Australian
Environment
Review

Groundwater, rivers and ecosystems: comparative insights into law and policy for making the links

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Amid the raging debates about environmental water during the Millennium Drought, and the prelude to new management arrangements for the Murray-Darling Basin (MDB), a general silence fell on the subject of groundwater — eloquently communicating its perceived irrelevance to these debates. Yet groundwater can, and often does, feed rivers,[1] lakes, wetlands, springs, floodplains, estuaries, aquifer-dwelling fauna and even terrestrial vegetation (all groundwater-dependent ecosystems, or GDEs).[2] Some GDEs are iconic — take river red gums along the Murray, millennia-old mound springs in the Great Artesian Basin, and Coorong wetlands[3] — others are less well known, but can support astounding biodiversity.[4] Pumping groundwater can "pull" water away from connected rivers, and inadvertently damage or destroy GDEs (adverse pumping impacts). As groundwater demand increases, and coal-seam gas and shale gas industries increase the incidental extraction of groundwater,[5] laws and policies need to recognise the potential for these adverse pumping impacts. While they should not needlessly discourage groundwater use (indeed, sometimes using groundwater is environmentally preferable to using surface water), they must be alert to threats to hard-fought environmental flows and valuable GDEs — not to mention consumptive surface water entitlements.

This article briefly reviews the state of Australian water law and policy mechanisms for preventing and remedying adverse pumping impacts (linking mechanisms), with a focus on groundwater-dependent surface waters and their associated ecosystems. Using legal analysis and interviews with water agency staff across 22 states in Australia and the western United States (US), it investigates key gaps and challenges that affect these mechanisms and their implementation, and suggests ways to overcome those challenges based on experiences across these states. These regions have much in common: water scarcity, over-allocation, generally similar legal systems, levels of development, and acknowledgement of the ecological value of water. However, groundwater demand is higher in the western US, adverse pumping impacts have manifested themselves earlier and more severely, and underlying state water allocation laws are more numerous and varied.[6] The similarities are sufficient to make law and policy experiences mutually relevant, but different enough to produce a "living laboratory" of useful approaches to similar problems.

Approaches to protecting rivers and ecosystems from groundwater pumping

Focus on the level of an individual groundwater entitlement

Rather than the water planning focus of very useful previous work,[7] this article focuses at the level of individual water entitlements or other statutory rights to extract groundwater, while acknowledging the influence and value of water plans and other higher-level arrangements relating to monitoring and water accounting. There are four reasons for this alternative focus. First, an individual bore can have very localised pumping impacts on river reaches (particularly pools in unregulated river systems) and other GDEs. Accordingly, it is important to consider decision-making tools at that local level, in light of specific local conditions (which may not appear distinctly at the water plan level) and a specific predicted impact. Second, this emphasis uncovers statutory linking mechanisms not previously discussed in the literature, and largely overlooked by national-level policy work, which has focused on plans.[8] Third, water plans typically only take effect "on the ground" through constraints or considerations that they apply to licensing processes, alongside other statutory provisions.[9] Fourth, significant areas of Australia, in which groundwater use is less intensive, lack water plans (or water plans that cover groundwater), although extraction there can have significant localised adverse impacts managed through licences or other arrangements.[10]

Picture law and policy mechanisms for controlling adverse pumping impacts as being grouped into two toolboxes. Tools in the *preventive* toolbox can apply before pumping itself commences, when an agency receives the application and considers its predicted impacts against acceptable thresholds of impact. Tools in the *remedial* toolbox can apply after pumping commences, when an agency can deal with any unacceptable impacts that have manifested in practice, and that were unanticipated earlier or were permitted before the introduction of a preventive licensing policy. A single jurisdiction may use multiple tools in these toolboxes, and most do.

Each toolbox has compartments structured by the method used to set a threshold of acceptable impact: regulatory (mandatory), economic or voluntary. These distinctions, along with comparisons with the western US, serve to expose gaps in these toolboxes and potential for future development.

The preventive toolbox

Regulatory mechanisms for preventing unacceptable impacts involve using water plans or statutory provisions to set either *numerical* or *principle-based* thresholds, beyond which groundwater pumping will not be permitted.

Simple numerical thresholds are one option. They can:

- prohibit or restrict new groundwater uses or bore permits:
  - — completely, or for most types of uses, within a water plan area, based on impacts on rivers;[11]
  - — within a set distance of a stream or other GDE (for example, a spring);[12] or
  - — above a certain prospective total volume of groundwater extraction (cap), which is set considering adverse pumping impacts — for example, reserving a proportion of recharge for environmental purposes;[13] or
- much more rarely, apply a cap or allocate water to surface water and groundwater users in a joint or linked way.[14]

Once they are set, simple thresholds are easy to administer: an agency simply compares a pumping application to a cap figure, or a geographical "no-go zone", to determine whether the pumping may proceed. However, they are relatively imprecise. A large-scale cap can translate into very different levels of impact at a point, depending on the location of bores, particularly in heterogeneous hydrogeological environments. In addition, a simple "no-go zone" that does not follow hydrogeological conditions can allow bores just outside its boundary, which have much the same effect as bores just inside its boundary.[15]

More **complex numerical thresholds**, which are rare in Australia, set impacts more precisely by requiring a modelled calculation of the pumping impacts of an individual groundwater licence application. The trade-off is that they are more expensive and time-consuming to administer, and raise questions about the accuracy of the technical models used to predict impacts. An example is refusing a new licence that would result in exceeding a maximum allowable decrease in water table level, or pressure, at a set distance from a river or spring.[16] A related, but less onerous, approach is to set thresholds that require calculating individual pumping impacts using average local values of hydrogeological parameters.[17] Western US states commonly use complex thresholds, typically requiring an agency to refuse an application for a well that would draw more than a certain proportion of its water from a river within a certain period of time.

Numerical thresholds in Australia tend to allow comparatively large adverse pumping impacts. New South Wales (NSW) has banned new groundwater licences in certain areas where 70% of the water pumped from bores is drawn from connected surface waters within a single irrigation season (a "70% in 9 months policy").[18] In formulating sustainable diversion limits for the MDB, the MDB Authority used a "50% in 50 years policy" as a key threshold of risk related to setting groundwater extraction caps.[19]

By contrast, numerical thresholds in western US states are much stricter in areas with fully allocated surface water, even in areas that would be considered to have low connectivity between surface water and groundwater in Australia.[20] Colorado adopts a 0.1% in 100 years policy; Washington and Montana prohibit groundwater pumping having *any* impact over the long term.[21] Groundwater offset programs — conceptually similar to carbon or habitat offsets — make these thresholds politically possible. Pumping above these levels of impact is not banned outright; rather, a groundwater permit applicant can offset adverse pumping impacts to ensure that there is no *net* exceedance of the threshold. Methods of offsetting include replacing the water that the bore would capture from the river, by buying and retiring, or leasing and not using, a surface water right or groundwater right that affects the same river;[22] using replacement water from another source;[23] or, sometimes, paying financial compensation[24] or undertaking environmental projects to benefit the affected areas.[25]

Rather than being quantified, **principle-based thresholds** are expressed as:

- qualitative standards — for example, requiring that granting a licence be in "the public interest";[26] or

- a set of specific environmental issues to be considered — for example, the effects of extracting water on ecosystems[27] and the integrity of watercourses, lakes, springs or aquifers;[28] ecological sustainability;[29] and similar matters.[30]

In practice, agencies frequently seem unable to specify exactly how they consider these standards and issues, though they appreciate the flexibility that they offer. In addition, courts view the requirements as very broad[31] and are unlikely to offer particularly specific guidance. Policy guidelines setting out detailed deliberative criteria that clearly correspond to these statutory licensing provisions seem very rare. The resulting high degree of discretion afforded to decision makers considering principle-based thresholds means that they are unlikely to be used consistently or systematically to protect rivers or other GDEs. Sometimes these thresholds are assumed to be satisfied if the applicable water plan has not identified the potential for adverse impacts, or the pumping comes within an applicable cap, and no public protest ensues,[32] even though caps, for example, are not necessarily set with regard to the same kinds of statutory considerations as apply to the grant of individual licences.[33] One solution is to set out explicit locally tailored criteria that define principle-based standards, like the public interest, using water plans (as has occurred in New Mexico and Idaho),[34] regulations that are triggered if public comment raises the issue (as in Oregon),[35] or formal implementation guidelines.

The economic and voluntary compartments of the Australian preventive toolbox are almost empty. Some statutes explicitly allow for economic approaches,[36] which could regulate effects on GDEs by, for example, charging a pumping fee to constrain groundwater pumping to acceptable levels. These provisions are rarely used for this purpose in practice.[37] Voluntary tools are theoretically possible — for example, to allow groundwater users to purchase voluntary groundwater offsets before pumping commences, mirroring voluntary carbon offsets and voluntary surface water offsets that have emerged in the Pacific Northwest.[38] These types of formal arrangements to control groundwater pumping impacts have appeared in practice in neither Australia nor the western US in relation to groundwater.

The remedial toolbox

After pumping begins, and when it becomes obvious that groundwater pumping impacts have become unacceptable, the remedial phase commences. Policy statements about entrenched overallocation suggest that remedial tools are more necessary than one might hope.

The regulatory compartment of the remedial toolbox bristles with possibility, but is rarely used. A water minister often has wide discretion to curtail pumping to protect ecosystems.[39] This rarely occurs in practice, however, other than in fairly uncontroversial or emergency situations — for example, where there has been illegal overuse, or dramatic increases in salinity caused by pumping.[40] Water plans can, and sometimes do, reduce groundwater entitlements[41] or allocations.[42] Bitter experience and ongoing litigation over cutting groundwater entitlements suggest the political wisdom of reducing groundwater allocations, which is perceived as less threatening.[43] Buying back water entitlements or offering "structural adjustment" payments often soothes the sting of regulatory reductions.

Economically determined thresholds of impact are almost unknown. However, one could imagine at least two possibilities that would serve as both preventive and remedial tools. A simple approach could impose fees in areas where GDEs are more "valuable" than average. A more complex approach could impose location-dependent pumping fees that reflect the monetised adverse impacts of groundwater pumping. One approach to valuing these impacts would be to use ecosystem services, which has assisted setting surface water diversion limits in the MDB.[44] Either would encourage groundwater pumpers to locate — or relocate — to areas in which pumping is cheaper and has fewer adverse impacts. Though this would doubtless strike challenges in reflecting environmental costs that vary (probably non-linearly) in time and space,[45] the underlying concepts are very similar to voluntary trading zone tools, discussed below, and recent NSW policy that requires a large-scale project involving "aquifer interference" to provide a security deposit that reflects "the level of risk to the aquifer or its dependent ecosystems from the proposed activity".[46]

Voluntary tools (as defined here, which neither rely on mandatory thresholds of acceptable impact nor compel a groundwater pumper to act in a particular way) are rare. Existing voluntary tools include one-way water trading rules, which ensure that groundwater entitlements may only be transferred out of a sensitive area, or away from a river-side zone, or from one water source to another, such that adverse pumping impacts diminish over time;[47] and engineering solutions — for example, pumping water into high-value wetlands, caves or river pools affected by groundwater use.[48] Individuals may also elect to reduce their groundwater pumping voluntarily, on a more informal basis.

In summary, then, Australia's preventive toolbox favours imprecise, relatively high-threshold, macro-scale protections that are easy to administer; and little else is widely used in practice. Our remedial toolbox contains regulatory tools that are used even more rarely, and are politically and (in practice) financially burdensome for governments.

Implementation challenges and potential solutions

Many cross-cutting challenges face laws and policies for controlling adverse groundwater pumping impacts, regardless of the particular tool used.

Groundwater information and burdens of proof: The general paucity of information on the stream-connectedness of aquifers and other information required to predict adverse pumping impacts[49] poses a profound challenge to decision makers. They can respond by taking one or more of the following actions, most of which are emerging slowly in Australia, but are more common in the western US:[50]

- assume that groundwater and surface water are connected, in the absence of evidence to the contrary, at least in high-risk areas — a recommended approach that has largely not been adopted in practice in Australia, though various statutory and policy options are available to do this;[51]
- require applicants to prove that they will have minimal impacts,[52] which would require some agencies to confront sensitivities about requiring applicants to undertake potentially expensive investigations;[53]
- grant a licence, conditional on the holder collecting additional data during an initial pumping term;[54] and/or
- invest in studying groundwater-surface water interaction[55] in a pragmatic way by systematically prioritising investigations based on groundwater demand, the ecological value of groundwater, and hydrological complexity.[56]

Prioritising protections: There is often little existing scientific knowledge about the locations or water needs of GDEs, and determining their water requirements is an emerging and time-consuming science.[57] A slew of new scientific tools and maps, released after a period of substantial government investment into GDE research, will help identify GDEs,[58] but prioritising them for protection is an ongoing challenge. A number of bases for prioritising GDEs have emerged:

- community values, usually in conjunction with another basis;[59]
- advice from special-purpose technical committees[60] or regional natural resources agencies;[61]
- pre-existing lists of valuable species or ecosystems — for example, endangered species or Ramsar wetlands, or GDEs within protected areas;[62]
- basic threat assessment (such as the surrounding level of consumptive demand for groundwater); or
- sophisticated multi-criteria or multiple-input risk assessment.[63]

Impacts distributed in time: Long time lags can separate pumping groundwater and impacting streamflow or other GDEs — both because groundwater often moves slowly, and because ecosystems take time to respond to reduced water availability.[64] Australian laws and policies are frequently silent on the time horizons within which impacts must be felt to be considered material. Commonly adopted short-term views[65] can inadvertently "lock in" cumulatively significant future impacts that are considered too distant (or too politically difficult) to worry about. One groundwater expert has suggested that in the MDB, groundwater pumping that commenced in 1993 will deplete streamflow by at least 711 GL/yr by 2050.[66] By comparison, this is over a quarter of the volume of water required to be recovered for the environment under the MDB plan. Failing to consider a long enough time horizon could also mean investing in expensive remedial measures that could prove futile in changed future climatic conditions — a current policy issue in Western Australia's drying climate.[67]

Cumulative impacts of licence-exempt groundwater uses: Groundwater uses that do not require a licence — typically domestic or stock bores, and sometimes wells[68] used by extractive industries, such as unconventional gas[69] — fall outside the scope of many of the tools discussed here, which generally operate only on licensed uses. Several solutions to controlling their individually small, but sometimes cumulatively significant, impacts present themselves. Many are very recent:[70]

- provide for special regulatory controls that apply to licence-exempt uses — for example, plan provisions, ministerial orders, or conditions on the siting of bores,[71] or monitoring and mitigation requirements for coal-seam gas activities;[72]
- apply a cap[73] or other threshold[74] to all licensable and licence-exempt extraction; or
- remove licence exemptions in areas of intensive groundwater use;[75] or require a special licence for incidental extraction.[76]

Involving third parties: Water planning processes generally provide for community comment and participation on committees formulating management plans, and some water licensing processes (arguably not enough) also provide for public comment.[77] Western US states almost universally require public comment processes in licensing.[78] Third-party input is particularly valuable in the context of adverse pumping impacts because many GDEs are highly localised and are therefore unlikely to be described in water plans, and scientific data about them are often scarce. However, gaining meaningful third-party input in this context is a significant challenge: public awareness is low; time lags obscure connections between groundwater pumping and environmental change; Australian environmental non-government organisations (NGOs) are not generally highly engaged with groundwater matters; and environmental water holders and managers seem generally unengaged with groundwater licensing decision makers. On the other hand, new accessible tools such as the Australian National GDE Atlas[79] could help inform agencies and the public about the presence of GDEs near proposed or existing bores. In addition, endangered species issues, which have driven strong concerns for certain GDEs in the western US,[80] are emerging in Australia,[81] building on older movements to protect wilderness caves.[82]

Opportunities for Australia

Australian jurisdictions can improve both the range of mechanisms available to control the adverse impacts of pumping groundwater on rivers and other GDEs, and the implementation of existing mechanisms. With an eye to current economic concerns, and water reform fatigue, the most pragmatic way to pursue these improvements is by working within existing law and policy structures, as far as possible. Based on the analysis above, I offer the following seven recommendations for water agencies and stakeholders:

1. Re-emphasise the importance of licence-level considerations, in addition to water plan-level mechanisms (such as caps), in controlling adverse pumping impacts. The former can be more tailored to the local situation than the latter.
2. Consider lowering numerical thresholds of pumping impacts deemed to be worth preventing, using a long (or at least explicit) time horizon, and encompassing all groundwater use, whether licensable or not. Focusing on prevention accords with Australia's forward-looking planning philosophy, and will avoid locking in undesirable future impacts that are politically and financially difficult to remedy.
3. Consider developing formal groundwater offset programs, building on western US experience and existing mentions in Australian groundwater policy,[83] and current ad hoc and emerging use of them in various groundwater contexts.[84] Offset programs can reduce the political risks of more robustly protecting surface waters in fully allocated catchments, particularly in the context of large, economically significant extractive projects.
4. Increase the effectiveness of flexible, principle-based thresholds (such as the "public interest" test, and statutory environmental considerations) by detailing locally specific, compulsory deliberative criteria in water plans or formal implementation guidelines.
5. Encourage community and NGO involvement in groundwater licensing and planning by emphasising places, benefits and species that people can relate to — for example, use the freely available National GDE Atlas, ecosystem services concepts, and connections between groundwater and endangered species to raise awareness.
6. Consider developing economic tools using existing powers to impose environment-related pumping fees,[85] and national policy support.[86]
7. Invest in methods and policies for prioritising the protection of GDEs. They are vital to systematically implementing all of the tools discussed here. Consider imposing a burden of proof on groundwater applicants to demonstrate that pumping will not result in unacceptable adverse impacts in high-priority areas.

Together, these measures would help to enhance the Australian toolbox of mechanisms for preventing and remedying the adverse impacts of pumping groundwater on rivers and other GDEs, and increase the effectiveness of our existing tools.

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This work was carried out with financial support from the Dow Sustainability Program, through the United States Studies Centre, University of Sydney. I gratefully acknowledge the helpful comments of Howard Bamsey, Sandford Clark, Andrew Fahlund, Rob Freeman, Ian Houshold, Peter Hyde and Moya Tomlinson on an earlier version of the article, and the guidance of my JSD committee (Barton H ("Buzz") Thompson Jr, David Freyberg and Michael Wara) in relation to the larger project of which this work forms a part. All opinions expressed here, and any errors, remain my own.

Footnotes

1. Note that in some cases, diverting surface water impacts groundwater supplies and ecosystems by reducing recharge to aquifers in "losing" streams, and laws and policies must deal with this reverse situation — for example, Natural Resources Management Act 2004 (SA), ss 132(1)(a)(iii), 132(1)(c). For reasons of brevity, this article focuses solely on the impacts of pumping groundwater on surface waters and ecosystems.

2. For a formal definition, see C Clifton, B Cossens and C McAuley, *A Framework for Assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems: Report 1 Assessment Toolbox*, 2007, p 1.
3. Sinclair Knight Merz Pty Ltd, *Environmental Water Requirements to Maintain Groundwater Dependent Ecosystems*, National River Health Program Environmental Flows Initiative Technical Report Number 2, 2001, pp 4, 8.
4. M T Guzik et al, "Is the Australian subterranean fauna uniquely diverse?" (2010) 24 *Invertebrate Systematics* 407, p 411.
5. R Nelson, "Unconventional gas and produced water" in *Australia's Unconventional Energy Options*, ed Committee for Economic Development of Australia, 2012, p 27.
6. The dominant system for allocating water in the western US is prior appropriation, under which a right to extract water that developed earlier in time is "senior" to, and more reliable than, a "junior" right that developed later. An administrative permit system generally applies. If there is insufficient water to satisfy all users, the right of the most junior will not be fulfilled, in order, to ensure supply to seniors. See J L Sax et al, *Legal Control of Water Resources: Cases and Materials* (4th ed), 2006, pp 124–6.
7. Sinclair Knight Merz, *National Framework for Integrated Management of Connected Groundwater and Surface Water Systems*, 2011; M Tomlinson, *Ecological Water Requirements of Groundwater Systems: A Knowledge and Policy Review*, 2011; National Water Commission, Australia, *National Water Planning Report Card 2011*, 2011.
8. For example, principle-based thresholds: below, nn 26–30 and accompanying text.
9. Water plans do very occasionally contain "self-executing" provisions that control pumping that does not need to be licensed: see below, n 71.
10. For example, declared subartesian areas in Queensland: Water Act 2000 (Qld), s 1046; Water Regulation 2002 (Qld), Sch 11.
11. For example, Water Sharing Plan for the Bega and Brogo Rivers Area Regulated, Unregulated and Alluvial Water Sources 2011 (NSW), cl 54.
12. *Tomlinson, Ecological Water Requirements*, above, n 7, p 127.
13. *Tomlinson, Ecological Water Requirements*, above, n 7, p 17.
14. For example, the Peel Valley in New South Wales: Sinclair Knight Merz, *National Framework*, above, n 7, p 61.
15. Interview with Jennifer Fraser, Director, Groundwater and Licensing, Victorian Department of Sustainability and Environment, and Patrick O'Halloran, Manager, Policy and Licensing, Victorian Department of Sustainability and Environment, Melbourne, 24 May 2012. Alternatives to simple no-go zones have been proposed, which would involve a multiple zone approach: R Evans, *The Effects of Groundwater Pumping on Stream Flow in Australia: Technical Report*, 2007, pp 71–6.
16. *Tomlinson, Ecological Water Requirements*, above, n 7, pp 52, 127.
17. For example, "cumulative spring factors": Department of Natural Resources and Mines, Queensland, Great Artesian Basin Resource Operations Plan, 2007, as amended, 2012, cl 39.
18. Interview with Michael Williams, Manager, Groundwater, NSW Office of Water, Sydney, 24 July 2012.
19. This threshold was used as part of the Recharge Risk Assessment Method process, the results of which were later modified in some cases in the formulation of sustainable diversion limits. Murray-Darling Basin Authority, *The Proposed Groundwater Baseline and Sustainable Diversion Limits: Methods Report*, 2012, pp 19–20.
20. I propose several hypotheses to explain this difference: adverse effects have been less severe in Australia, leading to a correspondingly reduced will to prevent impacts; remedial tools are theoretically easier to administer in Australia, since governments have commonly reserved to themselves the power to reduce entitlements (an act that would attract legal challenge in the western United States, based on being an unconstitutional "taking" of private property without just compensation); and the prior appropriation system brings home the impacts of relatively small adverse impacts to individual surface water right users, as opposed to being diluted among a consumptive pool, which excites correspondingly louder calls to restrain these impacts.
21. *Postema v Pollution Control Hearings Board* (2000) 142 Wn2d 68, p 94; telephone interview with Tim Davis, Water Resources Division Administrator, Montana Department of Natural Resources and Conservation, 2 August 2012.
22. For example, Revised Statutes of Nebraska, § 46-715(3)(e); Oregon Administrative Rules, rr 690-505-0610(3)(b), 690-505-0610(8); telephone interview with Tim Davis, above, n 21 (referring to buying "contract water" from federal government storage projects, for release to a stream).
23. For example, discharging water stored using managed aquifer recharge into the river: W Blomquist, T Heikkila and E Schlager, "Institutions and conjunctive water management among three western states" (2001) 41 *Natural Resources Journal* 653, pp 678–9; Idaho Administrative Code, r 37.03.11.043 (03)(d); telephone interview with Tim Davis, above, n 21.
24. Interview with Brian Patton, Planning Bureau Chief, Idaho Water Resource Board, Boise, 31 October 2011; interview with Kent Jones, State Engineer, Utah Division of Water Rights, Salt Lake City, 2 November 2011 (describing an early practice of accepting monetary compensation, which occurs less often now).
25. Department of Ecology, Washington (state), *Focus on Mitigation in the Yakima Basin*, 2012, p 2, available at https://fortress.wa.gov; interview with Brian Walsh, Policy and Planning Section Manager, Water Resources Program, Washington Department of Ecology, Lacey, 27 October 2011; interview with Kevin Rein, Deputy State Engineer, Colorado Division of Water Resources, Denver, 7 November 2011 (in relation to the Colorado Water Conservation Board allowing injury to an

instream flow right in return for another measure of environmental value if, for example, replacement water cannot be found). Note that some states specifically exclude certain types of offsetting measures by statute — for example, Colorado Revised Statutes, § 37-92-103(9) (prohibiting offsetting by removing vegetation that uses groundwater).

26. Natural Resources Management Act 2004 (SA), ss 147(6)(a), 149(3)(b), 150(8)(b), 156(3)(b), 157(5)(b); Water Act 2000 (Qld), s 210(1)(i); Rights in Water and Irrigation Act 1914 (WA), Sch 1 cl 7(2)(a).
27. Water Act 2000 (Qld), s 210(e).
28. Water Act 2000 (Qld), s 210(f); Water Act 1989 (Vic), s 40(1)(d)(ii).
29. Rights in Water and Irrigation Act 1914 (WA), Sch 1 cl 7(2)(b), (c); Water Act 1989 (Vic), s 40(1)(g); Water Management Act 1999 (Tas), s 63(1)(c).
30. Water Act 1989 (Vic), s 40(1)(c); Water Act 1992 (NT), ss 71C(3)(b), 90(1)(e); Water Management Act 2000 (NSW), 63(2)(b).
31. For example, *Minister for Environment and Conservation v Simes* (2007) 98 SASR 481; 153 LGERA 225; [2007] SASC 248; BC200705228 at [48]; *Harvey v Minister Administering the Water Management Act 2000* (2008) 160 LGERA 50; [2008] NSWLEC 165; BC200804598 at [74]–[75].
32. Telephone interview with Saji Joseph, Director, National and State Water Policy Water Resources Strategy, Water and Catchments Division, Department of Natural Resources and Mines, Queensland, 19 July 2012; interview with Jennifer Fraser and Patrick O'Halloran, above, n 15.
33. For example, in Victoria, groundwater caps, which are termed "permissible consumptive volumes", are not required to be set after technical assessments of resource sustainability or the requirements of GDEs, but statutory licensing requirements refer to a range of very specific environmental issues: interview with Jennifer Fraser and Patrick O'Halloran, above, n 15; Water Act 1989 (Vic), s 53(b).
34. New Mexico Statutes, § 72-14-3.1(C)(11); A Weeks, "Defining the public interest: administrative narrowing and broadening of the public interest in response to the statutory silence of water codes" (2010) 50 *Natural Resources Journal* 255, pp 283–5; *Taos Regional Water Planning Steering Committee, Taos Regional Water Plan: Volume 1 — Water Plan*, 2008, pp 2-5–2-10, available at www.ose.state.nm.us; *In the Matter of Application for Permit No 37-20742 in the Name of Robert G Friedman*, Idaho Department of Water Resources, 25 August 2003, Idaho Department of Water Resources Decisions 21, ¶ 19 (describing the Blaine County Local Public Interest Water Policy).
35. Oregon Revised Statutes, §§ 537.153(2), 537.170(8) (setting out detailed criteria that must be considered if a public protest against a groundwater application is made, which overcomes a presumption that granting an application would be in the public interest).
36. For example, Natural Resources Management Act 2004 (SA), s 103.
37. Telephone interview with Michael Fuller, Acting Director, Water Planning and Management, Department of Environment, Water and Natural Resources, South Australia, 11 September 2012 (in relation to the use of a natural resources management levy for a variety of activities, none of which directly related to environmental impacts).
38. T Reeve, "Harnessing a voluntary market to restore flow to dewatered rivers and streams", Global Water Forum, 2012, available at www.globalwaterforum.org.
39. For example, Natural Resources Management Act 2004 (SA), ss 132(1)(a)(i), 132(1)(d), 132(1)(e), 132(2), 132(5).
40. Telephone interview with Susan Worley, Branch Manager, Water Allocation Planning, Department of Water, Western Australia, 6 September 2012; telephone interview with Ingrid Franssen, Manager Policy, Department of Environment, Water and Natural Resources, South Australia, 11 September 2012 (referring to a Notice of Prohibition on Water Use in the Polda Basin in the Musgrave Prescribed Wells Area).
41. National Water Commission, *National Water Planning Report Card*, above, n 7, p 385 (in relation to the Lower Gascoyne River Groundwater and Surface Water Allocation Plan 2010); interview with Ingrid Franssen, above, n 40 (referring to the Clare Valley, McLaren Vale, and Tatiara Prescribed Wells areas).
42. Interview with Simon Cowan, Manager, Groundwater and Unregulated Systems, Goulburn-Murray Water, Tatura, Victoria, 30 July 2012 (describing seasonal allocations based on groundwater trigger levels that are set to maintain the direction of groundwater flow to avoid undesirable movement of saline groundwater); Natural Resource Management Standing Committee, *Case Examples of Managing Overallocated Groundwater Systems*, 2002, p 4.
43. NSW Office of Water, "Achieving Sustainable Groundwater Entitlements Program", 2011, available at www.water.nsw.gov.au; *ICM Agriculture Pty Ltd v Commonwealth* (2009) 240 CLR 140; 170 LGERA 373; [2009] HCA 51; BC200911041; interview with Michael Williams, above, n 18.
44. CSIRO, *Assessment of the Ecological and Economic Benefits of Environmental Water in the Murray-Darling Basin: The Final Report to the Murray-Darling Basin Authority from the CSIRO Multiple Benefits of the Basin Plan Project*, 2012, p 23.
45. Productivity Commission, Australian Government, *Water Rights Arrangements in Australia and Overseas*, 2003; Agriculture and Resource Management Council of Australia and New Zealand and Standing Committee on Agriculture and Resource Management, *Allocation and Use of Groundwater: A National Framework for Improved Groundwater Management in Australia — Policy Position Paper for Advice to States and Territories*, 1996, p 12, available at www.environment.gov.au.
46. NSW Office of Water, *NSW Aquifer Interference Policy: NSW Government Policy for the Licensing and Assessment of Aquifer Interference Activities*, 2012, p 30.

47. Interview with Robert Knowles, Water Resources Officer, Goulburn-Murray Water, Tatura, Victoria, 30 July 2012 (referring to the Lower Ovens River water plan encouraging the movement of water extraction from shallower, highly stream-connected aquifers to deeper, less connected aquifers); Sinclair Knight Merz, *National Framework*, above, n 7, pp 55, 70–1; Goulburn-Murray Water, *Upper Ovens River Water Supply Protection Area Water Management Plan*, 2012, pp 44–7.
48. Interview with Susan Worley, above, n 40; Tomlinson, *Ecological Water Requirements*, above, n 7, pp 131–2.
49. For a general overview of the reasons behind this paucity of information in relation to GDEs, and the information required to make decisions about protecting GDEs, see B H Thompson Jr, "Beyond connections: pursuing multidimensional conjunctive management" (2011) 47 *Idaho Law Review* 273, pp 298–301.
50. For examples of western US positions on these matters, see *Simpson v Bijou Irrigation* Co 69 P3d 50, 59 n 7 (Colorado 2003), pp 26–7 (in relation to presuming that groundwater and surface water are connected); interview with Tim Davis, above, n 21 (requiring an applicant for a groundwater permit in a closed basin to submit a formal hydrogeological assessment for the application even to be considered); P Barroll, "Regulation of water versus hydrologic reality in New Mexico" (2003) 2 *Southwest Hydrology* 20, p 21 (granting a temporary permit with a requirement to acquire more information); Revised Code of Washington, § 90.03.290 (providing for a preliminary permit, with the holder to provide further information required by the water agency within the period of the permit). In relation to scientific investigations, see below, n 56 for Montana's approach.
51. P Cullen, "Flying blind: the disconnect between groundwater and policy", *10th Murray-Darling Basin Groundwater Workshop*, 19 September 2006, p 4; C J Nevill, "Managing cumulative impacts: groundwater reform in the Murray-Darling Basin, Australia" (2009) 23 *Water Resources Management* 2605, p 2618; National Water Commission, *The National Water Initiative — Securing Australia's Water Future: 2011 Assessment*, 2011, p 100; I Fullagar, *Rivers & Aquifers: Towards Conjunctive Water Management (Workshop Proceedings)*, 2004, p 2; telephone interview with Ludovic Schmidt, Manager, Water Management Branch, Department of Primary Industries, Parks, Water and Environment, Tasmania, 13 July 2012 (does presume a high level of connectivity in the context of water plans, in the absence of data on the matter, but only one water plan includes groundwater so far, being the Sassafras Wesley Vale Water Management Plan 2012); Water Act 2000 (Qld), s 1006.
52. For example, Natural Resources Management Act 2004 (SA), s 147(1)(c).
53. For example, interviews with Simon Cowan, above, n 42, and Robert Knowles, above, n 47.
54. Department of Sustainability and Environment, Victoria, *Policies for Managing Take and Use Licences*, 21 September 2010, cl 15.
55. Such investigations have become very widespread in Australia. A recent wide-ranging example is Sinclair Knight Merz, *Impacts of Groundwater Extraction on Streamflow in Selected Catchments throughout Australia*, Waterlines Report 84, 2012.
56. For example, R Sheldon, *Groundwater and Surface Water Connectivity in Tasmania: Preliminary Assessment and Risk Analysis*, 2011, pp 52–77, available at www.stors.tas.gov.au; Clark Fork River Basin Task Force, Department of Geography, University of Montana and Montana Department of Natural Resources and Conservation, *Proceedings of the Montana Conjunctive Water Management Conference*, 8–9 June 2009, pp 2–3, 10, available at http://dnrc.mt.gov.
57. Tomlinson, *Ecological Water Requirements*, above, n 7, p 28; telephone interview with Moya Tomlinson, Principal Policy Officer, Groundwater Policy Unit, National and State Water Policy, Water Resource Strategy, Department of Natural Resources and Mines, Queensland, 16 July 2012.
58. For example, Australian Government, Bureau of Meteorology, *Atlas of Groundwater Dependent Ecosystems*, available at www.bom.gov.au; D Eamus, *Identifying Groundwater Dependent Ecosystems: A Guide for Land and Water Managers*, 2009; S Richardson et al, *Australian Groundwater-Dependent Ecosystems Toolbox: Part 1: Assessment Framework*, Waterlines Report Series No 69, 2011; P Howe and J Pritchard, *A Framework for Assessing the Environmental Water Requirements of Groundwater Dependent Ecosystems: Report 3 — Implementation*, 2007; interview with Ingrid Franssen, above, n 40 (describing a project to list, map and analyse the probability that wetlands around the state are connected to groundwater, to inform water planning processes); P E Dressel et al, *Mapping Terrestrial Groundwater Dependent Ecosystems: Method Development and Example Output*, 2010; for an overview of National Water Commission-funded projects, see http://archive.nwc.gov.au.
59. Interview with Moya Tomlinson, above, n 57 (referring to the Environmental Flows Assessment Program process); interview with Ingrid Franssen, above, n 40 (in relation to identifying GDEs in the Clare Valley).
60. Queensland's water planning framework involves setting up a special-purpose technical reference panel to assist in the preparation of each water plan. In a few cases, this process has included identifying and assessing the water requirements of "high priority" GDEs: interview with Saji Joseph, above, n 32; interview with Moya Tomlinson, above, n 57; SKM, *Callide Groundwater Dependent Ecosystem Assessment: Fitzroy Basin Water Resource Plan*, 2008, available at www.mackay.qld.gov.au.
61. Interview with Jennifer Fraser and Patrick O'Halloran, above, n 15.
62. In New South Wales, regional plans set out a list of "high priority GDEs" — typically those that are present on an external register. The comprehensiveness of these lists varies

greatly, with some being entirely empty. Compare, for example, Water Sharing Plan for the Dorrigo Plateau Surface Water Source and the Dorrigo Basalt Groundwater Source (2003), Sch 8, with Water Sharing Plan for the Lower Gwydir Groundwater Source (2003), Sch 5 (stating "To be inserted by the Minister …"). Tasmania's Conservation of Freshwater Ecosystems Values database (available at http://wrt.tas.gov.au) and the Atlas of Tasmanian Karst both contain GDEs.

63. NSW has completed a project to more comprehensively identify and value GDEs based on an ecologically driven classification system, rather than relying on pre-established lists: interview with Michael Williams, above, n 18; P Serov, L Kuginis and J P Williams, *Risk Assessment Guidelines for Groundwater Dependent Ecosystems: Volume 1 — The Conceptual Framework*, 2012. Further reports associated with these guidelines are available from the NSW Office of Water at www.water.nsw.gov.au. See also Sheldon, above, n 56.
64. Sinclair Knight Merz, National Framework, above, n 7, pp 9–11.
65. Nevill, above, n 51, p 2608.
66. Evans, above, n 15, p 53.
67. Interview with Susan Worley, above, n 40 (in relation to selecting groundwater-dependent wetlands to be protected in light of the effects of reduced precipitation).
68. In addition to wells proper, mine voids that intercept groundwater and cause significant "use" through evaporation are another such incidental use of groundwater, with the potential to affect streams and ecosystems. Sinclair Knight Merz, CSIRO and Bureau of Rural Sciences, *Surface and/or Groundwater Interception Activities: Initial Estimates*, 2010, p 95.
69. For example, Petroleum and Gas (Production and Safety) Act 2004 (Qld), s 185(3).
70. The NSW policy was only promulgated in late 2012; the provision in Queensland was introduced in 2010 (Water and Other Legislation Amendment Act 2010 (Qld), s 195), and as at the date of writing only one underground water impact report for a cumulative management area has been produced: Queensland Water Commission, *Underground Water Impact Report for the Surat Cumulative Management Area*, 2012.
71. For example, Natural Resources Management Act 2004 (SA), s 127(2); Water Act 1989 (Vic), ss 33AAA, 33AAB; Water Act 2000 (Qld), ss 22, 26.
72. Water Act 2000 (Qld), ss 361–454.
73. Water Act 2007 (Cth), ss 4(1) (take), 23 (long-term average sustainable diversion limits). Presumably under this approach, Basin states will either need to find ways to restrict exempt uses, or restrict licensed uses so that exempt uses can continue (and continue to grow) unimpeded; Sinclair Knight Merz, *National Framework*, above, n 7, p 53.
74. For example, Water Sharing Plan for the Greater Metropolitan Region Groundwater Sources (Sydney Basin Blue Mountains Groundwater Source) 2011 (NSW) (banning the granting or amending of bore approvals within 100m of high priority GDEs in the case of "bores used solely for extracting basic landholder rights").
75. For example, Natural Resources Management Act 2004 (SA), s 124(7); although Victorian statute does not require that public comment be invited in relation to a licensing process, it makes provision for it (Water Act 1989 (Vic), s 49(1)(a)) and, in practice, licensing processes usually include this step: interview with Jennifer Fraser and Patrick O'Halloran, above, n 15.
76. Water Management Act 2000 (NSW), s 91; NSW Office of Water, *Aquifer Interference Policy*, above, n 46.
77. For example, Water Act 2000 (Qld), s 210.
78. For example, Colorado Revised Statutes, § 37-90-107; Revised Code of Washington, §§ 90.03.280, 90.44.060; North Dakota Administrative Code 89-03-01-04.
79. Bureau of Meteorology, above, n 58.
80. Concerns focus particularly on endangered anadromous fish and spring-dependent species: interview with Ivan Gall, Groundwater Manager, Department of Water Resources, Oregon, Salem, 25 October 2011; telephone interview with Robert Mace, Deputy Executive Administrator, Water Science and Conservation, Water Development Board, Texas, 1 June 2012.
81. Interview with Moya Tomlinson, above, n 57 (referring to Great Artesian Basin mound springs).
82. For example, Colong Caves in NSW and Exit Caves in Tasmania: "'Invaders' fight a quarry", Sun (Melbourne), 24 April 1971; N Clark, "Quarry lobby re-opens the war", Hobart Mercury, 10 March 1993.
83. Sinclair Knight Merz, National Framework, above, n 7, pp 69–70; NSW Office of Water, Aquifer Interference Policy, above, n 46, pp 5, 6; Natural Resources Management Act 2004 (SA), s 160(2)(b)(i) (department to require a water user to contribute to an "environmental improvement program" to offset environmentally detrimental effects of water use). Its main use so far has been to require irrigators in the Angas Bremer area to plant deep-rooted vegetation to offset the salinising effect of applying irrigation water: interview with Ingrid Franssen, above, n 40; Department of Sustainability and Environment, Victoria, Western Region Sustainable Water Strategy, 2011, p 125; Murray-Darling Basin Authority, above, n 19, p 20.
84. For example, interview with Simon Cowan, above, n 42 (referring to a requirement of a Tylden quarry to pump groundwater intercepted by a quarry into a stream); interview with Susan Worley, above, n 40 (referring to the potential requirements to support GDEs affected by mine dewatering in the Pilbara until the water table recovers); Water Act 2000 (Qld), s 408 and following; Victorian Ombudsman, *Investigation into the Foodbowl Modernisation Project and Related Matters*, 2011, p 27 (offsetting impacts of Food Bowl Modernisation Project in reducing seepage to environmentally important wetlands).
85. Above, nn 37 and 83.
86. Productivity Commission, above, n 45.