Protecting Groundwater-Dependent Ecosystems: Gaps and Opportunities

Groundwater is an essential source for many aquatic ecosystems, including wetlands. However, many protections for groundwater-dependent ecosystems are based on surface water. The authors look at existing groundwater laws and policies, as well as gaps in protection, in the United States and abroad.

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Groundwater is well-recognized as a critical source of water for communities around the world. Many aquatic ecosystems, including wetlands, lakes, rivers, springs, and subterranean ecosystems, as well as many species, also rely on groundwater to meet their water requirements.[1] These are known as groundwater-dependent ecosystems (GDEs). In these ecosystems, groundwater provides water with different flow and chemical characteristics than surface water supplies, which has important consequences for their structure and function. Owing to their unique hydrology, GDEs provide critical ecosystem services, including water storage in vast aquifers, water supply, water purification, and species diversity. GDEs can support water supply needs by providing water storage during wet periods and sustained flows during dry times of the year. GDEs develop at the surface where groundwater discharges, and often occupy small areas, yet harbor many endemic, rare, and unusual species of plants and animals. Furthermore, groundwater discharging into rivers provides refugia for fish and aquatic macroinvertebrates by maintaining consistent flow and temperature conditions throughout the year.

As the global population grows, demands on water will increase dramatically. At the same time, surface water supplies are often over-allocated and becoming less predictable due to climate change. These factors are likely to cause increasing pressure on groundwater resources. Until recently, groundwater laws and policies focused on protecting water supplies for human uses, with little consideration of ecosystems and the goods and services they provide. Increasingly, ecosystem protection is included as a key aspect of groundwater management. To sustain GDEs now and into the future, laws and policies must protect the extent and condition of the GDEs and the water flow and water quality delivered to them. Here, we examine existing protections, as well as gaps in protection, for GDEs in the United States and abroad, and illustrate these trends with select case studies.

GDE Protection Through U.S. Federal Laws and Policies

The Clean Water Act (CWA) provides some protection to both habitat and water quality that support GDEs. Provisions of the CWA protect habitat within jurisdictional wetlands through the no net loss policy. Originally, this provided habitat protection for all wetlands; however, several U.S. Supreme Court cases in the last decade have questioned the CWA's jurisdiction, in particular, limiting its scope to wetlands that have a surface water connection to navigable waters.[2] While some groundwater-dependent wetlands are connected to surface waters, many are not, and are thus considered geographically isolated. These geographically isolated wetlands are prevalent throughout the country, and provide significant ecosystem services in the form of water provision, purification, and biodiversity, thus this ruling creates a significant gap in protection of GDEs.[3] This gap has been partially filled through state implementation of the CWA in places where wetlands are included as "waters of the state,"[4] but many states are left with weakened protections for groundwater-dependent wetlands.

The CWA protects water quality by regulating the discharge of pollutants into the nation's surface waters, including rivers, streams, lakes, and wetlands, and implementing pollution control plans and programs. The water bodies covered under the CWA may be GDEs, thus the Act provides some water quality protection for these ecosystems through regulation of surface water pollutants. However, the authority of the CWA to regulate groundwater pollution has been the subject of substantial debate,[5] and implementation of the CWA has been generally limited to surface water protection. This creates a significant gap for the protection of ecosystems that rely on groundwater for some, or all, of their water supply.

The Safe Drinking Water Act provides direct protection of groundwater quality when the aquifer is part of a drinking water system. Drinking water systems include all forms of municipal and rural water supplies. To the extent that GDEs are connected to drinking water aquifers, this policy affords some water quality protection. However, significant gaps exist in the extent and types of water quality protection for GDEs. An overlay of GDEs and drinking water systems in Oregon shows that only 18% of all identified GDEs would receive protection from this policy (Figure 1).

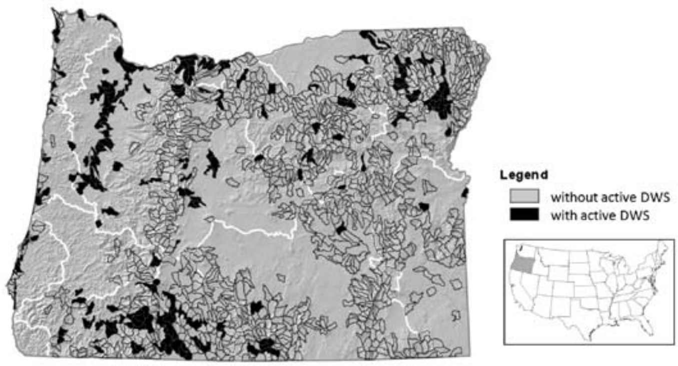

Figure 1. Overlap between watersheds with high concentrations of GDEs (GDE clusters) and active drinking water systems (DWS), in Oregon. The analysis shows that approximately 18% of GDE clusters are located in watersheds with active DWS.

Table 1: Groundwater dependence of species with status under the ESA, including listed, proposed, implied, and candidate species (Adapted from Blevins & Aldous, in prep).

Species	Total # of Listed Species	Listed Species That Depend on Groundwater	
		#	%
Invertebrates	325	84	26
Vertebrates	490	113	23
Vascular Plants	936	94	10
Lichens	2	0	0
Total	**1753**	**291**	**17**

The Endangered Species Act (ESA) also can provide protection of GDEs in locations where the GDE provides habitat to listed species. Geographically isolated GDEs, in particular, tend to be small and have unusual physical conditions, thus they harbor disproportionately large numbers of specialist species relative to their size.[6] A survey of all species with some status under the ESA indicates that 17% rely on groundwater for some part of their life cycle; this number rises to 26% when considering invertebrates alone (Table 1). Given this, the ESA is a tool that could be better applied to protection of GDEs.

State Laws and Policies

Water quantity and availability are generally managed by the states through state water law. Although most state laws do not explicitly protect water for GDEs, patchwork protection can be found in various states across the country. By far, the most common example of protecting groundwater for ecosystems is found in states that have made the link between groundwater levels and instream flows in rivers and streams. Fewer states have laws that protect water for groundwater-dependent springs, wetlands, or lakes. We illustrate these trends with examples of GDE protection within state law.

Instream Flow Protection

Michigan is an often-cited example of a state water program that limits groundwater withdrawals to protect freshwater ecosystems. Under Michigan law, a proposed withdrawal must not cause an "adverse resource impact" to waters of the state or to the water-dependent natural resources of the state. Adverse impacts are defined as changes in flow or water levels that impair the ability of a water body to support characteristic fish populations. The approach links models of stream flow, surface and groundwater withdrawal, and fish ecology to assess the potential impact of a proposed water withdrawal on one or more specific stream segments. Although Michigan law specifically evaluates groundwater withdrawals, the withdrawals are only assessed relative to their impacts on instream flows and fish populations. Fish are considered an indicator for overall stream health.[7] Thus, Michigan law serves to protect groundwater-dependent rivers and associated biota, but not the full suite of GDEs.

Oregon is an example of a western state that has legal mechanisms for limiting groundwater withdrawal to protect surface water resources. Oregon follows the "prior appropriation" doctrine, where the earliest water right holders are first to have access to water ("first in time is first in right"). In addition to consumptive uses such as irrigation and municipal supply, state law allows for establishment of instream water rights. In places where groundwater and surface water are hydraulically connected, the state's administrative rules require that groundwater withdrawals cannot substantially interfere with surface water rights. In addition, amendments to Oregon's Scenic Waterway Act require that groundwater rights not measurably reduce the surface flows necessary to maintain the free-flowing character of the scenic waterway. In the Deschutes Basin in central Oregon, instream water rights and scenic waterway flows are not always satisfied, thus new groundwater withdrawals require mitigation of surface water flows. For each new groundwater permit application, both the amount and location of mitigation are specified. The program established zones of impact, i.e., river reaches, in an attempt to ensure that the mitigation occurs where the proposed use will primarily impact surface water flows. Thus, this program protects instream flows and associated biota, but not the full suite of GDEs such as springs and non-river-associated wetlands.

Beyond Instream Flows

In Florida, the Water Resources Act (WRA) of 1972 provides various legal mechanisms for protecting water for GDEs. Water use is regulated through water use permits, which are issued to parties that can demonstrate that the proposed uses are "reasonable-beneficial," will not interfere with existing legal uses, and are consistent with the public interest. Florida water law is largely implemented through five water management districts, which establish the "basis for review" for the water use permits within their district. In some places, this "basis for review" is resulting in protection of wetlands from impacts due to groundwater drawdown. For example, the St. Johns River Water Management District developed a threshold-based screening approach to evaluate the impact of water use permits on potential changes in vegetation, aquatic species, and wetlands.

The WRA also requires each water management district to establish minimum flows and levels for water bodies within their district, which have been particularly beneficial in protecting springs. In north Florida, a number of springs have been identified as important, for example, for providing warm-water refugia for manatees or passage of native fish, such as Gulf sturgeon. To meet these resource protection goals, the districts have determined a suite of seasonally varying high and low water flows for the springs. The associated minimum groundwater levels are determined through modeling. The water management districts also must develop regional water supply plans that address water supply, water quality, and related issues.[8] These plans can be an avenue for protecting GDEs. For example, in its aquifer protection plan, the St. Johns River Water Management District utilized modeling to evaluate the effects of water withdrawal on springs and wetlands.

In Rhode Island, protection of groundwater for the benefit of wetlands occurs through the Fresh Water Wetlands Act of 1956, which authorizes the state to protect and restore the purity and integrity of all freshwater wetlands in the state. With certain exceptions, the rules require a proposed project that may alter a freshwater wetland must obtain a permit from the state. This includes projects taking place outside the wetland, which are likely to have an impact on the wetland, such as groundwater withdrawal from a well. An important aspect of the Act is that the permit review criteria include several provisions that protect groundwater flow rates and elevations. In practice, proposed groundwater withdrawals of greater than 10,000 gallons (38,000 liters) per day are required to demonstrate that there will be no impact on wetland functions or values. To determine the impact, the state may require the applicant to collect and analyze data related to groundwater elevations and flows, and water table elevations within the identified wetlands. This information is used to determine the impact of the proposed withdrawal on groundwater-dependent species and communities, for example sensitive wetland vegetation. Withdrawals may be limited to ensure that sufficient water is available for the ecological functions provided by the wetland.

International Laws and Policies

Although laws and policies in the United States can be used to achieve partial protection of GDEs, this approach is piecemeal. In most cases, ecosystems are viewed as being in conflict with people for water resources, rather than legitimate recipients of water that ultimately provide numerous tangible and intangible ecosystem services from which people benefit. In contrast to this, in other countries around the globe, a trend is emerging in the water policy arena, whereby freshwater ecosystems—including GDEs—are recognized as requiring certain allocations of groundwater. Adequate provisioning of water—including groundwater—is stipulated to guarantee ecosystem functioning to all aquatic ecosystems. Water policies enacted in the last decade in the European Union, Australia, and South Africa all include such provisions.

European Union

The development of new Europe-wide policies afforded the opportunity to develop a more sustainable approach to water management. In 2000, the European Union enacted the Water Framework Directive,[9] and six years later, the sister Groundwater Directive.[10] The Water Framework Directive included groundwater protection by requiring that specific environmental objectives be met for the surface water bodies and terrestrial ecosystems that depend on groundwater discharge, which includes GDEs. Environmental objectives include criteria for biological communities in addition to flow and chemistry. The biological criteria include measures of phytoplankton, aquatic flora, benthic invertebrates, and fish, and there are further criteria that consider the requirements of unique or vulnerable habitats, including wetlands. These objectives provide protections for GDEs because they stipulate the ecological requirements that must be met before water can be allocated for consumptive use.

While the passage of these two directives makes great strides in providing protection to GDEs, there remain gaps to ensuring full protection. These policies are implemented by means of water basin management plans, which to date have emphasized aquatic ecosystems associated with major rivers,[11] whereas many GDEs are geographically isolated from flowing waters. Furthermore, ecological criteria were never set for subterranean groundwater ecosystems despite significant knowledge gained over the last decade in understanding these ecosystems and despite the important role these organisms play in mediating groundwater quality.[12]

Australia

In 2006, Australia developed the National Water Initiative Agreement, with the goal of striking a balance between consumptive use of water and water to support ecosystem health. The following year, the Water Act of 2007 was passed to develop a management plan for the Murray-Darling Basin in southeastern Australia. This basin is considered the nation's breadbasket, but has been plagued by drought, crop failure due to rising soil salinity and declines in irrigation water supplies, and the widespread decline in freshwater ecosystems and their associated services.

In late 2010, the Murray-Darling Basin Authority released a draft guidance document that charts a course for balancing groundwater and surface water withdrawals. Implicit in the plan is the provision of environmental water to guarantee ecosystem functions and services, including to streams, wetlands, and other GDEs. Hydrologic models are paired with a risk assessment method to determine how much water can be allocated safely without affecting numerous factors, including the groundwater levels in target ecosystems (termed "environmental assets") and ecosystem functions (primarily baseflow in groundwater-dependent streams).

Because waters in the basin have been over-allocated for some time, one of the major impacts of the plan is the proposed large reduction in withdrawals: 99-227 billion liters per year (26-60 billion gallons per year) from groundwater and 3,856-6,983 billion liters per year (1,019-1,845 billion gallons per year) from surface water. These water reductions will be complicated to implement. Similar to Europe, a gap in protection of GDEs is the neglect of subterranean ecosystems, especially since there have been several major local studies of subterranean fauna.[13] Nevertheless, if Australia and Europe can move forward allocating water specifically for ecosystems, it will present a new frontier for holistically managing for the long-term persistence of GDEs.

South Africa

Perhaps one of the most environmentally progressive policies toward water management is South Africa's post-Apartheid Water Act of 1998. This Act guarantees a reserve of water to be set aside as a right to meet basic human needs, and to meet the environmental requirements of aquatic ecosystems. Unlike Australia, where environmental water is purchased from sellers such as farmers, the water reserve is an appropriation and takes precedence over all other uses. After those allocations have been met, permits for other uses may be granted based on water availability. Importantly, the Act recognizes that aquatic ecosystems provide the multiple ecosystem services described above, rather than simply being a competing "user" of scarce water.[14]

The procedure for water allocations to ecosystems is to inventory and characterize them, prioritize them in terms of risk, and then develop a sustainability threshold based on the water quality and quantity required to meet ecosystem function.[15] A recent inventory of GDEs[16] as part of this process included many ecosystems not associated with flowing streams, including subterranean GDEs. In theory, water allocations from the reserve do not differentiate between surface water and groundwater ecosystems; however, lack of technical clarity regarding groundwater resources has lead to an emphasis on surface waters. For example, evaluating instream flow needs for major river systems is being used as the main approach to set the ecosystem part of the reserve.[17] There are numerous other challenges, both socioeconomic, e.g., population growth, poverty, and technical, e.g., South Africa is close to reaching the limits of its water supply, however, these issues highlight, rather than diminish, the importance of this policy for equitable long-term water management.

Conclusions

It is clear from these examples provided in other countries, that there are alternative approaches of holistic water management that include protection for GDEs. This is being done in places with vastly different socioeconomic conditions, different climates and degrees of water scarcity, and different ecological conditions and levels of technical capacity. These examples are in contrast to the patchwork protection of GDEs we can achieve across most of the United States.

Nevertheless, no policy is perfect, and all offer lessons for work to be done elsewhere. First and foremost, GDEs—indeed all aquatic ecosystems—should be recognized and managed for the multiple ecosystem services they provide, and not be viewed simply as competing with human uses and welfare. To achieve this, we need to foster a greater awareness of the role of GDEs in the landscape among key stakeholders, including water resource managers, the freshwater conservation community, and freshwater scientists. Second, protection of groundwater for GDEs must go beyond its connection to instream flows and should include protection of water flows and levels in springs, lakes, and wetlands. This underlines the need for more data and technical expertise in quantifying the relationships between groundwater hydrogeology and the ecology of GDEs. The science of environmental flows has blossomed over the last decade, and groundwater ecohydrology needs to catch up. Without this technical understanding, it will continue to be a challenge to set flow and water quality requirements for GDEs. Finally, subterranean ecosystems must be better characterized and protected. In most of the United States, very little is known about the species and communities in aquifers and caves. In places such as Australia and Europe, where ecologists have studied these ecosystems, they were still largely excluded from federal water policies. Yet, the microorganisms found in these subterranean GDEs play an important role in purifying the drinking water of those who rely on groundwater for domestic supply[18]—one example of the many ecosystem services provided by GDEs. ■

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