Instituting Integration:

Findings of the Comparative Groundwater Law & Policy Program's Workshop 1

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Water in the West Working Paper 3

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About the Comparative Groundwater Law and Policy Program

The Comparative Groundwater Law & Policy Program seeks to improve groundwater management through research and international workshops that draw together policy-makers and experts on groundwater. The Program 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; and
- anticipating climate change in managing these connections.

The Comparative Groundwater Law and Policy Program 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 Program will develop policy recommendations for improving groundwater sustainability in both regions.

The Program approaches its task in two ways: through original research, and a series of four international workshops over three years, which bring together policy-makers and groundwater experts. It takes an interdisciplinary perspective on both, informed by law, engineering, and natural and social science.

The Program 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.

Workshop 1 of the Comparative Groundwater Law and Policy Program

The inaugural workshop of the Comparative Groundwater Law and Policy Program was held October 17-19, 2011 at Stanford University. The workshop brought together 44 groundwater managers and experts to share experiences and practical lessons in integrated groundwater management. The group included lawyers, policy-makers, government officials, academics, NGO representatives, scientists and consultants from the western U.S. and Australia. The workshop focused on a key issue in integrated groundwater management: using law and policy to manage connections between groundwater and surface water. It also covered two related issues: the impacts of pumping groundwater on groundwater-dependent ecosystems and developing aquifer storage and recovery.

Through a series of presentations and roundtable discussions, the workshop:

- Examined what we know about laws and policies for integrated groundwater management across the western U.S. and Australia (and what we still need to learn), at the level of states, regions, and groundwater basins;
- Highlighted new approaches to aquifer recharge, and identifying and mapping groundwater-dependent ecosystems, and investigated their policy implications; and
- Informed the research for the Comparative Groundwater Law and Policy Program to ensure that it is responsive to decision-makers' needs.

About this Working Paper

This working paper synthesizes the findings of the inaugural workshop of the Comparative Groundwater Law and Policy Program. The paper has three parts:

- Part A describes the foundations for integrated groundwater management in the western U.S. and Australia. It describes the key issue of groundwater-surface water interaction addressed by the workshop, and key catalysts that lead to action to deal with it.
- Part B summarizes the workshop's findings in relation to law and policy mechanisms for:
  - considering the impacts of new groundwater pumping on surface waters;
  - dealing with the impacts of existing groundwater pumping on surface waters;
  - storing surface water in aquifers, and later recovering it for use; and
  - recognizing how pumping groundwater affects species and ecosystems that depend on groundwater.
- Part C sets out findings in relation to two themes that cut across law and policy in all of the foregoing areas:
  - involving a broad range of levels of government, NGOs and other stakeholders in governing groundwater and implementing groundwater management tools; and
  - forging links between groundwater science and policy.

The working paper draws out its main messages in shaded boxes, highlighting "key lessons" that were emphasized repeatedly during the workshop in side-boxes. The main text derives from case studies presented by attendees, workshop discussions and debate, supplemented by additional research and reflection by the author (and as such, it does not necessarily represent the universal views of the attendees, nor those of their organizations). The case study states, regions and local areas are given in bold, and shown on the maps in Part A.

The findings of this inaugural workshop and paper highlight promising areas for creative policy development in important and challenging areas of groundwater management, and the key issues that policy-makers must confront in pursuing them. Its findings are necessarily preliminary—they lay the groundwork for expanding debates and research on groundwater management to help improve groundwater sustainability across Australia, the western U.S., and further afield.

Glossary

General water glossary

Aquifer	A subsurface body of rock or sediment that stores and transmits groundwater.
Aquifer storage and recovery (ASR)	Placing water in an aquifer by injecting it or by spreading it on the land surface, where it infiltrates, then pumping it out when needed.
Groundwater	Water that occurs below the surface of the land in soil pores, and fractures and cavities in rock (note that some definitions include only water in the part of the subsurface that is saturated).
Groundwater-dependent ecosystem (GDE)	An ecosystem that requires access to groundwater to meet some or all of its water requirements.
Baseflow (in the U.S., sometimes "*subflow*")	The part of streamflow that derives from groundwater seeping into the stream.
Surface water	Water that occurs in rivers and lakes or falls on the land surface.

United States-Australia water glossary

This glossary 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.

United States term	**Australian term**
Endangered Species Act	*Environment Protection 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)	*License/licensing* (of groundwater use)
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*

Policy-Makers' Brief – Integrated Groundwater Management:

Summary of the Findings of the Comparative Groundwater Law and Policy Program's Workshop 1, to accompany *Instituting Integration*, Water in the West Working Paper 3

Groundwater is a critical component of the water supplies for agriculture, cities, industry and ecosystems across the western U.S. and Australia. It can have significant advantages over surface water in terms of reliability and water quality. However, water law and policy have often considered groundwater in isolation from rivers and ecosystems that depend on it, and separate from holders of rights or entitlements in connected waters. History shows that this risks allowing a situation in which groundwater pumping can affect river flows, potentially drying rivers, and exacerbating conflict between holders of surface water and groundwater rights. It also increases risks of groundwater pumping damaging ecosystems that are fully or partially dependent on it. A wide variety of ecosystems may be groundwater-dependent, including those associated with rivers, wetlands, springs, terrestrial vegetation, and coastal, estuarine, near-shore, and marine areas. Law and policy tools for integrating groundwater management with surface water management seek to forge these missing policy links between groundwater and surface water, and between groundwater and ecosystems.

Integrated groundwater management means adopting policies that recognize the links between groundwater and the broader water system, including rivers, wetlands, other ecosystems, and users of connected waters

Across both Australian and western U.S. states, pumping groundwater poses a key law and policy challenge: how to deal with the impacts that pumping has on connected surface waters and groundwater-dependent ecosystems, while not unduly constraining groundwater use. We call management that achieves this "integrated groundwater management" because it integrates these considerations, rather than seeing groundwater in isolation from connected water sources and environments. Integrated groundwater management also requires carefully managing aquifers that are not connected to surface waters and GDEs: they are not only highly valuable resources in themselves; depleting aquifers can indirectly affect surface waters, by increasing pressure on them when aquifers are economically exhausted.

A comparative approach to integrated groundwater management

"It's a global issue, and having this kind of cross-country collaboration provides a powerful atmosphere for identifying solutions to universal issues."

–Steven Clyde, workshop attendee

The inaugural workshop of the Comparative Groundwater Law and Policy Program, held October 17-19, 2011, brought together a group of 44 Australian and U.S. groundwater managers and experts to identify promising law and policy tools for integrating groundwater management with the management of dependent surface water systems and ecosystems, and identifying the challenges that lie in establishing and using these tools.

A comparative approach is a powerful tool for identifying and developing policy solutions for integrated groundwater management

States in Australia and the western U.S. have pursued different elements of, and approaches to, the common challenge of achieving integrated groundwater management. Each has done so in the context of water scarcity, pre-existing legal frameworks, and the need to provide for consumptive and environmental uses of water. This combination of similarity and difference across jurisdictions makes a comparative approach particularly productive for investigating, developing and expanding the implementation of practical and successful policy solutions. A comparative approach uncovers promising policy tools previously unknown in other jurisdictions, and illuminates common policy themes and foundations for success that should guide future policy.

Initiating better groundwater management requires a catalyst

Intergovernmental agreements and compacts, federal law and policy, non-government organizations, and intensifying water demands have catalyzed the first steps towards integrated groundwater management in various locations across the western U.S. and Australia. Drought has also been a powerful driver of water reform. But there is a need to further catalyze and strengthen action across a broader geographic area, particularly at a local level. Workshop participants identified several powerful catalysts, which water managers can use to spur action, for example: calculating and communicating the local costs of failing to control groundwater pumping; using models to visualize scenarios of future groundwater conditions; and identifying and promoting natural “icon sites”, like wetlands and springs that are groundwater dependent. Expanding these tools would help achieve better groundwater management across both the western U.S. and Australia.

A range of policy tools is available to ensure that wells do not inadvertently deplete streamflow, or damage connected ecosystems, while minimizing economic disruption to groundwater pumpers. Aquifer storage and recovery and programs that allow pumpers to offset the impacts of groundwater pumping have been effective in this context in the U.S., and warrant further investigation in Australia.

Law and policy for integrated groundwater management must consider the potential for new and existing groundwater pumping to deplete connected streams. Across Australia and western U.S. states, placing a moratorium on new pumping, or new pumping that affects streams, is a relatively common policy response. U.S. states have also developed creative and sometimes complex mitigation programs to allow further economic development using groundwater, while requiring no net impact on connected streams. These programs typically require a prospective pumper to buy and retire existing water rights or carry-out conservation works to compensate for the stream-depleting impacts of using the new well. Some Australian states apply similar “make good” requirements in narrow circumstances, for example, in relation to groundwater use by petroleum tenure holders that affects nearby bores. Similar “mitigation” or “make good” policies could be considered for adoption more widely in stressed basins in Australia.

Dealing with the impacts of established wells, which support existing water uses, is naturally much more contentious than dealing with the potential impacts of new pumping. Two categories of mechanisms are commonly used to deal with these impacts: imposing measures that reduce pumping (in terms of volumes, controls on the timing of pumping, seasonal water assignments to tailor volumetric limits to climatic conditions, or efficiency requirements); and building physical infrastructure to facilitate increasing streamflow.

Successful initiatives to reduce groundwater pumping have allocated reductions in different ways, depending on local regulatory, hydrologic, cultural and political conditions. This has sometimes led to surprising reversals of commonly accepted water policy principles. Some local areas in the western U.S. have chosen to pool the existing withdrawal rights and “share the pain” of reductions, disregarding the seniority of individual rights, which usually regulates water allocations. Some basins in Australia have chosen to apply different levels of pumping reductions to different uses, based on the economic value of the uses, moving away from a common pool approach that normally applies to water allocations in Australia. These examples demonstrate that workable solutions to thorny problems can be found by adopting a flexible approach to managing water, rather than adhering rigidly to the principles (like priority according to seniority in time) that conventionally characterize allocation frameworks. Experience across both regions highlights the value of applying reductions using an incremental approach, and using markets to minimize the economic cost of reducing pumping by ensuring that high-value uses can continue to access groundwater.

A variety of infrastructure-based measures can deal with established pumping impacts. They include: developing and/or switching to sources of water that are under less stress; scheduling pumping among a group of well owners to even out their effects; and using aquifer recharge facilities to store floodwater underground and later recovering it or releasing it naturally to streambeds to mitigate the impacts of historic and on-going groundwater withdrawals.

More generally, aquifer storage and recovery (ASR) can be used to increase the reliability of a water supply system by storing excess surface water underground when it is available, and recovering it in times of surface water shortage. ASR is well-established in western U.S. states, but still in early development in Australia. U.S. experience suggests that market-based water banking systems (which facilitate an overlying owner “renting” access to aquifer storage space, and selling rights to recovered water) can greatly increase the utility of developing aquifer storage and recovery projects by expanding access to the stored water, beyond the overlying landowners.

Key challenges in expanding the use of ASR are better defining property rights to unconventional source waters, particularly urban stormwater and wastewater, defining access rights to aquifer space, retaining land suitable for recharge facilities in an undeveloped state, and investigating the potential impacts of the technology on groundwater fauna. In addition, it is imperative that an accounting system for the storage and future recovery of water is maintained by an independent and reliable authority, and that the ecological impacts of diverting “excess” streamflow are considered.

A variety of policy tools are evolving, particularly in Australia, to help agencies consider how wells may impact ecosystems that depend on groundwater. These approaches need further development and more widespread implementation. Even so, they suggest a promising path for protecting ecosystems in the western U.S.

In addition to recognizing the effects of pumping groundwater on streams, and on rights to water in streams, integrated groundwater management must consider the impacts of pumping groundwater on other, non-riverine ecosystems that depend on groundwater. These include wetlands, springs, forests, and life within aquifers themselves (for example, microbes, small crustaceans, and soil algae). In general, protections for such ecosystems take effect in a piecemeal fashion in the western U.S., via endangered species legislation rather than through water law, and there are few large-scale efforts to identify such ecosystems.

By contrast, protecting groundwater-dependent ecosystems is an area of rapidly growing attention and importance in Australia. Nascent policy mechanisms for protecting groundwater-dependent ecosystems in Australia include: using restrictions on groundwater pumping that vary, depending on surface water availability; applying buffer zones between wells and key environmental assets; allocating a percentage of recharge to water-dependent ecosystems; and constraining pumping to maintain groundwater at a level that enables dependent ecosystems to access the groundwater source. Western U.S. states could usefully consider Australian experience in this area.

Attracting and maintaining stakeholder involvement is a common challenge in managing groundwater.

Stakeholder participation and substantial local involvement in groundwater management are well established across the western U.S. and Australia. Indeed, local stakeholder buy-in is a central theme of success stories in governing groundwater.

Successful engagement with stakeholders often involves committees of stakeholders advising a governing body and developing management plans, however, attracting and maintaining the participation of stakeholders through lengthy and involved engagement processes are common challenges. A key factor in successful stakeholder groups is a “champion” who maintains the commitment of the group, and holds it together in the face of complex and contentious issues.

Beyond consultation, stakeholders can contribute powerfully to the development and implementation of groundwater management tools, in partnership with agencies

In addition to confirming the importance of stakeholder involvement in governing groundwater, the workshop discovered that stakeholders can contribute powerfully to the development of groundwater management tools. Agencies can increase the acceptance of groundwater models by establishing modeling committees comprised of experts and stakeholder representatives, and by using neutral third-parties to review models. Partnerships between environmental NGOs and government agencies can pool their expertise to develop protocols for identifying and monitoring groundwater-dependent ecosystems (GDEs). NGOs can also carry-out on-ground activities, such as conservation initiatives, which provide water for programs to mitigate the impacts of groundwater pumping that allow further groundwater development.

Law, policy, and science need to be better connected to manage groundwater more effectively.

Law, policy, and science need to be linked to effectively manage groundwater, surface water, and their dependent ecosystems. But traditionally, water law has developed around drastic simplifications of hydrologic science, and in complete isolation from ecological science. Integrating these elements is a common and ongoing challenge.

Experience shows that investing in science at the outset of a management planning process leads to better management solutions. Water managers can avoid “paralysis by analysis” by ensuring that the pursuit of better data is tied to the benefits yielded by more information, rather than gathering information for its own sake. Remaining areas of uncertainty should be used to trigger a transparent dialogue about who bears the risks associated with not having the desired information, or the overall uncertainty related to the information gathered and outcomes hypothesized.

Weak links remain in implementing policy for integrated groundwater management, particularly relating to protecting groundwater for ecological purposes.

In the western U.S., arguably the single largest groundwater policy gap is the missing link between regulating and managing groundwater pumping, on the one hand, and considering ecological requirements for groundwater, on the other hand. Though Australia has travelled further down this policy path, there is now a need to translate policy into action, expand policy horizons to encompass sustaining ecological processes as well as ecosystems, and ensure transparent decision-making on ecological water requirements.

Mitigation programs and ASR present significant opportunities to increase access to groundwater where appropriate and increase overall water reliability in Australia.

In Australia, substantial opportunities exist to better develop state law and policy frameworks for ASR, building on existing national guidelines, and to explore the potential for mitigation programs to safely allow increased groundwater pumping in basins where the available groundwater supply is fully allocated.

Many other important challenges remain across nearly every category of law and policy tool for integrated groundwater management identified by the workshop.

In addition to the significant policy opportunities posed by considering altogether new policy tools—mitigation programs in Australia and comprehensive GDE protections in the western U.S.—there is considerable scope to refine policy and practice across nearly every category of law and policy tool identified by the workshop.

- **Catalysts to spur integrated groundwater management**: policy-makers and water managers increasingly will need to consider how climate change, population growth, and population shifts will drive groundwater management in the context of connected surface waters and dependent ecosystems.

- **The impacts of new pumping**: given concerns in some states about whether mitigation programs truly offset the impacts of groundwater pumping, there is a need to assess whether these programs effectively deal with the broad range of potential impacts of pumping groundwater on streams including the volumetric impacts on surface water quantity, the timing of the depletion, temperature and water quality.

- **Reducing groundwater extractions to deal with the impacts of existing pumping**: economic impacts pose a key obstacle to reducing groundwater extractions. This warrants investigating whether more widespread groundwater trading and water banking could help reduce the economic impacts of protecting surface waters.

- **Using infrastructure to deal with the impacts of existing pumping**: allocating the costs of infrastructure is a key issue, given the broad range of actors involved. Policy should transparently consider how costs should be borne by irrigation districts whose infrastructure is used, neighboring well owners, downstream surface water users, and groundwater pumpers whose actions have the impact that the infrastructure is intended to address.

- **Aquifer storage and recovery**: ASR policy should proactively safeguard sites suitable for recharge, ensuring facilities are located in a strategic, rather than ad-hoc manner. This includes ensuring that recovery of stored water occurs within the area of hydrologic impact, to avoid negative effects on the area of recovery. Property rights in relation to ASR often need clarifying to further encourage this tool, particularly in Australia. l

- **Stakeholders**: investigating how to communicate groundwater issues more effectively, and how to ensure ongoing commitment to engagement processes, would help to improve and sustain stakeholder processes.

- **Linking science and policy**: significant government funding of groundwater science could be better linked to groundwater management by discovering how different ways of providing this information affect management decisions, and how varying degrees of data and policy complexity affect the success of management solutions.

Many of the successful policy approaches explored by the workshop are restricted to a small number of jurisdictions—groundwater management could be significantly improved by expanding the implementation of these approaches to more groundwater basins in both countries.

Next steps

The inaugural workshop of the Comparative Groundwater Law and Policy Program will be followed by a second workshop in Sydney in June 2012, which will focus on a number of important and interrelated issues highlighted during the inaugural workshop, namely: 1) managing the interfaces between hydrological and ecological science, groundwater policy and management, and stakeholder engagement; and 2) establishing and administering groundwater markets and trading, including buy-backs and water banking.

In addition, a website is under development to increase the reach of the findings of the Comparative Groundwater Law and Policy Program. It will include workshop materials; research outcomes, including peer-reviewed journal articles; and a “virtual tour” of integrated groundwater management, which will highlight successful approaches and opportunities for policy development across different regions of the western U.S. and Australia.

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PART A: FOUNDATIONS FOR INTEGRATED GROUNDWATER MANAGEMENT

1. Managing groundwater quantity and pumping impacts on streams and ecosystems in Australia and the western U.S.

1.1 Basic challenges in integrated groundwater management

States in Australia and the western U.S. face a key law and policy challenge in protecting streams and ecosystems from the effects of pumping groundwater, while not unduly constraining groundwater use.

In both the western U.S. and Australia, states have the primary role in managing groundwater quantity, as against the federal government (though in some states, like California, local entities have the primary role, in practice). With full development of surface water rights in many areas, and other stressors like drought, depleting streamflow by pumping connected groundwater is a crucial and contentious issue that is seldom easily resolved. Stream depletion can affect the holders of rights or entitlements to water in rivers, like cities and farmers, as well as riparian and riverine species and ecosystems.

As in Australia, most western U.S. groundwater law and policy traditionally did not recognize interactions between groundwater and surface water—that is, it ignored the potential for groundwater pumping to deplete connected streamflow. Figure 1 shows how falling water table levels, which can be caused by pumping groundwater, can dramatically change a stream system, from being a "gaining" stream, which receives inflows of groundwater ("baseflow"); to being a "losing" stream, which leaks water underground to the underlying aquifer; to being entirely disconnected from the aquifer. Figure 2 shows how even while a stream remains a gaining stream, falling groundwater levels deplete streamflow as the stream "gains" less groundwater. These effects are all symptoms of overdraft—conditions under which declining groundwater levels threaten serious economic, social and environmental harms.

Modern policy mechanisms for recognizing that pumping groundwater can deplete streams developed after many groundwater uses were well established, which has made reducing these existing groundwater uses difficult. Furthermore, in many places, law and policy fail to prevent new streamflow depletions caused by increased groundwater pumping. In some places, this is because one of the biggest threats to streamflow is the proliferation of domestic wells that are exempt from regulation. In other places, law and policy for preventing such impacts is not well implemented.

Common policy responses to depleted or overused surface waters- like imposing moratoria on further diversions- traditionally have prohibited only new surface water rights, and not new wells that tap groundwater connected to streams. Ironically, these moratoria put further pressure on the use of groundwater, exacerbating the problem of stream depletion.

Figure 1 also shows how, as groundwater levels fall, the resource may become inaccessible to vegetation that depends on it. Indeed, there is increasing recognition that groundwater pumping also damages groundwater-dependent ecosystems (GDEs)—both those that depend on groundwater-derived baseflow in rivers, and also terrestrial ecosystems, like forests and wetlands. This harm is only starting to be addressed by law and policy, and tools and strategies are needed to deal with it, to ensure that these systems are not inadvertently damaged. Impacts on GDEs also present a challenge for scientific frameworks that are more accustomed to environmental water management in the surface water context.

Effective groundwater management also requires carefully managing aquifers that are not connected to surface waters and GDEs: they are not only highly valuable resources in themselves; depleting aquifers can indirectly affect surface waters, by increasing pressure on them when aquifers are economically exhausted.

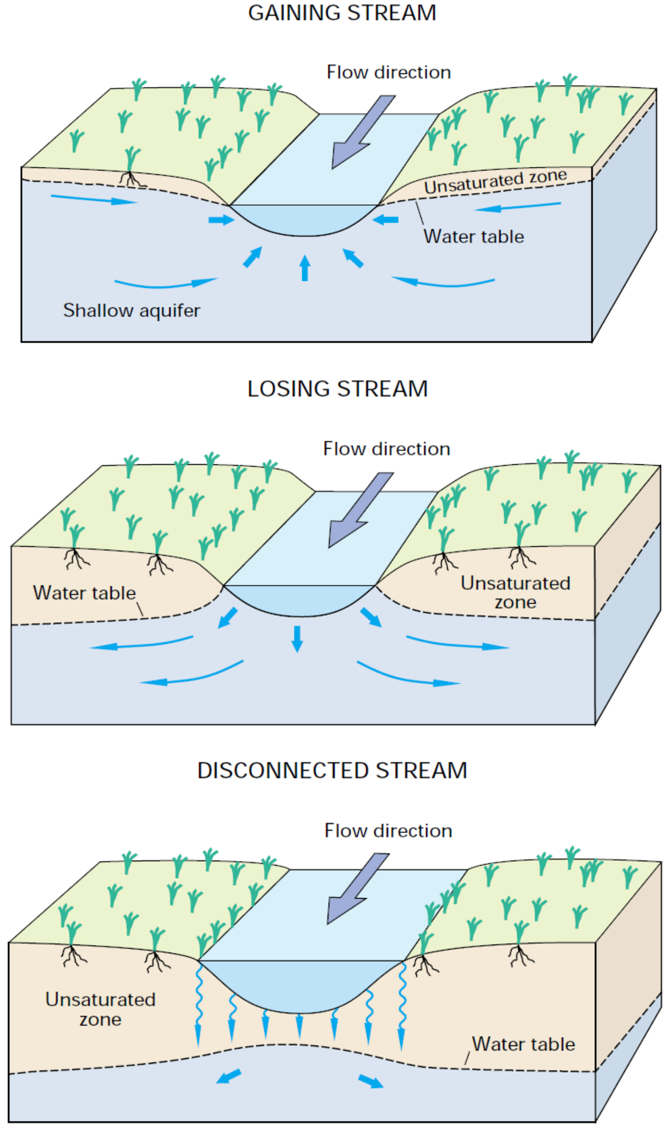

Fig. 1: Effects of a falling groundwater level on streams, showing transition from gaining stream, to losing stream, to disconnected stream (Winter, T. C., J. W. Harvey, et al. (1998). Ground water and surface water: a single resource (US Geological Survey Circular 1139). Denver, Colorado, U.S. Geological Survey).

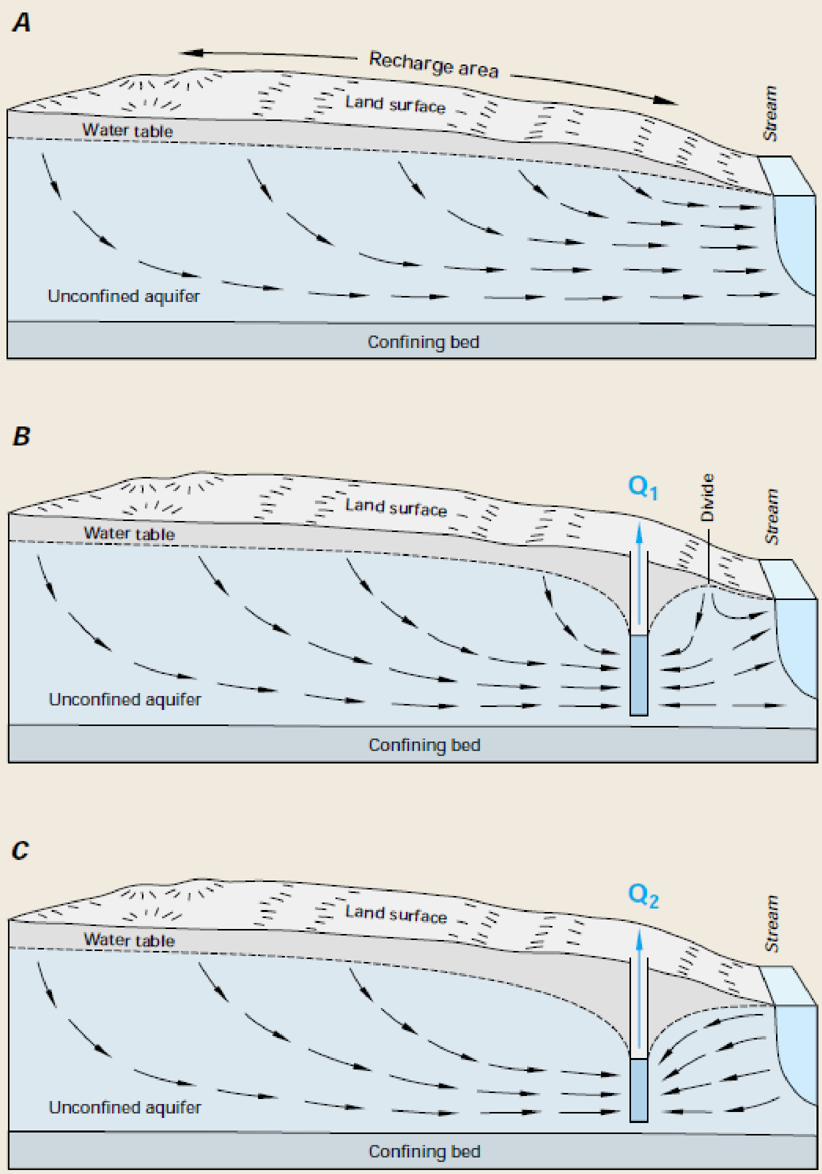

Figure C–1. In a schematic hydrologic setting where ground water discharges to a stream under natural conditions (A), placement of a well pumping at a rate (Q_1) near the stream will intercept part of the ground water that would have discharged to the stream (B). If the well is pumped at an even greater rate (Q_2), it can intercept additional water that would have discharged to the stream in the vicinity of the well and can draw water from the stream to the well (C).

Fig. 2: Effects of groundwater pumping on water table levels and discharge to streams (Winter, T. C., J. W. Harvey, et al. (1998). Ground water and surface water: a single resource (US Geological Survey Circular 1139). Denver, Colorado, U.S. Geological Survey).

1.2 Water allocation frameworks

Australian and western U.S. states address the need for integrated groundwater management using a variety of approaches, providing an extensive laboratory for testing policy solutions under different legal frameworks.

States in Australia and the western U.S. have pursued different approaches to common challenges of integrated groundwater management, each within the context of water scarcity and the need to provide for consumptive and environmental uses of water. These factors make a comparative approach particularly productive for further policy development. As a group, these jurisdictions function as a laboratory, testing potential policy solutions for integrated groundwater management.

While they face common challenges and have comparable legal systems in a general sense, states in the western U.S. and Australia use different systems for allocating rights (in Australia: entitlements) to water. The dominant allocation system in the western U.S. is prior appropriation, under which a right that is developed earlier in time is senior to, and therefore, more reliable than a right developed later in time. Water rights are limited to the amount of water needed for “beneficial use”. In some jurisdictions, a senior surface water right holder can seek redress if their right is impaired by a junior pumper of connected groundwater, provided the senior’s use of water is reasonable. This system can produce highly developed mechanisms for resolving conflicts between water right holders.

By contrast, the dominant method of allocating water in Australia is for a state agency to allocate entitlements to withdraw water under a license from a common “pool” of available water. Water allocations under these entitlements are announced and revised regularly by the government, depending on water availability. The reliability of entitlements in each of a small number of classes, for example, “high” or “low” reliability, is the same.

Under the Australian water allocation system, all the users of the common “pool” share the reduction in surface water availability caused by pumping connected groundwater. Accordingly, Australian policy typically has lacked the attention given to groundwater-surface water conflicts in the western U.S., where clearer and more substantial impacts on individual senior right holders are powerful motivators. However, Australian jurisdictions pay comparatively more attention to the need to protect ecosystems dependent on groundwater, though this is a nascent policy area that has arisen alongside attention given to the ecological effects of severe drought on surface water systems.

Fig. 3: U.S. and Australian state, regional and local areas discussed in this working paper

2. Catalysts for integrated groundwater management

This paper has already suggested that the nature of water allocation under the doctrine of prior appropriation drives, at least in part, the increased attention given to groundwater-surface water conflicts in western U.S. states, compared to Australian states. Australian history shows that long-term drought can be a catalyst for wide-ranging water reforms. Short-term "focusing events", like pollution scares, can also draw community attention to an issue and given policy makers the opportunity to propose new policies in a receptive environment. Moving beyond these structural factors and short-term events, policy-makers can benefit from understanding the catalysts for integrated groundwater management in various case study areas—state, regional and local—particularly those that can be used actively as tools to drive change. These suggest potential avenues for reforming law and policy to drive change in other geographic areas.

2.1 What we know

Federal law and policy, intergovernmental agreements, and new water demands drive integrated groundwater management in Australia and the western U.S.

Australian and western U.S. states have experienced some common catalysts for integrated groundwater management: federal law and policy, intergovernmental agreements, and new water demands. Each of these drivers has had effect to different degrees, and has taken different forms, in each region. Litigation has been important in some U.S. states, but is much less common in Australia.

The federal Endangered Species Act has been a key catalyst for addressing the ecological aspects of integrated groundwater management in the U.S.

Although primary control over water quantity management rests with the states rather than the federal government, we know that certain federal laws and policies have been important drivers for the development and implementation of mechanisms for integrated groundwater management across the western U.S. and Australia. In the U.S., the Endangered Species Act (ESA) concerns have affected groundwater management to protect baseflow-dependent, riparian, and subterranean GDEs. For example:

- In **Idaho**, water requirements for endangered salmon and spring-dependent snails were a driver of the development of the **Eastern Snake River** Plain Aquifer Comprehensive Aquifer Management Plan, which uses groundwater-to-surface water conversions, aquifer recharge, demand reduction, and weather modification to increase spring and river flows and water supply reliability.
- The Platte River Recovery and Implementation Program (Program) aims to restore **Platte River** flows to 1997 levels by 2019, chiefly 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 “offset” (mitigated).

- After protracted litigation, groundwater pumpers overlying **Texas**’ **Edwards Aquifer** are now subject to pumping restrictions, which are tied to water levels and spring flows, to protect endangered fish, amphibians, subterranean invertebrates, and plants. Pumping restrictions with such triggers have been effective in this physical system, in which pumping groundwater very rapidly affects springs. A Texas Supreme Court decision handed down in February 2012, ruling that groundwater is the personal property of overlying landowners, has created uncertainty about the ability of the Edwards Aquifer Authority to restrict groundwater pumping without compensation.

- Riparian habitat along the **San Pedro River** in **Arizona** harbors multiple species that are listed as endangered under the ESA, and experiences impacts from groundwater pumping from nearby Fort Huachuca military base and local agriculture. This led to new state legislation to protect baseflow in the river.

- Groundwater pumping also affected wetlands-dependent migratory shore-bird species at **Walnut Creek** in **Kansas**; and at the **Carmel River** in northern **California**, which drove the declaration of the Walnut Creek Intensive Groundwater Use Control Area, and a court order to restrict groundwater pumping, respectively.

Species protections have affected Australian groundwater management less directly, but new federal water legislation will greatly influence future groundwater management.

In Australia, the Environment Protection Biodiversity Conservation (EPBC) Act, which is analogous to the U.S. Endangered Species Act, has had a much less prominent role in in prompting the protection of GDEs from the impacts of groundwater pumping. The legislation does protect some GDEs, for example, the community of ecosystems and species dependent on groundwater discharge from the **Great Artesian Basin** springs. However, there has been no substantial EPBC Act litigation relating to GDEs.

By contrast with endangered species protections, the 2007 federal Water Act represents a much more profound federal driver of integrated groundwater management in the **Murray-Darling Basin** (though most of it does not apply to Australia as a whole). In that Basin, the Water Act’s requirements overlie the water laws of states and territories, which have the primary role in regulating water in Australia. The Water Act derives, in part, from concerns about biodiversity. It provides for setting binding “sustainable diversion limits” from surface water and groundwater sources in the Murray-Darling Basin—a process that is presently underway. This process links with endangered species protections, by deeming EPBC Act-listed species to be “key environmental assets” to be protected when setting sustainable diversion limits. The Water Act was the culmination of almost two decades of water reforms, and a response to ecological damage wrought by an era of severe drought.

Interstate compacts and intergovernmental agreements are further key catalysts of integrated groundwater management across the U.S. and Australia, respectively.

Interstate compacts in the U.S. typically do not deal with groundwater explicitly, and lack detailed accounting and compliance procedures and timeframes. Nonetheless, interstate compact obligations have led upstream states to mitigate or "offset" the stream-depleting effects of groundwater pumping within their boundaries to meet their supply obligations to downstream compact states. For example, in order to meet its obligations to Texas, **New Mexico** acquires groundwater rights from farmers, and uses fossil groundwater in "pump and dump" schemes to offset depletions to the **Pecos** and **Rio Grande Rivers**.

Groundwater pumping affecting interstate rivers has also driven interstate litigation and subsequent policy moves by western U.S. states to reduce the offending pumping. For example, in 1995 the U.S. Supreme Court awarded damages to Kansas of around US$35 million for excessive groundwater pumping in Colorado that breached the **Arkansas River** Compact. A comprehensive model and monitoring program are now in place to ascertain whether Colorado is in compliance with its obligations under the Compact. Ongoing litigation brought by **Montana** against **Wyoming** claimed, among other things, that groundwater pumping in Wyoming depletes water in tributaries of the **Yellowstone River**, breaching Wyoming's obligation under the Yellowstone River Compact to provide for certain water uses downstream in Montana. In an initial ruling, the Supreme Court ruled that although the Yellowstone River Compact does not explicitly mention groundwater, it limits groundwater pumping that is hydrologically connected to surface water.

By contrast, Australian interstate water allocation agreements have not been interpreted to deal with the effects of groundwater pumping on rivers. However, a key Australian intergovernmental water policy—the National Water Initiative—aims comprehensively to improve water management. Under the National Water Initiative, states agreed to a suite of water reforms aimed at water planning, dealing with stressed water systems, water accounting, trade, and pricing. Among other things, states agreed to provide environmental water entitlements for ecosystems that depend on water, including groundwater; to develop water resource accounts that integrate surface water and groundwater; and to identify areas where there is a high degree of interconnection between groundwater and surface water. However, groundwater-related measures traditionally have been the weakest link in implementing reforms under the National Water Initiative, which led to the creation of a Groundwater Action Plan in 2007, which is discussed further in Part C.

The recognition and assertion of tribal rights to surface water and groundwater have also spurred integrated groundwater management in the western U.S.

Tribal rights typically have high priority within prior appropriation systems. Tribal federal reserved water rights typically have a priority date that is earlier than state-created water rights. While the nature and extent of the tribal rights varies from tribe to tribe, increasingly these tribal rights form the basis for claims that ground water pumping affects these rights. For example, the Swinomish Tribe successfully challenged the approval of mitigation plans (which it asserted were inadequate) to compensate for the impacts of groundwater pumping on salmon populations in the **Skagit River Basin** in **Washington**.

Alternatively, tribes may have rights to groundwater directly. The Lummi Indian Nation has formal rights to groundwater underlying the **Lummi Reservation** in **Washington**; and in the **Snake River Basin** in **Idaho**, the Nez Perce Tribe has tribal rights to both surface water and interconnected groundwater. The recognition of tribal water rights, including rights to groundwater underlying the **Fort Hall Reservation** in **Idaho**, led the Shoshone and Bannock Tribes, which holds both surface water and groundwater rights, to establish the Shoshone-Bannock Tribal Water Bank, which leases (temporarily transfers) water entitlements. Water trading can be an important mechanism in integrated groundwater management, as discussed later in this paper. In **Arizona**, the **Gila River** Indian Community has state and federally recognized rights to groundwater beneath the reservation, which has led to state restrictions on groundwater pumping within a half-mile radius of the reservation's boundary, and state obligations to recharge the aquifer on or near the reservation.

By contrast, Australian policy has yet to address the potential effects of groundwater pumping on native title rights that depend on surface water flows, although the National Water Initiative mentions cultural uses of water.

In some cases, environmental NGOs drive integrated groundwater management through litigation, particularly in the western U.S.

In **Montana**, lawsuits brought by Trout Unlimited, a NGO that focuses on protecting coldwater fisheries, successfully argued that, contrary to existing practice, the state was obliged to consider the impact of granting groundwater pumping permits on surface flows. Trout Unlimited challenged both the state's general permitting practices, and also the granting of individual permits.

In **California**, another NGO, the Environmental Law Foundation, is presently undertaking litigation against the State Water Resources Control Board. The NGO argues that the Board should regulate groundwater, in the context of allegations that pumping groundwater has caused the decline of fish populations in the connected **Scott River**, a navigable waterway that is subject to the "public trust" doctrine. Under the public trust doctrine, the state holds its navigable waters, tidelands, and submerged lands of navigable waters in trust for the benefit of the people. The public trust protects navigation, fishing, recreational uses, fish and wildlife habitat, and aesthetics. In some states, such as California, the state has a duty to take account of the public trust in planning and allocating water resources, and a continuing duty to supervise the taking of water resources that are subject to the trust. If the Environmental Law Foundation's arguments were successful, the Scott River case would represent a substantial progression in the public trust doctrine, and a novel way of recognizing groundwater-surface water interaction.

By contrast, Australian environmental NGOs appear currently to be less engaged in groundwater management issues.

State and regional groundwater policy can also provide tools to catalyze better groundwater management within local groundwater basins, through facilitating collaborative management, mediation, and promoting public awareness of groundwater issues.

Collaborative approaches, which feature strongly in groundwater management in both the western U.S. and Australia, require a catalyst to bring people together. Litigation can force stakeholders to come together to confront a water management problem, but it is costly, and may not build community support for a common objective. Workshop attendees suggested that water policies could include a compulsory local mediation component to motivate action to address local problems while also helping to build trust among local actors. Agencies can also present scenarios that show the local costs of inaction to motivate local stakeholders and help to catalyze better groundwater management. To reinforce these tools, where groundwater is primarily locally managed (as in California), the risk of state intervention can support better local management.

Key lesson

Hydrologic models and graphic "conceptual models" can catalyze policy discussions about groundwater management by building visual scenarios of the future, using graphs of declining water tables, and examining the economic and

Identifying and promoting public awareness of iconic natural sites and values that depend on groundwater can catalyze a stewardship approach to groundwater management both among local communities and also more broadly, as shown by the Australian experience of identifying and promoting "icon sites" in the **Murray-Darling Basin**.

2.2 What we need to know

Climate change and increasing water demands may further drive integrated groundwater management in the future. Policy will need to develop to address these drivers.

While we can expect existing catalysts for integrated groundwater management, discussed above, to continue in effect in some form, additional drivers will likely further motivate law and policy for groundwater management in the future. Changing water availability and demands caused by climate change, population growth, and geographic population shifts will likely be important.

In many cases, it is unclear precisely how much climate change will affect groundwater and surface water availability and demands, but future policy will need to consider how to adapt to changes in these areas. For example, reduced surface water reliability may increase the demand for, and relative value of, groundwater. This could increase the value of surface water-to-groundwater trading, and the importance of regulatory frameworks for dealing with such trading.

Spatial variation in the degree of change to water availability and demands may also affect how different geographic areas are prioritized for introducing integrated groundwater management, and the degree of caution warranted in granting groundwater permits or licenses. A 2010 court order, for example, upheld the decision of a Victorian rural water authority to refuse to grant groundwater extraction licenses to irrigators in an area near **Port Fairy**, in **Victoria**, on the basis of a lack of certainty about the future availability of groundwater due to climate change.

A further likely catalyst for change in groundwater management is the continuing growth in groundwater demand, in some areas, for types of uses that presently regulatory frameworks largely exempt from controls that apply to other uses, like stock and domestic and other permit-exempt wells. Population growth in, and population shifts to, arid areas will be a contributing factor, since history suggests that they will place additional pressure on groundwater resources, which often form the major water supply in arid areas. New residential groundwater uses that take advantage of permit-exempt wells have already created tension between surface water and groundwater users, for example in **Montana** and **Washington**. In Australia, groundwater "intercepted" by stock and domestic wells, which generally do not require licenses, raise similar concerns. Future policy will need to consider how to deal with the cumulative impacts on surface water of these uses.

One possible approach to dealing with the stream-depleting impacts of groundwater pumping from wells that are not required to be permitted or licensed would be to require mitigation of these impacts. However, administering such a program for many wells could challenge agencies that already face stretched resources.

PART B: LAW AND POLICY MECHANISMS FOR INTEGRATED GROUNDWATER MANAGEMENT

According to workshop attendees, successful solutions for integrating groundwater and surface water in law and policy should start with mechanisms to prevent streamflow depletion becoming worse—that is, ensuring that new groundwater pumping does not place further pressure on surface waters. This then opens up the field for creative solutions to improve groundwater management, for example, by dealing with the impacts of existing pumping and developing tools to optimize overall water availability using ASR. Understanding the mechanisms that are already in place to do these things, how they operate, how they vary, and the key issues that arise in designing them, can inspire a fresh look at integrated groundwater management across both countries.

Workshop attendees discussed policy mechanisms belonging to four distinct categories:

- addressing the impacts of new groundwater pumping on the holders of rights or entitlements to surface waters at the permitting/licensing stage;
- dealing with the historical and ongoing impacts of existing wells on the holders of rights or entitlements to surface waters;
- maximizing water availability by storing surface water in aquifers, in addition to surface reservoirs, for later recovery and use; and
- dealing with the impacts of pumping groundwater on dependent species and ecosystems, which are not protected by water rights or entitlements.

Each category is discussed in turn, below.

1. Integrating groundwater and surface water: considering the impacts of new pumping

1.1 What we know

Some western U.S. states seek to prevent wells depleting streamflow by regulating surface water and groundwater rights together, connecting the reliability of these rights. This strategy is much less common in Australia.

Many western U.S. states, like **Washington**, **Idaho**, and **Kansas**, use the same water allocation system for both surface water and groundwater. That system is prior appropriation, which allocates water based on when the right was established. The system often accounts for physical interactions between the two sources, in terms of impacts on water rights, by administering the groundwater and surface water rights together. Applicants for permits are required to show that there will be no impairment of existing rights, whether groundwater or surface water, before a permit may be issued. In calculating the effects of a proposed well, some Groundwater Management Districts in **Kansas** include effects on baseflow by using "baseflow nodes"—fictional "wells" that are located every quarter-mile down in the middle of a stream. These are assigned a quantity of water that is equivalent to the estimated pro-rated baseflow at that point. In assessing a proposal to appropriate groundwater, the proposed well, together with every other water right (including baseflow nodes) within a two-mile radius of the proposed well, must not exceed a specified "safe" or "sustainable" yield value.

Under prior appropriation, stream depletion can also be dealt with after a groundwater permit has been issued: a senior surface water user (including the holder of a non-consumptive instream flow right) whose right is being affected by a junior groundwater user may request that the latter's use be curtailed.

Connecting the administration of rights to surface water and groundwater is also possible outside a pure prior appropriation system. **California**, for example, has different legal frameworks for surface water and groundwater. Groundwater law is based on a scheme of correlative rights, and surface water law is based on a complex hybrid of several systems. However, California law considers one legal "type" of groundwater—"subterranean streams flowing in known and definite channels"—to be subject to regulation like surface water. Accordingly, the State Water Resources Control Board, which is charged with regulating surface water, also regulates access to this type of groundwater, applying the same considerations to both. Unfortunately, there is no "bright line" test for determining whether a particular body of groundwater is a subterranean stream; definitively settling this requires litigation, the absence of which leads to uncertainty about whether groundwater permitting requirements apply (since pumping the more common "percolating groundwater" does not require a state permit). **Arizona** manages its surface water and groundwater supplies similarly, however, in the state's most populated groundwater basins (80% of its population resides in these basins), permits are also required to withdraw groundwater. Such permits will not be issued by the state if pumping is projected to deplete surface flows, including the subflow that supports the surface flows.

In some areas of Australia, the same allocation system is used to administer connected groundwater and surface water resources in a way that is roughly analogous to U.S. systems. The reliability of groundwater and surface water entitlements is connected because they are "pooled" for the purposes of announcing the level of water allocation that will be available under an entitlement, in a given season. This can prevent surface water being over-used when new licenses are issued to pump connected groundwater: a water availability determination covers both connected sources, meaning that the total amount of water allocated from the connected sources remains the same, even if new groundwater licenses are issued. On the other hand, making allocation announcements in an unconnected way would result in allocating the same water twice—once under a surface water entitlement, and once under a groundwater entitlement that, in reality, "pulls in" surface water. **Queensland** law, for example, enables the relevant minister to declare, similarly to the **California** situation, that an aquifer under a watercourse is water in a watercourse. An entitlement to water in such an aquifer has the same reliability characteristics as water in the overlying watercourse. **Victoria's** Upper **Ovens River**

Water Management Plan also allocates surface water and groundwater together, with the same effect.

In areas where all the available surface water has been allocated, a common response to the adverse impacts of pumping groundwater on holders of surface water rights, or ecosystems, is to impose a “cap” or moratorium on further groundwater development, creating “closed basins”. This has occurred, for example, in some **Victorian** groundwater management units, **Nebraska** natural resource districts, **Kansas** intensive groundwater use control areas, and areas of **Washington**.

Mitigation programs aim to enable increased groundwater pumping—and groundwater-dependent economic development—in basins that are already fully allocated, by protecting streamflow using schemes to offset the impacts of pumping.

Where a new groundwater pumping right would affect an existing right to connected surface water, or protected instream flows, obtaining that new right may be made conditional on mitigating (sometimes termed “offsetting”) the depletion to the stream caused by pumping from the new well. This is intended to prevent any change to the reliability of rights to surface water in that stream, caused by the groundwater pumping.

The key advantage of mitigation requirements is that they enable further economic development dependent on groundwater in basins that are fully allocated, while theoretically ensuring that the new pumping does not deplete a stream. Although they are relatively common in the U.S., mitigation programs are as yet apparently unknown to Australian water policy.

Mitigation programs can be very complex, aiming to mitigate not just the impacts of groundwater pumping on the volume of surface water, but also impacts on the quality and temperature of water, and the timing of the depletion. Mitigation methods include purchasing and retiring, or leasing, a surface water right; conserving water; or “pumping and dumping” water from an unconnected source into the affected stream.

Policies to mitigate the impacts of groundwater pumping on streams vary in a number of important ways, including: the elements that constitute significant streamflow depletion; the types of impacts on streamflow that require mitigation; the volumetric and geographic extent to which mitigation is permitted; and state-provided mechanisms for identifying replacement water. Each of these issues is described below, in turn.

Mitigation programs vary in how they determine when groundwater pumping becomes significant enough to require mitigation – the time it takes for groundwater pumping to deplete a stream, and the volume of the depletion, are crucial factors.

A key issue confounding integrated groundwater management generally, and mitigation programs in particular, is the time lag that commonly occurs between pumping groundwater and impacting streamflow. This time lag comes about because groundwater often moves slowly. Some states determine whether a proposed well will have a significant impact on a stream—one that requires mitigation—based on the volume of stream depletion that would occur within a certain time after pumping commences.

Western U.S. states adopt varying policy horizons to assess the significance of groundwater pumping for the purpose of mitigation programs. For example, **Arizona** has adopted a 100-year horizon, and **Montana**, a 500-year horizon, to assess the volume of stream depletion using hydrologic models. **Washington** takes a more conservative approach: it does not consider the lag between the pumping and the depletion; rather, it uses a "steady-state" approach that assumes that pumping occurs for such a long time that equilibrium is reached. This means policy-makers require mitigation for depletions that are potentially very distant in the future.

Given a particular policy horizon, states also vary in the calculated volume of stream depletion that they deem significant. For example, **Washington** applies the "one molecule rule", under which any ascertainable impact, determined using up-to-date scientific measurement techniques, is sufficient to require mitigation; **New Mexico** applies a similar approach. By contrast, under **Nebraska's** Platte River Recovery and Implementation Program, mitigation is required if a well would deplete the **Platte River** by 28% of the pumped volume within 40 years.

Mitigation programs also differ in the types of impacts on streams, caused by groundwater pumping, which the program requires a permit applicant to mitigate.

The most basic impact that groundwater pumping can have on streams is depleting streamflow, that is, an effect on water quantity. All mitigation programs require mitigation for this type of effect—but they do so in different ways. Some states require "bucket for bucket" mitigation, which require the volume of water that will be consumed by the new use to be replaced by adding the same volume of "new" water to the stream. A 1:1 ratio is used in **Montana**, for example. Other states require a higher ratio. For example, **Oregon's Deschutes** Groundwater Mitigation Program requires that leased replacement water amount to twice the volume of the depletion.

Complicating this impact on water quantity is the time lag effect discussed above. Some mitigation programs require that replacement water be put back into the stream at the same time as the depletion is taking effect. 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 water right—often, the most common type of water right available for mitigation purposes. Common policy approaches to dealing with mitigation timing are to calculate depletion on a monthly, seasonal or annual basis, with annual calculation being the least precise and arguably the least desirable.

Beyond water quantity effects, groundwater pumping can also affect the water quality and temperature of a stream. Some states require a mitigation measure to "make the river whole" along these dimensions, too. Mitigation requirements that do not include a temperature component have been controversial in **Oregon**, where salmon require cold water, and replacement water that derives from surface water sources tends to be warmer than the groundwater-derived baseflow.

Mitigation programs can help facilitate further groundwater development—up to a limit. Geographic and volumetric restrictions often apply.

Mitigation programs may be subject to limits in terms of the total volume of groundwater pumping that may be mitigated, and the geographic areas within which mitigation water may be sourced to compensate for depletion at a particular point in a stream. Geographic limits are intended to ensure that replacement water really does compensate for effects on streamflow at a particular location (and not at some more distant point); volumetric limits aim to provide an overall margin of safety, particularly in newly established mitigation programs.

Oregon's Deschutes Groundwater Mitigation Program imposes a cap on the permissible volume of new groundwater pumping that can be offset. It also uses zones within which mitigation must occur. These include a large "general zone of impact", and several smaller "local zones of impact", determined by subbasin boundaries, locations of low instream flows, and hydrogeologic information. In **Montana**, mitigation activities must occur in the same basin as the groundwater pumping, defined at the level of the 8^{th} Hydrologic Unit Code, a standardized watershed unit classification system used by the U.S. Geological Survey.

Some mitigation programs include a water bank component to help permit applicants find water rights to use as replacement water.

As well as the formal rules defining a mitigation program, some states use additional institutions to assist permit applicants to find or purchase water rights for mitigation purposes. For example, **Oregon's Deschutes** Groundwater Mitigation Program involves a state clearinghouse that functions as a water rights "bank" that groundwater permit applicants can access to find replacement water. In other cases, individual groundwater permit applicants must find their own mitigation measures, sometimes using private banking entities, for example, in **Nebraska**.

Some Australian states apply "make good" requirements that are similar to U.S.-style mitigation programs, in narrow circumstances, for example, in relation to groundwater use by petroleum tenure holders that affects nearby bores. In **Queensland**, petroleum tenure holders must enter "make good agreements" with the owners of bores, the capacity of which would be impaired by the former's activities. Make good measures include deepening or constructing a new bore, piping in water from an alternative source, and providing monetary or non-monetary compensation.

1.2 What we need to know

The complexity of developing and implementing mitigation programs gives rise to numerous unanswered policy questions.

Workshop participants raised a variety of unresolved policy issues related to mitigation:

- Are bucket-for-bucket mitigation requirements, which require one unit of water to be replaced in the stream for every one unit of water that would be consumed by a new groundwater use, sufficient? Should a lower ratio be used to account for uncertainty in the degree of groundwater-surface water connection? Should a higher ratio be used to account for other uncertainties in implementing the mitigation requirement, for example the lifespan of a corporate entity that is subject to the requirement?

- What is the best way to effect a culture change in a state agency that is seeking to implement mitigation requirements for the first time?

- Should it be permissible to use "fossil" (nonrenewable) groundwater to offset stream depletions? This occurs in some western U.S. states, for example, in **New Mexico**. Should there be other restrictions on source water for mitigation?

- How should public policy safeguard against businesses, which are subject to mitigation obligations, going out of business and not offsetting future stream depletions that will occur as a result of present pumping? How should it safeguard against approving mitigation using replacement water that may no longer be available due to management or climatic changes in the future?

2. Groundwater-surface water links: dealing with the impacts of existing pumping

2.1 What we know

Dealing with the unacceptable impacts on surface water of existing groundwater pumping is much more contentious than controlling new groundwater pumping to prevent impacts becoming worse, because individuals and economies have come to rely on the groundwater as a resource. Two types of mechanisms have been used to reduce existing groundwater pumping impacts: scaling back pumping and constructing infrastructure to offset stream depletions. This section discusses the key issues that arise in designing these mechanisms.

More generally, resolving groundwater problems can be more challenging than surface water problems, because groundwater users lack a shared point of diversion, and act independently of each other. Water management districts can be a helpful way to unite groundwater pumpers in search of common solutions to management problems.

Dealing with the impacts of established wells can be very contentious, making it vital to make decisions transparently and maximize the options available to reduce impacts.

Workshop participants agreed that, whatever the ultimate policy solution, there is a need for transparency about the processes, people, and evidence involved in making decisions about the acceptable impacts of groundwater pumping.

Where existing impacts are deemed unacceptable, participants suggested that negotiations with pumpers should focus on the pumpers' interests (for example, maintaining an agricultural way of life), rather than their position (for example, maintaining groundwater pumping at existing levels). This maximizes the options available to reduce existing impacts by illuminating potential alternatives to satisfy pumpers' interests.

Reductions in groundwater pumping can be allocated equally among all users, or differently among groups of users, based on priority in time, or economic value.

A key issue in designing policies to reduce groundwater use is how to allocate reductions among groundwater pumpers. Traditionally, Australian systems have favored equal reductions, and western U.S. systems have favored reductions based on the time that a right was established. However, case studies presented at the workshop demonstrate a wide variety of approaches: allocating reductions equally among all users, or differently among groups of users, based on priority in time, or economic value. Some approaches to reducing pumping involve market mechanisms in the form of government water buy-backs or pumper-to-pumper trading to minimize the economic and social impacts of reducing groundwater extraction. The Australian and U.S. examples presented here demonstrate that workable solutions to some of the most thorny groundwater management problems can be found by retaining flexibility in managing water, rather than adhering rigidly to conventional allocation frameworks.

The basic premise of the western U.S. system of prior appropriation is that when there is insufficient water available for a "senior" (that is, high-priority, earlier in time) surface water appropriator to fulfill his or her right, the rights of junior (later in time) water users, including junior groundwater pumpers, are curtailed to benefit the senior. Administering this system can be complicated, however.

Curtailing water rights based on priority can have sub-optimal economic outcomes if the economic value of lower-priority groundwater uses exceeds that of higher-priority surface water uses. Accordingly, various policy tools have been used in **Idaho**, **Kansas** and **Utah** to modify the effect of conjunctive administration based on priority. These tools involve allocating reductions among consumptive users on different grounds, or buying out senior rights holders:

- In **Utah**, the need to curtail a large number of junior groundwater uses under the prior appropriation system led to discussions of "unitizing" extractions and creating common pool resources, which would share cuts in water availability more evenly. Although this option was ultimately rejected as a state-level reform, local areas may voluntarily unitize under

2009 legislation. One area, in the **Escalante Valley** in southern Utah, has so far chosen to do so. This involves forming a groundwater management district, and agreeing on a groundwater management plan and pumping reductions with the State Engineer.

- **Kansas** law enables the Chief Engineer to declare an “intensive groundwater use control area” to manage water using an alternative method to prior appropriation. The **Walnut Creek** intensive groundwater use control area was declared in 1992, which led to the Chief Engineer reducing groundwater pumping by different groups of users by 22-72 per cent. This declaration enabled the Kansas Fish and Game Commission (now the Department of Wildlife and Parks) to fulfil its senior water right, which it used to water internationally important wetlands at **Cheyenne Bottoms**.

- In **Idaho**, groundwater pumping for irrigation impacted springs that fed trout hatcheries on the **Snake River**. Administering water rights based on priority would have had severe economic impacts, shutting down wells irrigating 58,000 acres to benefit spring-dependent trout production with a much lower total value. Ultimately, the state of Idaho and groundwater irrigators purchased the trout hatchery facilities, land and water rights and will use the water to satisfy the senior rights of adjoining trout producers, and avoid the need to curtail lower-priority groundwater rights for irrigation.

In rare circumstances, groundwater pumping may also be reduced to protect groundwater-dependent species under endangered species laws, which do not consider the economic impacts of the reductions. For example, in 2009, a court ordered California American Water, a private water utility operating near **Monterey, California**, to reduce its groundwater pumping by 60 per cent to protect connected surface water flows; the source groundwater body was judged legally to be a “subterranean stream” connected to the **Carmel River**, which harbors endangered fish.

Australian states have also applied varying approaches to reduce groundwater use in different situations, although the traditional policy preference is for equal across-the-board reductions:

- In **South Australia**, the Minister for Water may reduce the water available to consumptive users in prescribed areas to meet ecosystem needs. Reductions may affect all use types equally, or alternatively, local plans may treat different uses differently, for example, by allocating deeper cuts to lower-value pasture uses, compared to higher-value viticulture uses. In some cases, infrastructure solutions have been preferred to solutions that involve reducing groundwater use (see further discussion, below).

- **Victoria’s** first water management plan to recognize groundwater-surface water connectivity, the **Upper Ovens River** Water Management Plan, uses a negotiated cutback to groundwater allocations. A science-based environmental flow study found that ecosystems along the Upper Ovens River required 137 megaliters/day (56 cubic feet/second) baseflows during summer low flow periods, which would have meant making substantial reductions in groundwater use, and causing quantifiable damage, to irrigators. A reduction in the environmental flows actually delivered under the Plan (compared to the calculated ideal environmental flows) was due to the uncertain and unquantified nature of the risks to the environment posed by a changed flow regime. The Plan applies the same restrictions to groundwater users and surface water users in years of low flow, and schedules pumping to even out impacts on streamflow.

- Reductions in water allocations have recently formally been recommended under the proposed Basin Plan for the **Murray-Darling Basin**. The reductions aim to ensure that groundwater pumping and surface water diversions do not exceed the "sustainable diversion limit" for each sub-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. Though the Program has not yet bought back groundwater entitlements, it may do so in the future.

Implementing pumping restrictions using a phased approach can help reduce the potential hardships involved in reducing groundwater use.

Phasing in reductions in groundwater pumping—lowering the "cap"—is an important and common mechanism to allow users to adapt to the reductions, reducing hardships and increasing the social and political palatability of the policies:

- **Nebraska's** New Depletions Plan, which is part of the Platte River Recovery and Implementation Program, seeks to increase **Platte River** flows by phasing in reductions of groundwater use through decreased water allocations or fallowing presently irrigated acres, from 2013 to 2019.

- The pumping reductions required of California American Water in the **Carmel River** order (see above) are to be implemented incrementally over seven years.

- In response to declining groundwater levels in the **Escalante Valley** in southern **Utah**, a recent draft groundwater management plan provides for reducing agricultural groundwater pumping by around 45% over 120 years, to meet the calculated "safe yield" of the basin. This is a compromise position, reached from the initial 40 years suggested by the State Engineer, and a 180-year timeline proposed in an earlier draft plan by the Escalante Valley Water Users Association.

- Reductions in water allocations recommended under the proposed Basin Plan for the **Murray-Darling Basin** (see above) are being phased in over seven years.

Constructing infrastructure to develop "new" water sources or ASR projects, or require efficiency water use, combined with mitigation programs, can help reduce the existing impacts of groundwater pumping.

Infrastructure can reduce the impacts of existing groundwater pumping on surface waters by developing unconnected water sources as alternative supplies, or continuing pumping, but storing and releasing “excess” water to mitigate pumping impacts. For example, contractual arrangements between the state and 24 large irrigation districts in **Nebraska** have established a demonstration project, which diverts water during periods of high flood risk into irrigation canals for aquifer recharge purposes. This restores flows in the **Platte River**, as the recharged water flows through the subsurface to the river. As is discussed further below, **Perth** has constructed new desalination plants to enable it to reduce groundwater pumping that impacted important wetlands. Scheduling pumping under **Victoria’s** Upper **Ovens River** Water Management Plan effectively changes the operation of infrastructure, along with volumetric pumping restrictions, to reduce the existing impacts of groundwater pumping. Groundwater permits or licenses may also include requirements to use efficient irrigation infrastructure to create water savings.

2.2 What we need to know

Reducing the impacts of existing groundwater pumping on surface waters remains contentious, rare in practice, and subject to important policy gaps.

Despite the established and more recent examples given above of policies for addressing the impacts of existing groundwater pumping on surface water, such mechanisms remain relatively rare, highly contentious, subject to important policy gaps, and are sometimes challenged by poorly defined rights. In addition to better defining water rights, there is a need to further investigate the following matters, to reduce conflict, encourage more flexible policy solutions, and ensure that no inadvertent environmental harm is caused:

- The potential place of groundwater-surface water trading, groundwater-groundwater trading, and water banking in facilitating capping and reducing groundwater extraction, and the pre-conditions for efficient and well-functioning markets;
- Valuation mechanisms for compensating water right/entitlement holders;
- Policy for allocating the burden of paying for infrastructure, like aquifer recharge facilities, where they are intended to offset historical depletions to streams caused by over-pumping groundwater, between, for example: the state; irrigation districts that benefit from higher groundwater levels caused by recharge activities; the historical groundwater pumpers; or surface water users that benefit from higher river flows; and
- Policy for considering the ecological effects of changing the winter hydrograph, where flood flows are captured and “re-timed” to offset stream depletions caused by groundwater pumping.

3. Integrating groundwater and surface water: aquifer storage and recovery

3.1 What we know

Well-established aquifer storage and recovery (ASR) policies and projects in the western U.S. help to maximize water availability by creating additional storage for use in dry periods; poorly defined property rights present a key obstacle to ASR in Australia.

ASR refers to placing water in an aquifer by injecting it or by spreading it on the land surface, where it infiltrates, then pumping it out for use when needed. ASR can be used to increase the reliability of a water supply system by storing excess surface water underground when it is available, and recovering it in times of surface water shortage. Market-based water banking systems (which enable a water storer to sell rights to recover recharged water) are sometimes used in ASR schemes to expand access to the stored water, beyond the overlying landowners.

Western U.S. states have extensive experience in developing ASR projects and the policy frameworks to support them. In Australia, state law and policy frameworks for ASR are just developing, using a risk-based approach, with national-level guidance. However, property rights in relation to ASR are often not well defined—uncertainty surrounds rights to a share of aquifer storage space, rights to extract water, and rights in relation to unconventional source waters. For example, one current approach gives a water storer a credit on their water license, merely as an operating arrangement rather than a property right to the stored water. This presents an obstacle to developing market-based water banking systems using ASR.

A lack of legal certainty over the ownership of urban stormwater can also stifle projects that would use this unconventional source water. Practical experience of using aquifers to store reclaimed water for non-potable uses, and for future indirect potable reuse, is starting to develop in a limited number of locations (for example, in northern **Queensland** and **Perth**, respectively).

Key ASR policy issues in the U.S. are securing rights to recover stored water and access to aquifer storage space; facilitating the use of reclaimed water in ASR; and retaining undeveloped land suitable for recharge.

The U.S. experience of ASR displays some challenges in common with Australian jurisdictions, as well as those that Australia can expect to encounter as ASR projects develop further.

- A number of western states, for example, **Arizona, New Mexico, Oregon** and **Washington**, have complex frameworks that regulate many elements of an ASR project. Issues that arise for regulation include: the right to aquifer storage capacity; the percentage of water that should be "counted" as stored for later recovery; the acceptable duration of storage; the management of impacts on surface waters; accounting treatment of reductions in "natural" recharge caused by "artificially" storing water in aquifers; the establishment of title to the stored water and prevention of its extraction by third parties; and liabilities associated with the stored water potentially affecting contaminant migration, dependent species and ecosystems, the land surface, and the aquifer matrix; and the accounting system to be used for the storage and future recovery of water, and institutional arrangements for maintaining it.

- Although **California** lacks a regulatory framework for these elements, local agencies have significant experience in developing ASR projects. This is driven in significant part by substantial state bond funds that are available to local agencies to construct recharge facilities, particularly in the Central Valley. For example, the **Kings River** Conservation District uses over US$50 million of ASR infrastructure to respond to variable surface water supplies and significant overdraft. Flood flows are the key source water for this project. The recharged water is intended to achieve community-wide benefits by preventing excessive drawdown of groundwater levels, and associated adverse impacts, rather than for direct future recovery and use.

- Because of its reliability, treated wastewater is a high value source water for ASR. Using wastewater for ASR requires surmounting regulatory hurdles and inconsistencies relating to water quality: injected water is subject to federal standards, while percolated water is subject to generally lower state standards. In inland areas, the question of who owns wastewater that is proposed to be used for ASR is important due to effects on downstream users who depend on wastewater discharges, if this water is to be diverted. There are some well-established instances of injecting treated wastewater into aquifers ultimately serving potable uses (e.g. in **Orange County**, California). The **Santa Clara Valley** Water District in northern **California** is also investigating a pilot ASR facility for indirect potable reuse.

- In urban areas, an emerging policy issue is how to develop policies to retain land with recharge capacity, to maximize the potential for future development of ASR. Communication between city planners and water agencies is particularly important in this context. To encourage awareness of this issue, **California** will require local groundwater management plans to map recharge areas beginning in 2013.

3.2 What we need to know

In the U.S., a key challenge is making ASR more strategic. Workshop participants suggested that projects should be targeted towards increasing groundwater quality and preventing overdraft and subsidence, rather than determining ASR locations based on where it is convenient to apply excess surface water. It is also important to consider where the recovery of stored will take place to avoid the potential for negative impacts from future groundwater withdrawals. On the other hand, aquifers with storage space and recovery facilities available near a source of water demand can still provide a low-cost way to increase the overall reliability of a water supply system.

Integrated groundwater management in Australia would benefit from research into implementing policy frameworks for granting access rights to aquifer storage space, and market-based groundwater banking systems, which allow storers to sell rights to recover water. Australian states currently lack legal frameworks for dealing with these issues. In the urban arena, it would also benefit from clarification of property rights in relation to urban stormwater, a valuable potential water source for ASR, and policies for protecting recharge areas from development.

Participants also suggested, more generally, that the response of GDEs (particularly aquifer fauna) to differences between the quality of recharged water and native groundwater needs to be investigated. To that end, ASR monitoring requirements should cover groundwater fauna.

4. Integrating groundwater and the environment

4.1 What we know

Integrated groundwater management considers how pumping groundwater affects ecosystems and species, including those that do not benefit from a water right or entitlement, or endangered species protections.

In addition to recognizing the effects of groundwater pumping on consumptive rights to surface water flows, integrated groundwater management sees groundwater as part of the natural environment, linked to species and ecosystems that depend on it (groundwater-dependent ecosystems, or GDEs). Many workshop participants agreed that groundwater law and policy should balance water users' concerns to protect private water rights with the government's obligation to protect public values, and that relying solely on endangered species protections to infuse an ecological element into water management misses an opportunity to consider ecosystems more proactively and comprehensively. In Australia, states and territories agreed to take this broader view under the National Water Initiative.

Workshop participants discussed policies for protecting GDEs at both the state and federal levels. They concluded that although it has attracted some attention, particularly in Australia, this relatively new area of integrated groundwater management requires a great deal more policy and scientific work.

The Australian federal government provides a baseline of legal protection for GDEs, policy guidance, and funding for technical tools to manage and protect GDEs.

Australia's federal government contributes to protecting GDEs at the level of policy, law, and funding arrangements.

Although it is not yet finalized, the federally-approved Basin Plan for the **Murray-Darling Basin** will overlie state water allocation laws, and constrain groundwater pumping in sub-basins of the Murray-Darling Basin to sustainable diversion limits that represent an "environmentally sustainable level of take". These limits aim to maintain baseflow contributions to rivers and streams and maintain key environmental assets that depend on groundwater. Key environmental

Key lesson

Workshop attendees emphasized the need to establish a baseline level of environmental protection, around which there is common agreement, to avoid constant negotiation. Many also stressed that national leadership could help to protect GDEs. At a minimum, the federal government should become more aware of the impacts of its policies in related areas (for example, agriculture), on groundwater management.

assets are identified with reference to indicators that include ecosystems listed under international agreements, threatened species, degree of naturalness, and the level of biodiversity supported by the ecosystem.

At the policy level, Australia also has National Principles for the Provision of Water for Ecosystems, which set out high-level policy principles that apply to both surface water and groundwater.

Recently, the Australian federal government has funded significant scientific work on GDEs. This has included developing:

- A national atlas of “known”, “new”, and “potential” GDEs, developed using satellite data (MODIS and Landsat), which will be made publicly available using a central web-based portal;
- A “management toolbox” for GDEs, updated in December 2011, which covers, among other things, a framework for assessing the water requirements of GDEs, implementing an effective monitoring program, and dealing with data gaps; and
- Special studies on coastal GDEs and the impacts of varying water quality on GDEs.

Water laws and policies can protect GDEs by allocating them a percentage of aquifer storage or recharge, regulating well locations (requiring buffers between wells and GDEs), using volumetric pumping limits or limits that respond to surface water availability, or limits based on maintaining groundwater at a level that can be accessed by dependent ecosystems.

Australian states have the dominant role in protecting GDEs. They take diverse policy approaches to doing so, for example:

- **South Australia** uses legally binding water allocation plans, which assess ecosystem water needs and consumptive water needs. For example, in the **Padthaway** area, groundwater pumping must not lead to a significant increase in groundwater salinity, or declines in groundwater levels, to ensure that dependent ecosystems can continue to access the resource. A model assists decision-makers to consider these requirements in light of an application for a groundwater allocation. The state also allows the Minister for Water to reduce the water available to consumptive users to meet ecosystem needs.
- The city of **Perth** sources its urban groundwater supply from the Gnangara Mound groundwater system, which supports key wetlands. It protects these GDEs using a variable groundwater extraction rule: the volume of groundwater that the city is permitted to extract each year is based on surface water availability. Perth has also relied on infrastructure, being desalination facilities, to ratchet back municipal groundwater use to protect GDEs. Interestingly, this pathway was chosen despite economic modeling showing that the cost of desalination exceeded that of an alternative approach—restricting silvicultural and agricultural groundwater uses.

- Some **Queensland** water allocation plans protect GDEs by setting volumetric limits on groundwater extraction, either on an annual basis or even a daily basis; others use buffer distances around GDEs like springs, within which no increase in pumping is permitted. Buffer distances are also used to limit pumping around GDEs under some **New South Wales** water sharing plans.

- A draft water allocation plan for **South Australia's Eastern Mount Lofty Ranges** aims to preserve river baseflow, wetlands and river red gum complexes dependent on groundwater. The plan places a moratorium on new surface water and groundwater diversions. Water transfers and new wells are not permitted if a radial buffer zone around the proposed well intersects buffer zones around "environmental assets" like permanent pools, streams and wetlands. The size of well buffer zones and environmental buffer zones varies coarsely, depending on the aquifer, and whether or not the volume of pumping exceeds 10 megaliters (8.1 acre-feet) per year.

At the federal level, the sustainable diversion limits set under the proposed Basin Plan for the **Murray-Darling Basin** apply coarse volumetric limits to groundwater pumping by sub-basin.

Though some policy examples exist, most Australian water plans do not consider GDES, and operationalizing existing policies for protecting GDEs is at a relatively early stage.

The measures listed above are exceptional—most Australian water allocation plans still do not consider GDEs, and not all laws and policies are fully implemented. Workshop participants suggested that water plans may not incorporate GDEs to a greater degree because they are often not clearly identified, and generally not severely degraded. There may also be uncertainty regarding ecological water requirements for GDEs, and the connection between the water table aquifer, which supports GDEs, and the aquifer from which most pumping occurs, which may be deeper.

No western U.S. state manages GDEs comprehensively, within its water law framework.

In the western U.S., policies relating to GDEs have been slower to develop: GDEs are largely overlooked by state water plans and water rights frameworks. Some workshop participants suggested that, in the U.S., there is a need to manage water for GDEs more comprehensively than is presently the case, since GDE protections now generally rely on a species being listed under federal and/or state law as threatened or endangered (or in danger of being listed as such).

4.2 What we need to know

There is a need to better understand connections between hydrology and ecosystems to adopt a more comprehensive approach to water management that better protects GDEs.

At the workshop, participants suggested that further investments in natural and social science should be made to:

- better identify GDEs;
- investigate the response of GDEs to stress, to assist in determining how groundwater extraction interacts with drought stresses (as distinct from the science of determining ecological water requirements, and degrees of water dependence, which are better studied); and
- better communicate the value of GDEs to decision-makers and the public; it would be useful to inventory and evaluate methods of doing this.

Policy tools are needed to fill many remaining gaps in existing frameworks that deal with GDEs, to protect GDEs more comprehensively and transparently, and to extend policy to consider groundwater-dependent ecological processes.

Workshop participants supported investigating and developing a variety of policy tools to fill existing gaps in frameworks for protecting GDEs, including tools to:

- operationalize principles for protecting GDEs in allocating water, in practice;
- make overt connections between water law and non-baseflow-dependent GDEs, like springs and wetlands, which traditionally have not received as much attention as baseflow-dependent rivers;
- sustain ecological processes, as well as ecosystems and biodiversity: it appears that water policy in neither the western U.S. nor Australia presently considers and allocates water needed to support ecosystem services associated with groundwater;
- develop transparent processes for negotiating environmental water provisions, once science-based environmental water requirements are known, including providing publicly available peer-reviews of the science supporting a plan;
- include water quality (particularly salinity) aspects in groundwater quantity management for ecosystems, since they are commonly salt-sensitive;
- better coordinate agencies responsible for managing water quantity, water quality, and biodiversity conservation;
- ensure that water management includes ecological, as well as hydrological, monitoring to support the protection of GDEs; in particular, monitoring should aim to distinguish the effects of water availability from other effects on ecosystems;
- consider multi-objective engineering solutions to providing water to sustain GDEs, like reservoir re-operation, ASR, and where appropriate adding additional surface storage, particularly in highly modified systems; and

- determine when *restoring* seriously degraded systems is warranted, such as where groundwater has become disconnected from rivers, or dependent ecosystems, as distinct from *preserving* threatened systems.

According to workshop participants, policy research should also aim to gain a state-by-state understanding of the extent to which GDEs have been dealt with in science, law and policy. This knowledge is produced, to a certain degree, by the National Water Commission in Australia, for example, a recent report by workshop participant Moya Tomlinson entitled *Ecological Water Requirements of Groundwater Systems: A Knowledge and Policy Review*. There is no equivalent state-by-state knowledge base in the U.S.

PART C: CROSS-CUTTING THEMES

1. Partnerships between levels of government, NGOs and stakeholders

1.1 What we know

Many states rely heavily on a partnership approach to local involvement in groundwater management, using local agencies or stakeholder groups to identify local priorities and management preferences.

Although states vary in the degree to which they share or delegate power to manage groundwater to local entities, a substantial degree of delegation is relatively common, creating a partnership approach between upper-level and lower-level governments and local communities. Local involvement can take the form of local water districts; locally developed planning documents, often then approved at the state level; and local advisory groups, which commonly include individuals, business representatives and NGOs. For example:

- The **Nebraska** Department of Natural Resources and local natural resources districts undertake joint action planning to develop integrated water management plans, of which there are presently ten. The plans control surface water and groundwater use. Surface water users are protected from further withdrawals from connected groundwater bodies after basins are designated fully appropriated. The state must annually evaluate the status of groundwater basins, to determine which are fully appropriated and over-appropriated. Disputes between the state and local districts are settled by the Interrelated Water Review Board, which makes binding decisions.

> **Key lesson**
> Workshop participants emphasized that cooperation and consensus between local stakeholders are central to success in integrated groundwater management. Resilient management solutions rely on stakeholder buy-in.

- In **California**, non-binding integrated regional water management plans are formulated by groups of local agencies, with stakeholder advice. They consider groundwater in the context of surface water, flood management, and ecological resources, albeit without imposing any legal obligations. The state is only involved in an advisory capacity, or as a project funder, primarily using state bond funds.

- **Idaho's Eastern Snake Plain** Comprehensive Aquifer Management Plan was developed by an advisory committee of stakeholders. A key issue was defining sustainability. Ultimately, stakeholders agreed on the following goal: "Sustain the economic viability and social and environmental health of the Eastern Snake Plain by adaptively managing a balance between water use and supplies." The statement derives from the realization that the aquifer is a dynamic resource, that groundwater supply will change, and that a process for monitoring and adapting to change is critical.

- In **Kansas**, groundwater management districts manage groundwater. They develop regulations for their individual districts, which they then recommend to the state's Chief Engineer, who adopts them for application within the individual districts.

- In **Arizona**, groundwater management occurs in five active management areas. One of these, the **Santa Cruz** active management area, has sought to recognize the impacts of groundwater pumping on surface waters.

- In **Victoria**, stakeholder groups are formed to formulate groundwater management plans and local groundwater management rules, which are then approved by the state. The groups are comprised of government appointees, over half of which must be involved in agriculture.

In some cases, local management arrangements arise organically, and are later formalized in state law. For example, the regulatory scheme developed to safeguard flows in the **San Pedro River** in **Arizona** was developed cooperatively by the U.S. military, which pumps groundwater at Fort Huachuca, and the local community. The arrangements were then enacted as state legislation, which provided for the establishment of a unique kind of special district, specifically to focus on maintaining baseflows in the **Upper San Pedro River**.

At the workshop, participants noted that active steps are needed to engage, attract, and maintain the participation of stakeholders. Once the group is formed, a group "champion" can help maintain the commitment of the stakeholder group, and hold it together in the face of complex and contentious issues.

Key lesson

Workshop participants agreed that one size doesn't fit all: groundwater management should be tailored to the local area. However, some attendees cautioned that while local control over groundwater management can be extremely valuable in the face of varying local circumstances, it can be insufficient if the implications of management decisions extend beyond the local area. State frameworks are useful for guiding local implementation and overcoming such issues.

Funding is also a crucial issue in establishing and maintaining stakeholder groups. Varying methods are used to fund the work of local agencies, for example: state bond funds (as in **California**), levies based on property ownership and water licenses (as in **South Australia**), and a combination of local income and property taxes (as in **Nebraska**).

Groundwater management partnerships extend beyond governance arrangements, to implementation. NGOs, in particular, often collaborate with agencies, contributing resources to developing modeling, monitoring, and water banking tools.

A partnership approach to groundwater management extends beyond governance arrangements, to implementing groundwater management tools. Case studies presented at the workshop showed that this partnership approach can often help resolve particularly contentious issues. For example, scientifically determining the degree of connection between groundwater and surface water can be a key point of contention, and models developed by state agencies in isolation have attracted criticism from affected stakeholder groups. Measures for minimizing controversy include using models developed using a more collaborative process. For example, models have been developed by:

- the state, with stakeholder input, as in the development of the model for the Eastern Snake Plain Aquifer in **Idaho**, which used a modeling committee comprising state and federal agencies, universities and private industry experts;
- the state, and reviewed by an independent third party, like the Commonwealth Scientific and Industrial Research Organisation (CSIRO) or university research groups, which reviewed the science behind water allocation planning in **South Australia**; or
- a neutral third party, like the U.S. Geological Survey, as in the case of the stream-aquifer model for the **Yakima basin** in **Washington**.

In relation to monitoring, a partnership between The Nature Conservancy and the U.S. Forest Service is developing an inventory and monitoring protocol for GDEs on Forest Service lands, which will contribute to federal well permitting policies for these lands.

NGOs may also facilitate integrated groundwater management by participating in mitigation programs. The **Deschutes River** Conservancy has provided crucial support to **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. A non-profit organization, **Montana** Aquatic Resources Services, is proposing to establish the "Montana Statewide In-Lieu Fee Mitigation Program", under which it would sponsor projects designed to mitigate the impacts of activities that affect aquatic habitats, funded by groundwater permitting fees.

1.2 What we need to know

Though stakeholder participation and local involvement are well established in the theory and practice of integrated groundwater management, important questions remain.

The workshop confirmed the important place of partnerships between government agencies at different levels, stakeholders and NGOs, and identified key questions that require resolution to make the best use of these partnerships. These questions surrounded how to: optimize stakeholder involvement in different stages of managing groundwater; improve communication with stakeholders; and develop principles for delegating responsibility for managing water to the local level.

Maximizing the benefits of local stakeholder involvement in integrated groundwater management requires effectively attracting, engaging and informing stakeholders on complex issues, like groundwater-surface water connections. Investigating effective ways to communicate the nature and implications of these connections, for example, would help to attract, inform and engage stakeholders in ongoing management processes. Workshop participants suggested that agencies would also benefit from guidance on the procedural aspects of stakeholder involvement, for example, recommended stages for, and methods of, involving stakeholders; and the most effective areas for NGO involvement. In particular, it would be useful to explore the role of NGOs in contributing to groundwater information, to complement government resources for data collection.

Finally, workshop participants offered that some elements of water planning processes may need to be "hardwired" in state policy, whereas others should be negotiable, and open to varying local approaches. Law and policy would benefit from principles to guide the classification of different aspects of water planning into these categories, to guide upper-level governments in delegating groundwater management responsibilities (or additional responsibilities) to local agencies to carry out in a manner best suited to their particular circumstances.

2. Integrating science and policy

2.1 What we know

Law, policy, and science need to be linked effectively to manage groundwater and surface water and their dependent ecosystems. Governments recognize this.

Integrated groundwater management has, at its heart, the recognition of complex hydrologic realities in policy. Knowing that water management decisions tend to be as good as the information on which they are based, and that investing in science at the outset tends to lead to better management solutions, governments in Australia and the U.S. have made substantial investments in groundwater science to support management.

In Australia, the federal government has been a major funder of research into groundwater management and training, investing A$90 million (~US$97 million) in a Groundwater Action Plan to improve groundwater management over four years. The Plan has three components. The first is the National Groundwater Assessment Initiative, which funds hydrogeological and associated investigations, including assessing sites suitable for ASR nationally, assessing the vulnerability of GDEs, characterizing aquifers, and managing risks to groundwater quality. The second component is the National Centre for Groundwater Research and Training, which is co-funded by the Australian Research Council. The third is a knowledge and capacity-building component, which produces principles, guidelines, and good practice examples relating to groundwater.

Similarly, the U.S. federal government (through the Bureau of Reclamation) funds groundwater-related projects under cost-shared grants that focus on water supply and grants relating to reclaiming naturally impaired groundwater. It also undertakes conjunctive use projects with federally owned reservoirs, and develops scientific tools for groundwater management, relating to calculating evapotranspiration and recharge. In addition, the U.S. Geological Survey develops dynamic groundwater models capable of projecting the intersection between surface water and groundwater uses within a subject basin.

In addition to these investments by the executive, some judicial decisions in the U.S. also reflect the connections and complexities of integrated groundwater management. Some decisions now include sophisticated linked groundwater-surface water models, which are used to determine daily streamflow depletions from groundwater pumping at state lines, as in **Kansas-Colorado** litigation dealing with the **Arkansas River** Compact. A similar model is used in a case dealing with the **Republican River** Compact, which allocates water among Kansas, Nebraska and Colorado.

Workshop participants suggested that while there is an ongoing need to focus on gathering groundwater information and linking law, science and policy, there is also a need to avoid "paralysis by analysis": participants suggested that agencies should tie the pursuit of water information to a consideration of the benefits of having more information. Some participants offered that scientific uncertainty (such as uncertainty about climate change effects, ecological responses to water scarcity, and the degree of groundwater-surface water interaction), can be a motivator as well as a stumbling block. Ideally, such uncertainty leads to a dialogue about who bears risk, or the overall uncertainty related to the information gathered and outcomes hypothesized, rather than providing an excuse for inaction.

2.2 What we need to know

Further policy work, empirical research, and practical management tools are needed to better link science and policy for integrated groundwater management.

Workshop participants concluded that developing further policy and practical tools, and carrying out empirical research across key areas, would help to link science and policy more effectively.

First, integrated groundwater management would benefit from empirical research on:

- how characteristics of data—their type, method of provision, comprehensiveness, and format—affect policy and decision-making;
- how different methods of communicating water information to the public affect public perceptions of groundwater management problems and their desire for action; and
- how the varying complexity of integrated groundwater management tools (for example, determining groundwater-surface water connectivity by simple rules of thumb, versus using complex hydrological modeling) affects the success of a management solution.

Second, groundwater law and policy would benefit from:

- considering how water rights/entitlements can be structured to adapt to changing scientific information, changing water availability, and changing public values about the environment (for example, using time-limited, rather than perpetual rights/entitlements, and by making the right/entitlement subject to an ongoing public servitude);
- considering how to create economic incentives to lead to beneficial changes in groundwater pumping, for example, by balancing use of groundwater with other water

sources, and by encouraging pumpers to locate wells so as to attenuate the impact of groundwater pumping on surface water sources;

- clarifying and refining the meaning of the term “best available science”, to which law and policy frameworks in both Australia and the U.S. commonly refer in guiding decision-making related to the impacts of groundwater pumping; and similarly, the meaning of the terms sustainable yield and safe yield, especially in interconnected systems; and
- developing mechanisms to diffuse the potential for “combat science”, particularly in the litigation context.

Finally, at a practical level, groundwater management would benefit from:

- an expanded ability to monitor groundwater conditions inexpensively, for example, using remote sensing, multi-level monitoring; and telemetry systems;
- models to transparently evaluate the economic value of different groundwater uses, taking into account externalities;
- tools for valuing information, which would enable decision-makers to put a dollar value on extending monitoring systems, for example, in terms of their contribution to groundwater management outcomes; and,
- comprehensive data about how much groundwater is withdrawn annually within a basin.

Appendix A:

Attendees of the Comparative Groundwater Law and Policy Program's Workshop 1

October 17-19, 2011

Name	Organization
Anthony Aerts	Consulting Policy Analyst
Leslie Bach	The Nature Conservancy
Howard Bamsey	United States Studies Centre, University of Sydney
Felicity Barringer	The New York Times
Danielle Blacet	Association of California Water Agencies
Jesse Bradley	Nebraska Department of Natural Resources
Anne Castle	U.S. Department of the Interior
Juliet Christian-Smith	Pacific Institute
Steven Clyde	ClydeSnow
John Draper	Montgomery & Andrews
Denise Fort	University of New Mexico School of Law
Robert Freeman	National Water Commission
David Freyberg	Stanford University
Beau Goldie	Santa Clara Valley Water District (California)
Steven Gorelick	Stanford University
Jonathan Greenberg	Stanford University
Maurice Hall	The Nature Conservancy
Ellen Hanak	Public Policy Institute of California
Matthew Heberger	Pacific Institute
David Kennedy	Stanford University
Peter Kitanidis	Stanford University
Rosemary Knight	Stanford University
Daniel Lovell	Goulburn-Murray Regional Water Authority (Victoria)
Rita Maguire	Maguire & Pearce
Russell McGlothlin	Brownstein Hyatt Farber Schreck
Barry Nelson	Natural Resources Defense Council
Rebecca Nelson	Stanford University
Nick Odlum	Stanford University

David Orth	Kings River Conservation District (California)
Rachael Osborn	Center for Environmental Law and Policy (Washington)
Tim Parker	Groundwater Resources Association of California
John Peck	University of Kansas School of Law
Neil Power	South Australia Department for Water
John Ruple	University of Utah
Mary Scruggs	California Department of Water Resources
Lester Snow	California Water Foundation for the Resources Legacy Fund
Clive Strong	Office of the Idaho Attorney General
Sorada Tapsuwan	Commonwealth Scientific and Industrial Research Organisation
Greg Thomas	Natural Heritage Institute
Buzz Thompson	Stanford University
Moya Tomlinson	Queensland Department of Environment & Resource Management
Glen Walker	Commonwealth Scientific and Industrial Research Organisation
Laura Ziemer	Trout Unlimited
Greg Zlotnick	Zlotnick H2O

Appendix B:

Agenda for the Comparative Groundwater Law and Policy Program's Workshop 1

October 17-19, 2011

Field trip: Sunday, October 16 A tour to the Monterey area will present a snapshot of groundwater issues in California. It will include a tour of the area's famous vineyards and wineries. The excursion dinner will facilitate informal networking before the workshop commences.		Pajaro Valley Water Management Agency Château Julien Morgan Winery
Day One: Monday, October 17: Introductions; Research overview; U.S. and Australian state perspectives on groundwater-surface water links		
8:00 am 8.30am-9.00am	Shuttle leaves from Stanford Terrace Inn Registration and breakfast	
9.00am	Welcome and round-table introductions	Howard Bamsey Buzz Thompson David Kennedy
	Overview of research program plans and workshop agenda Overview of research thus far on integrated groundwater management across the U.S. and Australia; overview of the Comparative Groundwater Law and Policy Program and its research plan; introduction to the workshop agenda	Rebecca Nelson
10.10am	Morning tea break	
10.30am	**PANEL 1: How do U.S. states ensure water policy recognizes SW-GW links? (Part 1)** Presentations and discussion on how select states manage surface water-groundwater connections in relation to water rights, including instream flows, and key drivers for their state's approach	Clive Strong Laura Ziemer Rachael Osborn Moderator: Mary Scruggs

	PANEL 2: How do U.S. states ensure water policy recognizes SW-GW links? (Part 2) Presentations and discussion on how select states manage surface water-groundwater connections in relation to water rights, including instream flows, and key drivers for their state's approach	Denise Fort Jesse Bradley Steve Clyde Moderator: Greg Thomas
12.30pm	Lunch	
1.30pm	**PANEL 3: How do local U.S. water agencies and states with local-based groundwater management ensure water policy recognizes SW-GW links?** Presentations and discussion on how states that manage groundwater locally (rather than at the state level) manage surface water-groundwater connections in relation to water rights, including instream flows, and key drivers for their state's approach	John Peck Rita Maguire Lester Snow Moderator: Ellen Hanak
	PANEL 4: How do Australian states ensure water policy recognizes SW-GW links? Presentations and discussion on how states manage surface water-groundwater connections in relation to water entitlements and key drivers for their respective approaches	Neil Power Sorada Tapsuwan Moya Tomlinson Moderator: David Kennedy
3.30pm	Afternoon tea break	
3.50pm	**Discussion and synthesis** of drivers for, and barriers to, laws and policies on surface water-groundwater connections, considering insights from state approaches	Moderator: Buzz Thompson
5.15pm	Walk to Faculty Club	
5:30pm	Reception, Dinner and **Keynote Dialogue**; speakers give an overview of groundwater policy from federal perspective	Robert Freeman Anne Castle Moderator: Felicity Barringer

Day Two: Tuesday, October 18: Australian & U.S. case studies on groundwater-surface water links		
8:00 am 8.30am-9:00am	Shuttle leaves from Stanford Terrace Inn Breakfast	
9:00am	**PANEL 1: Case studies of SW-GW disputes in the U.S. (Part 1)** Presentations and discussion of case studies in which surface water-groundwater connections present a problematic issue	John Draper Rachel Osborn Leslie Bach Matthew Heberger Moderator: Danielle Blacet
	PANEL 2: Case studies of SW-GW disputes in the U.S. (Part 2) Presentations and discussion of case studies in which surface water-groundwater connections present a problematic issue	Jesse Bradley Rita Maguire Clive Strong Moderator: Lester Snow
11.20am-11.40am	Morning tea break	
11.40am	**PANEL 3: Case studies of SW-GW disputes in the U.S. (Part 3)** Presentations and discussion of case studies in which surface water-groundwater connections present a problematic issue	Russell McGlothlin John Ruple John Peck Moderator: David Freyberg
12.40pm	Lunch	
1.40pm	**PANEL 4: Case studies of SW-GW disputes in Australia** Presentations and discussion on experiences with water rights, where surface water-groundwater connections present a problematic issue	Neil Power Sorada Tapsuwan Daniel Lovell Moderator: Greg Zlotnick
2.40pm-3pm	Afternoon tea break	
3pm	**Focus: Groundwater Management in Australia**	Rob Freeman

	Discussion and synthesis of drivers for, and barriers to, the implementation of laws and policies on surface water-groundwater connections at the sub-state level, considering insights from the case studies discussed	Moderator: Buzz Thompson
5:00pm 5:30pm	Shuttle to dinner Reception and dinner (Spalti Ristorante, Palo Alto)	
Day Three: Wednesday, October 19: Emerging Issues in Integrated Groundwater Management		
8:00am 8.30am-9am	Shuttle leaves from Stanford Terrace Inn Breakfast	
9:00am	**PANEL 1: Intersections between emerging science/technologies and GW law & policy (Part 1)** Panel presentations and discussion regarding managed aquifer recharge / groundwater banking– how are emerging science and technologies in these areas likely to impact groundwater law and policy?	Beau Goldie David Orth Denise Fort Glen Walker Moderator: Rosemary Knight
10.20am-10.40am	Morning tea	
10.40am	**PANEL 2: Intersections between emerging science/technologies and GW law & policy (Part 2)** Panel presentations and discussion regarding groundwater-dependent ecosystems and technologies for identifying and mapping them – how are emerging science and technologies in these areas likely to impact groundwater law and policy?	Maurice Hall Moya Tomlinson Glen Walker Leslie Bach Moderator: Steve Gorelick
12:00pm	**Summary of take-home messages** from the workshop; discussion of **issues for further research** and analysis	Moderator: Buzz Thompson
1:00pm	Lunch and **discussion of future workshops** and networking options	
2:00pm	Adjourn	