4	5	6	7	8	9	10
1. Groundwater conservation and demand management	1									
2. Supply augmentation for metropolitan development	-.25**	1								
3. Efficient Infrastructure and reuse	.60**	-.017	1							
4. Multi-purpose delivery infrastructure	.44**	-.012	.33**	1						
5. Cross-sector water conservation	.61**	-.27**	.69**	.41**	1					
6. Water use for residential and economic development	-.32**	.51**	-.09	0.08	-.018	1				
7. Water use for environmental and social justice	.55**	-.016	.47**	.44**	.43**	-.09	1			
8. Effluent for ecosystem services	.33**	-.013	.34**	.44**	.39**	-.011	.34**	1		
9. Multi-stakeholder cross-sector planning	.64**	-.25*	.64**	.36**	.66**	-.24*	.60**	.40**	1	
10. Democratization of decision making	.41**	-.09	.21*	.28**	.32**	-.06	.48**	.32**	.48**	1

7. Discussion and Conclusions

The objective of this article was to present a survey of decision makers' evaluations of the desirability of plausible future states and processes in the water system in central Arizona. All together, the statements represent normative visions of water governance and use held by different decision makers. This knowledge is intended to inform the development of normative future scenarios and exploratory modeling and scenario planning exercises. Guided by an integrated conceptual framework for analyzing water governance systems (Larson, Wiek, and Withycombe Keeler, 2013; Wiek and Larson, 2012), we analyzed decision makers' preferences for the future of water supply, delivery, demand, outflows, and crosscutting activities. We used principal components analysis to identify latent components underlying the pattern of responses to the

individual items for each domain of the water system, created composite variables and evaluated decision makers' ratings of the desirability for the components, and used correlation analysis to identify strong associations between the components across the domains of the water system.

The results show that the highest rated or most desirable components for the future of water governance in Arizona were the groundwater conservation and demand management component of the future of water supply, the effluent for ecosystem services component of the future of water outflows, and the multi-stakeholder cross-sector planning component of the future of crosscutting activities. The desirability of groundwater conservation reflects respondents' agreement with the stated policy goals outlined in the Arizona Groundwater Management Act of 1980 (aka Arizona Groundwater Code). Under the Arizona Groundwater Code, an assured or adequate water supply designation is required by the Arizona Department of Water Resources (ADWR) for cities, towns, or counties to gain approval to plat a subdivision and obtain approval to sell lots from the Department of Real Estate. Passed in 1980, the Groundwater Management Act was a progressive policy designed to achieve water sustainability as defined through "safe yield," or a long-term balance between groundwater withdrawals and recharge in the urban population centers of the state (Jacobs and Holway, 2004). Many analysts, however, have pointed out that the original policy goals in the Groundwater Management Act have been circumvented and the law lacks adequate enforcement mechanisms (Hirt, Gustafson, and Larson, 2008). Thus, our findings show that decision makers want the future to align with the stated policy goals.

The respondents' high ratings for the desirability of the use of effluent for ecosystem services, such as maintaining water in habitat areas for wildlife and wetlands, represent a preference for system transformation in water outflows. Current estimates suggest the majority of municipal effluent in the Phoenix area is reused for power production (i.e., cooling at the Palo Verde Nuclear Generating Station), agricultural use, and groundwater recharge (Middel, Quay, and White, 2013). Only a small portion of municipal effluent, perhaps 10%, currently supports environmental purposes. There is, however, evidence of a growing interest among Arizona water management stakeholders in the consideration of environmental water demands as a component of overall water policy and management (Nadeau and Megdal, 2012). The findings of our study seem to indicate that, looking forward, this will be an increasingly important aspect of water governance.

In contrast, the two components rated as least desirable overall, with mean scores beyond the neutral point on the scale toward undesirable, were supply augmentation for metropolitan development, a component of the future of water supply, and water use for residential and economic development, a component of the future of water demand. Here, the respondents' ratings appear to be indicating that they desire the future of water governance in central Arizona to look markedly different from the present. It is commonly accepted that Arizona water policy in the last century generally prioritized supply-side solutions, including the development of new supplies from the Colorado River via the Central Arizona Project canal. Summarized by Hirt, Gustafson and Larson, (2008), "The story is paradigmatic: population growth and economic development strained the local water supply, which led to expensive water importation projects, which

supported more development, which led to the need for even more water—a self-perpetuating cycle of unrestrained growth driving a competitive, acquisitive water policy” (p. 483). Our results show that decision makers in this study support demand management approaches for the future of water governance in central Arizona. This finding is even more interesting in light of the results of prior research on Arizona water decision makers, which identified a strong supply-side orientation with support for supply augmentation to address water shortages (Larson et al., 2009). Our research shows a potential shift in priorities away from supply-side development strategies to demand management looking forward.

Considering the results of the correlation analysis, two distinct approaches to the future of water governance appear to emerge for this set of decision makers. One approach relies on groundwater conservation, efficient and multi-purpose infrastructure, and cross-sector water conservation, water reuse to support ecosystem services, multi-stakeholder planning, and democratic decision making. This vision is consistent with analysts’ calls for a new paradigm in water resources management that involves cross-sector planning (Gober et al., 2012), focuses on “soft path” solutions (Gleick, 2003), and incorporates multiple stakeholders in participatory environments to foster social learning (Pahl-Wostl et al., 2007). The alternative vision involves traditional supply-side solutions to support residential and economic development.

Moving forward, the results of this survey will inform the development of a set of normative scenarios for use in exploratory modeling and anticipatory governance activities. This process serves to develop distinct and “branded” value-based future scenarios for individual stakeholder groups, also within, and across groups. The resilience

of these “branded” scenarios can be defined by exploring their performance across a range of anticipated possible futures of drought, growth, and climate change. This process is designed to increase stakeholders’ capacity in systems thinking by illuminating various paths of greater or lesser sustainability of the “branded” values through this range of possible futures. Such analysis can suggest simple heuristics that can then be used by stakeholders to understand the strengths, weaknesses, similarities, and contrast of particular values if carried out in water policy and governance. This provides a simple neutral assessment that stakeholders can use to better understand the system implications of their own and others values when realized within the complex and highly uncertain system of water management. The value-based approach taken in this research is aimed at addressing existing deficits in scenario planning and policy analysis, which remain removed from real decision making contexts and do not sufficiently account for personal, institutional, and shared values that underlie decisions. Additionally, the survey approach, combined with scenario analysis, could be used to substantiate “softer” visioning activities in community and urban planning that do not adequately account for system characteristics, future challenges and diverging stakeholder perspectives.

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CHAPTER 6

Linking Stakeholder Survey, Scenario Analysis, and Simulation Modeling to

Explore the Long-term Impacts of Regional Water Governance Regimes

Abstract

Freshwater scarcity will be a pivotal challenge for cities in the 21st century as resources are threatened by increased demand, industrial contamination, and climate change, to name a few. The Phoenix metropolitan area shares many of these and other challenges with water-stressed cities around the world. Current governance approaches appear unable to respond to the looming threat of water scarcity, prompting many to call for anticipatory and sustainability-oriented water governance paradigms to facilitate sustainability transitions in water systems. Scenarios have the potential to guide transitions but their present usage, focused on narrow aspects of water systems, is not sufficient to transform water governance regimes. A new approach to scenario construction could guide transitions in urban water systems if the scenarios: (i) are governance focused, including the actors and activities that will guide transitions; (ii) are normative, incorporating the values and preferences of those responsible for carrying out transition activities; (iii) are presented as a small set of distinct and identifiable scenarios which stakeholders can comprehend and compare; and (iv) allow for interfacing with dynamic models to demonstrate the systemic impacts of different approaches to water governance. To this end, the research team employed a participatory, mixed-methodology including a stakeholder survey, qualitative scenario analysis and dynamic simulation modeling through WaterSim, to construct distinct, coherent, plausible and desirable governance scenarios of the Phoenix-region in 2030. Four scenarios are

presented: 1. Technical Management for Megapolitan Development; 2. Citizen Councils Pursue Comprehensive Water Sustainability; 3. Experts Manage Limited Water for Unlimited Growth; and 4. Collaborative Governance Makes Local Water Security a Priority. The approach provides a framework for comparing governance regimes across systems and regions while the scenarios are intended to inform transition-oriented policy making through stakeholder engagement.

1. Introduction

Transitions to *comprehensive* sustainability are needed in urban water systems throughout the world to manage the compounding stresses of population growth, urbanization, and climate change. Comprehensive sustainability goes beyond the presence of supplies in sufficient quantity and quality, to include the equitable provision of water resources for humans and ecosystems now and in the future (Wiek and Larson 2012). Facilitating transitions, to sustainability for urban water systems, defined here as long-term and compounding processes of fundamental change that lead to resilient, efficient, and equitable social-ecological-technical systems will require new approaches to water governance that are anticipatory, adaptable, and just (Gober et al. 2010, Quay 2010; Pahl-Wostl 2007). Generally, water governance is the effort and activities among stakeholders to manage collectively water resources. Traditional water governance regimes are criticized as ill equipped to prepare for and respond to a range of challenges, including climate change impacts, because they are typically expert-driven, involve complex bureaucracies, and depend on technocratic solutions to water challenges (Glieck 2003, Pahl-Wostl 2007, 2009). These traditional regimes often suffer from path dependence and lack the proper institutional incentives to consider or implement transformational change (Dietz et al. 2003; Lienert et al. 2006; Pahl-Wostl 2007). In contrast, Wiek and Larson (2012) define a comprehensive and sustainable water governance regime as: (i) systemic, accounting for the full complexity of water systems, challenges, and strategies (Lach et al. 2005; Reed and Kasprzyk 2009); (ii) actor-oriented, focused on who does what with water and how such activities and relationships contribute to water system problems and solutions (Lubell et al. 2008; Braden et al.

2009); (iii) transparent and value-laden, explicating values of local stakeholders and negotiating value conflicts (Ostrom 2009); and (iv) committed to comprehensive sustainability, in which a full suite of sustainability principles (e.g. Gibson 2005; Larson et al. 2013) are taken into account (Kallis et al. 2006; Pahl-Wostl 2009; Huitema et al. 2009; Wiek and Larson 2012; White et al. in press). Transitions to comprehensive, sustainability-oriented water governance require participatory future-oriented methods to explore and appraise alternative governance regimes and their impacts.

Scenarios are commonly used by water experts to anticipate changes to water quantity and quality, as well as to test policy options, and while these are important functions, the narrow focus does not capture a comprehensive picture of water governance (Alcamo et al. 1997; Varela-Ortega et al. 1998; Vorosmarty et al. 2000; Liniert et al. 2006; Liu et al. 2008; Mahmoud et al. 2009). By focusing particularly on ecological functions, however, scenarios have increased their predictive capacity related to climate change, incorporating downscaled global circulation models to predict changes in precipitation, runoff, evaporation, soil moisture, etc. resulting from different emissions or representative concentration pathways (Nakicenovic and Swart 2000; Moss et al. 2010). Ironically, the trend toward better predictions (often through increased complexity) can have the unintended effect of making scenarios less salient to end users for two reasons: uncertainty is sometimes increased as a result of increasing complexity in dynamic models, and humans have limited cognitive capacity to understand complex systems (Trenberth, 2010; Heugens and van Oosterhout, 2001; Tietje 2005). Improved simulation models are important for scenarios generally, and water research in particular, but by themselves they do not necessarily lead to more productive policy dialogues nor

are they intended, at present, to capture comprehensively a water system for use in transition activities (Sarewitz and Pielke Jr. 1999; Sarewitz and Pielke Jr. 2007; White 2013). What is needed is an approach to generating scenarios that marries the predictive and dynamic capabilities of simulation models with a scenario methodology designed with transition in mind.

Scenarios that inform transitions are more than advanced analytical tools, they incorporate both the processes and outcomes that contribute to transformation in a system while remaining comprehensible to stakeholders (Enfors et al. 2008; Wiek et al. 2006).

This requires that the scenarios and the scenario construction process:

- *Be governance-focused.* Significant changes in the structure and function of a water system will require shifts in the roles and responsibilities of those who govern the system (Ostrom 1990; Dietz et al. 2003; Pahl-Wostl 2007; Wiek and Larson 2012). Therefore, scenarios that aim to guide decision-making and activities for transition must reflect what actors in the water system will be doing and with what impacts. Such knowledge directly informs strategy development and policy making (Wiek et al. 2006).
- *Incorporate different normative frames – like sustainability.* The values and preferences of stakeholders who will participate in governance and transition activities should be used to design future scenarios and evaluate scenario results (Robinson, 2003; Swart et al., 2004; Wiek et al., submitted). In addition to stakeholder values, concepts like sustainability or justice can guide the development of scenarios that meet normative criteria. Normative scenarios can provide a vision of the water system transformed which acts as a “pull” to

motivate participation in transition activities (Robinson 2003; Wiek et al. 2006; White et al. in review).

- *Generate a small number of distinct scenarios.* The approach of generating large numbers of highly complex scenarios makes it difficult to identify and speak to any specific scenario in a policy context. Such is the case with the IPCC scenarios, which have been criticized for being too numerous and indistinguishable to be salient (Girod et al. 2009), exacerbating the climate change debate (Hulme 2009; Sarewitz 2011). For scenarios to guide transition activities and inform decision-making, stakeholders need to be able to compare key scenario features, weigh tradeoffs and evaluate differences between scenarios (Wiek et al. submitted). This requires that scenarios be of limited number, sufficiently distinct, and carry their own identity, so called “signature” scenarios.
- *Allow for interfacing with simulation models.* Dynamic simulation models are complex because they reflect the complexity of social-ecological systems they represent. This complexity cannot be entirely eliminated but it can be reduced, managed, and governed (Ostrom 2009). While dynamic simulation models are often too complex to engage stakeholders, they can serve as a “back-end” to water governance scenarios, providing critical feedback on the systemic impacts of different governance regimes.

To guide a sustainability transition in the Phoenix-area water system and inform such efforts elsewhere, we develop and present four signature scenarios of water governance in Phoenix in 2030, developed using multiple methods that include a stakeholder survey, qualitative scenario analysis, and system dynamics modeling. This suite of scenarios are

intended to be a point of engagement for researchers, stakeholders and policy makers to explore challenging trade-offs, build consensus, analyze policy options, among other transition activities (Mulder et al. 2010; Costanza 2000; Rotmans et al. 2001). Both the scenarios and the approach intend to bridge the gap between science and policy by presenting a small number of comparable scenarios in which policy makers and stakeholders alike can see impacts and weigh tradeoffs of different policy options. The scenarios are intended for engagement activities that will inform a sustainability transition in the Phoenix-area water system by guiding constructive and anticipatory policy-making and the development of distinctly different and comprehensive policy proposals (Reed and Kasprzyk, 2009).

2. Case Context

The Phoenix metropolitan area¹, in the US State of Arizona, was selected as a case study because of the water-related challenges the region shares with other arid and urban areas (e.g. complex and expensive delivery infrastructure (Pulwarty et al. 2005), urbanization (Westerhoff and Anning, 2000; Baker et al. 2004), drought (Morehouse et al. 2002; Balling et al. 2008), and industrial contamination (Wiek et al. 2012)) and the availability of future-oriented knowledge on aspects of the water system. There have been a number of water-related future studies conducted on the Phoenix-region, including scenarios of: water use to mitigate the urban heat island effect (Gober et al. 2009); effects of metropolitan expansion and local climate (Georgescu et al. 2012); land-use change and the impacts on water quality (Xu et al. 2007); watershed management (Mahmoud et al.

¹ Throughout the paper the Phoenix metropolitan area is referred to interchangeably as “the Phoenix area”, “metro Phoenix” “the Phoenix region” and “the Valley” short for “the Valley of the sun” a nickname derived from the city’s climate and geographic location. “City of Phoenix” and “Phoenix” refer to the specific municipality.

2011); land- and water-use in agriculture (Aggarwal et al. 2012); wastewater use (Scott et al. 2012); and integrated scenarios of water supply and demand (Gober et al. 2011).

There was also a recent effort by Larson and colleagues (2013) to synthesize research on the current state of the Phoenix-area water system that can serve as a basis to develop comprehensive and synthesized future scenarios. Though *water* governance in metropolitan *Phoenix* is the study focus, the scenario approach is applicable to different systems (e.g. energy or food) in Phoenix and elsewhere and provides a framework for comparison of governance regimes across systems and regions.

The Valley of the Sun, as Phoenix is called, is a model for the institutional and systemic complexity of water governance in water stressed regions. It is home to 4.33 million residents (US Census Bureau, 2012) and annual rainfall is 180mm. The Phoenix-region has three primary sources of water: groundwater, and surface water from the Colorado River and Salt-Verde River system, local to Arizona (ADWR, 2010). Supplies are acquired, stored, treated and delivered by a diverse array of city, state, federal and private actors with minimal engagement from the public (Larson et al. 2013). Population growth in the region was partly enabled by the 1980 Groundwater Management Act, which established Active Management Areas to control groundwater use in exchange for infrastructure to deliver Arizona's allocation of Colorado River water to metro Phoenix and Tucson (Connell 1982; Hirt et al. 2008). There has been extensive research on possible impacts of climate change on water in the region (Balling et al. 2009; Ingram and Lejano, 2007; Bolin et al. 2010; Gober et al. 2010). Reductions to in-stream flows of 9% are expected for the Colorado River Basin by mid-century (Bureau of Reclamation 2012) and between 20%-43% for the Salt and Verde rivers by 2080 (Switanek et al.

2013). Despite climate predictions, many local water experts argue that supply redundancies, policy efforts, infrastructure development, and water banking, have made the Phoenix-area water supply robust, at least for the 21st century (Gammage et al. 2011). In contrast, others argue that Phoenix' growth is unsustainable and is putting new residents at risk by guaranteeing them water on paper that is not physically available (Bolin et al. 2010). Still others point to an approach to water governance that favors industrial development and wealthy residents in the older areas of the city while neglecting poorer communities and future generations (Ross 2011). For these and other reasons, many researchers and community advocates argue that fundamental changes to the structure and function of the water system in central Arizona are needed to achieve comprehensive water sustainability (Larson et al. 2009a; Gleick 2010, Larson et al. 2013).

3. Method

We present a participatory, mixed-methods approach to constructing signature scenarios of the Phoenix region in 2030 that are distinctly different, coherent, plausible, and desirable (using different normative frames), following quality criteria suggested in the literature (Wiek and Iwaniec, in press). We combined a survey of stakeholder preferences as inputs for a qualitative scenario analysis to create normative and systemic water governance scenarios. The study builds on the results from a current state analysis of the central Arizona water system conducted by Larson et al. (2013) that focused on the five water system domains: supply, delivery, demand, outflows, and cross-cutting (governance) activities (Wiek and Larson 2012). These results were first used in a qualitative system analysis to understand key systemic interactions of the current water

system. Selected system variables were then used to generate normative governance scenarios, constructed with stakeholder preferences and other normative frames. These governance scenarios were finally used as inputs into WaterSim 5.0, a dynamic water model of the Phoenix area, to test scenario performance under different climatic conditions over the next 15-65 years (Sampson et al. in review). The mixed-method approach is summarized in Figure 7.

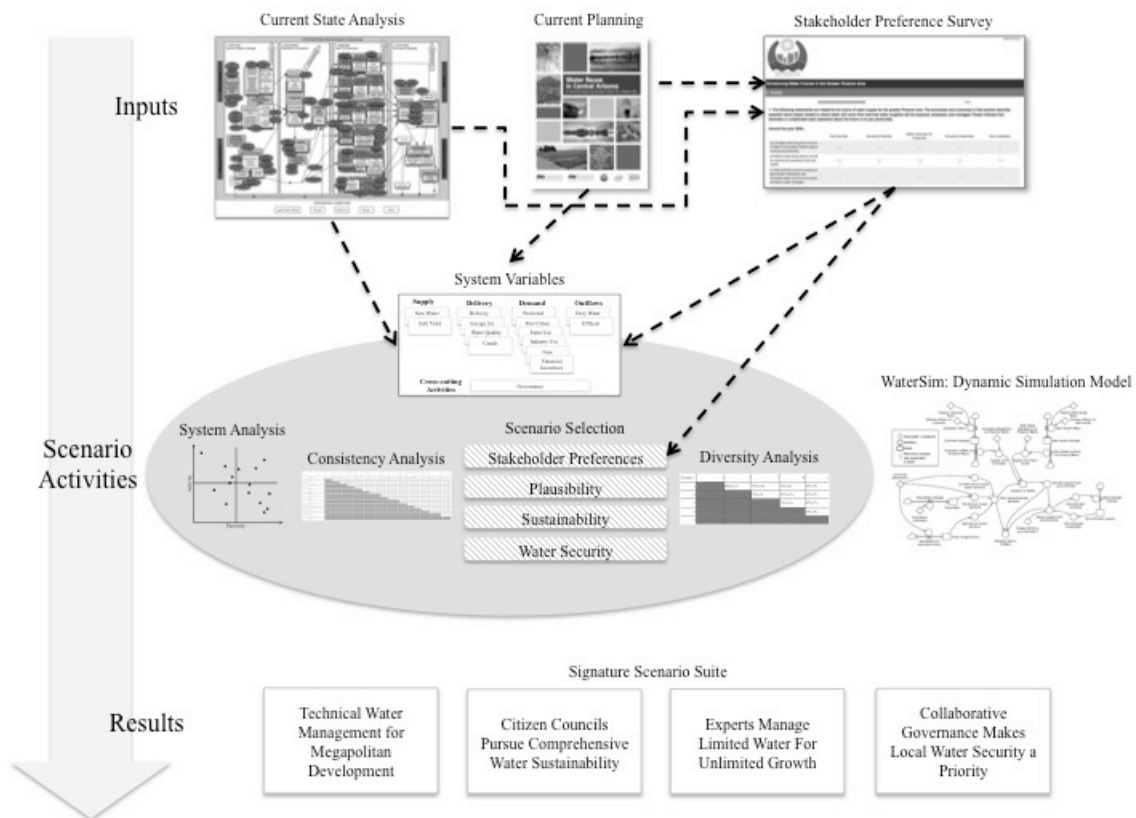


Figure 7. Mixed-method approach to constructing water governance scenarios.

Step 1 – Defining system variables and future projections

The procedure for selecting variables was adapted from Scholz and Tietje (2005, pp. 91-92) in which broad system domains are identified along with variables within each domain. The initial set of variables is then reduced by removing redundant or

unimportant. We present an adapted four-step procedure in which we integrate stakeholder expertise and normative preferences to develop variables that capture the complexity of the water system and future projections that account for a range of future states, ranging from status quo to radically transformational.

1. An initial set of variables was identified through an analysis of the Phoenix area water system across five water system domains: supply, delivery, demand, outflows, and cross-cutting activities (Larson et al. 2013).
2. For each variable from this initial set one or more normative future projections were defined based on existing water-related plans, activities, and policy discussions in Arizona and elsewhere. Overall, we develop 66 normative statements about future water governance in metro Phoenix in 2030 for use in a stakeholder survey (Step 2). White et al. (submitted), queried 106 stakeholders with diverse interests and expertise in an online survey using a Likert-type questionnaire. Respondents rated their preference for the 66 normative statements crafted in Step 1.
3. The research team analyzed the survey responses to refine a final set of variables based on stakeholder preferences. Principal component analysis was used to reduce the total number of survey items and identify key components. Survey items with the highest component loading for each component for each water system domain were considered primary and unique and were therefore selected as variables. Items that did not load were considered secondary and not included in the scenario analysis, with two exceptions. After review by the research team,

two additional survey items were included to ensure variables appeared in all five domains. The final set of 15 variables is detailed in Table 1.

4. The research team developed future projections for each variable by referring back to the original discussions, plans and policy proposals used to develop the survey statements. Each variable contains at least two future projections: one based on the policy proposal (etc.) and one based on the absence of such a proposal. Some variables contain multiple policy proposals, reflecting the richness of the discourse on the future of water resources. The full set of future projections is provided in Table 8.

Table 8

Variables, Future Projections, and Corresponding Water System Domain(s)

#	Variable	Future Projections	Domain
1	New water sources	1. New sources of water from outside Arizona are pursued to meet Phoenix area demands. 2. New sources of water are not pursued as an option for meeting water demand in the greater Phoenix area.	Supply
2	Protected Riparian	1. Natural areas along streams are restored and protected for fish and wildlife. 2. Natural areas along streams are not deliberately (by law) restored and protected	Delivery Use
3	Safe yield in water management	1. Safe yield is a central guiding principal in to water management. 2. Safe yield is not central to water management and is often circumvented to serve other (primarily economic) objectives.	Supply Cross-cutting
4	Delivery infrastructure	1. Expansions in water delivery infrastructure are frequently undertaken. 2. Expansion to water delivery infrastructure is often foregone.	Delivery
5	Energy for water	1. 100% of the energy for delivering water to the greater Phoenix area is generated from renewable sources. 2. Energy for delivering water to the greater Phoenix area comes from a variety of non-renewable and some renewable sources.	Delivery
6	Water quality regulations	1. Water quality regulations are limited to those basic safety standards for human health. 2. Water quality regulations are precautionary and protect against new and potentially harmful pollutants.	Delivery Outflows
7	Canals	1. Trees and walking paths line the canals throughout Phoenix. 2. Mixed-use development lines the canals throughout Phoenix. 3. Canals are not used for development throughout Phoenix.	Delivery
8	Grey water systems	1. Residents collect grey water for outdoor use. 2. Most residents do not collect grey for outdoor use.	Supply Outflows
9	Peri-urban farmland	1. Much of the farmland surrounding the greater Phoenix area is made available for urban development. 2. Irrigated farmland is maintained as a buffer so that water can be transferred to municipal uses during droughts. 3. Irrigated farmland is maintained and water is not transferred for municipal uses.	Cross-cutting Demand
10	Farm water use	1. Crop choice and farm water use is regulated through incentives and conservation targets. 2. Farm water is subsidized and crop choice is left to individual farmers.	Cross-cutting
11	Industry water use and regulation	1. Industry is required to reduce water consumption to meet specific conservation targets. 2. Water-intensive industries are not required to reduce consumption if economic benefits are significant.	Cross-cutting Demand
12	City growth	1. The greater Phoenix area controls growth to limit rising water demands. 2. The greater Phoenix area does not try to control growth and or limit new water demands.	Cross-cutting
13	Financial incentives	1. Cities provide financial incentives to reduce water use. 2. Cities do not provide financial incentives to reduce water use.	Cross-cutting
14	Effluent water use	1. Effluent is used first and foremost for projects that recharge groundwater and provide recreational and wildlife benefits. 2. Effluent is used first and foremost for high water-use industries. 3. Municipal wastewater is treated for direct reuse as drinking water.	Outflows
15	Water governance	1. Water decisions are made by water managers in collaboration with citizens and scientists, all of whom are actively involved of water management. 2. Citizens councils make decisions about how water is governed and used. This is led by the public but informed by experts. 3. Water decisions are made by water managers with minimal consultation from the public - consistent with current system.	Cross-cutting

Step 2 – System analysis

The system analysis followed Wiek et al. (2008) in order to reveal how the water system currently operates. The research team completed an impact matrix among all systems variables, which was analyzed using the software SystemQ®. The analysis identified active variables (exerting influence over the system), passive variables (absorbing influence in the system), mediating variables (both active and passive), and key systemic relationships.

Step 3 – Consistency analysis

Following Tietje (2005) and Wiek et al. (2009), a consistency analysis was performed to ensure that scenarios adhere to an internal logic with no substantive internal contradictions. The research team completed a consistency matrix among all future projections (of all systems variables), which was analyzed using the software KD®. The analysis generated an initial set of scenarios with no major inconsistencies and high additive consistency.

Step 4 – Scenario selection

From this initial and large set of consistent scenarios, the following four different techniques were used to select a small number of signature scenarios that represent distinct and unique perspectives on the water system.

Stakeholder survey

In the stakeholder survey by White and colleagues (under review) principal component analysis and correlation analysis of responses yielded two distinct sets of preferences for the future of water governance and use across the five water system

domains. These results were used to select two scenarios that most closely reflected each set of stakeholder preferences.

Sustainability appraisal

Following a comprehensive analysis of the central Arizona water system, Larson and colleagues (2013) specified Gibson's (2005) sustainability principles for water sustainability in metro Phoenix. These specified sustainability principles were used to select a scenario that maximizes comprehensive sustainability in the water system.

Plausibility evaluation

Plausibility is a ubiquitous term in scenario construction but has remained vague in its application. Wiek et al. (2013) outline how plausibility indications can be used in the construction and evaluation of scenarios. These plausibility indications were used to select one scenario that maximizes plausibility. If two scenarios had similar plausibility scores, the scenario with the higher consistency value was selected.

Governance analysis

Water security refers broadly to governance approaches aimed at maximizing the productivity of water resources while minimizing their destructive capacity (Grey and Sadoff, 2007). Using this framework, one scenario was selected that maximizes the productive potential and minimizes the destructive potential of water resources *locally*. The focus on local water security for the Phoenix area is a critical differentiator from the sustainability scenario.

This normative selection process yielded five water governance scenarios.

Step 5 – Diversity analysis

Diversity refers to variance in future projections across scenarios (Wiek et al., 2009). This study aimed to produce a small set of diverse signature scenarios that resonate with stakeholders and that can easily be compared, contrasted, and evaluated for developing policy proposals. Diversity analysis was applied to the selected scenarios to ensure the normative selection approach (Step 4) yielded sufficiently distinct scenarios. A robust diversity score is if at least 30% of the future projections of each scenario differ from every other scenario.

The diversity analysis reduced the set of signature scenarios to four, because of the lack of diversity between two of the scenarios selected in the previous step.

Step 6 – Impact analysis through WaterSim scenario simulation

WaterSim 5.0 is a simulation model of water supply and demand in central Arizona (Sampson et al. in review). Several variables in the scenario analysis are shared with variables in WaterSim. Each of the four scenarios was input into WaterSim to determine their systemic impacts under different climate scenarios. While the system features and scenario descriptions are for a 2030 timeframe, WaterSim results extend to 2080. The key output metric for WaterSim is groundwater dependence (Gober et al. 2010). Surface supplies and the structure of demand determine the percentage of demand that cities in the Phoenix area will need to meet with groundwater (Sampson et al. 2011). Results were analyzed for the Phoenix metropolitan area and select municipalities to understand the spatial distribution of groundwater withdrawal under the different scenarios.

4. Results

4.1 Overview

The scenario construction and selection yielded four distinctly different, so-called signature scenarios of water governance for metropolitan Phoenix in 2030 (Table 2).

The first scenario, *Technical Management for Megapolitan Development*, based on the stakeholder survey, describes a future in which water experts negotiate and acquire more water so Phoenix can continue to grow. The second scenario, *Citizen Councils Pursue Comprehensive Sustainability*, was selected using the sustainability appraisal. This scenario describes a future where watershed-like councils use policy levers and financial incentives to reduce water use as part of a comprehensive approach to sustainability that includes integrated policy making for water, energy, food, and urban planning. *Experts Manage Limited Water for Unlimited Growth* is the third scenario, selected using plausibility indications, which describes a future where water experts struggle to provide for a growing population without restricting water use or acquiring new water sources. Water governance reflects a classic “muddling through” approach. The final scenario, *Collaborative Governance Makes Local Water Security a Priority*, selected using the water security governance analysis, is a future in which water is very central to decision making. In this scenario, committees of water managers, scientists and citizens collaborate to secure water and reduce consumption to ensure the long-term viability of the metropolitan region.

Table 9

Signature Scenarios for Water Governance in the Phoenix Area in 2013 at a Glance

Scenario	Technical Management for Metropolitan Development	Citizen Councils Pursue Comprehensive Water Sustainability	Experts Manage Limited Water for Unlimited Growth	Collaborative Governance Makes Local Water Security a Priority
Variables/Future Projections				
1. New Water	Pursued	Not pursued	Not pursued	Pursued
2. Riparian Areas	Not deliberately protected	Protected	Not deliberately protected	Not deliberately protected
3. Safe Yield	Not central to WM	Central to WM	Not central to WM	Central to WM
4. Delivery Infrastructure	Built	Not built	Not built	Not built
5. Energy for water	Mix	Renewable	Mix	Mix
6. Quality Regulations	Limited	Expansive/precautionary	Limited	Limited
7. Canals	Not developed	Tree lined	Not developed	Not developed
8. Grey Water	Not collected	Collected	Not collected	Not collected
9. Ag water	Water transferred	Water not transferred	Water transferred	Water transferred
10. Farm water use	Subsidized and unregulated	Crops and water regulated	Subsidized and unregulated	Crops and water regulated
11. Industry Use	Water-intensive industries	Consumption reduced	Water-intensive industries	Consumption reduced
12. City growth	No growth controls	Growth controls	No growth controls	No growth controls
13. Financial incentives	Not provided	Provided	Provided	Provided
14. Effluent	Drinking water	Recharge and wildlife	Industrial use	Drinking water
15. Governance	Top-down	Public-driven	Top-down	Collaborative
Selection Technique	Stakeholder survey	Sustainability appraisal	Plausibility evaluation	Governance analysis
Additive Consistency	38	53	27	28
# of Inconsistencies	0	0	1 (1) and (12)	2 (1) and (4); (1) and (15)

For metropolitan Phoenix, as with any other city, population growth significantly affects water resources. Yet, population growth has long been fundamental to the central Arizona economy. The four scenarios reflect the different interactions between how water is governed and how the city grows (or not). In the *Technical Water Management for Megapolitan Development* scenario the Phoenix area continues to pursue this traditional development model and a top-down approach to water management enables the acquisition of new water resources to fuel urban growth. These three critical drivers and their systemic interactions strongly dictate the functioning of the scenario. In the *Experts Manage Limited Water for Unlimited Growth* scenario there is a similar dynamic between top-down governance and city expansion. However, the critical difference is that new water resources are not acquired. Therefore the scenario reflects a tension between traditional development models and the limits of human institutions to manage natural resources in service of those economic objectives.

There is, however, much research into how institutions can be changed to manage better natural resources like water. *Collaborative Governance Makes Local Water Security a Priority* experiments with water security as a governance approach. While *Technical Management* and *Limited Supply* utilize water governance for development purposes, *Local Water Security* makes providing water for the existing population the central focus. As a result, safe yield and water governance are more influential over all efforts to ensure supply availability in the long term. Finally, *Citizen Councils Pursue Comprehensive Water Sustainability* presents a very different scenario again with water governance at the center. The bottom-up approach to governance treats water resources as a mechanism to achieve sustainability objectives and therefore goes beyond merely

securing water to equitable distribution and restored ecosystem services. Key system features for all four scenarios are summarized in Figure 8.

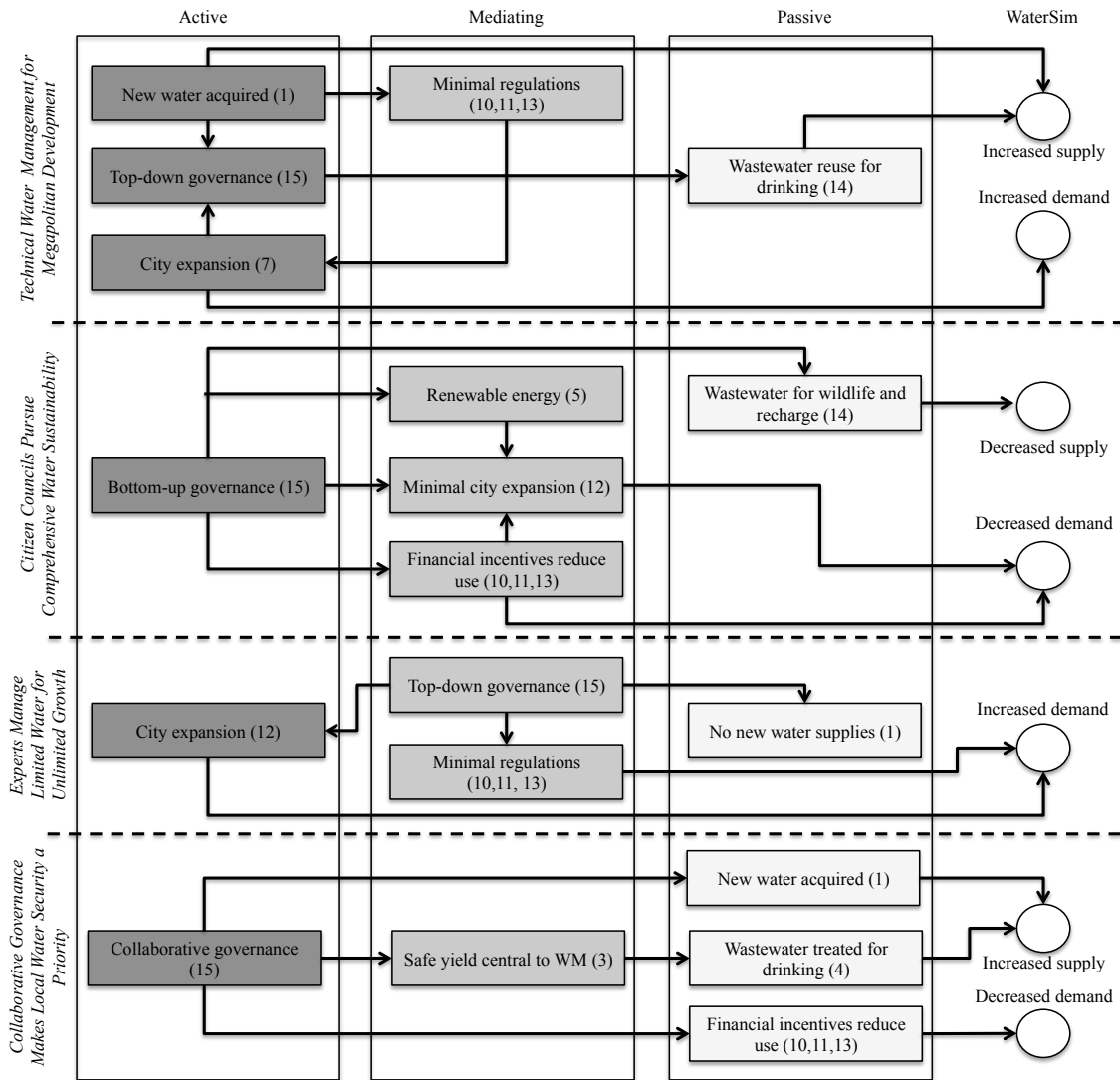


Figure 8. System features for the suite of governance scenarios.

4.2 Scenario descriptions

Each scenario is presented here in narrative form beginning with the governance thesis guiding the scenario and then describing key governance processes including actors, activities, intentions and outcomes for each water system domain. These are

linked to variables, key systemic linkages, and WaterSim results which appear italicized and parenthesized in the description (eg. *(1)*, *(1→2)*, and *(WS)* respectively) and are substantiated, where necessary, with relevant literature. Scenario outcomes are then discussed along four performance criteria: resilience, vulnerability, adaptability, and justice.

Scenario 1 – Technical Water Management for Megapolitan Development

The governance of water resources is, by in large, removed from the public domain *(15)*. Phoenix-area residents have varying degrees of knowledge about and investment in where water comes from and how it is used. Rather, water governance is a function of other citywide objectives like growth and economic development *(1→12→15→1)*.

Technical experts in the public and private sphere work together to acquire new water sources and ensure existing supplies continue to reach their constituents and customers *(15→1)*. Acquiring new water and delivering water supplies requires negotiation of legal compacts by policy makers and their technical advisors *(15→1)* (Wiek and Larson 2012). This supply is dependent on low-cost energy as the acquisition, treatment and delivery of these new sources is expensive and energy-intense *(5)*. Private firms develop delivery infrastructure overseen by state and federal departments *(4)*. While some land adjacent to canals has been developed for public use, most areas remain barren *(7)*. For consumers, minimal regulation leaves consumption to individual choice *(10) (11) (13)*. Outdoor water use is heavier in the central city where lush lawns persist while xeriscape is the favored landscape in the sprawling suburban areas *(12)*. Public comment is the extent of public engagement in water resource decisions *(15)*. Wastewater

is treated by utilities for direct reuse as drinking water (14). This achievement by water management experts provides a critical additional supply for the growing city (15 → 14).

The new water source makes metropolitan Phoenix more resilient to climate change by increasing the quantity and diversity of water supplies (WS). New water from outside Arizona is vulnerable to fluctuations in energy price and availability, regional climate change impacts, and disruptions to delivery infrastructure (1) (4) (5). The dependence on "hard path" solutions to water resource challenges has introduced a rigidity into the urban system (Gleick 2003). The building of new homes and water delivery infrastructure to accommodate makes adaptation to disruptions in water availability and distribution difficult (12) (4). The governance structure is not well equipped to address issues of differential access to water resources and this is not of particular concern (15).

Scenario 2 – Citizen Councils Pursue Comprehensive Water Sustainability

The governance of water resources is an extension of a comprehensive approach to sustainability across the Phoenix area. Water is governed to achieve sustainability objectives for the city in a way that empowers residents to be involved in city operations (15).

Citizens are directly involved in decisions about water resources through the establishment of watershed council-like organizations. This allows water to be governed across cities and in collaboration with residents from other parts of Arizona (15). Delivery infrastructure is maintained by cities and hired consultants to ensure that little water is lost in transport (4). Metropolitan Phoenix is no longer growing as it once was (12). More residents are spending time along canals throughout the city, as there has been

investment in city improvements to increase livability and promote walking and biking (7). Under a sustainability framework, citizen water councils work to ensure that water is available for all residents to meet their health and livelihood needs. This includes promoting water use for small businesses and farmers to ensure a thriving local economy (15 → 9-11). Experts consult with citizen water councils on technical matters. Residents have opted for financial incentive programs to reduce outdoor water use in the city center while still ensuring that moderate indoor water use is affordable (13). Utilities treat wastewater and discharge that water into streams or recharge aquifers (14). Citizen councils prioritize ensuring the integrity of the Sonoran desert now and for future generations (2).

Without new supplies, the Phoenix area is heavily dependent on groundwater beyond 2030 (1 → WS). By setting aside resources for wildlife, citizen councils have made the surrounding desert more resilient (2) (14). However, should climate change dramatically reduce water for urban areas (WS), this supply would be available to reintroduce into the urban system to meet basic and livelihood needs. Farm water is not transferred to the urban system during droughts as this might disrupt food availability and disproportionately burden farmers (9) (15). Residents are very engaged in water governance and are therefore aware of water-related vulnerabilities in the desert and are used to taking adaptation measures (15). However, many of these have already been taken so room for additional individual adaptive measures may be limited. Future dependence on groundwater varies by city (WS). This means some cities are more vulnerable to climate change than others (Sampson et al. 2011). However, the established

citizen water councils are better prepared to manage water across city lines to address issues of unequal resource distribution (15).

Scenario 3 – Experts Manage Limited Water for Unlimited Growth

There is no comprehensive approach to water governance for metropolitan Phoenix (15). Management activities are carried out by experts to serve the needs of municipalities. Water is a means to achieving economic development (15 → 12) therefore the most important aspect of water governance is that water is available, however, this is becoming more and more difficult to achieve for all municipalities (1).

Technical experts from municipal and private utilities work together with state and federal agencies to manage central Arizona's limited water supply (15). Utility managers and hired consultants acquire and deliver water through existing infrastructure which they also monitor and maintain (4). Without financial incentives there has been little reduction in per capita consumption within the city (13 → WS). Residents in the central areas use most water outdoors while the newer, suburban areas use less water indoors as well as outdoors as desert is the favored landscape. Farmers focus on growing mostly cash crops and with little regulation farm water use has remained relatively constant (9)(10). Utilities are still treating wastewater primarily for use in energy production and industrial activities (14). This is somewhat problematic in the face of increased scarcity but public aversion to drinking treated wastewater persists (14). Continued city expansion and no new water supplies has made the Phoenix area very vulnerable to climate change in 2030 (1, 12 → WS). All cities are heavily dependent on groundwater but this is even truer in the outer suburbs (WS). Communities new and old are vulnerable to extreme and persistent drought. Additionally, the viability of the

sprawling metropolitan area is heavily dependent on the availability of cheap energy (5 → 12) (Scott and Pasqueletti 2010). If this is not available many people will find the metropolis uninhabitable. Financial tools have not been used to reduce water consumption and farm water is still theoretically available to transfer (9) (13). These techniques could be employed, if necessary, to provide water for the urban areas in case of extreme drought. The Phoenix area is very much a place of water-haves and have-nots, depending on a city's historical water rights and groundwater aquifer. Groundwater dependence resulting from climate change could restrict some cities capacity to develop and possibly meet existing residents' demand (WS). The governance regime leaves little capacity or incentive for cross-city coordination to address differential access to water resources (15). Water and energy prices have remained low providing access to basic and livelihood needs for residents of varying incomes (13)(5). However, climate change threatens to increase the price of water and energy and this will disproportionately impact poor residents (Stern 2006; Garnaut 2008).

The consistency analysis found that the absence of new water sources (1) hinders the continued development of the city (12) because there may not be enough water physically available to add new residents. However, this represents a continuation of current development practices, in which new developments are “assured” water for 100 years with “paper water” that may or may not be physically available (Gammage 1999; Bolin et al. 2010).

Scenario 4 – Collaborative Governance Makes Local Water Security a Priority

Governance of water resources has the explicit goal of maximizing the benefits of water for local residents and businesses while minimizing the harm that water (or lack

there of) can bring (15). All resources, human and economic, are working toward local water security, this is an "all hands on deck" approach.

Technical experts work with citizens to define priorities for the acquisition and maintenance of new water supplies (1). Scientists are consulted to determine the feasibility and viability of water acquisition projects (15 → 1)). Delivery infrastructure is built and maintained by public and private utilities to ensure that water reaches users (4). However, infrastructure is not necessarily built with the explicit purpose of increasing water use, only accommodating existing demand (4). Canals have been left undeveloped as planting trees and creating walking paths would increase water consumption within the city (15 → 7). Financial incentives are in place to change the way residents, businesses and farmers use water (13 → 9-11). As a result there is a decrease in per capita demand and farm use has gone down as well (9-11 → WS). The urban landscape is far less green than it once was as residents are using less water outdoors. Urban amenities such as parks and shaded areas are forgone in favor of conserving water resources. Utilities treat wastewater for direct reuse as drinking water by residents (14). While this initially received opposition some opposition, water managers and scientists worked together to change public perception of water scarcity and the need for toilet-to-tap programs (15 → 14).

The acquisition of new water supplies and the introduction of financial incentives to reduce consumption has made metro Phoenix' water supply more resilient to climate change (WS). By limiting city expansion and diversifying water resources the Phoenix area is less vulnerable to fluctuations in supply availability (12)(1)(14). New supplies are vulnerable to changes in the price and availability of cheap energy to move the water

(Scott et al. 2011). Residents are accustomed to limiting water consumption and are therefore more adaptable to drought conditions (13) (Smit and Wandel 2006). Farm water is available for transfer to urban use when necessary (9). Energy prices have remained low for residents (4) but water prices have increased, hurting some low-income residents and farmers (13). Many neighborhoods have minimal walkability and inadequate public space, this has especially hurt low-income neighborhoods where tree coverage and park access are low (Harlan et al. 2006).

The consistency analysis found that the acquisition of new water resources (1) is hindered by an aversion to developing new delivery infrastructure (4) and a collaborative approach to governance that includes citizens and scientists (15). Presumably the aversion to developing new water delivery infrastructure in this scenario is a result of efforts to limit water demand, which aligns with the other objective of ensuring sufficient water for existing residents. Therefore its possible that new infrastructure is built to acquire new water but not to accommodate new demands. Similarly, at present many scientists support policy changes over acquiring new water from sources outside Arizona, such as Midwest rivers (e.g. the Missouri), the Pacific Ocean or Sea of Cortez (Larson et al. 2009). However these are scientists currently engaged in debates over water governance and use. Conceivably, a different set of scientists will need to be involved in new water acquisition as it will require significant research and development on infrastructure, energy, and treatment systems.

4.3 Technical details

The following sections describe diversity and consistency of future projections for the four scenarios in the signature scenarios suite. The technical details are summarized in Table 2. See supplemental material for more details on the selection techniques.

Diversity

The four selection techniques originally yielded five scenarios, however two of the scenarios fell below the 30% diversity threshold set by the research team. When applied to select scenarios, the stakeholder preference survey yielded two distinctly different scenarios, *Technical Management* and an additional scenario with 12 out of 15 future projections identical to *Citizen Councils Pursue Comprehensive Water Sustainability* (20% diversity). The research team opted to include the *Citizen Councils* scenario and exclude the second stakeholder preference scenario to demonstrate the breadth of selection techniques that can be used in this approach (see White et al. in review for further details on the stakeholder-derived results). We feel the range of normative preferences among surveyed stakeholders are accurately represented with the *Citizen Councils* scenario, as evidenced by *Citizen Councils* and *Technical Management* having the largest variance among the scenarios with 14 distinct future projections, 93% diversity. *Technical Management* and *Local Water Security* are the most similar, with 5 distinct projections, 33% diversity. Diversity analysis results are summarized in Table 10.

Table 10

Diversity Values in Percentages Indicating the Diversity between Scenarios Based on a Comparison of Future Projections for Each of the 15 Variables

Scenario	Stakeholder Survey (2)	Technical Management	Citizen Councils	Limited Water	Water Security
Stakeholder Survey (2)		80% (12)	20% (3)	67% (11)	47% (7)
Technical Management			93% (14)	33% (5)	47% (7)
Citizen Councils				80% (12)	60% (9)
Limited Water					47% (7)
Water Security					

Note. 100% = all vary and 0% = none vary. Table contains whole numbers in brackets, indicating unique divergences.

Consistency

The selected scenarios have no major inconsistencies and no more than two minor inconsistencies, which are described following the narratives with inconsistent variables parenthesized and italicized. All four scenarios are in the top n% for consistency among n possible scenarios. Consistency values and inconsistencies for all four scenarios are summarized in Table 3. The full consistency matrix is available in Appendix B. The scenarios range in additive consistency from 27 – 53. *Citizen Councils Pursue Comprehensive Water Sustainability*, selected using the sustainability framework, has the highest additive consistency (53), meaning the future projections most support each other, giving the scenario the strongest internal logic. *Experts Manage Limited Water for Unlimited Growth*, selected using the plausibility indications, has the lowest additive

consistency (27), meaning the future projections have the weakest internal logic of the scenario set. Interestingly, this reflects a common trope in the discourse on the Valley of the sun; its very existence at times seems to defy logic.

5. Discussion

The scenario construction process yielded four distinctly different, signature scenarios of water governance in the Phoenix-region that reflect a variety of stakeholder values and have a range of impacts on the water system. The versatility of the method is demonstrated in the use of four different normative frames to select the scenarios. This type of flexibility means in workshops stakeholders can collaboratively define their priorities and select scenarios based on those priorities. While traditional visioning activities are criticized for lacking sound methodology (Shiple 2002), this approach incorporates consistency analysis to ensure the logical coherence of scenarios deductively selected. The method then allows for normative scenarios to interface with dynamic modeling (through WaterSim), which during stakeholder engagement activities can provide feedback to participants on the impacts of their priorities, particularly on the availability of surface and groundwater for future generations. Stakeholders can then modify or dictate preconditions for their priorities (in the vein of Wiek and Binder's (2005) Sustainability Solution Space) and, if necessary, select new scenarios. This type of iteration and feedback with differing levels of stakeholder involvement is critical in transdisciplinary research generally (Stauffer et al. 2008) and for participatory scenarios that inform transitions in particular (Kemp et al. 2005; Wiek et al. 2006). The scenario suite provides some interesting additional insights; which emerge, in part, because the suite is comprised of a small number of distinct and comparable, "signature"

scenarios. First, regardless of the governance approach, if the worst climate change impacts come to fruition the Phoenix-area will need additional water resources beyond the current portfolio to meet 2013 level demand. Second, very different governance approaches function similarly under best-case to moderate climate scenarios over the next 30-50 years, therefore stakeholder engagement activities with these scenarios might focus on preferable and sustainable governance arrangements, in particular what individual and collective activities should water resources support and who will control water-related decision-making. Third, fundamentally different approaches to water governance require varying levels of transformation in the governance regime, which has significant implications for transition processes. For example, currently water from underground aquifers, the Colorado and the Salt-Verde are managed for end-users by municipal and private utilities, who all have different water portfolios (Larson et al. 2013). This persists in the *Technical Management for Megapolitan Develop* and *Experts Manage Limited Water for Unlimited Growth* scenarios but is completely changed in *Citizen Councils Pursue Comprehensive Water Sustainability*. Such a change would require re-writing water laws in the state of Arizona. If this scenario were selected to guide a water system transition for the Phoenix-region, state and federal lawmakers, attorneys representing private landholders, and tribal governments, among many others, would all need to be involved. This demonstrates the importance of governance scenarios to guide transitions. By focusing on who does what with water, the scenario is clearly linked to those responsible for carrying out transition activities. Engaging stakeholders will likely yield interesting insights into the implications of the scenario suite, and individual scenarios, for different stakeholder groups.

In generating governance scenarios the study team tried to negotiate the tension between presenting scenarios that reflect a transformed system and providing information that can guide decision-making. For the Phoenix-area water system, and others, sustainability will require fundamental changes that cannot be achieved through incremental and disconnected policy-making focused on individual water system components (e.g. residential demand). This study builds on – but deviates from - work by other experts to increase the saliency of scenarios by making the scenario results closer to the scale at which decisions take place and incorporating functions that are under the control of certain decision-maker stakeholders (Gober et al. 2011). This requires establishing a link between the current decision-making regime and the future water governance regime, to be further elucidated in a strategic transition plan and navigated through transition activities. To do this, normative scenarios of transformed water governance arrangements are presented alongside results from a simulation model, WaterSim, which was built and refined with the explicit intent of informing decisions as they are currently made. A sustainability transition can be guided by normative scenarios but will inevitably need to be managed through coordinated efforts of actors throughout the water system. Stakeholder engagement activities to develop a transition plan can define the necessary changes to governance roles and responsibilities.

The various individual and institutional stakeholders in the current water system, who have different levels of knowledge of, interest in, and power over water governance activities and system functioning, will be responsible for carrying out any transition activities. It is the role of boundary organizations to coordinate and facilitate knowledge exchange between and among different expert and stakeholder groups (Guston, 2001).

The normative scenario approach, with its explicit focus on co-construction of scenarios between stakeholders and model experts, allows for the explicit negotiation of tradeoffs within and among stakeholder groups, enabling collaboration and communication about water management priorities while increasing systems understanding among participating stakeholders (Swart et al. 2004). This type of deliberation is critical for those stakeholders responsible for carrying out transition activities (Kemp et al. 2005).

The scenarios in this study can be considered boundary objects, which allow for knowledge exchange between different actors related to their opinions, values, and preferences regarding all or parts of the water system. In this capacity, the scenarios present different water governance regimes with different power arrangements in a way that is comprehensible to broad audiences. This has the potential to achieve an important objective of boundary organizations - mitigate power imbalances between stakeholders that diminish certain interests and impede collaboration. For the Phoenix-region the scenarios can also act as a boundary object to facilitate conversations with other regions about water governance. Bounding the governance regime to the Phoenix-region is a necessity of the scenario construction process that does not necessarily reflect the governance or hydrological reality. In the future, Phoenix will be negotiating for water with other state and regional actors, particularly those with rights to the Colorado River. Selecting a scenario to guide transition activities provides boundary object with which to communicate Phoenix' priorities with our partners on the Colorado. Such efforts could contribute to further coordination of sustainable water governance across the Southwest.

6. Conclusion

The Phoenix-region currently faces a number of water-related challenges and climate change threatens to exacerbate these challenges by reducing surface water flows in the Salt, Verde and Colorado Rivers, which constitute the majority of the water for the metropolitan area. The current governance regime, which is controlled by a small group of deeply experienced, technical experts with limited public engagement, is not well poised to pursue alternatives to “hard path” solutions. This leaves the acquisition of new supplies as the primary means by which the current governance actors in their current capacities can meet the demands of an expanding metropolitan Phoenix. This approach will likely have high financial and environmental costs and may not be feasible. While there is skepticism among decision-makers regarding the ability of bottom-up governance arrangements to make better decisions there has been limited effort to engage the public in new and different ways. Traditional public forums and comment periods draw a small number of issue advocates that do not represent the breadth of values and preferences present in the Valley. However, there is evidence that well-designed public engagement that is discursive and citizen empowering can lead to more creative solutions (Carpini et al. 2004). The scenarios presented in this paper explore possible futures for water governance in Phoenix that different stakeholders might find desirable. As a part of the boundary work taking place at Decision Center for a Desert City, the scenarios should be used to facilitate broader stakeholder engagement in water governance in an effort to expand the breadth of proposed solutions to regional water challenges.

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CHAPTER 7

Conclusion

Research in sustainability science is motivated by current and anticipated problems facing society. Rather than the historical conception of science as an amoral and objective endeavor of discovery, sustainability scientists make explicit the intent of their research to generate societal benefits (Miller 2013). This dissertation aimed to generate knowledge that could contribute to a sustainability transition in the Phoenix-area water system and in other systems and regions. The normative nature of a post-normal sustainability science requires the inclusion of non-scientific actors in defining what are urgent problems and viable solutions (Backstrand 2003). Several studies in this dissertation focused on the appropriate engagement of stakeholders in future-oriented research. Engaging stakeholders productively in thinking about the future and designing desirable and sustainable futures requires new and adapted methods that can incorporate broader stakeholder values and non-scientific expertise – so-called transdisciplinary methods (Lang et al. 2012). The methodological studies and case study presented as a part of this dissertation contribute to transdisciplinary sustainability science by refining descriptive analytical, anticipatory, and normative methods to integrate knowledge across academic disciplines and from society to generate societally-relevant knowledge. This knowledge requires different evaluative criteria commensurate with its intent. Beyond reliability, validity, and credibility to a narrowly defined scientific elite, many have argued that knowledge generated in sustainability science should also be legitimate, salient and relevant to broader society and in particular those responsible for carrying out sustainability transitions (Funtowicz and Ravetz 1993; Pereira et al. 2007). This

dissertation aimed to meet expanded quality criteria while contributing to the growing body of transdisciplinary sustainability science research and generating knowledge to improve the sustainability of the water governance regime in Phoenix, Arizona, while yielding generalizable insights for other systems and other regions.

The first research question posed was “How can anticipatory and normative knowledge be generated (and combined) to inform sustainability transitions and how can this be applied to the Phoenix-metropolitan water system?” To answer this particular question the first two studies focused on refining scenario construction methodology. Scenario construction is popular in sustainability science but also in business, public policy and military planning. It has been well studied and its impacts well documented. Despite their seeming ubiquity and the enthusiastic discourse around the potential of scenarios contributing to sustainable solutions, many of these problems continue to get worse, leading to the conclusion that a disconnect exists between the way scenarios are constructed and used and the way change actually occurs in the real-world.

To address the disconnect between scenarios and real-world impact the first study examined the construction and use of climate change scenarios in participatory settings and made recommendations for future participatory scenario studies. The study concludes that generating anticipatory and normative knowledge in participatory settings can contribute to the efficacy of scenario studies aimed at informing policy making and sustainability transitions, particularly related to climate change. Those climate scenarios constructed with stakeholder input have been more relevant for policy design and resulted in greater use of climate information (e.g. Kok et al. 2006 and Loibl and Walz 2010). Existing participatory climate scenario studies indicate that the structure and intensity of

participation can and will vary based on the scope of the research, resources, interest of the public, etc. and there are costs to such efforts – but if “real-world” outcomes are an objective those costs may be worth it. The focus on climate change is important for sustainability and for the later case study in this dissertation. Climate change is arguably the largest (in scale and complexity) problem in sustainability with the most anticipatory knowledge generated over the last 25 years. Yet, as Sarewitz and colleagues have pointed out on numerous occasions, inaction persists (2004; 2007). The first study provides insights for how to structure participatory climate change scenario activities to increase their relevancy for decision-making and their saliency and transparency to stakeholders. These and other insights were used in the case study to define project goals, select participants, design the participatory activity, and design results for further stakeholder engagement.

The second study in the dissertation focused on scenario construction as efforts to generate *plausible* anticipatory knowledge. In situations with high complexity, high degrees of uncertainty, and necessary tradeoffs, traditional evaluative criteria for scientific information may not be applicable or relevant. Such is the case with probability, as this study concludes. Plausibility has been offered as an alternative to probability but has remained vague. For scenarios that intend to inform policymaking or sustainability transitions such fuzziness can present a barrier to their credibility and legitimacy and, therefore, their use. In reference to the first research question, to inform sustainability transitions, anticipatory and normative knowledge need to be constructed and evaluated along a clear set of criteria. Plausibility is an oft-used term that many have argued is subjective. The plausibility indications proposed and tested in this study

provide a clear and replicable structure for plausibility for use in constructing and evaluating future scenarios. The plausibility indications also provide a framework for discussion among researchers and stakeholders about what kinds of futures may occur. While there is often resistance to and difficulty with non-linear thinking, the plausibility indications provide a means of discussing transformed futures and how or why they might occur. In sustainability this is of particular importance for two reasons: first, climate change and other disruptions to planetary systems (e.g phosphorus and nitrogen cycles) may yield impacts far outside historical precedent that need to be considered in planning and policymaking; and second, a sustainable future for many cities and systems requires radical and unprecedented transformation which can be explored and evaluated through scenarios. The plausibility indications generated in the second study can be used to generate scenarios that are credible and legitimate to policymakers and the broader public even if they portray transformed futures. This dissertation put into practice these results through a case study generating plausible future scenarios of water governance in the Phoenix metropolitan area.

The case study portion of the dissertation is comprised of three chapters, each building on the next, and is focused on water governance in the central Arizona metropolitan region of Phoenix. The goal of the case study was to put into practice the first two studies and answer the second research question: What are different, plausible, and desirable water governance regimes for the Phoenix region, what are their impacts, and how can they inform governance which contributes to a sustainability transition in the local water system and with what implications for other systems and regions? To begin to answer this question the third study in the dissertation (and first in the case

study) analyzed and appraised the current water system and governance regime in central Arizona to determine who is doing what with water, why and with what impacts. The results provide a comprehensive and integrative picture of the Phoenix-area water system and its governance, including social actors and their activities, technological infrastructure, and ecological resources across the five water system domains: supply, delivery, demand, outflows, and cross-cutting activities. The sustainability appraisal evaluated the current water system against sustainability criteria specified to the specific case, including: social-ecological system integrity, livelihood sufficiency and opportunity, resource maintenance and efficiency, inter- and intra-generational equity, civil engagement and democratic governance, interconnectivity from local to global, and precaution and adaptability. The study concludes that the current water governance regime and the current state of the water system fail to meet aspects of all the sustainability criteria. In particular, ecosystems continue to be degraded so that water resources can meet anthropocentric demands. While there has been no effort as of yet to collaboratively define what human demands should be met with freshwater resources the trend is toward residential and commercial landscaping, economic and industrial uses, and irrigating cash and food crops over preserving the desert environment. Diverting water from natural streams for human use is compromising the social-ecological system integrity of the region. The distribution of costs and benefits of this redistribution of water resources disproportionately benefits wealthy residents –through the building of amenities such as golf courses and the accruing of capital through investment and stake in high water consumption industries - and leaves vulnerable poor and minority residents – as nighttime temperatures increase in low income neighborhoods and contaminated

groundwater seeps through the soil and off-gases carcinogens into homes. There has been no systematic effort across cities toward demand management to reduce net water consumption in the entire Phoenix region or ensure equitable distribution of costs and benefits related to water acquisition, delivery, use, and treatment. In the face of diminishing water quantity and quality there are a range of choices to consider for water governance in the region. The current water governance regime is expert-driven, focused on technological solutions, and minimally concerned with long-term sustainability, beyond meeting safe-yield requirements established by the 1980 Groundwater Management Act. The critical challenges facing Phoenix and the Southwest demand rethinking who does what with water in order to make the water system more sustainable. For example, the study concludes that Phoenix could benefit from establishing organizations to manage water resources at the scale of hydrological systems (e.g. watershed councils) and allow and reward sharing of water resources across municipalities in times of scarcity. To define the best governance arrangements for a sustainable water system in the future requires stakeholder input. Insights from this study were used in the subsequent two chapters to construct a stakeholder survey to determine preferences for future water governance and use and to generate future scenarios of different water governance regimes, respectively.

The fourth study in the dissertation and second in the case study surveyed stakeholders who influence water governance and use in central Arizona. These stakeholders were asked to rate the desirability of value-based normative statements related to future water processes and outcomes in the water system which were derived from existing plans, strategies, and policy discussions in Arizona and elsewhere – a

technique informed by the second study on plausibility indications. The results reveal two distinct visions for water in governance in central Arizona – across the five water system domains investigated in the previous study. In the first vision, experts and policy makers govern water resources with little public input in pursuit of additional water supplies to serve metropolitan expansion and economic development. The second envisions water governance through broader public engagement and the use of policy instruments and limitations on metropolitan expansion to reduce water consumption and restore ecosystem services in the urban and surrounding desert environments. Both visions include a strong preference for groundwater conservation and the need for policies aimed at reducing per capita water consumption. What happens to the conserved resources and who makes such decisions remains a point of divergence. There is also a shared preference for using treated wastewater to restore ecosystems downstream of the city. Currently there are a few pilot projects in metropolitan Phoenix experimenting with exactly this and the survey indicates that some from the water management community see restoration of riparian ecosystems as important to the future of the city. Implementing such efforts would significantly transform the wastewater system and urban and downstream riparian ecosystems – making a significant contribution to improving social-ecological system integrity. The value-based approach taken in the survey is important for capturing the values, preferences, and norms that underlie decisions about water resources. The different approaches to water governance and different desirable outcomes reflected in the two visions were used as inputs for the normative scenario construction in study five of this dissertation. Follow up activities with survey participants will explore the systemic impacts of shared visions and allow stakeholders to reevaluate their

responses and develop new, shared visions. The link between survey, scenario construction and future stakeholder engagement is an important methodological innovation for boundary studies. In an effort to facilitate knowledge sharing between different epistemic communities, this approach provides both a boundary process (the multi-method) and boundary objects (the visions and scenarios) with which to coordinate collaboration between researchers, policy makers, and the broader public.

The final study in the dissertation integrates the four previous studies to build future scenarios of water governance in the Phoenix-area in 2030. The multi-method approach generated four distinctly different, signature scenarios selected using different frames, including: plausibility indications (study 2); sustainability appraisal (study 3); stakeholder preferences (study 4); and a governance analysis based on local water security. The governance scenarios have different outcomes roughly appraised along criteria of resilience, vulnerability, adaptability and social justice for the Phoenix region. In particular, results indicate that scenarios in which more water resources are acquired are more resilient to climate change but more vulnerable to disruptions to water supply from fluctuations in energy price and availability or infrastructure breakdown, among others. And this resilience comes at a price. Efforts to increase Phoenix' water supply rely on the acquisition and movement of new supplies from other states which can be very costly and requires experts to execute most management activities. However, efforts to manage water use through policy levers alone leave the Phoenix-region heavily dependent on groundwater under harsh to moderate climate scenarios. And, while they present a rosy picture of cooperative watershed-like management of water resources, significant barriers exist to achieving such a governance regime, including powerful

business and political interests who may be negatively impacted by such a scenario. Overall, each approach to water governance presented in the signature scenarios yields a mixed bag of costs and benefits that vary by geographic location within the city and by social group. To inform a sustainability transition further evaluation of these scenarios and the creation of more scenarios is necessary. Significant changes to the structure and function of the water system will need to occur to meet human and livelihood needs in metropolitan Phoenix under even moderate climate scenarios. In future stakeholder engagement activities the scenarios can act as boundary objects around which different stakeholder groups can discuss what they want from water resources and what tradeoffs will be made to achieve certain objectives. These engagement activities can further inform a sustainability transition in the water system by identifying actors, institutions and policy levers that can be used to achieve an agreed upon, desirable, and sustainable future.

The comprehensive approach to water governance applied in this dissertation has addressed a critical gap in water research which, historically, has been narrowly focused on particular aspects of the water system, neglecting important interactions across social, environmental and technical systems. There are also important implications for research and boundary work on water and other systems beyond Phoenix. By focusing on who does what with a natural resource across the current system (be it water, food, energy, etc.) and in transformed, future systems, knowledge is generated that directly informs transition activities. In particular, the actors who will be responsible for transition activities are identified in this process and how their roles and responsibilities might change is also explored. While this dissertation does not generate strategic knowledge by

outlining a transition plan for the water system in Phoenix, for example, the identification of important actors, activities and governance processes will be key inputs into such strategic and transition planning activities in the future, as will knowledge of the systemic impacts of different governance regimes.

The multi-method scenario approach, Study 1 on participatory climate scenarios, and Study 2 on plausibility indications make progress toward innovating scenario methodology to generate anticipatory and normative knowledge that can inform sustainability transitions, addressing a gap in current research. Insights from Study 1 are critical for designing participatory scenario studies and using the results in participatory settings. In particular, by co-constructing knowledge about the future through participatory scenario construction, researchers can address the perceived lack of transparency in scenario construction and generate scenario results that are more relevant and salient to policy makers. These insights were used to design the Phoenix scenario study, which incorporated stakeholder values and preferences in the selection of relevant scenario variables and future projections and also the selection of signature scenarios. While traditional scenario studies, regardless of the objectivity they claim, obfuscate the normative assumptions of researchers embedded in model parameters, variables, and systemic interactions – the scenario technique applied in this dissertation makes explicit such assumptions and bases them on stakeholder expertise and preferences in the qualitative scenario analysis and combines this best available evidence on water system functioning, which is made available for analysis and scrutiny (see Sampson et al. in prep or WaterSim 5.0 on the web). This is why the interface between the normative scenarios created through qualitative scenario analysis and the dynamic simulations in WaterSim is

critical; the dissertation attempts to navigate the tension between transparency and overwhelming stakeholders with model information.

The signature scenarios contain a limited number of variables and stakeholders are presented with limited systemic interactions that convey the functioning of the water system in a way that is comprehensible to broad audiences. Qualitative variables from the signature scenarios that link with WaterSim variables were given quantitative values for input into the simulation model. These values were based on existing research into, for example, the amount of water that might be available annual to Arizona through desalination. Maintaining transparency is a priority. Experts have the opportunity to delve deep into the WaterSim model to see exactly what values are given to qualitative variables and how particular outcomes are generated, to verify whether the model structure reflects reality. WaterSim 5.0, the newest edition, was used to run simulations of the normative scenarios and itself was created through an iterative process of vetting model components and functioning with experts from the Phoenix-area water management community over a period of years. The model was validated with existing data from 2000 – 2010 on runoff in the Colorado and Salt-Verde rivers and the reservoirs. Model future projections were validated to 2070 with the Colorado River System Simulation Model used by the United States Bureau of Reclamation (Sampson, in prep). For these reasons, WaterSim results are valid, reliable and considered legitimate and credible to an extended peer community.

The results presented in this dissertation meet normal and post-normal scientific quality criteria and each study refers to the theoretical and methodological assumptions that underpin the research and addresses uncertainty in the results. The WaterSim results,

for example, present the performance of the signature scenarios across a range of climate scenarios because the exact impacts of climate change on the region remain uncertain. The signature scenarios themselves, before input into WaterSim, contain degrees of uncertainty as well. There is embedded in the variables and future projections assumptions that are based on the best available evidence – as scenario variables and future projections were constructed using existing plans, strategies and policy dialogues. For example, there is some debate over the efficacy of policy instruments, like financial incentives, at reducing per capita water consumption. The scenarios contain variables related to financial incentives to reduce water use (process) and the presence of reductions in water use (outcome). To deal with the uncertain effectiveness of financial incentives, scenarios are not claiming that the process of using financial incentives leads to the outcome of reductions, nor are the financial incentives specified (e.g. payments to reduce turf grass or stepped pricing). The scenarios only convey that financial incentives and real reductions are present simultaneously. Selecting and testing policy instruments to achieve particular scenario outcomes will be important next steps for this research.

New challenges emerge when integrating theories and methods from different disciplines, for example in the combination of the analytical survey instruments and the qualitative scenario methodology. The correlation of the components in the survey analysis and their use in selecting future projections to create stakeholder preference-based scenarios presented a particular challenge. While the Principal Component Analysis (PCA) creates like components and the correlation analysis links like components across water system domains, the method does not assume an underlying causal structure underpinning the survey items. The scenarios selected using the

plausibility indications, sustainability appraisal, and local water security governance analysis assumed an underlying causal structure to the future projections based on the applied frameworks. However, when the PCA and correlation analysis results were used to select future projections there was insufficient evidence to select future projections for all 15 variables (because certain projections were excluded from the components because their component loading was too low ($>.50$) but were included as variables and future projections to ensure the water system was captured in its entirety). Because the analytical instruments from the survey assume no causal link between items, it was not possible in the scenario analysis to select additional future projections based on an underlying framework, as with the other scenarios. Such interpretation would assume causation where no causation exists. To overcome this obstacle the consistency analysis was used to determine which combination of additional future projections resulted in the most consistent scenario. The *Technical Management for Megapolitan Development* scenario emerged from this process as the most consistent of 12 possible scenarios that aligned with survey results. To ensure that interdisciplinary multi-method approaches meet scientific (and expanded) quality criteria it is critical to retain the integrity of results, including their theoretical underpinnings, when combining methods. While this can be time consuming, selecting appropriate methods that integrate well before the research begins can ease the process. The successful selection and integration of methods across disciplines is necessary for generating robust, societally-relevant, and solution-oriented knowledge about “real-world” problems which are inherently non-disciplinary.

While this dissertation makes important contributions to sustainability science there are limitations to the work presented and further research is needed. First and

foremost, the research contributes to solution-oriented knowledge about water governance and sustainability in the Phoenix region but it does not produce strategic knowledge necessary to put insights into practice. Strategic knowledge takes the form of plans, policies, strategic documents, and transition strategies and is used in sustainability to generate results in the real world. This dissertation focused primarily on generating descriptive analytical, normative, and anticipatory knowledge. The combination of these knowledge types underpins strategic knowledge so that it may successfully contribute to a sustainability transition. So, while this dissertation innovates traditional scenario methodology to better contribute to sustainability transitions and yields interesting insights about the sustainability of current and future water governance regions, more research is needed to develop robust transition strategies. In addition, before any strategy development can take place, results from the scenarios need to be further vetted with stakeholders. While Study 2 outlined the benefits of participatory scenario construction, the case study only partway applies these insights. Further iterations are to come, including intense stakeholder appraisal and possibly revision of scenarios. Finally, this research looks at a single case study of water governance in the Phoenix metropolitan region. The generic framework from Wiek and Larson (2012) was applied throughout but more case studies are needed on other regions to determine the generalizability of results related to key features of sustainable (and un-sustainable) water governance regimes now and in the future. This dissertation research provides the first in what will hopefully be a series of case studies that will yield generalizable insights.

There is a real-world need for the type of research presented in this dissertation and the specific results generated. On March 5th, 2014 the Decision Center for a Desert

City hosted a Water/Climate Briefing on water transfers from agriculture to urban uses in times of drought. This topic is directly addressed in the signature scenarios, which take different approaches to transferring water from agriculture. The scenarios allow for exploring the consequences of transfer versus non-transfer for the Phoenix-region and further engagement activities can allow expert and lay stakeholders to consider in more detail when water should be transferred and in what quantities. Additionally, during the briefing a panelist representing farmer interests from the Yuma Valley in Southwestern, Arizona asked very pointedly, “What does Phoenix intend to do with the water that's taken from agriculture?” Because the Phoenix region does not have a comprehensive vision of water governance and use in the future this question was difficult to answer. However, if water is to be taken away from food production, in particular, and farmers asked to fallow their fields, a solid justification for more beneficial uses for those water resources is certainly necessary. Many in the Southwest have taken for granted that agriculture water will be available for urban use when needed, but social, political and technical barriers exist to such a strategy. The scenarios presented in this dissertation provide a means of communicating with other regions and other actors about what the city will be doing with water resources, what tradeoffs Phoenixians are willing to make, and why it might be necessary for other regions and other actors to make similar tradeoffs. The Phoenix-region along with other water stressed urban areas need productive and forward looking dialogues that design how water will be governed and used in the future and by whom, rather than just reacting to changes as they come. This research makes a strong contribution to establishing and facilitating such a dialogue for Phoenix, which can serve as a model for other regions and systems.

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APPENDIX A
SUSTAINABILITY APPRAISAL OF WATER GOVERNANCE IN PHOENIX,
ARIZONA

<i>Sustainability Principles</i>	<i>Activity Domain</i>	<i>Appraisal of Water Governance in Metropolitan Phoenix, AZ</i>
1. Social-Ecological System Integrity		
a. Maintain or restore minimum flows.	Supplies	<ul style="list-style-type: none"> • Little water dedicated to in-stream flows → dry channels & endangered species • Some projects recharge or treat water thru wetlands → habitat & recreational opportunities • Emerging effluent laws discourage recharge to streams → institutional constraints
b. Maintain or enhance the quality of water resources.	Cross-cutting	<ul style="list-style-type: none"> • Untreated pollutants (salinity, endocrine-disruptors, etc.) & nutrients → mixed & unknown effects • Contaminated groundwater → VOC gases emitted from Superfund water used for irrigation • Naturally occurring arsenic → emerging challenges with treatment with new federal limits
c. Ensure aquifers not over-taxed to points of instability.	Supplies / Uses	<ul style="list-style-type: none"> • Overdraft continues despite GMA goal of “safe yield” → land subsidence, fissures & other problems
d. Address resource uses, impacts, & tradeoffs across physical units & sub-systems.	Supplies / Uses	<ul style="list-style-type: none"> • Active Management Area corresponds to groundwater basins → but not replenishment • Select coordinated efforts across basins → East Valley Water Forum’s groundwater modeling • Separate laws & agencies → yet recognized need for conjunctive management & integrated planning
2. Resource Efficiency & Maintenance		
a. Reduce water use or enhance water-use efficiency.	Uses	<ul style="list-style-type: none"> • Disincentives to conservation & ecological flows → ‘use it or lose it’ principle & cheap rates • Yet some gains in efficiency → water-saving fixtures, landscaping & new infrastructure • Limited progress in meeting water use (GPCD) standards → regulatory erosion & high demand rates

b. Reuse water or recycle wastewater for various uses.	Uses / Outflows	<ul style="list-style-type: none"> • Treated wastewater for industrial cooling & landscaping, plus recharge → increasingly used! • Private yards do not use effluent → few ‘grey water’ reuse & rainwater harvest systems too • <i>Barriers</i> to effluent → perceptions & salinity, plus treatment locations, technology & regulations
c. Eliminate water losses	Supplies / Deliveries	<ul style="list-style-type: none"> • Open-air lakes, canals & pools → evaporative water losses, plus leaky infrastructure
d. Groundwater extraction should not exceed recharge.	Supplies / Uses	<ul style="list-style-type: none"> • Not currently achieving safe yield despite state charge → some recharge efforts
3. <i>Livelihood Sufficiency & Opportunity</i>		
a. Basic livelihood needs met for drinking & sanitation.	Supplies / Uses	<ul style="list-style-type: none"> • Widespread access to cheap water for basic needs → some exposure to contaminated water
b. Water provided for personal (human) wellbeing.	Supplies / Uses	<ul style="list-style-type: none"> • Recreational enjoyment → man-made lakes & water features, plus canal redevelopment • Some restoration projects → limited projects for water treatment, recharge, etc.
c. Livelihood (economic) activities supported.	Supplies / Uses	<ul style="list-style-type: none"> • ‘No new irrigation’ rule → privileges industrial & commercial uses • High water-use industries welcomed → e.g., Intel chip-processing

4. Civil Engagement & Democratic Governance		
a. Involve stakeholders who affect or are affected by water governance.	Cross-cutting	<ul style="list-style-type: none"> • Decision-making largely centralized → SRP & other providers wield disproportionate power • Limited participants → mostly water providers, plus urban, mining, and agricultural stakeholders • Little participation → limited to comment periods, which often illicit no to little input
b. Illicit input over various stages of decision-making.	Cross-cutting	<ul style="list-style-type: none"> • Limited public involvement → short commenting & planning periods • GMA sets out 5 planning stages → continual planning & involvement of regulated entities
c. Establish collaborative endeavors for participatory decision-making.	All / Cross-cutting	<ul style="list-style-type: none"> • EVWF collaboration on groundwater modeling → examine pumping effects across GW basins • Attention to integrated issues → consideration of land-water-energy connections in Phoenix • Greater science-policy collaborations → DCDC facilitating as boundary organization
5. Inter- & Intra-Generational Equity		
a. Ensure a fair distribution of benefits & costs for all.	All / Cross-cutting	<ul style="list-style-type: none"> • Unfair distribution of costs & benefits → variable access to water sources means varying impacts • Native Americans historically denied prior appropriate rights, requiring costly adjudication
b. Facilitate stakeholder representation.	Cross-cutting	<ul style="list-style-type: none"> • Mexico excluded from YDP talks in U.S. → receives diminished flows downstream • Mining & urban interests favored, along with farming → no environmental representatives • Little overall involvement in local decision-making → water providers & big interests dominate
c. Ensure consideration of future generations.	Uses	<ul style="list-style-type: none"> • Future generations not represented • AWS rules only cover 100-year period, yet groundwater depletion ultimately irreversible

6. Interconnectivity across Scales & Sectors		
a. Reduce or eliminate negative impacts on/from other regions.	Supplies / Uses / Outflows	<ul style="list-style-type: none"> Downstream impacts minimally considered → onus for tracing problems is on affected areas Upstream pumping of groundwater in Big Chino Basin → downstream effects on Verde flows
b. Planning & managing across sectors & jurisdictions within hydrologic units.	Supplies / Uses	<ul style="list-style-type: none"> Rising attention to interconnections → yet limited integration across planning sectors, laws, etc. Fragmented water providers → though AMA linked to groundwater basins of Phoenix area Joint EVWF modeling of groundwater pumping & impacts → but replenishment not done at source
c. Recognize & coordinate activities across scales & sub-system sectors.	All / Cross-cutting	<ul style="list-style-type: none"> Workgroup collaboration in Lower Colorado Basin → yet Mexico excluded Federal rules & intervention affects activities → treatment, supplies, etc. Some increasing attention to resource interconnections → land-water & energy-water tradeoffs
7. Precaution (Mitigation) & Adaptability		
a. Anticipate & plan for potential stressors or changes to system.	Cross-cutting	<ul style="list-style-type: none"> Limited data & information → e.g., small wells exempted, plus small towns lack resources Diminished funds for local to state efforts → some studies work supported by DCDC Problematic assumptions → ‘there will be water’ following the growth imperative
b. Mitigate or lessen potential water shortages, pollution & other problems.	All / Cross-cutting	<ul style="list-style-type: none"> Mitigation so far due to storage infrastructure → no bans on water use despite long drought Diminished capacity may threaten future → lack of political support & impacts of recession Some progress with conservation & demand management, though varying successes across region
c. Adapt to water shortages & water quality problems.	All	<ul style="list-style-type: none"> Culture of consumption may hinder changes → need for lifestyle change to reduce demands

- Limits to adaptation strategies → supply augmentation costs & reduced flexibility for water transfers
- Difficulties with regulatory compliance → technologies & political constraints

APPENDIX B

IMPACT MATRIX AND CONSISTENCY MATRIX

Variable Label	1. New water sources	2. Protected Riparian areas	3. Safe yield	4. Delivery infrastructure	5. Energy for water	6. Water Quality regulations	7. Canals	8. Grey water systems	9. Peri-urban Farmland	10. Farm Water Use	11. Industry Water Use and Regulation	12. City Growth	13. Financial incentives for water use	14. Effluent Water Use	15. Water governance
1. New water sources	1	1	1	1	2	1	0	0	1	1	1	1	1	1	0
2. Protected Riparian areas	1	0	0	0	0	0	0	0	0	1	1	1	1	1	0
3. Safe yield	1	0	0	0	0	0	0	0	1	1	1	1	1	1	0
4. Delivery infrastructure	1	0	0	0	1	0	1	2	0	2	0	0	0	0	1
5. Energy for water	2	1	0	1	0	0	0	0	0	2	2	2	1	1	0
6. Water Quality regulations	1	0	0	0	0	0	0	2	0	1	1	1	1	0	0
7. Canals	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
8. Grey water systems	0	1	1	2	1	2	0	0	0	0	1	1	1	0	1
9. Peri-urban Farmland	1	0	2	1	0	0	0	0	0	2	0	2	0	0	0
10. Farm Water Use	1	1	2	1	0	1	0	0	2	0	0	1	0	0	0
11. Industry Water Use and Regulation	1	1	1	1	0	1	0	0	0	0	0	1	1	0	2
12. City Growth incentives for water use	1	1	2	2	0	0	0	0	0	0	1	0	0	1	0
14. Effluent Water Use	0	2	0	1	0	2	0	2	0	0	1	1	1	0	0
15. Water governance	1	2	2	1	0	2	2	2	2	2	2	2	2	2	2

Variable Label	1. New water sources	2. Protected Riparian areas	3. Safe yield in water management	4. Delivery infrastructure	5. Energy for water	6. Water Quality regulations	7. Canals	8. Grey water systems	9. Peri-urban Farmland	10. Farm Water Use	11. Industry Water Use and Regulation	12. New residential water use	13. Financial incentives for water use	14. Effluent Water Use	15. Water governance						
Future Projection	Pursued Not pursued	Protecte No delibe to WM central	Central Not central	Built Not built	Renewa Mix	Limited Expansi Tree	Mixed Not	Collecte Not	Develop Water transfer not	Crops Subsidi and	Consum high use	Growth No	Provide Not	Recharg Industri Drinkin	Public- Top-						
						veprealined use	develop id	collece id	Water	Water	ption	controls growth id	provide id	at use g water scientifi driven	down						
1. New water sources	Pursued	1	2	2	-2	1	0	0	1	0	1	0	2	1	1	1	0	-1	-1		
2. Protected Riparian areas	Not pursued	0	1	0	1	0	0	0	-1	0	1	0	1	-1	0	0	1	0	1	0	
3. Safe yield in water	Not pursued	0	0	0	1	0	0	0	-1	0	0	0	0	0	0	2	-1	0	0	0	0
4. Delivery infrastructure	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5. Energy for water	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6. Water Quality regulations	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7. Canals	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
8. Grey water systems	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9. Peri-urban Farmland	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
10. Farm Water Use	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11. Industry Water Use and Regulation	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12. New residential water use	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13. Financial incentives for water use	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14. Effluent Water Use	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15. Water governance	Not pursued	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0