


COMPARATIVE GROUNDWATER LAW AND POLICY PROGRAM

TAKING POLICY FROM PAPER TO THE PUMP:

LESSONS ON EFFECTIVE AND FLEXIBLE GROUNDWATER POLICY AND MANAGEMENT FROM THE WESTERN U.S. AND AUSTRALIA

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Executive Summary

This working paper is the product of a workshop held among 47 groundwater managers and experts from the Australia and the United States, who gathered to share experiences and practical lessons in integrated groundwater management with an emphasis on law, policy and management. The findings lay the groundwork for expanding debates and research on groundwater law, policy and management, to help improve groundwater sustainability. Experience across the Western U.S. and Australia points to four broad approaches for improving the effectiveness of groundwater law and policy − for taking policy from paper to the pump.

1. Build bridges among science, law, policy and management.

Scientific data has a significant role to play in modern groundwater law, policy and management, informing decision-makers about the resources available and the impacts of using them. But there is often a disconnect between science, on the one hand, and law and policy on the other, and confusion about the goal of integrating the two, and how to do so.

Fundamentally, science should inform rather than dictate policy decisions. Bridges between science on the one hand and law and policy on the other can be built in many ways: institutional arrangements that connect individuals across disciplines; "integrative science" that connects economics and other social sciences with the physical sciences, like the concept of valuing ecosystem services; and "integrators" − individuals who are specialists in their discipline, but who can effectively communicate with others from other disciplines.

2. Deal with, and move beyond, concerns about uncertainty.

Even with herculean scientific efforts, policymakers and managers will always have incomplete knowledge about groundwater systems and the consequences of pumping. Often, though, there is enough information to move forward with groundwater policy, and the dominant paradigm should change from *we don't know enough* to *let's make a decision*. Policymakers should also seek to minimize unnecessary data gaps by being aware of, and reforming, laws and policies that encourage "willful uncertainty." Such laws and policies leave out requirements that would increase information about groundwater and reduce uncertainty, like monitoring, metering and information sharing.

3. Invest in good communication between agencies and stakeholders.

Heading off conflict and motivating action to improve groundwater management are important goals of communicating about groundwater. This is an area in which there is often little guidance available for managers and policymakers. Practical experience shows that, particularly where policies are controversial, effective communication has common elements. These include: messages tailored to their audiences, visualization tools, genuinely deliberative discussions with stakeholders, and neutral third-party facilitators.

4. Use collaborative partnerships to implement − not just inform − policy

Innovative groundwater partnerships also emerge as an under-recognized but important way to avoid conflict, surmount political barriers to changing management practices, and encourage a long-term view. The common use of these partnerships in the Western U.S. proves the value to agencies of going beyond mere consultation, and engaging with NGOs and businesses in productive projects to jointly implement groundwater management and monitoring activities.

Moving beyond general, broad approaches to groundwater management and governance, experience across the Western U.S. and Australia also highlights four specific tools as particularly promising ways to offer water users flexibility. This makes groundwater policy effective from their perspective, while accomplishing other social and environmental goals.

5. Create the right conditions for groundwater markets and trade.

Groundwater markets can increase water use efficiency and potentially benefit the environment. Realizing these benefits requires conscious institutional work. Agencies must correct underlying weaknesses and flaws in a water allocation system, like poor monitoring and compliance, and uncertainty about the legal nature and scope of water rights, as a pre-condition to effective markets. It is also necessary to consider a range of tools for lowering transaction costs for acceptable trades.

6. Remove unnecessary barriers to aquifer storage and recovery.

Aquifer storage and recovery is used to increase the flexibility of water supplies, by storing surplus surface water in groundwater basins, then later recovering it for consumptive or environmental use in times of water scarcity. But in many places across the Western U.S. and Australia, laws and policies (or their absence, or lack of clarity) can be a key barrier to establishing ASR projects and realizing their benefits.

7. Consider mitigation policies as an alternative to regulatory restrictions.

Pumping groundwater can have a wide range of impacts, which can trigger justifiable regulatory concern and groundwater use restrictions. Rather than banning pumping on these grounds, a more flexible approach is to allow a groundwater pumper to incur the “debt” of an adverse impact as long as they “pay it back” through a mitigation or offset mechanism. This facilitates economic development, minimizes or neutralizes unacceptable impacts, and decreases the pressure to overlook these impacts. The Western U.S. provides a wide menu of possible institutional arrangements for mitigating impacts on surface waters, which could be useful to consider in Australia and in Western U.S. states that presently lack them. A key policy question for all jurisdictions is the extent to which mitigation frameworks should be expanded to recognize impacts beyond those on surface waters, which are the current focus.

8. Consider payments to recover groundwater rights or reduce groundwater use.

Where it becomes necessary to reduce groundwater use, for example to meet interstate compact requirements or protect endangered species, water buybacks (permanently retiring water rights in exchange for payment) or forbearance agreements (paying water users not to exercise their right) are under-recognized tools for providing valuable flexibility compared to strict regulatory options. They have involved creative partnerships among governments and NGOs, which have sought to reduce the overall economic cost and increase the political palatability of reining in groundwater use.

While there is no one formula for effective groundwater law, policy or management, the eight paths laid out here encourage the kinds of connections and flexibility that can increase effectiveness from both a water agency and water user perspective.

About the Comparative Groundwater Law and Policy Program

The Comparative Groundwater Law and Policy Program (CGLPP) seeks to improve groundwater law, policy and management through research and international workshops that draw together policymakers and experts on groundwater. The CGLPP focuses on strategies to manage groundwater along with other connected waters and ecosystems − in other words, through "integrated groundwater management." This approach includes:

- Regulating and managing groundwater conjunctively with surface water, including by "banking" surface water and other sources of water in aquifers for later recovery and use.
- Considering how groundwater allocation affects surface water systems, water quality, and dependent ecosystems.
- Anticipating climate change in managing these connections.

The CGLPP focuses geographically on Australia and the Western U.S. Both regions face water scarcity and the challenges of providing water to support both consumptive and environmental values. They also have broadly comparable cultures, legal systems and levels of development. By understanding, comparing and contrasting their successes and challenges in developing and implementing law and policy for integrated groundwater management, the CGLPP will develop policy recommendations for improving groundwater sustainability in both regions.

We approach our task in two ways: through original research, and a series of international workshops, which bring together policymakers and groundwater experts. We take an interdisciplinary perspective on both, informed by law, engineering, and natural and social science.

The CGLPP is a collaborative project between the Water in the West initiative of the Stanford Woods Institute for the Environment and the Bill Lane Center for the American West at Stanford University, and the United States Studies Centre at the University of Sydney. It operates with funding provided by the Dow Chemical Company Foundation and the Alcoa Foundation, through the United States Studies Centre's Dow Sustainability Program; and the S.D. Bechtel, Jr. Foundation.

About Workshop 2 of the Comparative Groundwater Law and Policy Program

The second workshop of the CGLPP was held June 20 to 22, 2012, at the University of Sydney. The workshop brought together 47 groundwater managers and experts to share experiences and practical lessons in integrated groundwater management. The group included lawyers, policymakers, government officials, academics, NGO representatives, scientists and consultants from the Western U.S. and Australia. The workshop focused on the links between groundwater science and policy, the use of partnerships between organizations to manage groundwater, and groundwater trading. It also focused on what each region can learn from the other − and suggested that the answer is "a lot." Three-quarters of feedback forms identified a case study, phenomenon or lesson from the other nation as the most practically useful, valuable or insightful takeaway from the workshop.

About This Working Paper

This working paper takes the form of a series of short, stand-alone thematic papers, organized as chapters, with a final appendix listing questions and areas for further investigation generated by the workshop process. The introductory notes clarify the focus on law, policy and management, and present a glossary to assist readers with differences in terminology between the U.S. and Australia.

Each chapter is based on a discussion paper circulated to inform the corresponding workshop session, combined with a synthesis of the discussion that took place during the session. Each chapter also includes a compilation of the feedback received from participants about the most insightful lesson of each workshop session; the information that they learned, which they could most readily put to use in their work; and responses to a draft report. Key insights are presented in blue boxes at the start of each chapter. Other key summary points are presented in shaded boxes in each chapter. The contents of each chapter do not necessarily represent the universal views of the attendees, nor those of their organizations.

The findings of this workshop and paper highlight promising areas for creative policy development in important and challenging areas of groundwater management, and the key issues that policymakers must confront in pursuing them. Its findings lay the groundwork for expanding debates and research on groundwater law, policy and management, to help improve groundwater sustainability across Australia, the Western U.S. and further afield.

Glossary

Groundwater law, policy and management involve different actors and approaches to dealing with groundwater planning and groundwater problems − although there are many areas of overlap in common usage of these terms, and each is capable of having multiple meanings in different contexts. As used here:

(a) Law refers to formal rules and regulations made by legislatures or courts.

(b) Policy refers to:

- (i) the formulation of broad objectives about groundwater management by government agencies (which law may express through rules); and
- (ii) the statements or practice of government agencies in relation to implementing law (for example, exercising functions like groundwater licensing/permitting) or spending money to pursue particular objectives (for example, establishing non-statutory incentive programs for farmers to use groundwater more efficiently).

(c) Management refers to on-ground actions taken by private parties or government agencies that relate to groundwater, for example, decisions made by groundwater users about how much groundwater to use, where and when to use it, and the purpose for which it will be used; or decisions made by agencies or user groups to establish and use groundwater monitoring systems. Some of these decisions may require permission from government agencies, which those agencies will consider granting pursuant to law and policy.

The glossary below is included as a brief guide to differences in water-related terminology between Australia and the U.S.; the “translations” are necessarily approximate. Note also that individual states may use terminology that varies from that presented here.

U.S. term	**Australian term**
Endangered Species Act	*Environment Protection and Biodiversity Conservation Act*
Exempt well	*Private right; stock and domestic right*
Interstate compact (e.g. Rio Grande Compact)	*Interstate agreement* (e.g. Murray-Darling Basin Agreement)
Permit/permitting (of groundwater use, often requiring proof of beneficial use to fully “mature”)	*License/licensing* (of groundwater use, usually “mature” when granted)
Water marketing	*Water trading*
Water right; under the Western U.S. prior appropriation doctrine, a right to extract water that developed earlier is “senior” to, and more reliable than, a “junior” right that developed later	*Water entitlement*; an Australian water entitlement (whether to groundwater or surface water) has the same reliability as all other entitlements in its class. The time that the right was developed does not affect its reliability.
Well	*Well* or *bore*

1. GROUNDWATER AND THE SCIENCE-POLICY INTERFACE: How groundwater amplifies the science-policy divide, and how to bridge that divide and avoid scientific combats in the policy process

Key insights:

1. Science should inform, but not determine, groundwater policy decisions. Policy always requires making judgments and trade-offs.
2. Bridging science and policy can occur in a variety of ways in practice, from creating water science research institutes specifically to answer policy questions, to rotating agency employees among policy and science roles, to giving scientists an opportunity to contribute to the framing of research questions designed to inform policy.
3. Individual “integrators” − specialists in their discipline, who can effectively communicate with others from other disciplines − can help span the science-policy divide.
4. In addition to the physical sciences, social sciences, including economics, should inform groundwater policies and management strategies. The concept of ecosystem services has the potential to be an important “integrative” science in groundwater management.
5. Since science produced in response to a crisis cannot meet timeframes required to make water policy in response to that crisis, support robust, ongoing scientific research.

Discussion

Traditionally, water law has developed around drastic simplifications of hydrologic science, and in complete isolation from ecological science. This is now changing, as demands for water increase, and science and technology advance. Few could dispute that science has a clear and direct role in groundwater law, policy and management, since the task of allocating resources relies fundamentally on accurately understanding the resources available and the impacts of using them.

Science-based principles − in particular, hydrological principles − are increasingly infused into water law and policy.

Science-based principles that were unfamiliar at the time when many present laws and policies were first established are increasingly employed in water law and policy in Australia and the Western U.S. For example, the groundwater policies of many states within the Western U.S., like Kansas, Washington, Idaho and Montana, now legally recognize surface water and groundwater as interconnected sources and use the same system to allocate both surface and groundwater supplies. Australian groundwater policy also aspires to recognize these connections. Better understanding and appreciation for science is also seen in state policies and regulations that require applicants for new groundwater diversions to prove that the source basin can sustain increased pumping.

A key outstanding (and relatively recent) issue requiring better integration of science and groundwater law relates to groundwater-dependent ecosystems: locating them, determining how much water they need, when they need it, their ecological response functions (i.e. how they respond to changes in water regimes), how best to measure their health, how to prioritize them and how to reflect these things in legal protections.

In important ways, science and policy − and scientists and policymakers − have different worldviews. Efforts to link them must recognize these differences.

Science and policy are characterized by fundamental differences in approach and worldview, some of which are particularly amplified in the context of groundwater issues. Key differences between science and policy relate to the influence of public concerns; temporal and spatial scales; the ability to deal with complexity, change and uncertainty; the desirability of challenging the status quo; and the adoption of objective versus subjective approaches.

Scientists produce knowledge based on observation, models and testing hypotheses, striving to be objective. They express findings based on evidence, using probabilities, avoiding definitive or absolute statements, and often using specialized language that is not easily understood by the lay public. The production of scientific knowledge is fundamentally iterative: new information builds on old; sometimes these cycles of knowledge-building are short, but sometimes years or decades are required to answer scientific questions; and failure is seen as a source of learning. The subject matter of scientific inquiry is by its nature extremely complex, and it sometimes focuses on extreme or outlier situations as particularly interesting. To many scientists, the value of scientific knowledge is not determined by the perceptions of the general public about its value. Scientists have a personal stake in overturning established scientific knowledge and challenging conventional assumptions.

Policy and policymakers differ fundamentally in relation to each of these factors. Policymakers are driven by social values that are subjective by nature. They seek to appeal to the public and the regulated community using narrative, persuasive techniques and simple language. Short political cycles ensure that policymakers focus on short-term impacts of decisions. Policy and law involve path dependence that often renders them unable to quickly adjust to new information. Law or policy complexity is generally seen as undesirable (though sometimes unavoidable), since it can lead to difficulties in implementation and communication to the regulated community and the general public. Certainty is highly valued in the context of law and policy, since the general public and the regulated community make decisions in the expectation that current laws and policies will generally continue. Policymakers in democracies must respond to the demands, views and values of the majority. They make policy with a view toward covering the most common situations, and sometimes find it difficult to deal with "extreme" or unusual situations. Learning from "error" is seen as inherently threatening and evidence of failure. Policymakers have a personal stake in avoiding "making waves."

Groundwater issues tend to amplify some of the fundamental differences between science and policy.

These differences can be particularly stark in the groundwater context.

(a) Information about groundwater is often subject to a high degree of uncertainty (see Chapter 2 about uncertainty for further discussion of this point).

(b) The impacts of decisions about using groundwater will sometimes be felt only decades or even centuries into the future and, in any case, multiple political cycles into the future.

(c) Groundwater systems are very complex and differ radically in their nature from place to place, making general policy prescriptions more difficult (for example, Western U.S. “safe yield” principles struggle to deal with fossil, or non-recharging, groundwater bodies).

(d) The general public often has little understanding of groundwater-related terminology or even groundwater systems themselves, or their value. Public perceptions can sometimes be overly influenced by old, high-profile litigation over groundwater contamination, rather than knowledge about more recent science or policy.

(e) There is sometimes a mismatch between the impacts of using groundwater on a localized minority and the more widespread benefits for the majority of the groundwater-using activity (mining being an example of this mismatch).

The differences between science and policy can create problems for groundwater law, policy and management.

These differences can create problems for groundwater law, policy and management. At a fundamental level, insufficient links between science and policy (including inadequate communication of science to policymakers) prevents the increase of policymakers’ knowledge of the resources available and the impacts of using them, and thereby hinders the effective allocation of those resources. Inadequate communication between scientists and policymakers also results in an inordinate emphasis on knowledge gaps, and insufficient appreciation for significant existing knowledge. This provides an opportunity for those who prefer status quo law, policy or management to use gaps in scientific knowledge as a strategy to create delay in changing the status quo.

Scientists should relay their findings to decision-makers in a way that ensures they are understood, to maximize the chance of them being taken up. To bridge the gap between science and policy, scientists should help policymakers to formulate questions to get the kind of policy-relevant answers that they seek. They should also communicate the limitations of their work, and the implications of this in using it. Where models are involved, this often means communicating that the best use of a model is in measuring the change in a system, rather than absolute values.

Adaptive management principles can help bridge the differences between law and policy − to a point − but groundwater presents particular problems for these principles.

Scientists may need to make inferences to help transfer scientific information into a legal or policy context, and to use metrics and measures that are easily understood by lay people, which relate to values that are important from a policy perspective (see also Chapter 3 on communication). Increased cooperation between scientists and policymakers would help to make scientists aware of the questions that policymakers need to see addressed, and help policymakers understand that scientists cannot always provide exact information which is consistent through time. Scientists can increase the chance that their findings inform policy by accepting that timelines will be dictated by policy or statute, and planning research accordingly; presenting results in a way that speaks to the issues that are important for making a policy decision; and, in addition to presenting full research findings, summarizing results in one page.

Water law and policy have adopted principles of adaptive management as a way to adapt to changing scientific information − both increasing amounts of information, and information about changing conditions. Adaptive management principles seek to transform policymaking into an iterative process that relies on feedback between monitoring systems and decision-making. Adaptive management, in a stronger form, also helps address uncertainty by allowing experimentation that ideally reduces the degree of uncertainty in the science over time (though it may increase uncertainty for water users, as noted in Chapter 2). Adaptive processes help deal with knowledge gaps because they represent a commitment to learning more, and acting on that further information. Without such processes, a fear that policy decisions will be "forever" can lead to "combat science" (about which, see further below). On the other hand, the fear that a water right will be reduced, for example, as the result of an adaptive process, also has the potential to fuel combat science.

Some water laws and policies adopt explicitly adaptive mechanisms. Some water management planning statutes require plans to include a monitoring component, and require that plans be reviewed regularly. Some water entitlements issued under Australian water laws are capable of being permanently reduced in response to changing climatic conditions. Finally, some types of Australian water entitlements (though rarely groundwater entitlements) are expressed as shares in a consumptive pool (which may change with a drying climate, for example), rather than as rights to take a volume of water in absolute (and static) terms.

While often a feature of water policy rhetoric, the application of principles of adaptive management is generally more limited in the context of groundwater than in that of surface water. In the former, much longer lag times can occur between an action (e.g. increasing pumping) and its effects (e.g. declines in the health of groundwater-dependent ecosystems). This can make it impossible to react effectively to remediate the adverse effects of a policy decision that is intended to be reviewed and changed based on observed effects, since impacts can be "locked in" by much earlier decisions. For further discussion about the limitations of adaptive management principles in the groundwater context, see Chapter 2 on uncertainty.

Water management is often criticized for being "politicized." But water policy involves considerations outside science. Rather than trying to "de-politicize" water policy, political factors should be made transparent, and resolved through collaboration.

Water issues are often politically contentious. Separating scientific and political processes, so that the influence that each has on decisions about water is transparent, is one approach to managing contentious issues. The Australian federal Water Act creates an independent water science organization, the Murray-Darling Basin Authority, to prepare a legally binding water management plan to cap water extractions. The Authority provides the plan to a federal political decision-maker, who may then make policy-based changes (though some question how separate the science and politics are in practice). Alternative approaches to maintaining separate political/regulatory and scientific processes are to ensure that scientists, rather than politicians, lead government science agencies; and to establish systems under which scientists review and evaluate policies or decisions that are justified by scientific findings.

An initial question in groundwater management is often whether to collect additional data. Policymakers routinely must determine when they need additional information to make a decision. Though it is rarely explicit, this can entail evaluating the costs and value of additional information. A key issue worthy of further discussion is how to determine when law or policy should use a simple pragmatic solution (such as a rule of thumb about average local hydrogeological conditions) for making a decision rather than an expensive requirement to collect detailed scientific data. See Chapter 2 for further discussion about dealing with data gaps and uncertainty.

A key operational issue for policymakers is how much science is required to make a decision.

Policymakers are sometimes required to make decisions based on the "best available science" (BAS), rather than collecting more information. While BAS is employed in multiple state and federal jurisdictions, including Australia's National Water Initiative and the European Union Water Directive Framework, there remains no clear or consistent articulation of the term or guidance on how to apply it. Indeed, the phrase can be problematic in several ways. Some suggest the "availability" of science is generally determined by the providers of scientific information rather than the needs of policy and decision-makers. In addition, it can sometimes be difficult to determine what information qualifies as "science." The U.S. Endangered Species Act defines "best" science as information that is collected by established protocols, properly analyzed and peer-reviewed before release to the public. Ultimately, courts often defer to agency discretion in determining what constitutes BAS.

Some scholars propose a process of "best evidence synthesis" that they suggest could improve the integration of scientific information into water policy and decision-making by empowering an interdisciplinary group to address a defined question using the following principles:

- *Create and support a cooperative process that enables interdisciplinary teams to produce shared knowledge that meets the needs of all users.*
- *Articulate a clear management or policy question and translate it into research questions and supporting hypotheses.*
- *Define the knowledge needs in terms of its properties (scientific, supporting and indicative).*
- *Create an a priori and case-specific hierarchy of "best" information (well-established theories, peer-reviewed published and unpublished literature, expert opinion).*
- *Develop study designs and analyses that are appropriate for the hypotheses being tested.*
- *Clearly state assumptions, define terms, and identify uncertainties and associated risks.*
- *Build in revision as uncertainties, limitations and inconsistencies are addressed over time.*
- *Ensure a record exists of the decision-making process.*

- *Communicate research methods, supporting rationale, results and management applications via the peer-reviewed literature and through reports or other formats as preferred by the management and policy audience.*[3]

At a more operational level, differences between expert opinions of how to interpret groundwater information can lead to “combat science” or “dueling models.” Combat science commonly involves one stakeholder alleging that his or her model is superior and should be used instead of another. In some cases, “gold-plated” science commissioned by an agency is rejected by an affected community, which then invests in competing science. This occurred in Washington state, in response to scientific research about the nature of connections between surface water and groundwater in areas subject to intense competition for access to water. See Chapter 4 for a collaborative, partnership-based approach to technical modeling that has successfully avoided combat science, and has helped to bridge the science-policy divide by involving scientists and water users.

Collaborative efforts between political entities, or stakeholders, can reduce the contentiousness of scientific information in the interstate context. Idaho, Washington state and the U.S. Geological Survey collaborated to put together an interstate aquifer study − the Spokane Valley-Rathdrum Prairie Aquifer Study − as the foundation for cooperative management of the aquifer. A similar approach was adopted for the Eastern Snake Plain Aquifer in Idaho: see Chapter 4.

Because obtaining and interpreting water information can be expensive, a practical aspect of the science-policy interface is allocating the costs of doing so.

The science-policy interface also raises the practical question of how policy should allocate the cost and burden of obtaining and interpreting groundwater science between: (1) government agencies, which hold groundwater in trust for the public (and, by implication, taxpayers, which fund government budgets and ultimately own the resource, at least in most states), and (2) groundwater users, who benefit from using a common resource. Resolving this question is intimately related to ensuring that sufficient high-quality groundwater information is available to support effective management. It is also a particularly contentious question, given that collecting groundwater information tends to be much more expensive than collecting information about surface water.

Generally speaking, water pricing does not presently allow for recovering management costs. This can threaten the financial sustainability of water management, particularly where subsidies from government budgets are not secure or sustainable. It also misses an opportunity to secure funding to cover the costs of managing the environmental effects of groundwater pumping. Australia’s National Framework for Improved Groundwater Management (1996) encourages jurisdictions to employ groundwater user charges or “user pays” approaches to enable groundwater to be managed as an economic commodity, potentially increasing its capacity to be more equitably managed and allocated. The Framework suggested that funds paid by water

[3] Darren S. Ryder, Moya Tomlinson, Ben Gawne, and Gene E. Likens (2010). “Defining and Using “Best Available Science”: A Policy Conundrum for the Management of Aquatic Ecosystems”, *Marine and Freshwater Research* 61: 821-8.

users should be used to recover direct management costs, such as the costs of licensing; and indirect costs, such as the costs of formulating policy, where this was “realistic.” It further recommended making transparent any subsidies where recovering indirect costs was unrealistic and increasing public awareness of the value and vulnerability of groundwater. These recommendations have not been fully adopted, though sometimes state legislation provides clear mechanisms for doing so. South Australia’s Natural Resources Management Act enables the government to set a water levy based on factors that include “the effect that taking or using water has, or may have, on the environment, or some other effect or impact that, in the opinion of the Minister, is relevant and that is capable of being determined, measured or applied.”

2. GROUNDWATER AND UNCERTAINTY: How law and policy can help, how they can hurt, and recommendations for managers

Key insights:

1. We will never have a complete understanding of groundwater systems, but we often have enough information to move forward with policy. Focus on what is known. Often, the dominant paradigm should change from “we don’t know enough” to “let’s make a decision.” Such decisions should account for uncertainty through adaptive management processes, ensuring that the decisions do not give groundwater users unrealistic expectations that they have absolute rights.
2. To avoid decision-making paralysis, identify the areas of uncertainty that are most important, involve meaningful risks and would change policy choices. Fund science in these areas based on an analysis of the cost of the research versus the gain in improving the policy decision.
3. Laws and policies sometimes encourage “willful uncertainty” where they omit requirements that would increase information about groundwater and reduce uncertainty, like monitoring, metering and information sharing. Willful uncertainty is often at the center of conflict.
4. In a data-poor environment, consider the cost of not making a decision against the potential cost of making a poor decision.
5. We often lack data about groundwater-dependent ecosystems (GDEs). Jurisdictions with similar physical systems can cost-effectively increase the information available to them about GDEs by coordinating and planning monitoring across jurisdictions to test hypotheses about ecology-hydrology relationships, and sharing the resulting knowledge.

Discussion

Groundwater policymaking and management can encounter uncertainty in a number of scenarios. It can appear as factual and scientific uncertainty, uncertainty or risk associated with future resource availability and conditions, and uncertainty about the costs and benefits associated with different management regimes. Managers often operate in the absence of full information about the physical characteristics of aquifers (e.g., extent, storage volume, etc.), groundwater hydrology (e.g., connections between surface water and groundwater systems, recharge rates, quality fluctuations, etc.), the relationship of groundwater to ecology, the effects of current levels of groundwater use, the expected future conditions of groundwater systems and alternative resources, and future levels of groundwater demand. As a result, there is often a great deal of uncertainty regarding the costs and benefits of management options − and, indeed, how these costs and benefits should be valued. In addition, individual groundwater users face the risk that their rights or entitlements will not receive a full allocation of water because of unfavorable climatic conditions or competition from other users. Law and policy can also contribute to uncertainty through ambiguous policy formulations.

Uncertainty in groundwater management can take four forms: risk, incertitude, ambiguity or ignorance. Each of these indicates a different suite of potential solutions.

Generally, uncertainty can appear in the guise of:

- Risk, that is, the chance that a known harm will occur, where we can approximate the probability of harm occurring. In this case, risk assessment is a suitable tool. Risk assessment in the groundwater quantity arena lags behind that in other areas of water management, for example, dam safety.
- Incertitude, where known outcomes have an unknown probability of occurring. Adaptive management techniques can be useful in this scenario.
- Ambiguity, where socio-political rather than technical uncertainty arises. Socio-political consequences of groundwater management are frequently subject to a great deal of uncertainty. Enhanced public participation and investment in social science can help deal with this situation.
- Ignorance, where both the outcomes and their probability are unknown. Possible responses are to prohibit the potentially damaging activity, to apply precautionary presumptions, and/or to require the proponent of the activity to prove that the activity is safe or the harm can be mitigated.

Conceptual models of groundwater systems, including groundwater flow and groundwater-dependent ecosystems, can be a useful way to identify uncertainties.

At the water resource level, law and policy can help managers and individual water users deal with uncertainty regarding groundwater conditions through legal presumptions, adaptive management principles, the precautionary principle and water planning processes.

At a high level, jurisdictions adopt different groundwater law and policy tools to help policymakers and individual groundwater users deal with these forms of uncertainty in a variety of ways.

First, legal and policy presumptions are a key tool that can reduce the cost of making decisions where there is incertitude or ignorance in relation to the physical characteristics of groundwater systems. Colorado, for example, presumes that all groundwater outside certain basins is connected to surface water, but water users who believe that their groundwater is not connected can seek to rebut the presumption. Idaho has adopted the same approach in relation to the Snake River Basin water right adjudication. Other states, by contrast, often start with a presumption that surface water and groundwater are legally separate and require surface water users to establish that groundwater withdrawals are materially interfering with their use, or vary the presumption depending on whether a current surface water user is objecting to an established groundwater right or a proposed new groundwater permit. Yet others, like Oregon, assume material connection in certain factual settings (e.g., where a groundwater well is within a set distance from a surface waterway). In Australia, the National Water Commission recommends that "unless and until it can be demonstrated otherwise, surface water and groundwater resources should be assumed to be connected,"[4] but this recommendation is yet to be implemented by all states.

[4] National Water Commission (2009). Australian Water Reform 2009: Second Biennial Assessment of Progress in Implementation of the National Water Initiative, Canberra, ACT: National Water Commission.

Second, adaptive management principles deal with uncertainty, as well as changes in dynamic hydrologic systems, by allowing for revisions in the law or regulation when new information becomes available (see Chapter 1 on the science-policy interface for an initial discussion of adaptive management). Since scientific uncertainty will always exist, and the "best available" information will always change, the best policies will contain elements of flexibility and adaptability. However, these principles cannot deal with irreversible outcomes, and therefore need to be considered carefully where outcomes like seawater intrusion, loss of groundwater-dependent species or land subsidence are possible results of groundwater management decisions. Equally, flexible legal structures that allow for changes in law or regulation may help to respond to new information, but can also contribute to uncertainty from the perspective of water users. Where unforeseen changes in groundwater conditions require changes to groundwater management, an important policy consideration is the degree to which those management changes result in reduced water availability to consumptive water rights holders versus ecosystems.

In Australia, groundwater licenses that contain adaptive management provisions have been the subject of legal challenge on the basis that they are not sufficiently well specified, or depend substantively on the results of monitoring that will occur in the future (e.g. the *Castle v. Southern Rural Water* case in Victoria). Nonetheless, flexibility does not necessarily mean a complete lack of certainty: Regular reviews of extraction limits set in Australian water allocation plans, for example, can affect the reliability of water entitlements, but regulatory frameworks can preserve certainty for water users in relation to how cuts in entitlements will be shared. Some have suggested that a viable legal definition of adaptive management is required to enable it to be used more effectively in the water rights context.

Third, the precautionary principle − whether in policy or law − deals with uncertainty. One definition of the precautionary principle, which is often included in Australian legislation, states that "if there are threats of serious or irreversible environmental damage, lack of full scientific certainty as to measures to address the threat should not be used as a reason for postponing such measures." A stronger form of the precautionary principle urges policymakers and managers to err in favor of protecting the environment, including by using law and policy. The precautionary principle speaks particularly to the groundwater context, since a variety of groundwater problems, such as subsidence, seawater intrusion, contamination by pollutants, and loss of unique groundwater-dependent biodiversity, are often irreversible in practice. Indeed, a New South Wales state policy adopts as a guiding management principle the idea that "[w]here scientific knowledge is lacking, the precautionary principle should be applied to protect groundwater dependent ecosystems." However, as is common in relation to such statements, no guidance is provided on precisely what is required to act in accordance with the principle. In the 2010 *Alanvale* case, a Victorian tribunal cited the precautionary principle in upholding a water authority's decision to refuse to issue a license for groundwater extraction where there was uncertainty about the impacts of climate change on the groundwater source − a rare example of the principle being used in the context of litigation over groundwater. In the Western U.S., preliminary permits that precede the issue of a full water right can theoretically serve a "precautionary" function.

Fourth, water planning can help to reduce uncertainty as it appears in several guises. Ideally, water planning processes bring together stakeholders to inquire into the consequences of a course of action − for example, the impacts to a groundwater resource and its dependent ecosystems of allowing a certain volume of groundwater to be extracted. This can involve collecting information, defining unacceptable impacts, assessing risk and providing for adaptive management arrangements such as (in Australia) regularly reviewing water allocation levels in light of new information. Planning processes generally involve stakeholders quite extensively, which also helps to reduce socio-political uncertainty (although funding cuts can lead to constraints on stakeholder involvement, as recently occurred in Queensland). In practice, challenges to the ability of water plans to carry out these uncertainty-reducing functions include using excessively short time horizons; not assessing key factors that influence outcomes, like land use change; and stakeholders' resistance to participating or implementing the plan due to a lack of knowledge about how the plan will impact them or an unwillingness to accept measures that are economically detrimental in the short term. In the Western U.S., the ability of water plans to carry out these functions is quite different than in Australia, since most Western U.S. states do not provide for water plans to influence the allocation of water, but rather usually only supply-side measures and voluntary demand-side measures.

Finally, the legal system can be used to impose obligations on decision-makers to make decisions and reduce the potential for uncertainty to be used to create unnecessary delay. Where additional data is required from an ongoing groundwater monitoring program to provide input into a decision, trigger points can be established to ensure that decisions are made at particular points, rather than unnecessarily delayed.

It is important to note that these law and policy tools help in dealing with various forms of uncertainty on a day-to-day basis. While it may be desirable to obtain more information to deal with some day-to-day management issues, these should be distinguished from arguments that more science is needed in order to design groundwater policy. Such arguments can often unnecessarily delay policymaking: "We don't have to know where the car is going to design the car, we only need to know what the driver needs the car to do."[5]

At the level of individual water users, law and policy can reduce risks associated with not receiving full access to permitted water rights by preventing over-allocation, facilitating water augmentation measures, and using water trading and insurance mechanisms.

In addition to dealing with uncertainty at a macro level, to varying degrees, groundwater law and policy provide tools to minimize the cost to individual water users of uncertainty associated with the security of their groundwater rights and entitlements. At the permitting stage, different states place the burden of proving the facts required to obtain a groundwater permit or license on different parties − either the permit applicant or the state agency assessing the permit is responsible for assembling the evidence. That is, the cost of uncertainty about the underlying physical conditions can rest with different parties to the permitting process. Some argue that placing the burden on the proponent can unfairly advantage corporate applicants that are wealthy by comparison with individual farmers.

[5] Maurice Hall, workshop participant.

The risk of receiving less than one's full entitlement to water is an inherent quality of water entitlements and allocation schemes, which law acts to distribute. There are many examples of legal mechanisms designed to allocate (and possibly reduce) risk in a way that minimizes the cost of uncertainty. As noted in Chapter 5 on water trading, markets reduce the cost of uncertainty by increasing the flexibility of a property right to extract water and allowing reductions in availability to be shifted to those who are better equipped to bear them, or more in need of the right. Other legal mechanisms employed to manage uncertainty or allocate risks borne by groundwater users include:

- Groundwater mitigation exchanges and augmentation planning (which require new groundwater pumping to be offset by supplementing the source with water from an outside system).
- Aquifer and surface storage (which allow water to be stored in times of surplus and recovered in times of scarcity).
- Capping basins (which involves prohibiting further groundwater pumping from fully allocated basins).
- Call mechanisms within the U.S. prior appropriation water allocation system (a security tool under which a senior water right holder may prevent a junior user from pumping that would reduce the amount available to the senior, to which he or she has a legal right).
- Water right insurance (a less common mechanism that provides title insurance for water acquisitions).
- Carry-over (which involves allowing a groundwater right/entitlement holder to delay the use of a water allocation until a future water accounting period).
- Water right pooling (a stakeholder-driven strategy in the U.S., and a standard feature of Australian water allocation frameworks, which spreads the risk of unfulfilled water deliveries across a broad set of individuals).

A further option that has been a feature of surface water management in Australia, but is rarely encountered in the groundwater sphere, is specifying groundwater entitlements with reference to their variability and the probability of obtaining a full allocation in a given season.

As well as their positive influence on dealing with uncertainty, groundwater law and policy can also contribute inadvertently to uncertainty through unclear or ambiguous principles.

Groundwater law and policy can also contribute to, rather than reduce, uncertainty. Legal or policy principles can be unclear, for example, about when a permit is required to pump groundwater, or how to operationalize broad principles that limit groundwater pumping. The laws of two very different jurisdictions illustrate this. Under California water law, pumping groundwater from "subterranean streams flowing in known and definite channels" requires a state-issued permit, but pumping "percolating groundwater" does not. Unfortunately, there is no clear, "bright line" test for determining whether a particular body of groundwater is a subterranean stream for the purposes of California water law. Definitively settling this question requires litigation, the absence of which leads to uncertainty about whether groundwater permitting requirements apply. Standards designed to protect groundwater supplies from overexploitation can be similarly unclear, particularly where those standards move beyond relatively simple concepts like safe yield. Australia's 2007 Water Act prohibits pumping groundwater from the Murray-Darling Basin beyond an "environmentally sustainable level of take," defined as a level of diversion that does not compromise any of four factors: key environmental assets, key environmental outcomes, the productive base of the resource and key ecosystem functions. However, the Act gives no guidance on what some of these terms mean, nor how to prioritize "key" elements against those that may be compromised.

In many cases, uncertainty is no accident. Groundwater law and policy may allow various degrees of "willful uncertainty." "Willful uncertainty" occurs where a legal system omits requirements that would increase information about groundwater and reduce uncertainty, like monitoring groundwater conditions, metering groundwater use or making other private groundwater information public. Such requirements may be absent because of the economic or political cost of imposing them, relative to other groundwater management activities.

Law can also contribute to uncertainty for groundwater users when rights to groundwater are not readily quantified. This is the case in states of the Western U.S. (such as California) that require court adjudication to settle groundwater rights. Groundwater rights that are limited to the volume of "reasonable" beneficial use, which is common throughout the Western U.S., are also, by nature, uncertain (at least in theory), since the reasonable use standard changes with time. In both Australia and the Western U.S., some types of groundwater uses are exempt from regular licensing or permitting processes, meaning that they are largely unmonitored and not quantified. Activities that are commonly exempt from such requirements include mining, oil and gas activities, forestry plantations, and stock and domestic bores. In the Western U.S., groundwater impacts of large-scale residential development projects can also remain unquantified because many states, like Montana and Washington, exempt such projects from regulatory review. These unmonitored and unquantified uses cannot effectively be controlled, and as a result, they may erode the security of other water rights, increasing the uncertainty associated with water allocations available under those other water rights.

Where groundwater law and policy require a decision-maker to consider the impacts of pumping groundwater on ecosystems or communities, important issues of uncertainty arise for groundwater policymakers and managers.

As one of the most recent concerns of groundwater laws and policies, groundwater-dependent ecosystems (GDEs) pose particular challenges for law, policy and management in terms of uncertainty. GDEs have received relatively little scientific attention in the U.S. and Australia compared to surface-water ecosystems, and comprehensive assessments are needed to reveal the types of ecological services provided by GDEs, sources of threats to those services, types of indicators that might be used to estimate the health of GDEs, and systems by which to value and prioritize the protection of GDEs. Australian water law and policy at the national and state levels often requires that GDEs be considered in determining sustainable aquifer yields, and sometimes priority GDEs are mapped and well placement or drawdown restrictions applied to protect them, generally set out in water allocation plans (as in New South Wales). However, some postulate that the significant scientific uncertainty surrounding the water requirements of GDEs has contributed to the fact that most Australian water allocation plans do not consider GDEs. If this explanation holds, it appears to contrast with the requirements of the precautionary principle (discussed above), which would seem to require that measures to protect GDEs not be postponed in the face of credible threats of irreversible damage to them. One approach proposed in response to this lack of scientific information is the establishment of strategic monitoring systems, which are designed to test hypothesized relationships between hydrological alteration and ecological responses for various types of groundwater bodies. Documenting "best suggested practices" for managing GDEs could also be helpful.

Research on GDEs in the U.S. and Australia is beginning to receive more attention. Australia's National Groundwater Action Plan has invested millions of dollars in studies and reports related to GDEs, including a National GDE Atlas. In the U.S., in 2007, the Nature Conservancy developed a methods guide to identifying data inputs needed to characterize the types and locations of GDEs, and how GDE water requirements can be integrated into conservation planning. The U.S. Forest Service has recently incorporated the guide into its groundwater resource management plan (groundwater being a new management emphasis for the agency) and is testing the methods in a pilot grazing plan on Oregon Forest Service lands. The study is intended to inform federal groundwater management on a nationwide scale.

The socio-economic impacts of pumping groundwater (or reducing groundwater pumping) are also frequently unknown. In some cases − a prominent example being Australia's federal Water Act − policymakers must explicitly consider the socio-economic impacts of particular levels of extraction. Such information is often not available. The approach of the Murray-Darling Basin Authority in Australia, which operates under that Act, was to commission more than 20 special studies, as well as seek feedback from stakeholders, to assess these likely impacts.

In addition to requiring consideration in groundwater law and policy, uncertainty about groundwater gives rise to practical issues of communication between scientists and agencies; between agencies; and between agencies and the public.

Scientists face particular challenges in assessing uncertainty about groundwater information for the purposes of advising policymakers. Several different approaches to assessing uncertainty are available. A simple sensitivity analysis approach produces a range of estimates around a "true" value, without assigning probabilities to various points in the range or producing a distribution of values. More sophisticated approaches, such as Monte Carlo analysis and expert elicitation, can often provide a more useful and appropriate characterization of uncertainty, but they also can cost more money, increase the complexity of the analysis or both.

Good intra-agency communication strategies can help efficiently to reduce factual and scientific uncertainty by sharing monitoring designs and results that may be applicable across jurisdictions. This could be especially valuable in the context of GDEs, where knowledge transfer and intra-agency coordination could help deal with the generally poor availability of ecological data, combined with challenges in obtaining funding to collect new (and frequently expensive) data.

Communicating with the public about uncertainty surrounding groundwater can be challenging. There is no agreed-upon way to do this. One approach to explaining the variable reliability of entitlements or rights to water uses probabilities of the rights being fulfilled in a given year. Risks to groundwater management posed by lower water availability (as well as the impacts of incertitude about other important factors, like changing land uses), can be considered through scenario modeling that uses different values for these factors to predict the impacts of different management actions. In addition to educating the public, there may also be a need to educate the judiciary and board members of local water agencies, particularly in the Western U.S., about the role of uncertainty in groundwater management.

See Chapters 1 and 3 on the science-policy interface and further discussion of communication with the public.

3. COMMUNICATING ABOUT GROUNDWATER: Ideas for how to do it, what to say and whom to engage

Key insights:

1. Parties affected by a policy should understand and trust information about how a groundwater system behaves and causal relationships − management actions and their consequences.
2. In some cases, communication about groundwater has been unidirectional: from regulators to the regulated community. A deliberative dialogue − which involves asking people to suggest options, and providing immediate feedback on the consequences of those options − is often more valuable.
3. Gleaning groundwater knowledge from the community not only builds information, it can also encourage community acceptance and "ownership" of the resulting scientific model or policy.
4. External, neutral facilitators can be valuable in building trust, particularly where groundwater policy is controversial.
5. Visualization tools are particularly helpful in communicating about groundwater.

Discussion

Effectively communicating with stakeholders is a key element of groundwater management necessary for motivating action and achieving buy-in to policy initiatives.

Communicating about groundwater can have various goals: influencing the behavior of water users, getting stakeholder buy-in for groundwater management initiatives, obtaining substantive information about groundwater conditions or community values associated with groundwater resources or their dependent ecosystems, or simply increasing understanding about groundwater among the general public.

Stakeholder participation and substantial local involvement in groundwater management are well established across the Western U.S. and Australia. Local stakeholder "buy-in" is a central theme of success stories in governing groundwater. Local expertise in relation to environmental and cultural conditions can inform local-level management plans. Cooperation between stakeholders and managers can also increase the effectiveness of essential management activities by ensuring that both groups are working toward the same goal. More philosophically, some argue that stakeholders should be able to define their own management goals and, implicitly, acceptable levels of impacts of groundwater pumping in their region.

Maximizing the benefits of local stakeholder involvement in groundwater management requires effectively identifying, attracting, engaging and informing stakeholders on complex issues, like groundwater-surface water connections and trade mechanisms. Effectively communicating groundwater issues can help attract and ensure the ongoing commitment of stakeholders to engagement about groundwater management. Improving upon what are frequently low levels of public understanding about groundwater issues is also important, particularly to ensure that environmental views are heard. In addition, in some cases, public awareness is a precondition to the NGO community developing interest in groundwater issues − one reason suggested for the relatively low levels of NGO interest in groundwater issues in Australia, compared with the Western U.S. In turn, NGO involvement is a valuable "check and balance" on the implementation of policy and a precursor to NGOs becoming involved in valuable groundwater partnerships (see Chapter 4 on partnerships).

Key questions in relation to communicating about groundwater are: What information should be presented, to whom, in what form, by whom, and in what forum?

Forming a communication strategy involves identifying stakeholders, building trust and developing a consensus around key issues for discussion.

An important first step in formulating a groundwater communication strategy, and initiating stakeholder involvement more generally, is to carry out a stakeholder analysis to identify stakeholders − both in terms of broad interest groups as well as individuals − to allow messages to be tailored to their audience. The audiences for groundwater information can be very diverse − for example, state regulators, land-use planners, indigenous/tribal groups and water users. This may mean using very different ways to communicate depending on background levels of understanding and motivations. Where groundwater users are concerned, messages should clearly translate groundwater conditions or management actions into impacts on individual users. Valuable work has been carried out in Northern Australia to assess tools used to communicate groundwater to predominantly indigenous groups. More research is required on how to communicate, consult and engage with indigenous/tribal groups, including the strategies and tools that have been used, successes, challenges and lessons learned.

In addition to carrying out a stakeholder analysis, it may also be necessary at an early stage to build trust between the community and the agency managing groundwater if there has been a history of poor experience or no history of interaction. Joint work, demonstrating a commitment to appreciating local conditions, and using independent facilitators are three important avenues for building trust. Forming a technical committee that understands community values and receives input into conceptual models (see below) has been an important step to gaining trust in water planning processes run by the Goulburn-Murray Rural Water Corporation in Victoria, Australia. The experience of the Murray-Darling Basin Authority in Eastern Australia shows that where a higher-level (i.e. state or federal) agency interacts with local communities, demonstrating thorough local knowledge can be vital for building trust, as can individualized meetings with local leaders and peak bodies. Undertaking consultation through local water managers can often gain local acceptance relatively easily. Using neutral, independent facilitators has also been extremely effective in moderating challenging discussions during water planning processes both in Australia and the Western U.S. An independent Member of the Northern Territory Parliament took such a role in Howard East (Northern Territory, Australia); professional facilitators have been used in the formulation of multiple Integrated Regional Water

Substantively, important information to communicate includes conceptual models about groundwater systems and observed data and predictions about groundwater conditions − quality and levels − in response to proposed management changes.

Management Plans in California.

A third preliminary activity is developing a consensus about the key issues for discussion.

Visual conceptual models can be particularly effective to show interactions among different elements of a groundwater system − for example, groundwater use by vegetation, directions of groundwater flow and interactions with surface waters. They can be generic or show how behavior changes under different climatic conditions. Observed data about groundwater quality and levels at monitoring wells over time can be communicated using graphs or maps, including via interactive databases. Visualization tools should be used carefully to avoid miscommunicating, for example, giving the impression of a higher degree of certainty about groundwater conditions or predictions than is actually the case.

Approaches to communicating about groundwater vary significantly by agency and by the context − for example, regular updates as distinct from major policy changes. They occur along a wide spectrum in terms of the degrees to which they are interactive and tailored to the audience. Common approaches include providing online or paper data, condition reports, newsletters or brochures. Much of this kind of information is freely available on agency websites and in reports. A more intensive form of communication for the purposes of updating stakeholders on groundwater conditions and policies can involve regular workshops at key milestones both to deliver information and receive input. California regional water boards hold regular stakeholder workshops to discuss hot topics within regional water management and present informational policy briefings, which include the opportunity for public comment. Many of these workshops are also webcast and allow comments to be posted remotely. Even more intensive groundwater management activities and major policy initiatives have involved “kitchen-table,” focus-group and town hall-style meetings in local communities, sometimes for the purpose of generating data for conceptual models or scenario modeling. It is important to identify the right representative of a constituency to make sure that small-scale communication is productive. Forms of communication at the more participatory end of this spectrum have been found to be very effective in engaging stakeholders, but tend to be time- and resource-intensive.

An education and outreach component to communication can improve understanding of groundwater issues and facilitate interaction among stakeholders, experts and water managers. This was the goal of the Colorado Rocky Flats Superfund remediation effort, where several federal, state and local agencies formed a coalition to address major groundwater pollution within a nuclear weapons development and disposal site. A central project component involved scientists educating a range of stakeholder groups and engaging them in cleanup and coalition activities. The collaboration led to regular communication between agencies and stakeholders, accelerated technical studies, an expedited cleanup, and considerable savings in taxpayer money.

In Australia, Dow Chemical has been part of an enduring communication forum, the Altona Complex Neighbourhood Consultative Group, along with other chemicals manufacturers, local residents groups and regulators. The Group was established in 1989 to facilitate open discussions with the community, using newsletters and meetings about environmental performance issues (including groundwater contamination issues) at the largest site of chemical manufacturing industry in the Southern Hemisphere. The Altona Complex also uses direct telephone lines between the Complex and local schools to advise of emergencies, and a 24-hour telephone hotline that residents can use to report environmental nuisances.

More research is needed on how forms of communication affect stakeholder perceptions. In addition, key gaps that affect much current groundwater communication relate to ecological, economic and socio-economic elements of groundwater management.

It seems likely that different methods of communicating water information to the public and stakeholders may affect perceptions of groundwater management problems, desire for action and preferences for the kind of action sought. However, there is limited research about what information to convey, how to convey it effectively, and the strengths and shortcomings of current efforts. An ongoing research project at the Australian National University will survey water license holders in New South Wales, in areas that have experienced groundwater management changes, about their communication preferences − a rare example of "back-end" research on communication about water.

At face value, a key shortcoming of much groundwater communication (using any of the methods set out above) is that it contains little interpretation about the ecological, economic or socio-economic impacts of changes in groundwater management. In addition, there is no established metric or system for valuing groundwater, particularly in ecological settings. Such a metric would provide a clear basis for communicating the importance of groundwater and help decision-makers and the public appreciate the consequences of different groundwater policies. Tools that assist decision-makers to value ecosystem services − like the Natural Capital Project's InVEST software, which has a hydrological component − could form the basis for communicating in an impactful way about the importance of groundwater to people, as well as the ecological ramifications of groundwater management options. It could also gain taxpayer and water user support for re-allocating groundwater to the environment, where this is justified by the economic value of ecosystems and aquifer services, like decontamination.

Simple graphics, conceptual models and scenario modeling can engagingly deliver information to stakeholders. Scenario modeling can also form a basis for discussing the consequences of different management options.

Even simple graphics and maps can be effective in creating interest and understanding among a range of stakeholders. A project of the California Water Foundation and the Kings River Conservation District will pilot real-time groundwater elevation monitoring to help groundwater managers understand the effects of drought and floods, and identify suitable lands for recharge projects. A Kansas study highlights the effects of groundwater pumping in a striking way through maps that show changes in the lengths of perennial streams after the advent of intensive groundwater pumping (see Figure 1) and rapid changes in aquifer levels before and after major groundwater-dependent development occurred (see Figure 2). In Arizona, the U.S. Geological Survey recently presented new maps and interactive graphics created to explain possible effects of groundwater pumping and artificial recharge on the Verde Valley watershed. The report emphasized the need for water managers to obtain more information on the timing of proposed groundwater pumping and recharge effects on surface water and evapotranspiration, and illustrate how mapping efforts could help extrapolate such impacts (see Figure 3).

Graphics can also be used to show more general information about how groundwater systems work. Victoria's Goulburn-Murray Rural Water Corporation uses an interactive visualization with a time slider to demonstrate the impacts of pumping groundwater in different types of aquifers, in different climatic conditions (see http://www.g-mwater.com.au/water-resources/ground-water). A similar effort has also taken place in Queensland, with research also undertaken to evaluate stakeholder responses to the information.[6] Australia's National Water Commission has recently published a graphics-rich booklet ("Groundwater Essentials") designed to simply communicate basic information about groundwater, such as its basic nature, place in the water cycle, important processes, connections with ecosystems and the impacts of extraction (see http://www.nwc.gov.au/publications/topic/groundwater/groundwater-essentials).

Conceptual models of groundwater systems are designed to represent hydrogeological settings and explain the dynamics of various processes and interrelationships that underpin system mechanics. Scientists use models to "predict responses to disturbances to water regimes, identify appropriate predictor and response variables for statistical analysis, and help develop detailed hypotheses that can be tested in monitoring."[7] Once models have been developed, stakeholders may offer insights about the extent to which groundwater models accurately represent local conditions. A useful conceptual model was developed by the European Water Framework Directive (EWFD), using "3-D cutaways" and "vertical cross-section" graphics to illustrate groundwater pressures on hydrogeological systems in Britain and Ireland (see examples in Figure 4). The images emphasize the interconnection and interdependencies among groundwater, surface waters and ecosystems. The website www.wfdvisual.com houses hundreds of groundwater-related images.

Stakeholder discussions can help inform the efficient development of conceptual models. A series of studies was conducted by environmental engineers and communications researchers in Refugio County, Texas, in the context of groundwater management planning.[8] The studies used stakeholder focus groups in which a moderator facilitated discussions about issues facing the basin − for example, a city proposal to export water from the region and its potential impact on county groundwater supplies. Specialists observed the communication dynamics between stakeholders in response to the technical models presented, and analyzed the discussion for the range of values that were sought to be protected and preferences about allocating risk. The studies suggest that evaluating stakeholders' communication processes can help to tailor

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[6] Poh-Ling Tan et al., 'Water Planning in the Condamine Alluvium, Queensland: sharing information and eliciting views in a context of overallocation' (2012) *Journal of Hydrology*, vol. 474, pp. 38-46; Claudia Baldwin et al., 'How scientific knowledge informs community understanding of groundwater' (2012) *Journal of Hydrology*, vol. 474, pp. 74-83.

[7] Moya Tomlinson, *Environmental Water Requirements of Groundwater Systems: A Knowledge and Policy Review* (2010) Canberra, ACT: National Water Commission.

[8] Ric Jensen and Venkatesh Uddameri, 'Using communication research to gather stakeholder preferences to improve groundwater management models: a South Texas case study' (2009) *Journal of Science Communication*, vol. 8, pp. 1-8.

environmental conceptual models to address stakeholder concerns while also increasing the efficiency with which modeling tools are developed.

Scenario modeling provides a way to predict and communicate anticipated costs and tangible impacts of specific groundwater management proposals in a way that is engaging to stakeholders. Where the goal of communicating about groundwater is to change the behavior of water users, a key role of scenario modeling is to demonstrate what would happen to groundwater conditions if status quo management continued.

Uncertainty about the consequences of groundwater management actions poses a particular communication challenge. As well as using graphical representations of uncertainty, scenario modeling can be used to demonstrate how impacts vary with different assumptions. Further research is required on how best to communicate uncertainty.

Examples of scenario modeling are found across the Western U.S. and Australia. The Sonoma Valley groundwater management plan (GWMP) assesses the benefit of different management options (including, crucially, the "no action" option) by modeling them under a range of different water availability scenarios, taking into account projected changes in demand. The results are presented as quantified changes in groundwater storage and levels to 2030 for each scenario. The plan anticipates (but does not quantify) changes in extraction costs, quality degradation, stream flow and environmental conditions. Similarly, the Eastern San Joaquin Basin GWMP describes a process of modeling groundwater elevations and groundwater salinity based on a no action (status quo management) scenario, projected to 2030. The plan then considers a wide range of management options related to groundwater quantity, including options relating to surface supply, groundwater recharge and demand reduction. For each option, it compares the cost per acre-foot of water, infrastructure requirements, land requirements, effectiveness, and operation and maintenance requirements.

Scenario modeling can also be done in a highly participatory way, with stakeholders contributing to the information foundation of an interactive "groundwater visualization tool," and testing their own management scenarios. Facilitated community meetings, discussions with bore drillers, school visits and shopping mall information stalls contributed to both building such a tool and using it to communicate groundwater information about the Howard East Aquifer in the Northern Territory, Australia.[9] The tool was also made available on CD for stakeholders to use at home. Participatory modeling can also be combined with deliberative multi-criteria analysis, where community leaders are trained in how to use the tool and public meetings are used to bring out community values.

An important ingredient in a communication strategy to prompt behavior change is information about the consequences of not changing current management practices. Examples of failure

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[9] Sue Jackson, Poh-Ling Tan, and Sharna Nolan, 'Tools to Enhance Public Participation and Confidence in the Development of the Howard East Aquifier Water Plan, Northern Territory' (2012) *Journal of Hydrology*, vol 474, pp. 22-28.

can also be very useful − that is, circumstances in which groundwater mismanagement, or lack of management, led to undesirable consequences. One example is the town of Happy, Texas, where long-term overdraft of the Ogallala Aquifer has caused groundwater level declines that now render irrigated farming unfeasible, and the town's population is falling rapidly.

Communicating uncertainty to stakeholders and policymakers is a challenge frequently faced by scientists in the management of natural resources. This is particularly so in the case of groundwater, where uncertainty can characterize many aspects of its management (see Chapter 2 on uncertainty and methods of assessing it). To communicate effectively, scientists should communicate uncertainty in a manner that does not overwhelm the recipient or lead them to disregard or misinterpret the information. However, there appears to be no universal, standardized practice for communicating and visualizing uncertainty in groundwater information. The practice of scientific bodies in other contexts can be instructive − the Intergovernmental Panel on Climate Change provides one such example. It suggests that uncertainty should be described using a common language and graphical approaches and that uncertainty assessments should be "up front" and not buried in appendices. A major issue is whether to report uncertainty as "error bars," statistical deviations or ranges (on the one hand) or as probability distributions (on the other hand). It may be more meaningful to an audience to report the results of scenario modeling, where the different scenarios represent outcomes with different probabilities, than it would be to use single-point projections with error bars.

III. EXAMPLES OF GROUNDWATER GRAPHICS

Figure 1: Major perennial streams in Kansas, 1961 versus 1994 (Sophocleous, 2002, adapted from Angelo, 1994).

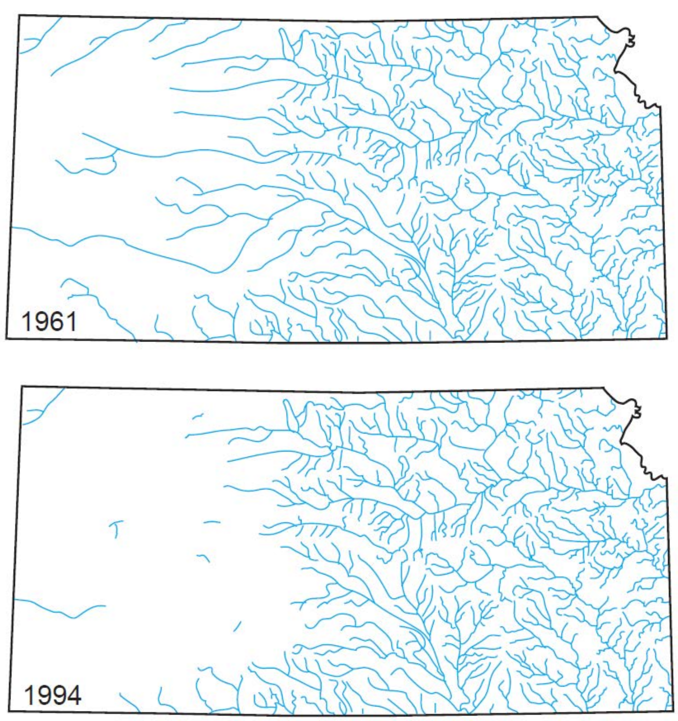


Figure 2: Water level changes in the High Plains aquifer (a) predevelopment to 1980; (b) 1980 to 1995 (Sophocleous, 2002).

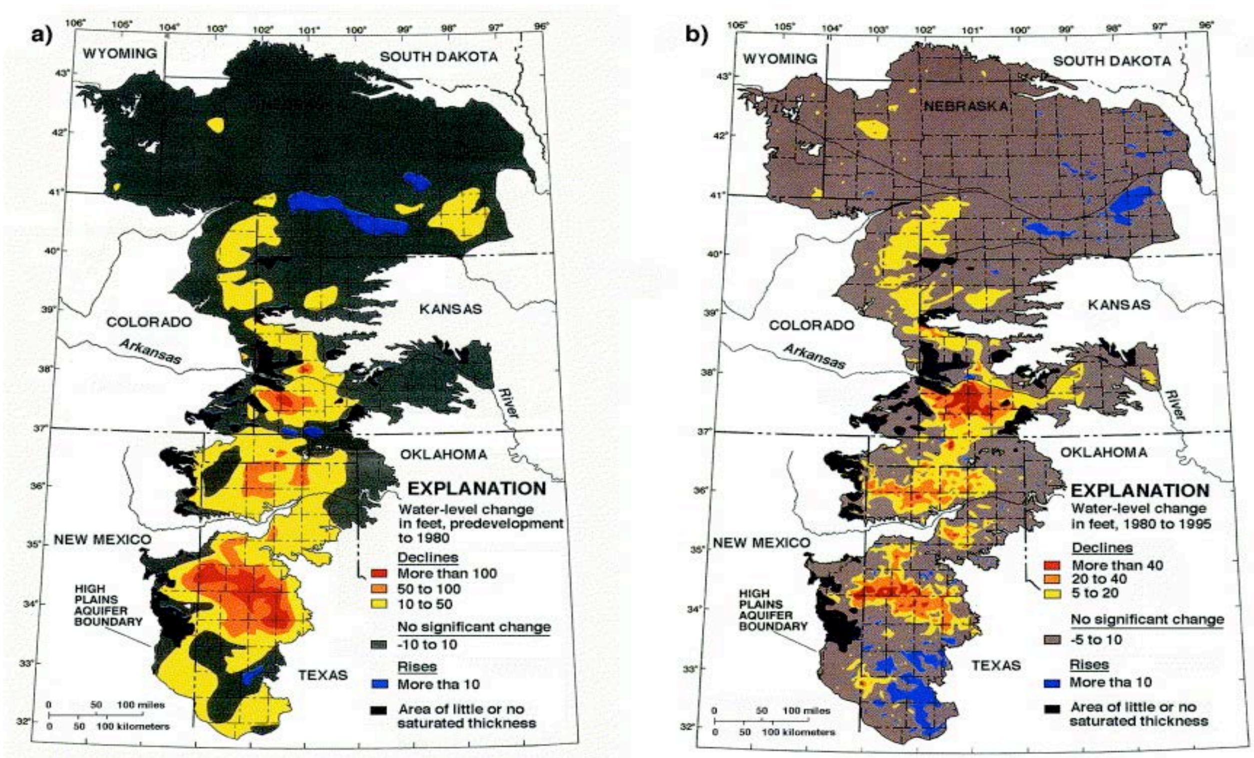


Figure 3: Depletion response to proposed aquifer pumping in Verde Valley watershed after 10 years (left image) and 50 years (right image) (USGS, 2000).

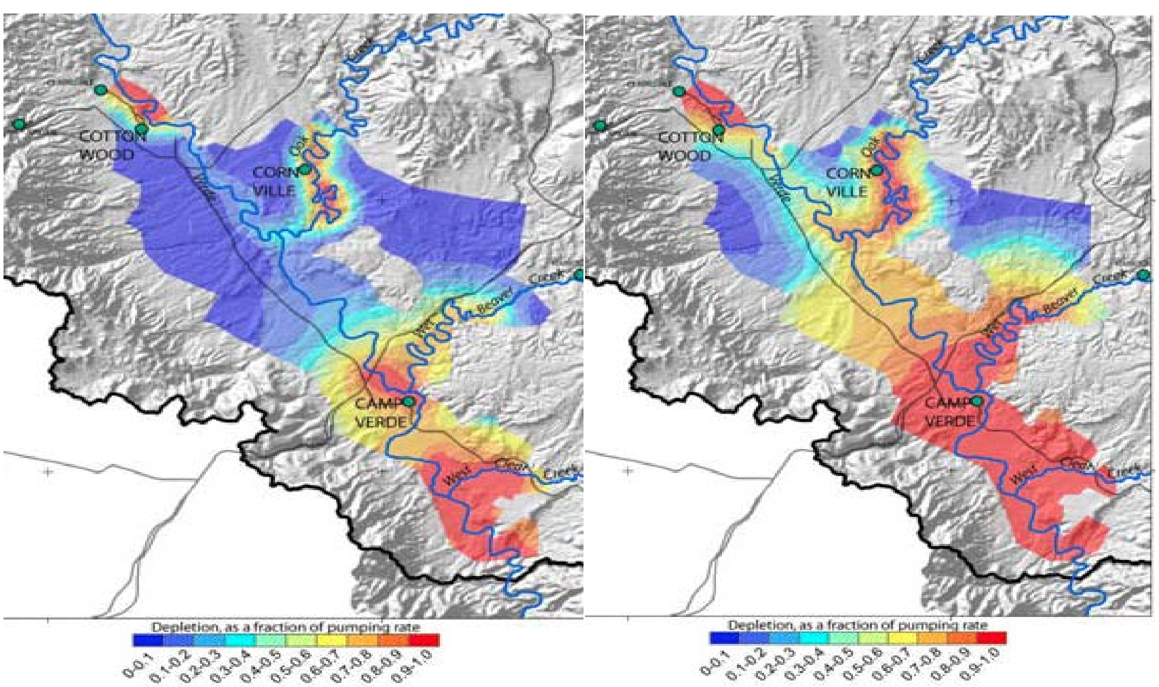


Figure 4: Three-dimensional conceptual models illustrating groundwater-surface water connectivity in rural and urban settings, available from http://www.wfdvisual.com/

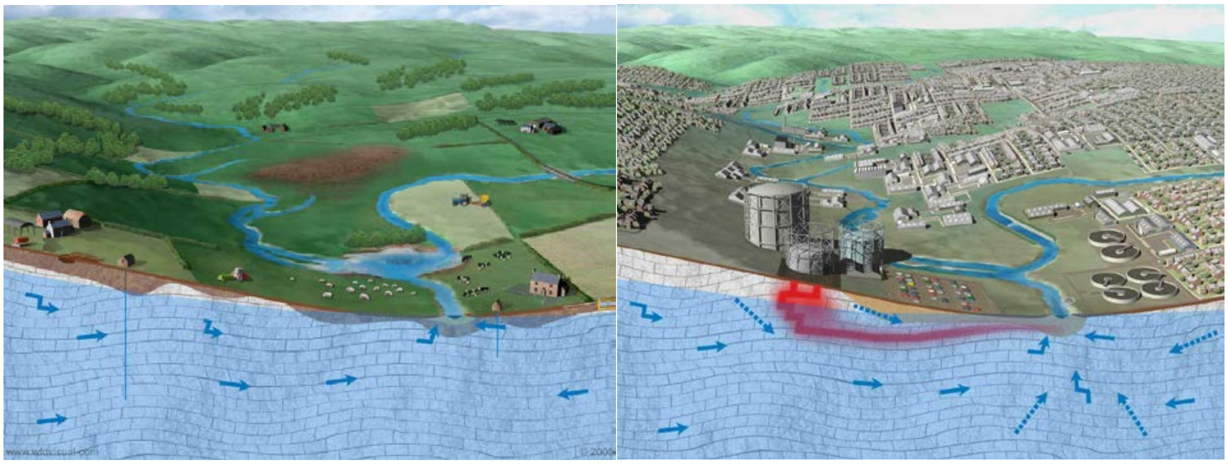
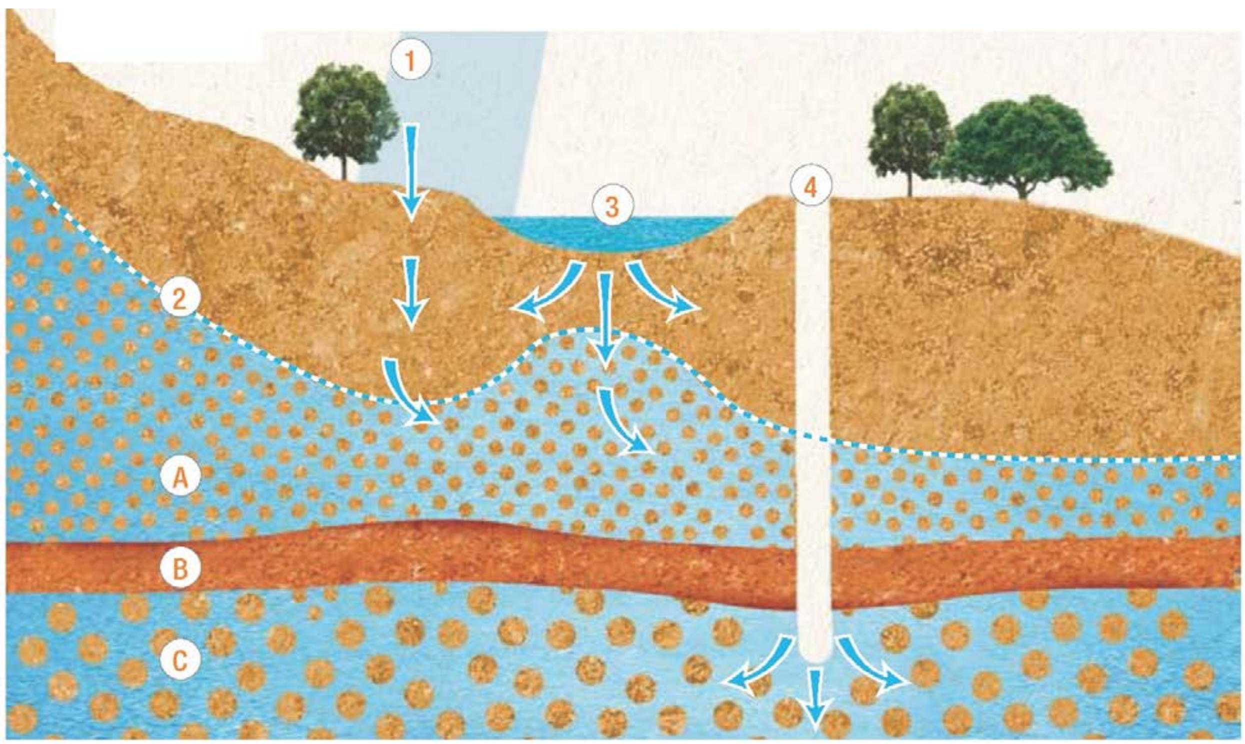


Figure 5: Groundwater recharge figure (1. Precipitation; 2. Water table; 3. Stream/river; 4. Managed aquifer recharge well; A. Unconfined aquifer; B. Impermeable layer; C. Confined aquifer), from National Water Commission, *Groundwater Essentials* (2012).



4. GROUNDWATER AND PARTNERSHIPS, BEYOND CONSULTATION: How the private sector, public-interest NGOs and government agencies can work together to build groundwater management tools and implement policy

Key insights:

1. Groundwater partnerships among governments, businesses and NGOs can be used in a wide variety of contexts, beyond their traditional place in formulating management plans and rules. They can also put together groundwater models, propose and carry out water supply augmentation and water conservation projects, and develop management tools. Partnerships can even be an alternative to regulation to achieve groundwater policy outcomes.
2. Partnerships can be particularly useful where a groundwater management issue is very controversial (for example, coal seam gas in Australia) and there is a need to reach stable, negotiated solutions among groups of stakeholders, and head off potential future conflict.
3. Agencies can derive important benefits from working on relationships and communicating with NGOs. Their lack of regulatory power can make them non-threatening to other stakeholders, and they tend to take a longer-term view of management than political actors.
4. Building trust may be a prerequisite to developing productive partnerships. Multi-stakeholder partnerships take time to develop trust and understanding of each other's needs.
5. There is room to enhance the creative use of partnerships, particularly with NGOs, in Australian groundwater policy and management, rather than relying solely on government-initiated regulatory and management processes.

Discussion

Water policy and management literature has much to say about stakeholder consultation, often in the context of government agencies seeking public input on permitting and licensing decisions, or formulating water management plans. In some cases, stakeholders are the primary parties involved in formulating policy, with government oversight and final approval. Much less discussed is how a variety of types of partnerships that connect one or more agencies, businesses and NGOs can contribute more actively to implementing groundwater policy or undertaking management efforts.

There is evidence of innovative groundwater partnerships in a number of jurisdictions. Such partnerships can offer benefits by:

- Increasing the expertise and human and other resources available for groundwater management.
- Forming coalitions that lend broad-based legitimacy to, and reduce possibly threatening aspects of, potentially controversial policy and management approaches.
- Involving a neutral partner, such as a public-interest NGO, which can broker a "deal" between opposed interests.

- Offering an opportunity for the representation of interests − for example, environmental interests − that may not otherwise appear in law, policy or management solutions.
- Reducing the resources needed to undertake groundwater management in the longer term by heading off future conflict.
- Enabling partners to leverage networks of existing local relationships.
- Increasing political will.
- Extending the time horizon considered in the management context.
- Facilitating innovative pilot projects that solve mutual problems for groups of stakeholders, where these may be difficult for governments to carry out either because they are novel and unproven, or because they require knowledge, resources, and trust between local groups to "get off the ground."
- Ensuring a focus on on-ground, rather than political, outcomes.

In the Western U.S., natural resource management commonly involves varying interest groups that work simultaneously − and sometimes collectively − on related planning, implementing and monitoring efforts. In groundwater quantity and quality management, many states rely heavily on the contributions of partnerships comprising public and private interest groups, individual and associated water users, and all levels of government. Groundwater-related partnerships are also found in several Australian states, though they appear to be much less common in groundwater quantity management than in the Western U.S. However, groundwater quality concerns, particularly salinity, have spurred the creation of a network of local and regional land and water management groups across Australia.

Groundwater partnerships can take the form of formal or informal delegations of government functions to the local level. Experience shows that these partnerships can be very valuable, but they can be time-intensive to develop.

Partnerships in the context of groundwater management arise with a variety of motives. Many states delegate significant responsibility to water stakeholders at the local or regional level to formulate plans or rules, which then sometimes undergo the further step of state approval. These local-state or local-regional partnerships offer a means by which to capitalize on local knowledge of groundwater issues, increase the managerial workforce at the community or watershed level (particularly at the monitoring stage), and provide incentives for stakeholders to support management action by affording them a larger role in the decision-making process.

In Victoria, stakeholder planning groups are comprised of government appointees, more than half of which must be involved in agriculture. In California, local agencies and broad groups of stakeholders assume primary responsibility for producing non-binding groundwater management plans (GWMPs) and integrated regional water management plans, which consider groundwater in the context of surface water, flood management and ecological resources. The state is involved in setting broad standards for the plans, advising agencies and often acting as a project funder.

Partnerships can also be used in relation to delegating technical matters. Developing technical models in partnerships with stakeholders can help head off future conflict and "combat science."

Formulating Idaho's Eastern Snake Plain Comprehensive Aquifer Management Plan involved establishing a technical committee, to which major stakeholders sent representatives to formulate a numerical model (where policy functions were retained by the state government). The committee assisted with the modeling effort, and helped ensure local buy-in to the model results. Useful elements of this exercise included transparent meetings open to the public, rules for the conduct of the committee, and the use of a committee coordinator. The strength of this approach has been demonstrated: In multiple court cases involving groundwater use, the model itself has not been challenged by the litigating parties (see also discussion of combat science or dueling models in Chapter 1).

The Australian Landcare movement is a well-known and celebrated example of partnerships relating to groundwater quality. It involves community groups, business, NGOs and multiple levels of government jointly implementing a broad range of natural resource policies. Community Landcare groups formed during the 1980s to tackle water and land management issues, triggered by broad-based community concern about increasing groundwater salinity in Victoria and Western Australia, caused by irrigation and vegetation clearing. The now-widespread movement of around 4,000 local groups was formally established in 1992 as a joint national initiative of the Australian Conservation Foundation (an environmental NGO) and the National Farmers Federation. Later, regional umbrella groups were established by statute (for example, Catchment Management Authorities in Victoria) to coordinate the activities and strategic direction of multiple local Landcare groups, with state government assuming an advisory role, and with funding contributed by local groups along with local, state and federal governments.

Undeniably, broad stakeholder involvement takes time. Some groundwater management planning efforts that cover large areas report years of consensus-building and negotiation with dozens of stakeholder groups. However, broad stakeholder involvement brings multiple perspectives to help meet multiple objectives, and can help avoid conflicts that have the potential to derail groundwater management efforts. Their involvement also helps to ensure that plans and programs are consistent across agencies. This can aid in avoiding intergovernmental conflict, which can be particularly problematic in the groundwater sphere, when jurisdictional boundaries are blurred and may overlap. Strategic alliances can sometimes work better than trying to form partnerships with large numbers of stakeholders. The key to identifying such alliances is identifying common interests, and preferably a "champion."

Funding opportunities can prompt groundwater partnerships to form around supply augmentation and water conservation projects.

Some regional water management schemes are designed to unify smaller stakeholders as a means to increase the region's funding and bargaining power needed to acquire new water rights and infrastructure. In Colorado, water "authorities" are sophisticated, quasi-governmental groups that advise their member constituents (municipalities, sanitation districts, etc.) as to how they can obtain renewable water resources in a fully appropriated basin. The authorities frequently partner with the state to carry out the necessary negotiations to secure new water rights, build infrastructure, and transport and store water for the benefit of their members.

Many coalitions form in response to funding made available to particular interests. For example, partnerships were formed in Oregon, Idaho, California and Colorado in response to the 2008 Farm Bill, under which the U.S. Department of Agriculture provides several conservation programs that can be used to help farmers and ranchers increase water use efficiency. With an emphasis on water conservation and quality enhancement, one Farm Bill program − the Agricultural Water Enhancement Program − expressly invites “partners or groups” (comprising NGOs, Indian tribes, agricultural associations and/or state or local governments) to submit conservation proposals pertaining to a specified area, like a watershed. In return for five years of federal funding, the partner or group, often an NGO, designs the proposed conservation plan with oversight from the local Department of Agriculture staff; engages with participants; locates funding to help cover the costs required from the producers; and monitors and evaluates the program. Program analysts have found that the good working relationships among federal agencies, NGOs and participating farmers are imperative to achieving program objectives. Chapter 6 on aquifer storage and recovery (ASR) describes landholder-government partnerships to undertake ASR.

Other partnership-based groundwater supply augmentation projects include the Sacramento Valley Conjunctive Water Management Program, a joint initiative of the Natural Heritage Institute and the Glenn Colusa Irrigation District to examine conjunctive management of surface water and groundwater storages to achieve both increased environmental flows in rivers and enhanced water right reliability. A similar conjunctive management project is being explored by The Nature Conservancy in the Cosumnes River area in Northern California.

Groundwater monitoring is another key area in which groundwater partnerships operate − both in developing tools and in carrying out ongoing monitoring activities.

NGO partnerships also contribute to developing groundwater monitoring tools, as well as facilitating regular monitoring activities. A partnership between The Nature Conservancy and the U.S. Forest Service is developing an inventory and monitoring protocol for groundwater-dependent ecosystems on Forest Service lands. As one component of the Forest Service groundwater resource management program, *TNC’s Methods Guide* identifies a variety of data inputs needed to characterize the types and locations of GDEs at a coarse scale across the landscape. These methods are being developed and tested within a grazing management plan revision in Oregon, and are intended to inform a federal groundwater permitting policies protocol on a nationwide scale. In Arizona, volunteer “citizen scientists,” coordinated by The Nature Conservancy and the U.S. Bureau of Land Management, have mapped the spatial extent of surface water flows in a portion of the San Pedro River over more than a decade. The San Pedro is affected by baseflow reductions, which are thought to be due to increased groundwater pumping from wells near the river and changes in riparian vegetation. The data collected shows year-to-year variability in flow length, which indicates changes in local groundwater conditions. In Victoria, groundwater license holders double as “citizen scientists” when they return groundwater sample bottles to the Goulburn-Murray Rural Water Corporation, under a voluntary program in which the Corporation supplies the bottles in order to gather data on groundwater salinity trends. The program helps to maintain and improve customers’ understanding of groundwater management. In the Blue Mountains outside Sydney, the public also has a role in monitoring stygofauna (cave- or aquifer-dwelling organisms).

Most visibly, stakeholders joined by common interests can lobby for new legislation or litigate to drive policy change. In Montana, an alliance between Trout Unlimited and surface-water right holders successfully led to new legislation integrating groundwater and surface water, which requires mitigation of the impacts of groundwater pumping on surface water. The new legislation controls groundwater-intensive suburban expansion in Gallatin County. In Texas, the Environmental Defense Fund and Southwestern Energy worked together to establish groundwater recharge standards for hydraulic fracturing projects in the Ogallala Aquifer.

In the Western U.S., groundwater partnerships have also catalyzed new groundwater policies and new institutional tools and approaches to implementing existing policies, particularly those that relate to environmental protections.

Stakeholder partnerships can also effectively establish and administer new institutional tools to implement existing policy. This has been particularly evident in the development of groundwater mitigation or offset programs in the Western U.S. In Montana, Trout Unlimited is in the process of establishing a private nonprofit corporation, Montana Aquatic Resources Services (MARS), designed to administer a statewide in-lieu fee program that would collect and disburse mitigation fees to preserve, enhance and restore aquatic resources (see Chapter 7 on mitigation programs). Where practical, MARS will use mitigation fees (obtained from a federal Clean Water Act permit process) for projects in partnership with other entities to enhance resource benefits while carrying out mitigation mandates required by law.

The establishment of another mitigation program in Walla Walla, Wash., was driven by stakeholder engagement. Stakeholders sought to localize groundwater management and protect senior water rights in the face of impending federal mandates to deliver water to imperiled fish species. The mitigation program was born from a collaborative process that involved forming a NGO that eventually assumed program administration, oversight by the state water agency and an emphasis on educating basin water users.

The NGO Deschutes River Conservancy has played a critical role in implementing Oregon's Deschutes Groundwater Mitigation Program (a form of water bank) by carrying out conservation activities, such as piping and lining canals, which make water available for mitigation. The state of Washington authorized the private sector to develop and operate groundwater mitigation banks in Yakima County (the Kittitas Water Exchange), though the Department of Ecology oversees market activity.

NGOs also balance and complement agency operations by seeking multiple benefits from state water management efforts. For example, The Nature Conservancy collaborated with water managers from Colorado, Nebraska and Kansas to implement an interstate conservation plan that would protect particular groundwater-dependent ecosystems in the Republican River Basin. The states' central motive was to fulfill surface water deliveries required by their interstate water compact by buying and retiring connected groundwater rights. The Nature Conservancy's primary objective was to ensure the plan augmented the flow of the Arikaree River, a tributary of less economic value to the delivery effort (because it was only connected to the main stream in the winter), but of higher value to groundwater-dependent species.

A different and more controversial partnership between The Nature Conservancy and the U.S.

Forest Service involves an effort to restore river flow using a version of a practice known as "buy and dry." In Southern Arizona, The Nature Conservancy has been pursuing an effective strategy of buying agricultural lands along the San Pedro River, placing conservation easements on the properties, then re-selling the land with drastically restricted groundwater pumping rights. The collaborative effort has received mixed reactions from those who resist permanent retirement of agricultural land and others interested in protecting streamflow (see also Chapter 8 on water buy-backs).

There is scope to make more widespread use of groundwater partnerships in Australia, and to involve businesses in such partnerships more generally.

Groundwater partnerships are much more common in some jurisdictions than others. Broadly, they are much more likely to be found in the Western U.S. than in Australia. In particular, businesses have rarely contributed to general water planning tools, although this may be changing. Few examples exist of monitoring and models developed by a business also being used by government, with an exception being BHP Billiton's work on central Australian mound springs as part of its compliance activities. Broad public concern about the groundwater impacts of extracting coal seam gas (coal bed methane) is prompting joint involvement by governments, natural resources managers and companies to produce "bioregional assessments" to scientifically analyze the ecology, hydrology and geology of areas that may experience risks from coal seam gas development.

One reason for the relative paucity of groundwater partnerships in Australia could be due to concerns about their suitability in specific situations. For example, in some cases, concerns about the quality of data collected through non-scientist groups have discouraged some NGOs from undertaking monitoring activities. Another explanatory factor may be the more top-down approach that characterizes water management in Australia. This may "crowd out" collaborative approaches between government and local groups in implementing policy, or discourage entirely grass-roots solutions that do not involve government. In this context, it is important to note that while the state and federal governments tend to take no or only a minor role in groundwater partnerships in some Western U.S. states, this is not always the case. In Idaho, for example, the state government plays a key role in bringing partners together. It could also be argued that the project-oriented emphasis of groundwater management solutions in the Western U.S. lends itself more to partnership approaches than the more regulation-based approach used in Australia, but again, the examples set out above disclose the use of partnerships in a range of policy and regulation formulation and implementation functions. A further alternative explanation could be that Australian NGOs − or at least NGOs that have taken an active interest in groundwater − generally have fewer resources to participate in groundwater partnerships.

This chapter demonstrates the use of partnerships in administering or otherwise implementing key elements of a state's groundwater regulatory policy (as in mitigation schemes) or technical work on groundwater. Though they are not a focus of this workshop, partnerships in groundwater management could also be used as the core of the regulatory process, as an alternative to traditional government-based regulation, for example, through self-regulation, co-regulation and community-based management.

5. GROUNDWATER MARKETS AND TRADE: Why and how to facilitate trade and control third-party impacts

Key insights:

1. Water markets accentuate underlying weaknesses and flaws in a water allocation system, like poor monitoring and compliance and enforcement − particular challenges in the groundwater context, where the resource is hidden. Uncertainty about the precise nature and scope of groundwater rights can also hinder markets, particularly in the Western U.S. Correcting all of these flaws is a crucial pre-condition to effective markets.
2. Groundwater markets can mitigate the economic impacts of restricting groundwater use, since those affected can purchase more water.
3. The transaction costs of groundwater trading can be reduced by clarifying trading rules and requirements for showing that no harm would be caused by a transfer of water. Temporary transfers could be treated more permissively than permanent transfers. Reducing transaction costs could be achieved by using predetermined trading zones, in which trading can occur with minimal evidentiary requirements. Transaction costs may also be reduced by institutional arrangements that help identify transfers that would have clearly unacceptable impacts on the environment or third parties.
4. Certifying wells that have been actively used can avoid the potential for the transfer of unused rights ("paper water" or "sleeper licenses"), which would activate those rights and increase total extraction. On the other hand, sleeper licenses may not be problematic in areas that are not under pressure.
5. Unregulated groundwater trading can pose environmental threats. But it can also be used to benefit the environment directly, through strategic purchases for environmental purposes, or indirectly, by decreasing pressure to make "new water" available in stressed water resources areas, and by allowing trade to move extraction only out of (rather than into) over-allocated areas.

Discussion

Groundwater markets can provide important benefits by facilitating water re-allocation in heavily used systems, but their development lags behind surface water markets.

In parts of Australia and the Western U.S., water managers have established market-based institutions to facilitate the trading of groundwater rights or entitlements[10] as a way to distribute water − without transferring land − in heavily allocated systems. Water markets (or "trading regimes") can be particularly effective management tools in water-scarce regions because they increase the flexibility inherent in a water right/entitlement and enable water users to more quickly respond to changes in climate and commodity prices. Additionally, water markets

[10] This paper discusses the trading of water entitlements or rights as they are defined in legally recognized instruments like licenses or permits, rather than the trading of water that is extracted under a license or permit and sold by the extractor to someone else.

can encourage efficiency in the use of water, and promote the transfer of water to uses with higher economic value as between competing interests. During periods of water shortage, they enable those who are best able to deal with reductions in water availability to sell water to those less able to do so. Water markets can also reduce the total economic impact of legally mandated reductions in water use by enabling people who find it more difficult to reduce their use to acquire water from those who find it easier to cut back. While markets are well established in many surface water systems throughout the Western U.S. and Australia, groundwater trade regimes have emerged at a slower pace and in fewer regions.

However, water markets accentuate underlying weaknesses and flaws in a water allocation system, like poor monitoring, compliance and enforcement. Good monitoring and enforcement is required to ensure that those who sell water pump correspondingly less, to avoid the potential for a market to increase overall use. Monitoring and enforcement are often particularly challenging in the groundwater context, where the resource is hidden, metering is often uncommon or at least not universal, and monitoring funds are often scarce. In the Western U.S., the nature of groundwater rights can also be uncertain, for example, before the rights have been adjudicated by a court or other process. Correcting all of these flaws is a crucial pre-condition to creating effective markets.

In Australia, groundwater trade can occur in relation to both water entitlements (buying/selling shares to water), known as "permanent trade," and water allocations (buying/selling water allocated to an entitlement), known as "temporary trade." All jurisdictions in Australia have legislation that permits groundwater trading; however, market activity is minimal or nonexistent in the Australian Capital Territory, Tasmania, the Northern Territory and Western Australia. Groundwater trading in Queensland consists almost entirely of temporary trades. In New South Wales, Victoria and South Australia, there are developing markets in temporary and permanent groundwater. A majority of Australia's groundwater trade has occurred in regions of New South Wales with large alluvial aquifers, large license numbers and high levels of water scarcity. The steep rise in surface-water trade in recent years may suggest a similar fate for groundwater trade, particularly in drought years. (Surface water entitlement volume trade increased by 75 percent between 2007-08 and 2008-09, then by a further 20 percent between 2008-09 and 2009-10; and seasonal allocation volume trade increased by 41 percent and 22 percent in those years, respectively.)

Looking across Australia and the Western U.S., groundwater trade is concentrated in particular states and sub-state areas.

Several states in the Western U.S. also have some form of active groundwater trade. Market frameworks vary widely and are initially informed by the state groundwater regime (whether states prioritize security for groundwater rights acquired *first in time* under prior appropriation; correlate groundwater rights with overlying property ownership; allow unlimited pumping of *reasonably used* groundwater; etc.).

Where states have not assumed authority over groundwater trade in a general sense, as in California, markets are commonly operated and further regulated at the county level or among water users in a local district. This is true of water districts in Southern California, in areas where rights have been adjudicated (finalized). In other areas, legal uncertainty about unadjudicated groundwater rights discourages trade. In Arizona, groundwater trade primarily occurs within regulatory management jurisdictions called Active Management Areas (AMAs) that encompass only 13 percent of the state land area, but comprise about 85 percent of Arizona's total water use. On lands outside of AMAs, groundwater pumping is minimally restricted (subject only to the reasonable use doctrine), but can only be traded if bought or sold in conjunction with the overlying property.

Many other groundwater markets in the Western U.S. are specifically implemented to serve as administration mechanisms for mitigation water that is used to offset new groundwater pumping in fully allocated basins (see Chapter 7 on groundwater mitigation). For example, Oregon's Deschutes Water Bank Alliance is a cooperative water bank among the Deschutes River Conservancy, irrigation districts and municipal water suppliers. The bank facilitates new groundwater pumping (mostly for municipal supply and development) by retiring corresponding surface water rights, with additional agreements to designate water to benefit environmental flows and endangered species.

A prerequisite for active groundwater markets is having readily tradeable rights or entitlements; this may require legal reforms.

Since the transferability of groundwater is a product of the legal structure of the instrument traded, some jurisdictions have created or reformed water license properties to support increased groundwater trade (among other policy objectives). For example, the primary type of groundwater traded in Arizona is a "Groundwater Extinguishment Credit," which is created by retiring one of the three other types of groundwater rights, and can only be traded within designated trade zones. These groundwater credits are marketable assets for landowners because the credits enable groundwater pumping for "assured water supply" (a demonstration of water availability often required to support new development), and can also be used for water stored within aquifer recharge projects. In addition to simple trades of groundwater rights or credits, more sophisticated forms of water trading are also appearing. "Dry year options," for example, enable buyers to pay in advance for access to water in dry years.

In Australia, many states are contemplating whether or not to "unbundle" their water license system, so that the right to access groundwater (a "water entitlement") is separated from the right to use the resource, and is defined in terms of some portion of the entitlement that is made available in a given year (a "water allocation"). The decision in New South Wales to move to an unbundled water license system significantly contributes to the fact that it has the highest trade activity in the country (along with the nature of irrigation businesses, which have varying seasonal demands).

States can facilitate groundwater trade, and reduce costs for traders, by introducing institutional mechanisms to help buyers and sellers find each other. Such mechanisms should be targeted − they are unlikely to be worthwhile everywhere.

Some Western U.S. states, like California, Oregon and Nevada, use groundwater banks (where the bank buys, holds and sells water) to facilitate groundwater transfers and administer underground storage. In Arizona, the state acts a clearinghouse between agricultural water sellers and municipal water buyers. In the Western U.S., the majority of groundwater market transactions that occur outside of a water bank are bilateral trades between a single seller and single buyer. Buyers and sellers can incur significant expenses in identifying trading partners, and limited information is typically available to assist in negotiating a transaction price. Market participants that have invested resources in obtaining market information often have a strategic advantage in price negotiations. As a result, large price differences within a market are often attributable to differing levels of price information between trading partners. In some cases, private water brokers may arise to facilitate information transfer about market conditions, either in addition to state-sponsored information systems (as in northern Victoria) or instead of such systems.

Establishing special institutional structures to facilitate groundwater trading will not be worthwhile everywhere. In areas where the demand for trade is likely to be limited, such as where existing rights or entitlements are underutilized, the administrative costs of reforming entitlement systems to enhance tradeability, and putting in place associated trading rules and administrative systems for processing and registering trades, may be less justified.

Other situations in which groundwater trading is unlikely to mature, even with institutional structures to facilitate it, are where aquifers are small and discontinuous, so that the potential pool of buyers and sellers is very small (assuming that trading is only permitted between connected water sources − see further below); and where a significant proportion of groundwater licenses are not intended to be tradeable because they were issued on the basis of location-specific environmental benefits − for example, reducing excessively high groundwater levels and associated soil salinity.

A key issue for developing efficient groundwater markets is dealing with potential adverse impacts on third parties and the environment. Geographical restrictions on trade are a common approach. Avoiding "thin" markets is a competing consideration, leading to potential tension between maintaining a market and principles of sustainable resource management.

A key concern of legal systems across the Western U.S. and Australia is reducing or eliminating third-party − including environmental − impacts of groundwater trades. This can be done either by a government agency closely scrutinizing each proposal, or by pre-determining zones within which trading may occur without causing unacceptable impacts. Individualized assessments can be administratively burdensome, which has encouraged the latter approach to develop, particularly in Australia, to reduce the cost of transfers. Both approaches occur in the Western U.S. and Australia, to some extent.

Identifying acceptable boundaries within which groundwater trading may occur is complicated by the fact that multiple jurisdictions may govern parts of the same aquifer. Australia's National Water Initiative advocates that boundaries be drawn as large as possible, based on evidence of hydrologic connectivity. Institutional factors, such as transactional efficiencies, may also be taken into consideration. Overly small trading zones, or environmentally based restrictions on trade, may mean that a market is too "thin" to support active trading. This creates a key tension between the conditions desirable for a market to operate, and the rules desirable to minimize its impacts on third parties and the environment. It may be useful to consider how markets in other resources, such as energy, deal with similar tensions, and other ways of setting parameters within which a market can operate while minimizing these impacts.

Hydrologic connectivity is a particularly important factor in defining trading zones in jurisdictions that allow "source switching," in which a surface water user is allowed to switch to groundwater pumping, or vice versa. The same applies in systems that allow one user to sell groundwater to a user who will extract the entitlement in the form of surface water (or vice versa). Where there is insufficient information describing aquifer recharge, or there is a long lag time between extracting groundwater and in-stream impacts occurring, source switching without close monitoring may result in unanticipated source depletion and negative impacts to third parties. New South Wales has delineated some ephemeral rivers that are associated with shallow alluvial aquifers, treating both water source users in these areas in the same way, which simplifies trading. Water plans for these systems contain rules that control water extraction on a daily rather than an annual basis. To protect the environment and third parties, surface and groundwater users' access rights are tied to a river gauge height or water table level; pumping is permitted when this level is equaled or exceeded.

In the Western U.S., some rural areas discourage or prohibit trades that export groundwater from a basin for fear of reducing return flow and causing detriment to local water-dependent economies. Moreover, government tax revenues may shrink if farmers leave land fallow or nonprofit entities purchase water rights or secure long-term water leases (see Chapter 8 on buybacks). As a result, some county ordinances in California require those wishing to export groundwater to go through an environmental review process to obtain a transfer permit. "The very low number of permit applications suggests, however, that this process is more useful as a deterrent than as a screening mechanism. High up-front costs and the likelihood of negative public opinion guiding the decision process are both factors discouraging parties from filing."[11] On the other hand, restricting market activity by zone or basin boundaries can constrain the economic potential of the water right (though arguably this just reflects the true value of rights that would not have been permitted to be traded after an alternative, more costly assessment process). It can also constrain potential trade within aquifer storage programs (see Chapter 6 on aquifer storage and recovery).

Even where entitlements are traded within basin boundaries, the issue of third-party impacts arises. Because groundwater resources are collective in nature, increased groundwater extraction at one location (resulting from a trade) can increase drawdown beyond that location, potentially reducing the security of supply to groundwater-dependent ecosystems and groundwater users outside the transaction.

To reduce potential adverse effects on third parties, some Western U.S. states and local agencies attach strict mitigation and monitoring requirements to groundwater transactions. Most Western U.S. states also prohibit water trades that would cause environmental harm (although, arguably, insufficient information and awareness about groundwater-dependent ecosystems exists to ensure that this is meaningful in the groundwater context). Glenn County, Calif., has articulated rules for determining whether pumping activity associated with a transfer should be curtailed. It employs a multi-party monitoring framework for transfers, and requires that third parties be at least as well as off as they would be without the transfer (a common "no harm" principle). Oregon employs special enforcement-monitoring agents called water masters;

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[11] Ellen Hanak, *Who Should Be Allowed to Sell Water in California? Third-Party Issues and the Water Market* (2003) San Francisco, California: Public Policy Institute of California.

however, water master districts typically cover too large an area to maintain comprehensive monitoring records. Transfers that are either controlled by a single water right holder or have clear ecological benefits often require less monitoring to ensure compliance; more complex transfers linked to biological outcomes are sometimes monitored by the Oregon Water Trust.

In Australia, some jurisdictions use trading zones explicitly to prevent environmental harm. In Western Australia, the Gnangara Mound groundwater system is classified into 51 separate trading zones, among which no trade is allowed. While one effect of this is to reduce the number of potential participants due to small market sizes, it prevents inward trades from causing additional damage to sensitive groundwater-dependent ecosystems such as wetlands and caves in areas in which outward trade is not permitted. In northern Victoria, intensity rules seek to avoid pumping "hotspots" by prohibiting trades into areas that are already highly developed. In addition, where trades are proposed to move water outside a specified radius of the existing pumping location, which is set out in local management rules, more extensive information is required to clarify the impacts of the move.

In both Australia and the Western U.S., water trading has become an increasingly popular avenue through which water rights and entitlements change hands to benefit the environment. A major difference in the two countries' approaches involves the role of water trusts and conservation organizations. In the U.S., groups such as the Freshwater Trust and the Arizona Land and Water Trust are well established and acquire water for environmental benefit. More than US$100 million has now been invested through such water trusts. There is no clear example of a water trust acquiring groundwater for environmental purposes, though such transactions could hold promise.

Though they are often considered to pose a potential threat to the environment, water markets can be used to achieve environmental benefits. This is rarer in the groundwater, as opposed to surface water, context, but there is potential for this to occur.

Some Western U.S. NGOs include a water trust component, like Trout Unlimited in Montana. Such groups can combine participation in water markets with complementary activities aimed at improving sustainability, like involvement in federal and state water law reforms based on lessons learned from their water market experiences. This has allowed new laws to provide new water supply through water trading as opposed to simply reducing or eliminating new water uses.

A key ongoing challenge is ensuring that water purchased for the environment is available at environmentally valuable times and places. An environmentally optimal time to use water may not coincide with irrigation seasons − irrigation being the former purpose of many water rights purchased for environmental reasons. However, this former purpose may constrain the times at which water may be taken for a new environmental purpose. In general, more geographically strategic and prioritized, rather than opportunistic, acquisitions of water rights would be desirable to maximize environmental benefits. These lessons should also be kept in mind in the groundwater context.

In Australia, governments have driven environmental water purchasing, and there is relatively little philanthropy for that purpose. Large volumes of entitlement water have been traded to the Commonwealth Environmental Water Holder and other government environmental water managers for ecosystem and water supply restoration (though this has not yet occurred with groundwater entitlements). While environmental water transactions have continued to diversify in strategy and ecological contexts, they are limited in extent. Moreover, water traded into some regions has produced significant water quality and other environmental concerns, like increased salinity and changes in the spatial distribution of groundwater discharge and recharge. Water trusts are in their infancy, with existing trusts, like the New South Wales-based Environmental Water Trust, established to mirror successful land conservation trusts.

In California, aquatic species loss has driven increased environmental water demand requirements (setting and sustaining minimum flows in streams), which has resulted in increased groundwater pumping to meet local demands, with less surface water available for consumptive purposes. The Environmental Water Account was established in 2000 to provide water for the protection and recovery of at-risk fish species beyond water available through existing regulatory actions related to operations of the State Water Project and Central Valley Project. Established primarily to provide protection to at-risk species in the Bay Delta estuary, the approach involves pumping curtailments in the Delta, and acquiring water (transfers and operational improvements) for fish habitat actions.

There is some evidence that groundwater markets have resulted in indirect environmental benefits.

Aside from the potential to directly purchase groundwater for environmental purposes − for example, to safeguard aquifer-connected rivers or groundwater-dependent ecosystems − there are several more indirect methods of using water trade to benefit the environment. First, in the Western U.S., water user associations, such as irrigation districts, participate in large-scale trade programs that aim to replenish water supplies (*see* Chapter 8 on buybacks), which can have indirect environmental benefits. A second indirect method is exacting a percentage of the volume of each water trade and reserving that volume for the environment. Oregon uses such a system. Similarly, some Nebraska natural resources districts apply a 10 percent "discount" to the number of irrigable acres associated with a groundwater right when it is traded, to reduce effects on connected streams. Some criticize this approach for concentrating the costs of recovering water for the environment on those undertaking water trades, rather than on all water users. Third, water trading − in the form of buying and retiring water rights − can help new water users offset the environmental impacts of their use (see Chapter 7 on mitigation programs). Fourth, one-way trading zones can be used to redistribute groundwater use spatially, away from environmentally sensitive areas. This approach has been used in the surface water context to deal with increasing groundwater salinity in Victoria and Tasmania. Finally, and less concretely, the presence of water markets may make it more politically feasible to cap extraction in stressed water systems by enabling new groundwater-dependent economic development, relative to a cap alone.

Surface-water markets can interact with groundwater, and vice versa. This can pose both threats and opportunities for both sources.

Surface-water trading can be used to achieve benefits to groundwater systems by establishing one-way trading zones that allow water to be traded out of areas in which excessive application of irrigation water contributes to rising groundwater salinity. Conversely, unintended groundwater impacts can also appear as a result of surface-water trading systems. California experienced large volumes of surface-water trading in the 1990s, accompanied by corresponding increases in groundwater pumping, where groundwater pumping was not regulated. Some pumpers sourced groundwater from aquifers connected to surface waters, highlighting the failure of California water law to recognize connections between groundwater and surface water. In response to these “substitution transfers,” more than 20 California counties now restrict this type of surface-water trade. Conversely, Nebraska natural resources districts use the concept of a “stream depletion factor” to ensure that a groundwater transfer that would increase stream depletion results in a corresponding decrease in the area that can be irrigated with a groundwater right.

Groundwater markets can accentuate existing flaws in water allocation systems, particularly those related to enforcement and unused water rights or licenses. Before introducing markets, it is important to ensure that the background water rights system is robust.

Trading systems can accentuate flaws in a water allocation system, which can lead water markets and trades to have unintended impacts. Incomplete metering programs or poor enforcement of groundwater rights or licenses can allow their holders to trade their rights while unlawfully continuing to pump, thereby increasing overall water use. Nebraska addresses gaps in its metering system by undertaking aerial surveys to monitor irrigated acres. Some agencies, such as Goulburn-Murray Water in Victoria, have compliance units that read meters regularly and have prosecuted entitlement holders for unlawful water use.

“Sleeper” licenses or permits (also called “paper water”) can pose a further problem: Introducing a market can act as an incentive for water right holders to activate previously unused rights, which can cause unanticipated increases in stress on the resource or dependent ecosystems. Nebraska deals with this problem by using a certification process under which a right holder must establish that they have recently used their right, and must link “certified acres” to a particular well. Other Western U.S. states consider rights to be abandoned in such a situation, and therefore require evidence of a history of using the right before trading will be allowed. Some states, like Kansas, minimize the “paper water” problem by using a “perfection period” after a permit is initially granted: After a certain number of years, they issue a certificate of appropriation only for the maximum annual quantity of water pumped within that perfection period.

Finally, before embarking on an aggressive program to refine legal systems to facilitate markets, it should be remembered that markets are one useful tool in the toolbox of groundwater management, and should not be considered to the exclusion of other legal and policy approaches.

6. AQUIFER STORAGE AND RECOVERY: Uses, broader benefits, incentives, novel legal issues and approaches to addressing them

Key insights:

1. Aquifer storage and recovery (ASR) can occur directly, by injecting surface water or deliberately allowing water to percolate into an aquifer. "In lieu" groundwater banking can offer an attractive indirect alternative to physical ASR projects, by deliberately using surplus surface water supplies in situations in which groundwater would usually be used, and accounting for this difference. Both approaches can deliver low-cost water storage.
2. ASR projects can be the basis for linking urban growth and water supply, by requiring subdivision developments to demonstrate access to recharged water.
3. ASR projects can benefit the environment (for example, by providing variability in surface water flows), augment water supplies, and reverse historically lowered water table levels. Policymakers and project proponents should consider the potential to achieve multiple (including indirect) benefits.
4. When aiming to achieve environmental goals, ASR proponents need to consider trade-offs between the benefits of natural flood flows and more controlled management of water for environmental purposes through ASR.
5. Legal and policy institutions (or their absence) can be a key barrier to ASR projects. Addressing these issues is important in many jurisdictions in both the Western U.S. and Australia. For example, in some states, regulatory jurisdiction over ASR is unresolved, as are important questions of liability, and ownership of “artificially” recharged water.

Discussion

Aquifer storage and recovery (ASR)[12] refers to the process of storing surplus surface water within groundwater basins, then later recovering that water for use during times of water scarcity. Aquifers with available storage capacity are most commonly “recharged” either by injection or infiltration. The infiltration approach involves spreading water on a land surface or streambed and allowing it to percolate down into the aquifer below. It is a relatively low-cost recharge method, but requires sufficient land area with porous surface characteristics. Injection wells require greater investment, but allow for “storage of large quantities of water in deep, confined aquifers in areas where there is insufficient room for infiltration ponds or conditions are not favorable for recharge and storage of large volumes of water in shallow, unconfined aquifers.”[13] After recovery, the water may be used for potable, environmental, industrial, agricultural, emergency supply and a variety of other uses.

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[12] The term is here used loosely, and synonymously with managed aquifer recharge (MAR), a term which is more common in Australia. The terms have different technical meanings in the U.S. “Managed underground storage” and “artificial recharge” are other U.S. terms used to cover these types of projects.

[13] Walter Burt and Jeff Barry, ‘Advantages, Challenges, Applications & Approaches for Expanding ASR in the West’, (2011) *The Water Report* 91.

A related, more indirect conjunctive management strategy is “in lieu” storage. This refers to a strategy of using additional surface water “in lieu” of groundwater, thereby storing the equivalent volume of groundwater in an aquifer without developing any additional storage infrastructure, and without the need for extensive legal arrangements (see discussion of legal issues below).

ASR projects are often motivated by water supply augmentation goals. They can be used as storage alternatives to surface water reservoirs, or in combination with them, to permit dam reoperation; and as part of water supply schemes using recycled water or stormwater.

ASR is used in several key contexts. In many cases, ASR is a substitute for surface storage. Related to this, ASR is proposed as a mechanism for permitting reoperation of major dams in order to allow greater environmental flows and increased water supply. ASR is also sometimes used to allow groundwater pumping to continue while protecting against saltwater intrusion or other problems of chronic groundwater level declines. Finally, ASR can be used as a means of putting recycled water, stormwater or floodwater into use for domestic and other purposes − practices which have been used for decades in some parts of California and in other areas, but which are still generally regarded as emerging practices elsewhere.

In particular, escalating economic costs, environmental costs and environmental permitting requirements associated with surface reservoirs, as well as declining availability of land and suitable sites, have driven water managers to explore ASR. Compared with building new surface reservoirs, ASR is relatively less expensive and can involve fewer environmental impacts: Aquifers provide natural storage space rather than requiring construction of expensive storage facilities; while water is stored within a basin, the basin serves as a natural distribution system and thereby obviates some of the need to construct additional conveyance facilities (depending on the location from which the source surface water is transferred); water stored underground is not lost to evaporation as it is from surface reservoirs; and groundwater serves as an emergency supply in the event of disruptions to surface water systems.

Aquifer storage technology has been active in the U.S. for more than 80 years, and many states have extensive experience in developing ASR projects and associated policies. ASR was initially developed to augment municipal water supply, often by bolstering the storage capacity of surface reservoirs and using a larger percentage of annual runoff. More recently, ASR has expanded to provide water for agriculture, industry and environmental water supplies, and to attempt to restore water supplies in overdrafted aquifers. Regions in Washington state use ASR water to combat forest fires. South Carolina reserves ASR water to ensure supplies in case of hurricanes. Iowa stores supplies for the event that floods reduce the quality of surface water supplies and render them unsuitable for use. Colorado uses ASR to augment streamflow and support migratory fowl species. Arizona uses ASR as a means to make use of its entire Colorado River allocation supply, much of which is transported through the Central Arizona Project and released into recharge basins near central Arizona’s urban centers.

In Australia, the practice of ASR tends to be more narrowly focused, and comparatively underutilized, for a range of technical and legal reasons. The focus of Australian ASR investigations and projects tends to be on urban water supply using stormwater or recycled water, rather than storing surface flows (e.g. flood flows) for a wider range of uses, as in the

U.S. At present, ASR projects have a significant presence only in South Australia. Australian water agencies hold concerns about the impact of recharged water on native groundwater resources, and the quality of stored water after it is recovered. Some also fear that ASR could amount to privatizing water resources. The economic feasibility of ASR projects may be more limited under Australian geological conditions than is the case in the U.S., although efforts to protect potential recharge land through land use planning were undertaken in many urban areas in the 1980s. The historically higher political acceptance of regulatory water use limits in Australia, relative to the Western U.S., may have resulted in a lesser motivation to explore ASR as a supply augmentation measure. In addition, a host of regulatory challenges arise, including those pertaining to water right and entitlement trade within the context of ASR, the ownership of aquifers, and groundwater "poaching" (see further below). These issues are likely to be dealt with quite differently in Australia than in the U.S., with greater state involvement and incorporation into water planning mechanisms, given the general lack of support in Australia for local, privately financed water projects.

Aquifer storage presents significant opportunities in Australia to increase access to groundwater where appropriate and increase overall water reliability. There is clearly an appetite for ASR projects in Australia, as demonstrated by the significant number of schemes that are proposed and investigated (but fail to proceed due to the challenges outlined above), and the commissioning of a number of technical and policy guideline documents by the National Water Commission. Many Australian states have begun developing ASR law and policies using a risk-based approach, with guidance from the national level. Notably, in late 2012, New South Wales issued an Aquifer Interference Policy that will cover ASR projects. Substantial opportunities exist to further develop state law and policy frameworks for ASR to reduce the disincentive to developing ASR projects posed by regulatory uncertainty. Other policy settings can also act as disincentives to developing ASR, including failing to put a price on evaporative losses from surface storage (which ASR projects avoid), and encouragement of on-farm water harvesting and surface storage. State laws could build on existing national guidelines, and potentially explore the use of ASR in conjunction with other types of new groundwater policy tools, like mitigation schemes (*see* Chapter 7) to safely allow increased groundwater pumping in basins where the available groundwater supply is fully allocated. States could either attempt to fit ASR-related rights into existing legal frameworks, minimizing the need for legal change (the approach pursued by Victoria), or create special-purpose licenses.

ASR projects can also be used to provide environmental benefits, as either the major or an additional goal.

Many states in the Western U.S. use aquifer storage to provide water for various environmental benefits. In addition to providing a mechanism to protect groundwater resources from overdraft and water for groundwater banking, ASR is commonly used to boost supply needed for connected surface systems and groundwater- and/or surface-water-dependent species. For example, The Farmington Program is a large-scale groundwater recharge project in eastern San Joaquin County, Calif., which is jointly administered by the U.S. Army Corps of Engineers and the local water district. An objective of the program is to provide seasonal or permanent habitat for migratory birds by seasonally rotating field flooding to create temporary recharge basins (a "percolating-type" ASR system). Permanent spreading basins that could support permanent habitat are designed to protect adjacent lands. The project also aims to reduce overdraft of the basin and prevent the migration of saline water from the west. The Kern Water Bank has contributed to re-establishing long-dry wetlands along the Pacific Flyway through wet-year groundwater recharge. In Colorado, the Lower South Platte Water Conservancy District uses ASR primarily for stream augmentation and whooping crane recovery.

More indirect environmental benefits can also be written into law and policy for ASR. Arizona provides for two different kinds of ASR projects to recharge more water than will later be extracted, seeking to ensure the overall sustainability of the resource and provide groundwater for ecosystems. First, water recovery from direct recharge projects (using injection or infiltration) is limited to 95 percent of the water recharged; second, water recovery from managed recharge projects (using infiltration into dry stream beds) is limited to 50 percent of the water recharged, leaving the remainder to support riparian zones.

In-lieu groundwater storage can also be used to deliver environmental benefits. The Natural Heritage Institute is investigating the use of in-lieu storage combined with reservoir reoperation as a way to capture presently uncontrolled flood flows and deliver this water as flows aimed at matching specific flow variability targets in selected California rivers. Such projects involve weighing the ecological benefits of flood flows as against the benefits of "tailoring" water deliveries to achieve particular elements of a flow hydrograph. Some argue that the latter can achieve ecological benefits more efficiently than "uncontrolled" floods.

Governments in the Western U.S. have used various economic incentives to encourage ASR projects, including grants and payments through public-private partnerships.

Market-based instruments, in the form of incentive programs, can be used to encourage the take-up of ASR programs. In Arizona, ASR provides opportunities for innovative public–private partnerships, in which rural landowners may be able to enter into incentive-based agreements that would allow recharge facilities to be placed on their lands in return for financial and physical benefits. The Marana High Plains Effluent Recharge Project benefits from such an agreement. The Project was constructed in 2002 as a collaboration among the Bridle Bit Ranch, the Pima County Regional Flood Control District, the U.S. Bureau of Reclamation, Arizona Water Protection Fund, the Cortaro-Marana Irrigation District and the Town of Marana. The Ranch, which provides land for recharge ponds, benefits from a more dependable water supply and higher groundwater levels; riparian zones that benefit migratory birds are supported by effluent conveyed from the town's treatment plants to the recharge ponds; and the project creates recharge credits that are used to offset other pumping (see Chapter 7 for a broader discussion of offset/mitigation schemes).

Markets also appear in the context of ASR projects in the form of groundwater banking, through which multiple parties contract to use aquifers to store and later recover groundwater.

Market-based instruments also feature in ASR projects for environmental purposes. Oregon's Klamath River Basin Pilot Water Bank augments federally mandated surface water levels in the basin to protect threatened salmon species. One way in which stream levels are supported is by providing compensation to irrigators who switch from using surface water to groundwater or store their water underground, which can later be released to augment streamflow.

Market-based groundwater banking (which enables a water storer to sell rights to recover recharged water) is a relatively new form of water banking and is sometimes used in ASR schemes to allow access to the stored water by individuals and entities beyond those owning the land overlying the aquifer. From the perspective of the ASR water bank operator, projects provide funding for infrastructure developments, ongoing income or a contribution of water "left behind" that is not made available for recovery. Projects governed by contract in California can provide for "leave behind" water that is as much as two or three times the volume of recoverable stored water. Privately run groundwater banking schemes of this nature are unknown in Australia, and concerns over ASR projects "privatizing" water seem strongest in this context.

States can also participate in groundwater banking projects: California and Nevada have paid Arizona more than US$330 million to store groundwater. The purchasing states will be able to access the stored water using an exchange mechanism, by pumping water from surface reservoirs to which Arizona has rights, while Arizona will use the stored groundwater directly.

ASR projects raise many novel legal issues, the resolution of which can facilitate groundwater banking and other ASR initiatives.

Groundwater banking requires a sound law and policy system for managing the aquifer. A number of U.S. states, like Arizona, New Mexico, Oregon and Washington, have complex frameworks that regulate many elements of an ASR project. Other states, like Colorado and California, have notable experience implementing ASR projects. They have not established special-purpose legal frameworks for ASR, however, and rely on a combination of court-made law and project-specific agreements to regulate ASR projects. Property entitlements in relation to ASR are often not clearly defined, leading to a battery of uncertainties that can become especially important in the context of groundwater banking ASR projects, due to the involvement of multiple parties with potentially uncertain rights and liabilities.

Key legal issues include:

(a) The right to aquifer storage capacity.

(b) Interaction with other aquifer storage activities, such as carbon capture and storage.

(c) The percentage of water that should be "counted" as stored for later recovery, and whether this should be determined through ongoing scientific study, or a constant proportion.

(d) The acceptable duration of storage, and the need for any associated legal changes (e.g. extending permissible "carryover" periods for groundwater in Australia).

(e) The zone within which recovery is permitted (e.g. hydrologically connected to the location in which artificial recharge or injection occurred).

(f) The management of impacts on connected surface waters.

(g) The management of impacts on the quality of native groundwater (e.g. through "anti-degradation" policies).

(h) The establishment of title to the stored water and prevention of its extraction by third parties (i.e. groundwater "poaching").

(i) Restrictions on the rate of water recovery (i.e. preventing a "run on the bank").

(j) Legal restrictions (e.g. in county ordinances) on the export of "banked" water.

(k) Administration of and authority over importing and exporting surface water to and from the aquifer, and approving transfers of water in ASR projects that involve banking.

(l) Liabilities associated with the stored water potentially affecting contaminant migration, dependent species and ecosystems, the land surface, and the aquifer matrix.

(m) Accounting treatment of reductions in “natural” recharge caused by “artificially” storing water in aquifers, and liabilities associated with displacing native groundwater.

(n) More generally, the accounting system to be used for the storage and future recovery of water, and institutional arrangements for maintaining it.

(o) Monitoring requirements in relation to impacts to groundwater systems and connected surface systems, and the institutional framework for carrying out monitoring.

(p) Protecting sites that have suitable hydrologic, geologic and geochemical conditions for ASR by prohibiting or requiring a permit for high-risk land uses, including by establishing aquifer protection districts, or requiring local groundwater management plans to map and/or protect recharge areas (e.g. California’s recharge mapping requirement of groundwater management plans).

(q) Allocating the costs of ASR projects, including the costs of incentive schemes used to encourage the projects, particularly where there are broader public benefits beyond increasing water supplies for the storer − for example, improving groundwater quality, preventing overdraft and subsidence, and augmenting flows in connected surface waters.

Not all of these issues are commonly addressed in existing statutory frameworks in Western U.S. states, and they may be resolved through a combination of court decisions and legislation. Often the only tailored laws relate to regulating potential contamination issues associated with storing groundwater. In the absence of more general special-purpose storage legislation, for example in California, court cases were critical to clarify the law in relation to the rights to make groundwater “deposits” and “withdrawals." This was critical to providing sufficient legal certainty to enable a project like the Kern Water Bank to develop. Both California and Texas have seen significant litigation over who owns aquifer storage space.

Legal gaps can be exacerbated by institutional siloes and the need for proponents to navigate a complicated institutional landscape to gain the required approvals.

In many cases, proponents need approvals from multiple agencies to operate an ASR project, and those that involve groundwater banking can be particularly complicated. Relevant agencies include those with responsibility for health, pollution, water rights, wildlife, water supply and wastewater. This complex institutional landscape can be especially challenging because of institutional “siloes” that mean that approval processes are often not coordinated and information is not shared. The Arizona Water Banking Authority demonstrates one approach to solving the common problem of fragmentation between agencies: The Authority members are all agency directors of diverse agencies who have an interest in groundwater recharge.

Establishing channels of communication can be an issue at the project level, as well as at the agency level. Special arrangements may be required to govern project-specific issues and build trust between groundwater banking parties and adjacent landholders. California’s Kern Water

Bank uses a collaborative approach, combined with using neutral third parties. Its monitoring committee comprises multiple parties to a memorandum of understanding, and third parties carry out metering.

7. MITIGATING THE IMPACTS OF PUMPING GROUNDWATER: Aiming for “water budget neutral” groundwater pumping

Key insights:

1. Law and policy frameworks for mitigating the impacts of pumping groundwater are relatively common in the Western U.S. There, they provide an important way to deal with competing water rights by allowing a new use, subject to the user reducing or eliminating their impacts on others. They are almost unknown in Australia, but may be useful to consider in fully or over-allocated groundwater systems.
2. Existing frameworks tend to focus on the volumetric impacts of pumping groundwater on aquifers and connected surface waters. In fact, impacts are much broader, relating to water quality, recharge rates, land surface conditions, ecosystems and energy use. A key policy question is the extent to which mitigation frameworks should consider these other impacts.
3. Models are critical to the implementation of mitigation frameworks. Beware the potential for “garbage in, gospel out.”
4. It is important to consider the cumulative and long-term impacts of a development to ensure that its impacts are truly mitigated (as well as the potential for impacts to manifest, which cannot be mitigated − for example, loss of groundwater-dependent species). Current groundwater mitigation frameworks struggle to do this.
5. Though mitigation requirements impose a cost on groundwater users, a variety of institutions can lower these costs, for example, by providing groundwater pumpers with the option of sharing mitigation requirements among multiple individuals.

Discussion

Taking a broad view, groundwater pumping can have a wide range of impacts, including on:

- Connected surface waters and existing surface-water users who are affected by changes to surface-water flows.
- Aquifer levels or pressures, and existing groundwater users who are affected by changes in these conditions.
- Groundwater-dependent ecosystems.
- The quality of groundwater or connected surface water.
- Other aspects of the hydrologic cycle, such as changes in recharge rates.
- The land, for example, through land subsidence, salinization, development of acid sulfate soils and surface flooding.
- Energy use, since groundwater pumping typically requires more energy than surface water supply systems.

These impacts can be conceptualized as “debts” incurred by pumping groundwater, though, as discussed below, most of these categories of debts are not recognized as such by water allocation systems.

Groundwater mitigation programs allow increased groundwater pumping in fully or over-allocated water sources, provided the pumper "repays the debt" incurred by pumping.

Groundwater mitigation/offset programs aim to facilitate increased groundwater pumping while minimizing or neutralizing unacceptable impacts that that pumping could have on certain other water users and entities. In exchange for permission to pump groundwater, the diverter is required to offset the withdrawal. For example, in the case of impacts to connected surface waters, they may be required to acquire replacement water from another source ("mitigation water"), which is then used to supplement streamflow. This amounts to "repaying" the "debt" to the river caused by pumping from the well.

Unlike general trading schemes that enable greater flexibility in how, when and who uses a particular water right/entitlement, mitigation programs aim to effect water budget-neutral or near-neutral water transactions − some degree of compensation for impacts being the condition to any use at all. Mitigation is particularly useful in basins that are fully allocated and capped to further diversions: it enables increased groundwater consumption and groundwater-dependent development to continue, provided the consumer/developer is willing to "reimburse" the basin's overall water supply or otherwise compensate for the increased impacts of pumping. In basins that are not fully allocated, mitigation would not be required, since the impacts of permitted extraction are implicitly accepted, in at least volumetric terms.

In theory, mitigation programs could take a broad view of the impacts of groundwater pumping in view of the many types of impacts outline above. In practice, jurisdictions tend to focus − to widely differing degrees − only on impacts on surface water quantity and quality, aquifer levels or pressures, and (to a small extent) groundwater-dependent ecosystems. The increasing academic and popular emphasis on the nexus between energy and water points to the importance of considering the energy costs of delivering groundwater within mitigation programs. It would be necessary to monitor the wide range of potential impacts of pumping groundwater before developing mitigation requirements for this expand range of impacts, to understand baseline conditions.

States use mitigation programs to neutralize the effects of in-state groundwater pumping on interstate rivers that are subject to compacts. Individual groundwater pumpers use them to negate effects on holders of senior water rights to connected surface waters, or effects on endangered species that rely on connected surface waters.

Surface waters are the key beneficiaries of Western U.S. mitigation programs. These programs occur in several contexts. One important context is that of upstream, groundwater-using states, which use mitigation programs to ensure that groundwater pumpers within their territory do not compromise their ability to deliver particular flows of surface water across their border to downstream states pursuant to the upstream state's obligations under an interstate compact or agreement. In some places, the focus on the stream depletion impacts of groundwater pumping is so strong that corrective measures in place under mitigation programs may view groundwater and aquifers as disposable resources. New Mexico's "buy and dry" program, for example, involves pumping fossil (non-recharged) groundwater into the Pecos River to replenish surface flows and meet treaty obligations.

A common second context for mitigation programs is avoiding the impacts of stream depletion on senior surface water right holders, caused by intrastate junior groundwater pumpers. Programs in this context may be imposed by legal requirements that apply uniformly statewide, or only in basins closed to new surface water rights as in Montana, or through regionally unique programs, as in Washington state.

Mitigation programs also arise in an important third context − to offset the impacts of groundwater pumping on a species that is endangered or may become so. In this context, water quality and temperature, as well as depletion volumes, can also serve as central factors informing when and how mitigation is required, since groundwater contributions to streams can affect these characteristics of surface water flows. Programs in Washington and Oregon aim to ensure mitigation efforts support habitats of anadromous fish species, protected under the U.S. Endangered Species Act, which have in-stream water quality and temperature requirements.

Fundamentally, mitigation programs in the Western U.S. seek to right the historical legal "wrong" of failing to recognize the interactions between groundwater and surface water. Taking hydrological reality to its logical conclusion can create some creative policy scenarios. In Washington state, despite initial policy objections, owners of domestic septic systems can now claim credit for returning wastewater to aquifers, and developers who cut down groundwater-using trees in subdivisions can claim credit for effectively reducing groundwater extraction from the relevant aquifer.

Although Australian jurisdictions have not yet developed groundwater mitigation frameworks, they are likely to be useful where groundwater is very intensively used, and bear many similarities to the analytical requirements of groundwater trading frameworks.

While Australian states have not employed formal mitigation programs in regular water allocation frameworks to date, they may be well-suited to adopt this approach, especially in areas of high water demand where surface and groundwater are managed as a connected system. At present, mitigation programs are restricted to the context of mining impacts on water rights, in the form of "make good" provisions, and some policy support for "offsets" in the more general groundwater context − though without any detailed framework of principles that would apply to a more fleshed-out policy. Offset requirements are also applied on an ad hoc basis in some stages, without a surrounding policy framework. A key issue in the development of formal mitigation programs in Australia will be the contexts in which they are practical, and for which there is demand − whether only for intensive groundwater uses with high economic value, like mining, or more generally for groundwater development in over-allocated aquifers. In the context of very large projects, some may query whether there is a limit to mitigation − whether some impacts are simply too significant to be "made good," particularly where mitigation efforts are required long after impacts occur.

A fundamental difference in emphasis between Australian and Western U.S. state policy thinking on mitigation relates to the scale at which the impacts of groundwater pumping are conceived. Mirroring the emphasis on individual water rights under prior appropriation principles, Western U.S. states focus on the impacts of individual wells. In Australia, policy dialogues around mitigation (such as they are) focus at the scale of "bulk" regional impacts, in line with

Australia's "share the pain" groundwater allocation principles and statutory water planning frameworks.

The Australian conceptualization of the impacts of groundwater pumping has led to various legal and policy instruments that seek to prevent impacts on surface waters, but which do not have the same flexible, "currency"-like character as mitigation programs in the Western U.S. For example, New South Wales seeks to prevent new groundwater pumping having unacceptable impacts on streams by closing some highly stream-connected basins to new groundwater pumping, and restricting new pumping to less utilized, brackish or saline groundwater bodies. Nonetheless, some argue that there is a need for a more currency-oriented approach to considering the impacts of pumping groundwater on streams, since this is instrumental in establishing "exchange rates" for groundwater trading, which is strongly supported by national water policy. Stated differently, the degree to which a well derives its water from a stream should influence the permissible extraction volume if the groundwater entitlement is transferred to a new well, which derives a different proportion of its source water from a stream. A key question on the horizon for Australian policy frameworks that deal with this issue is the appropriate time frame over which to assess impacts, and whether impacts that manifest far into the future, and are more uncertain, should be somehow "discounted" against nearer-term impacts.

In addition to impacts on surface waters, Australian law and policy frameworks for groundwater focus heavily on groundwater-dependent ecosystems, though often law "on the books" is much stronger than law as it is implemented. Although no Australian jurisdiction adopts a structured policy framework for mitigation in the context of GDEs, there are several isolated examples of mitigation requirements being imposed on individual licenses or sectors, particularly in the mining context.

There is no single design prototype for groundwater mitigation programs. Experience shows that basin-specific needs and stakeholder interests inform a mitigation program's regulatory structure, supporting policies and degree of complexity. However, there are a number of common variables. The following discussion is based on the experience of programs that aim to mitigate the impacts of increased groundwater pumping on surface waters, which form the bulk of such programs across the Western U.S.

Groundwater mitigation programs have a number of key policy variables: the level of impact that is significant enough to require mitigation; whether mitigation actions can be carried out collectively; whether water banks or trusts are used; the degree of equivalence required between the impact and the offset; and whether mitigation mandates are imposed prospectively or retrospectively.

Threshold of significance for requiring mitigation

Since there are varying impetuses for establishing mitigation programs (e.g., complying with related statutory mandates; increasing groundwater-dependent development; localizing water management and conservation; etc.), states differ in how they determine when groundwater pumping becomes significant enough to require mitigation. Some determine significance with reference to the types of impacts to streams, the time it takes for groundwater pumping to deplete a stream, and the volume of the depletion. By contrast, in Nebraska's Platte River basin, mitigation is triggered when an aggrieved party can show that they suffered an economic loss due to the groundwater depletion caused by development or conservation activities initiated since the granting of their water right.

Methods of mitigation: Individual vs. group action

Mitigation water is typically obtained either by retiring existing rights to pump groundwater or by transferring surface water rights to a mitigation purpose (e.g. reassigning the designated use for a water right from irrigation to mitigation). Some programs, such as in Idaho and Colorado, allow applicants to pursue direct exchanges with other entitlement holders who are willing to sell or retire their right, without transacting through a third party institution to purchase a credit. In some states, Colorado and Idaho again being examples, well associations and irrigation districts purchase surface water for mitigation use by their members, reducing individual transaction costs. Administration costs are also reduced relative to individual mitigation plans because water users can take advantage of a single basin-wide hydrologic model and a single ongoing water accounting exercise, as in the Rio Grande and Arkansas basins in Colorado, rather than many, as in the South Platte in Colorado.

Facilitating mitigation using water banks or trusts

Mitigation banks and trusts may also be employed to help applicants find water rights and track collective bank activity. In Walla Walla, Wash., a relatively simple mitigation model is used, under which all mitigation is conducted through a single bank and applicants pay a fixed fee per "mitigation credit." By contrast, mitigation in Kittitas County, Wash., involves exchanges through multiple privately operated water banks that negotiate the terms of individual exchanges and determine the market price of mitigation water for the Yakima River basin. The Kittitas system is praised for its active exchange and precision in mapping areas where groundwater pumping is allowed (if mitigated), but criticized for using the program to control development patterns (since the "mitigation suitability areas" were identified based on their aptness for future development).

"Apples for apples" rules

A key consideration in designing mitigation programs is determining what degree of equivalence is required between the mitigation action and the impact sought to be mitigated in terms of the connectedness between water sources and temporal and spatial aspects of depletion.

To ensure the mitigation credit balances the pumping debit, many states mandate a "bucket for bucket" or "drop for drop" exchange, which requires that the groundwater pumped or consumed is replaced by the same amount of mitigation water. Other states require that more mitigation water be returned than was pumped. Oregon's Deschutes Groundwater Mitigation Program operates within a basin that has completely allocated its water rights and allows leased groundwater pumping only if the diverter returns *twice* the amount of mitigation water that was diverted.

Different approaches are taken to ensure that mitigation bears a reasonable hydrologic connection to the proposed groundwater diversion. Many states require that mitigation water be applied within the hydrological "zone of impact" of the proposed groundwater pumping, which is largely defined by the underlying aquifer characteristics. For example, since Oregon's Deschutes River basin is deep and fed by multiple diverse hydrologic systems, the state most often requires that mitigation water be returned near the point of groundwater pumping to ensure the credit actually balances the debit. In Walla Walla, however, the underlying aquifer is shallow and homogenous; therefore, the program merely asserts a preference that mitigation occur upstream of the diversion site and be used in high-density areas. In Montana, it was proposed that mitigation water be used for specific stream restoration as a means to replenish the basin's most dewatered areas, outside the immediate zone of impact of a particular permit-exempt well (though the state has not yet adopted a mitigation program for permit-exempt wells). Where mitigation programs are motivated by the need to meet compact obligations to deliver certain volumes of surface water to downstream states, the state line is the relevant location for assessing whether depletion to a stream has been offset.

In addition to geographic accuracy, temporal proximity is also a key consideration of mitigation effectiveness. Timing issues are particularly important where a municipal water utility seeks a *year-round* groundwater pumping permit, and proposes to mitigate its water use under the permit by buying and retiring a *seasonal* irrigation surface right. Common policy approaches to dealing with mitigation timing are to calculate depletion − and, therefore, the requirement to provide an offset − on a monthly, seasonal or annual basis, with annual calculation being the least precise and arguably least desirable in terms of truly neutralizing the effect of the pumping. A further issue arises in relation to temporal proximity − whether a program requires replacement water to be arranged at the time that a groundwater pumping application is made, or only when the depletion would be felt, based on hydrologic modeling, as in New Mexico's Middle Rio Grande mitigation program. The latter has been controversial, since it may increase the uncertainty that the mitigation action will in fact occur, on account of businesses failing or replacement water being unavailable.

"Oranges for apples" rules

Some states permit non-water-based mitigation ("oranges for apples" rules). In Colorado, it may be possible for a junior groundwater user to compensate senior surface water right holders using cash or crops. It may also be possible for water users contractually to accept a degree of impairment of streamflows. In Washington, there is precedent for "habitat for water" mitigation, where groundwater pumping affects species dependent on the affected surface waters. In the environmental context, some have suggested that non-water mitigation in the form of contributing money to an environmental trust may be more efficient than simple volumetric "apples for apples" replacement, if the money can be used to target a different and more ecologically valuable area.

Administration of mitigation programs

Depending on the structure and motive for establishing a groundwater mitigation program, a number of institutions may be well suited to administer the exchange. State and local partnerships may increase transaction efficiency where state water regulatory agencies are already overburdened. They also present an opportunity to capitalize on local expertise in relation to water markets, water rights, monitoring, etc. Two years after founding the exchange in Walla Walla, Wash., the state partnered with a nongovernmental pilot organization to create local management plans; after another two years, it transferred primary administrative duties to the organization. (See Chapter 4 for further discussion of groundwater partnerships.)

Regardless of its scale, any system for administering mitigation programs must include effective monitoring and enforcement provisions. This can take the form of:

- Metering water use, as in some areas of Washington, to ensure that water users who sell their rights for retirement as part of mitigation schemes do not continue to divert water.
- Undertaking hydrological monitoring and annually comparing monitored and predicted values to determine the effectiveness of augmentation plans, as in some newer Colorado augmentation plans.
- Imposing penalties for illegally diverting water in contravention of mitigation requirements, as does Colorado to the tune of $500 per day.

Mitigation programs implemented to date reveal that legal loopholes and high costs of mitigation can cause problems for administering agencies and water users. In addition, climate change is likely to challenge mitigation programs in the future.

Experience of mitigation programs in the Western U.S. highlights a range of key policy challenges. In Washington, legal loopholes leave domestic wells and sometimes wells that tap deep aquifers outside mitigation program requirements. This has led mitigation programs to have the unintended effect of shifting demand for groundwater to these situations.

Mitigation requirements have also led water prices to increase dramatically in Washington. Colorado's experience demonstrates the greater cost-effectiveness of group rather than individual mitigation plans. It also suggests that the costs of hydrologic modeling associated with mitigation plans may mean that well users can save money and reduce conflict by agreeing to over-mitigate, based on simple calculations and conservative assumptions, rather than undertaking a much more costly exercise to model stream depletion much more precisely.

In the future, climate change is likely to pose a challenge to mitigation programs if higher evaporation rates, for example, increase the consumptive component of water use. That would result in uses, which have been approved based on mitigating a smaller consumptive component, having an unanticipated net impact. Conversely, future reductions in natural groundwater recharge would also pose challenges.

8. GROUNDWATER BUYBACKS: How governments and private actors can bring groundwater systems back from the brink

Key insights:

1. Groundwater buybacks can help reduce chronic overdraft and resolve conflicts among water users and other stakeholder groups. They can take several forms, including purchasing and retiring water rights, and making contractual payments in exchange for reduced water use − the latter being more common in the Western U.S. than Australia.
2. In the Western U.S., funding models include the federal Farm Bill, local taxes and public boards. In Australia, special-purpose federal and state appropriations are most common. The additional involvement of NGOs in water buybacks in the Western U.S. suggests a potential model for Australia.
3. The extent to which governments should fund buybacks of water rights in over-allocated areas is a key policy issue. Even in the absence of funding, governments can valuably facilitate buybacks that are privately funded.
4. Buyback programs need to be supported by information on the historical use of the water rights, to ensure that money is not paid for "paper water."
5. Buybacks are one policy option. Their efficiency should be compared with other options, such as ASRs targeted to obtaining environmental benefits (see Chapter 6), to achieve water supply and streamflow reliability. Governments should establish clear policy principles for when buybacks are the preferable policy option.

Discussion

Broadly, Australian water allocation systems could be described as planning-based systems (given their emphasis on predetermining management rules and consumptive limits at the basin scale), and Western U.S. water allocation systems as adaptation-based systems (given that the prior appropriation doctrine essentially regulates access to water reactively in accordance with previous established rights). Despite this difference in basic approach, over-allocation of water, including groundwater, is present in both regions. The trigger for dealing with over-allocation tends to be different, though. In the Western U.S., the trigger is frequently a private contest over the exercise of water rights − as when a senior appropriator alleges that a junior appropriator is adversely affecting their right. In Australia, the trigger for dealing with over-allocation tends to be a government agency's assessment that current impacts on the environment or the reliability of water rights are unacceptable.

"Buying back" groundwater rights, or paying water users to forgo pumping or reduce their water use, is one approach to bringing back over-allocated groundwater systems, while avoiding the potential equity concerns associated with mandatory reductions in water use.

A key issue in dealing with over-allocation in both regions is how to remedy the situation without causing undue economic damage, and considering the expectations and dependence that the holders of water rights or licenses have developed. “Buying back” groundwater rights or licenses is an alternative, or complement, to regulatory reductions in water use in over-allocated systems. Under this approach, a government entity or private party purchases and temporarily or permanently relinquishes: (1) a right to pump groundwater, in order to protect the sustainability of the aquifer or connected surface waters; or (2) a right to divert surface water, to facilitate the continued pumping of connected groundwater. Where a buyback accompanies a regulatory requirement to reduce groundwater use, funded purchases of entitlements from willing sellers are used to avoid across-the-board reductions to entitlement holders.

A closely related approach involves paying a farmer not to irrigate with groundwater (and not to extract groundwater), or to reduce their groundwater extractions, rather than buying the water right/entitlement per se (a “forbearance agreement”). Forbearance agreements can take place outside the formal processes for water right changes and trades (particularly in the Western U.S.), which provides a potential advantage by minimizing administrative requirements, and therefore transaction costs.

Typically, buyback programs and forbearance agreements target license or right holders whose water consumption is large and potentially flexible, like agricultural irrigators. The instigators tend to be governments in Australia, and a combination of governments and environmental NGOs in the Western U.S. Their aims include protecting senior surface-water right holders or endangered species, meeting interstate compact obligations, or providing broader conservation benefits.

Also related to buyback programs and forbearance agreements are other payments made to the holders of water rights or licenses whose entitlements are reduced by regulation. In light of the lack of a legal requirement for Australian states to provide just compensation for compulsory acquisition (exercise of eminent domain), some states do not provide compensation for the acquisition of water entitlements (e.g. Victoria), and others do, at least in the case of individual, rather than across-the board, reductions (e.g. Western Australia, based on findings of harm). The Achieving Sustainable Groundwater Entitlements program is jointly administered by New South Wales and Commonwealth agencies and is designed to provide financial “structural adjustment” assistance in relation to regulatory reductions in groundwater entitlements in over-allocated inland areas, but this assistance does not amount to “just terms” compensation.

Australia has well-developed policies for governments systematically to buy back surface-water entitlements from willing sellers in over-allocated areas for environmental purposes. Current policy statements suggest that this will be extended to groundwater entitlement holders in areas in which the current level of entitlement exceeds the “sustainable diversion limit” set by the Basin Plan for the Murray-Darling Basin. To assist the transition to reduced water allocations, the Australian Government’s AU$3.1 billion (US$3.3 billion) Restoring the Balance in the Murray-Darling Basin Program buys water entitlements from willing sellers to protect and restore rivers and wetlands. The program has made purchases through more than 4,100 individual trades. Australian NGOs like the Waterfind Environment Fund are also emerging as potential agents of buyback projects, though they are presently focusing on only surface-water purchases. A long-established program in the Great Artesian Basin − the A$140 million (~US$140 million) Great Artesian Basin Sustainability

Initiative −sees government agencies working with farmers to cap uncontrolled artesian bores. It aims to reduce water waste, improve groundwater pressures and protect discharge spring wetland ecosystems.

In the U.S., state groundwater buyback programs seem to be directed toward “hotspots,” for example, as a response to the otherwise economically crippling effects on groundwater users of strict administration of the prior appropriation system in favor of senior surface water right holders. This is exemplified by the Idaho buybacks to support spring-fed trout hatcheries on the Snake River, discussed below. Conservation-oriented NGOs have considerable experience using buyback strategies to support surface water systems, and are increasingly extending that focus to include groundwater buyback opportunities as conjunctive management becomes more widely recognized throughout the West. The U.S. federal government also plays a significant role in funding and administering a number of agricultural land-fallowing programs to provide incentives for irrigators to reduce water consumption − a practice that is not widespread in Australia.

Programs that buy back groundwater to benefit ecosystems and water-dependent species (sometimes as an ancillary objective) are increasingly used in the U.S., where fishery and migratory bird species require protection under the Endangered Species Act. For example, New Mexico implemented a Strategic Water Reserve buyback program to augment streamflow in response to litigation within the Pecos River Basin. The state purchases or leases water rights from willing sellers/lessors, pools the publicly held water rights, and commits them to fulfilling contractual delivery obligations to downstream states and benefiting surface water-dependent endangered species. The sale, lease or donation of groundwater rights may only be used for the purposes of cessation of pumping or for limited short-term stream augmentation.

The Platte River Recovery and Implementation Program aims to restore Platte River flows to 1997 levels by 2019, to benefit endangered fish and migratory birds, and to prevent the need to list further species. The Program involves Nebraska, Wyoming, Colorado and the federal government. Each party has adopted a “depletions plan” under which water use activities commenced since 1997, including groundwater pumping, must be mitigated. As part of the program, Nebraska’s New Depletions Plan seeks to increase Platte River streamflows by phasing in reductions of groundwater use through decreased water allocations or fallowing presently irrigated acres, from 2013 to 2019.

In Idaho, the state contributed to purchasing a trout hatchery business that used spring flows fed by the regional aquifer in order to resolve complaints by adjacent spring water right holders affected by the pumping. A portion of the acquired water rights were redistributed to the adjoining senior spring water right holders. The practical effect was to reduce the overall demand on the spring flows to a sustainable level. The alternative of strict administration of the groundwater rights to satisfy the seniors would have had severe economic impacts, shutting down wells irrigating 58,000 acres to benefit water use with a much lower economic value. Subsequently, the groundwater users acquired additional hatcheries to mitigate for two other delivery calls by senior surface-water right holders.

In hydrologically connected systems, reducing groundwater use by purchasing or leasing rights is a common method of fulfilling instream delivery obligations and providing water for surface water and wetland ecosystems (as in the Pecos River Basin, noted above). As a further example, in Idaho’s Eastern Snake River Aquifer, depletion of spring flows as a result of reduced incidental recharge from surface irrigation, groundwater pumping and drought have led to ongoing litigation between groundwater pumpers and the holders of aquifer-fed spring water rights. Initially, the state used federal Farm Bill funding (discussed below) to buy and retire irrigated land in an attempt to augment groundwater sources and fulfill water requirements for endangered species mandates. When the basin was still not in balance, Idaho’s governor organized the Comprehensive Aquifer Management Plan (CAMP) that comprised state agencies, spring-user stakeholders, groundwater stakeholders and conservation NGOs. The group aimed to reduce water usage over five years by switching 10,000 irrigated acres to dry-land farming, and implementing aquifer-wide reduction incentives and assistance to farmers to convert to less water-intensive crops.

Environmental NGOs and other private parties can play a role in funding buybacks or forbearance agreements.

There are also a number of examples of U.S. environmental NGOs purchasing groundwater rights to benefit streamflow and dependent species. The Nature Conservancy has employed a strategy in areas of Southern Arizona of purchasing agricultural lands along the San Pedro River (thereby acquiring a right to divert groundwater appurtenant to that property, according to state law) and reselling the property with an attached easement that dramatically reduces the volume of groundwater the buyer is permitted to pump. While this practice, commonly known as “buy and dry,” is effective in augmenting streamflow and reducing aquifer depletion, it has received criticism for retiring land available to the irrigation community. As an alternative, Arizona’s Land and Water Trust has also bought and sold agricultural land with the purpose of reducing groundwater withdrawal, but often builds in a requirement that water continue to be used for agricultural use. The strategy aims to balance protection of the ecological values of surface and groundwater, as well as its agricultural and ranching communities. The presence or absence of economic incentives (e.g. tax deductions) may influence the degree to which NGOs participate in buybacks and forbearance agreements.

In order to buy back groundwater to benefit surface flow systems, state laws must recognize “instream flows” or “environmental purposes” as being a legally permissible use of water. NGOs are involved in advocacy on this issue related to buybacks. Several states in the Western U.S., including Idaho, Wyoming and Utah, do not allow transfers of water designated for an instream beneficial use. Montana NGOs like Trout Unlimited devoted six years to lobbying the Montana Legislature and state agencies before surface water and groundwater were managed as a single, connected system and “instream flow” was legally recognized as a beneficial use of transferred water.

Several of the examples above reference arrangements by which private landowners (typically large-scale irrigators) agree to temporarily or permanently reduce water use by fallowing land in exchange for some form of compensation. These voluntary land-fallowing agreements are often funded by the U.S. Farm Bill Conservation Programs, in which the U.S. Natural Resources Conservation Service (NRCS) offers financial and technical assistance to help willing participants manage natural resources in a sustainable manner. Generally, states, NGOs or other willing project organizers submit contract proposals to NRCS that describe how the group will achieve conservation practices that address natural resource concerns or opportunities to help save energy, improve soil, water, plant, air, animal and related resources on agricultural lands and non-industrial private forest land. A common challenge for these large-scale fallowing projects (which may receive up to 10 years of Farm Bill funding) is that the project requires well-developed working partnerships among all participating parties, including federal and state agencies, all volunteer landowners and any participating NGOs. Two programs that are commonly used to reduce groundwater and/or surface water use are the Environmental Quality Incentives Program (EQIP) (along with its sub-program called the Agricultural Water Enhancement Program, mentioned in Chapter 4 on partnerships) and the Conservation Reserve Enhancement Program (CREP). From 2003 to 2010, EQIP contracts were arranged in every U.S. state and the annual funding ranged from US$1 billion to US$1.2 billion.

Another related form of irrigation-driven incentive that is common in the Western U.S. involves rotational land-fallowing programs, in which individual farmers in a group are paid to fallow their land in a cycle, so that no one section of the farm economy is greatly affected, and long-term agricultural production is maintained. An alternative often preferred to “buy and dry” approaches, these programs focus on balancing sustainability efforts between agriculture and water supplies. Colorado’s Lower Arkansas Valley Water Conservancy District, for example, has adopted a “rotational land fallowing program [that] involves removing irrigated parcels from production on a periodic basis, once every three or four years for example, and transferring the associated water to an economically higher-valued use, such as municipal use.”[14] For these rotational land fallowing-water leasing programs to be successful, it is important to encourage the participation of the larger ditch companies in a particular region as a means to increase the pool of available water supply and farmland that can be fallowed.

A key challenge facing buyback programs and forbearance agreements is minimizing economic impacts on third parties that rely indirectly on groundwater use. Economic factors like high crop prices can also challenge the success of programs by making them less attractive to rights holders.

As mentioned above, and in Chapter 5 on groundwater trade, some buyback programs in the Western U.S. are criticized for their effects on third parties, namely, negatively affecting agricultural economies when farmers idle cropland to sell water. Many rural areas discourage or prohibit trades that export groundwater from the basin for fear of diminished return flow and detriment to local water-dependent economies. Moreover, government tax revenues may shrink if farmers fallow land or nonprofit entities purchase water rights or secure long-term water leases. California’s widespread use of these buyback agreements for its drought water bank generated notable difficulties in some agricultural counties.

Recent studies in the Murray-Darling Basin report that the third-party effects of surface water buybacks proved lower than anticipated in some regions within the Basin, and that the impact of buybacks on house prices could even be positive. Since farmers are fully compensated, any income losses will be offset by the annuity arising from buyback proceeds. The study also compared the impacts of drought and the impacts of buybacks within the Basin, and found that

[14] HDR Engineering, Inc, *Rotational Land Fallowing-Water Leasing Program – Engineering and Economic Feasibility Analysis* (2007) Executive Summary. Prepared for the Lower Arkansas Valley Water Conservancy District.

drought impacts were significantly higher than direct buyback impacts in terms of productivity and job retention.

Favorable economic conditions can diminish the effectiveness of buyback programs and forbearance agreements, if high commodity prices mean that irrigation is economically much more attractive than selling rights or receiving payments for idling land. It appears that none of the Western U.S. forbearance agreement programs, which use predetermined prices, adjust these prices in response to changes in the value of commodities. This has led to under-subscription to these programs in some states.

Water buybacks and forbearance agreements must be supported by effective monitoring and enforcement provisions to ensure that the investment can meet its goals.

Monitoring and enforcement are critical for ensuring the success of buyback programs and forbearance agreements. This is clearly required to ensure that water right or license holders do not continue to pump contrary to the program or agreement. The need for monitoring and enforcement also extends beyond this immediate context: Where the source covered by the program or agreement is an aquifer-connected stream, compliance and enforcement tools are needed to ensure that excessive groundwater pumping does not reduce streamflow, effectively reversing some of the gains that have been made in buying water back.

9. WORKSHOP PARTICIPANTS

First name	Surname	Organization
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Moya	Tomlinson	Queensland Department of Natural Resources and Mines
Dick	Wolfe	Colorado State Engineer
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10. WORKSHOP AGENDA

Preliminary meeting: Wednesday, June 20: Field trip and dinner

A tour to the World Heritage-listed Blue Mountains area will present a snapshot of groundwater issues in the region, with a focus on groundwater-dependent ecosystems. The excursion dinner will facilitate informal networking before the workshop commences. The tour will be led by a Blue Mountains groundwater specialist and ecologist, and a National Park ranger.

11.00 am	Wentworth Falls Lake: Issues regarding catchments, groundwater-dependent swamps and urban impacts
12.00 pm	Wentworth Falls Lookout: Warragamba and cliffline catchment issues
1.00 pm	Blackheath National Parks and Wildlife Service Heritage Centre: Presentation on groundwater issues in the Blue Mountains catchments and visit to Govetts Leap Lookout (led by Geoffrey Smith)
2.30 pm	Katoomba Falls: Guided walk through the Katoomba Falls area (sandstone, claystone, waterfalls, spray-zones, erosion, catchment quality, threatened species, impacts of tourism) to the base of the escarpment

Day One: Thursday, June 21: Science, Policy and Partnerships

8.00 am	Registration and breakfast
8.30 am	Welcome and round-table introductions
9.00 am	Overview of workshop agenda and research program so far
9.20 am	**Groundwater and the Science/Policy Interface:** How can we ensure that policy better reflects hydrological and ecological knowledge about groundwater?
10.40 am	Morning tea break
11.00 am	**Groundwater and Uncertainty:** How should uncertainty in hydrological and ecological knowledge about groundwater be presented to policymakers and stakeholders, and how should it be incorporated into policy?
12.20 pm	**Lunch**
1.10 pm	**Communication about Groundwater:** How can we best communicate to stakeholders the nature of groundwater problems − as they relate to water supply, cultural and ecological requirements − to motivate action? What information should be presented, and in what form?
2.30 pm	Afternoon tea break
2.50 pm	**Groundwater Partnerships:** How can the private sector, public-interest NGOs and agencies across government contribute to gathering information and building groundwater tools for use in policy, including tools to monitor and model groundwater resources and dependent ecosystems?
4.10 pm	**Summary and key take-home messages from Day 1**

5.00 pm	Break
6.15 pm	**Reception, dinner (Sancta Sophia College) and keynote dialogue**

Day Two: Friday, June 22: Groundwater and market instruments

8.00 am	**Breakfast**
8.30 am	**Policy frameworks for groundwater trade (groundwater-groundwater and groundwater-surface water)**, i.e. a strategy of allowing a person who pumps groundwater to sell their right/entitlement to a purchaser who will pump groundwater or surface water from a different location (or vice versa); and source switching, i.e., allowing a person who pumps surface water to switch to groundwater (or vice versa)
9.50 am	Morning tea break
10.10 am	**Policy frameworks for trade in the context of aquifer storage and recovery**, i.e. a strategy of allowing a person who owns a right to artificially stored groundwater to sell the right to recover that water to someone else, or to recover the water and sell it to someone else
11.30 am	Short break
11.40 am	**Policy frameworks for mitigating the impacts of pumping groundwater**, i.e. a strategy of allowing a person to pump groundwater in an already over-appropriated/over-allocated basin, on the condition that the person takes action to offset the effects of pumping, e.g. by buying and retiring a surface water right/entitlement, or by undertaking managed aquifer recharge
1.00 pm	Lunch
1.50 pm	**Buybacks in relation to groundwater rights/entitlements**, i.e. a strategy in which a government agency or private party purchases and temporarily or permanently relinquishes a right to: (1) pump groundwater, in order to protect the sustainability of the aquifer or connected surface waters; or (2) divert surface water, to facilitate the continued pumping of connected groundwater
3.10 pm	Afternoon tea break
3.30 pm	**Summary and key take-home messages from Day 2**
4.20 pm	**Closing round-table discussion**
5.00 pm	**Adjourn to USSC board room: wind-down, cocktails, canapés, and informal discussion**