doi: 10.2166/9781789062786_0011

Chapter 2

The politics of groundwater allocation and the transition from open access

William Blomquist[1] *and Christina Babbitt*[2]

[1]*Indiana University, Indianapolis, US*
[2]*Environmental Defense Fund, San Francisco, US*

ABSTRACT

Groundwater allocation is a key institutional instrument for restoring sustainability in overdrawn aquifers, especially those that have been used on an open-access basis in the past. Many suggestions for improving groundwater management – pumping reductions, fees on overuse, transferability of pumping rights or shares – are based on the establishment of groundwater allocations. Therefore, how groundwater allocations can be created and maintained is a critical foundational issue in sustainable water resource management. In this chapter, we review the institutional and policy issues associated with establishing groundwater allocations: how they differ from and relate to allocations of surface water; the various values to be taken into account when developing allocations; and why the allocation of groundwater is an inescapably political process. We also review examples of groundwater allocation efforts and identify some patterns among those examples. Combining the review and the examples, we present and explain a set of considerations regarding the process of establishing groundwater allocations. Our considerations are intended to be useful to practitioners as well as researchers interested in this subject, and therefore potentially beneficial in practical ways in the advancement of water sustainability.

Keywords: Agricultural use, allocation, groundwater management, open access, politics, stakeholder involvement, transition, water policy

2.1 INTRODUCTION: THE IMPORTANCE OF ESTABLISHING GROUNDWATER ALLOCATIONS

Groundwater is a largely hidden resource, filling the porous rock and soil layers that exist beneath the places we live, work, and recreate. While less visible than the water flowing in our rivers, streams and reservoirs, groundwater is critical to sustaining people, economies, and natural systems. Globally, groundwater is the primary water source for more than 2 billion people and makes up half of drinking water and 40% or more of irrigation water worldwide (Lall *et al.*, 2020). Increasing groundwater withdrawals have led to significant depletion, posing risks to drinking water reliability, groundwater quality, ecosystem health, agricultural productivity, and water, food, and livelihood security, and raising dangers from land subsidence and sea water intrusion (Bierkens & Wada, 2019; Foster & Chilton, 2003; Gorelick & Zheng, 2015).

The extent and severity of the groundwater challenge is daunting. Satellite observations show major aquifers are being depleted on every continent except Antarctica (Lall *et al*., 2020). Famiglietti (2014) warned, 'Because the gap between supply and demand is routinely bridged with non-renewable groundwater, even more so during drought, groundwater supplies in some major aquifers will be depleted in a matter of decades.' Compounding the challenge, many impacts of over pumping are effectively irreversible, either physically (i.e., land subsidence) or economically because remedies are cost prohibitive (e.g., saltwater intrusion, anthropogenic contamination, mobilization of geogenic contaminants) (Lall *et al*., 2020). Climate change is exacerbating these problems in many locations by reducing soil moisture and increasing evapotranspiration, both of which affect the vulnerability of groundwater-dependent species (Condon *et al*., 2020).

Consequently, in areas where people, economies, and natural systems are at risk from groundwater depletion or degradation, unregulated groundwater use is no longer tenable. The severity and urgency of the situation varies by location but increasing competition for water overall intensifies the need for improved water resource management, including systems to improve how water is allocated between and within user groups (Meinzen-Dick & Bruns, 2000).

Groundwater allocation is a key institutional instrument for restoring sustainability in overdrawn aquifers, especially those that have been used on an open-access basis in the past. How groundwater allocations can be created and maintained is a critical foundational issue in sustainable water resource management. Many suggestions for improving groundwater management – pumping reductions, fees on overuse, transferability of pumping rights or shares – are based on the establishment of groundwater allocations.

In this chapter, we focus on the institutional and policy issues associated with establishing groundwater allocations, including: how they differ from and relate to allocations of surface water; the values to be considered when developing allocations; and why the establishment of allocations is an inescapably political process. We also review a small but diverse set of examples where groundwater allocations have been developed, with particular attention to allocation development in agricultural and mixed-use settings. Combining the review and the examples, we present and explain a set of recommended considerations regarding the process of establishing groundwater allocations. There is no proven formula or linear path for devising an allocation system to manage groundwater resources. Instead, we offer a set of considerations intended to be useful to practitioners in the advancement of water sustainability.

2.2 OPPORTUNITIES AND DIFFICULTIES IN ALLOCATING GROUNDWATER

The primary strategy for arresting groundwater depletion in overdrawn aquifers involves setting limits on the quantity of water that can be pumped and assigning enforceable allocations defining how much users can pump per time period (Garner *et al*., 2020). This concept is well accepted and widely used in surface water management. While there are similarities in managing surface water and groundwater, establishing rules to allocate groundwater entails distinct opportunities and challenges.

2.2.1 Opportunities

Groundwater's slower movement through the subsurface layers of the earth and the ability of aquifers to receive and store water partially dampen the variability and vulnerability that are characteristic of surface water. Consequently, groundwater can serve as a strategic reserve, or savings account, to buffer against water scarcity and prolonged drought. Moreover, the coordinated management of groundwater and surface water can enhance the overall resilience of water systems in ways that benefit multiple uses and users of water (Blomquist *et al*., 2004). In most places groundwater and surface water systems are closely linked (OECD, 2017) and in many circumstances, groundwater can be recharged either naturally or through designed groundwater replenishment operations.

Groundwater also allows for distributed access without massive infrastructure (unless large-scale treatment is needed), which can complement surface water systems' reliance on reservoirs, canals, and other conveyance facilities.

These characteristics of groundwater and their complementarities with surface resources open up prospects for improved water management. As we will discuss further in Section 2.3, the process of developing groundwater allocations can be pursued in ways that capitalize on these advantages.

2.2.2 Difficulties

Other characteristics of groundwater present challenges to allocation development. Many arise from the relative invisibility of the resource. Unlike surface water, groundwater is nearly impossible to observe directly, making its use and conditions difficult to monitor and manage (Moench, 2004). Further, compared with the data available for surface water, in most countries, groundwater quality, quantity, and use data are poor and incomplete (OECD, 2017; Theesfeld, 2010), partly due to insufficient investment in data collection but also because groundwater's movement creates considerable lag times that complicate monitoring and assessment. These challenges make it harder to determine what amount of groundwater use can be sustained over time without harm, and a groundwater resource can be in substantial difficulty by the time it is realized. These challenges do more than increase the technical difficulties associated with groundwater management. They also make allocating and managing groundwater more prone to conflict.

To start, groundwater's relative invisibility blurs governance boundaries. Uncertainties about recharge areas, flow and discharge characteristics, and connectivity with surface water make it difficult to identify hydrogeological boundaries precisely (Theesfeld, 2010). Uncertain boundaries complicate the identification of users and stakeholders (Blomquist & Schlager, 2005; OECD, 2017) and diminish users' awareness of their interdependent reliance on a shared aquifer system – especially compared to the more recognizable upstream/downstream dynamic among surface water users. Furthermore, aquifer boundaries often do not neatly align with surface water watersheds or river basins (OECD, 2017), so jurisdictional boundaries established to manage surface water do not necessarily match those appropriate for managing a groundwater resource even where groundwater and surface water are interconnected.

Surface water allocation and management have usually developed first, and groundwater rules have lagged or been absent altogether (Mechlem, 2012). Where it has been managed at all, groundwater has been governed and managed differently from surface water. Surface water is often regulated by a state authority through a standardized permitting system, whereas groundwater governance has generally evolved toward local planning and management (Peck *et al*., 2019). Whether one governance mode is better than the other is largely beside the point; what matters more is that the two modes exist and reconciling them in any way – including any effort to fit the governance of surface water use into the management of groundwater or vice versa – can be expected to spark battles over control.

In addition, the physical nature of aquifer structures often renders overlying groundwater users to be differently situated (Blomquist, 2020). Two groundwater users may extract water from the same aquifer, but the aquifer's underlying geological structure can render one groundwater user more or less vulnerable than their neighbor. Users' relative vulnerability also depends on their financial or technical capability to access the resource (e.g., dig a deeper well). Situational disparities such as these complicate reaching an agreement on allocations.

Other differences among groundwater users – such as wealth, family size and influence, history in the area, ethnicity or tribal identity, and extent and location of land holdings – may also contribute to making allocation assignment conflictual. When we model or theorize about groundwater allocations, we typically disregard those differences and treat users as identical. In actual settings, any effort to transition from open access to allocations will occur among users who are not abstractly homogeneous, and their differences mean that distributional effects of any allocation system will be layered onto these distinctions as well.

Groundwater use also varies. Even where agricultural use predominates, groundwater will also be used for purposes such as a village's water supply and sanitation. Drinking water and other domestic uses clearly must be accounted for and protected, even if the predominant use of groundwater is for agriculture. Groundwater also supports surface water flows and habitat. Allocating groundwater therefore becomes more than a question of how much each user gets; it becomes a matter of how much is allocated to one kind of use compared with another (Endo, 2019; Jarvis, 2014).

Taken together, these differences among users and uses make choosing any basis for groundwater allocations prone to conflict. Groundwater allocations can be, and have been, based on various criteria, including property size, current land and water use, historical use, access to other water sources, and more (Babbitt *et al.*, 2018; Bruns & Meinzen-Dick, 2005; Ostrom, 2005; Theesfeld, 2010). These options will have location-specific effects on groundwater management – ease or difficulty of monitoring and enforcement, incentives and disincentives for greater conservation, and so on.

Further, choosing and implementing any of these allocation bases raises equity questions. If property size is used, should all land count or only arable land? If land use is the basis, should allocations be adjusted by soil type, crop type, irrigation needs? If historical use is chosen, what time period will be selected for determining users' histories, and will users inflate their use to secure a larger entitlement? If access to other water sources is used, should groundwater allocations take account of the variability or quality of those other sources and, if so, how?

The selection of any allocation basis will be contestable. No allocation basis is objectively or neutrally best, and each choice will leave some groundwater users comparatively better off and others worse off. The perceived fairness or unfairness will affect how users respond to or resist an allocation arrangement (Daigneault *et al.*, 2017; Hammond Wagner & Niles, 2020; Rinaudo *et al.*, 2016; Syme *et al.*, 1999).[1] As Babbitt *et al.* (2018) observed:

> *Groundwater management often requires asking people to change what they do in a way that has an actual or perceived financial impact. This requires establishing trust within that group of people – acceptance of a fair system that will allow them to use a sustainable amount of groundwater that supports their livelihood over the long-term.*

Because of these unavoidable aspects of developing groundwater allocations, adopting an allocation system is ultimately a political decision. It is political in the fundamental sense of who gets to decide and how. The decision might be made by users themselves through some locally situated process or by some governing body on which their interests and opinions are represented, mandated and imposed on them by some external authority without their voice, or some variation or combination along this spectrum. In the end, a decision to adopt and implement an allocation system will be made by someone through some means, meaning that at the core, developing groundwater allocations is inescapably political. Deferring to whatever decision-making body allocates surface water is also a political decision – one that should not be expected to be received well by groundwater users as already noted. Relying on larger jurisdictions also does not erase the politics of groundwater allocation – it just means that the array and relative influence of the interests being heard and attended to will differ from what they would have been at a smaller scale (Lebel *et al.*, 2005).

One more important consideration is that people usually do not attempt to solve problems until they are aware they have them. A logical and amply verified extension is that by the time a group of people is having a problem, deciding upon and implementing a solution is inherently difficult because people will have to change something they have been doing that brought about the problem. Molle and Closas (2020c) characterize the resulting situation as a dilemma. There is little incentive (and

---

[1] Arguing that perceived unfairness can be mitigated later through side payments or transfers of water entitlements is logically compelling but temporally backwards; in transitioning from open access to groundwater allocations, what matters is getting an allocation system adopted in the first place. Even if there are potential *ex post* remedies, users can be expected to resist an allocation system they perceive *ex ante* as unfair.

substantial disincentive) to incur the costs of adopting and implementing a groundwater allocation or licensing program *before* negative effects on the aquifer occur, but it is harder to adopt and implement one *after* conditions have deteriorated. By the time people contemplate allocations, the resource will be showing signs of overuse and degradation and developing allocations will occur in the context of trying to remedy problems rather than prevent them.

2.3 MANAGING THE TRANSITION TO GROUNDWATER ALLOCATIONS

Viewed in terms of the groundwater allocation dilemma, the pressing challenge is to move away from the already problematic open-access status quo. Since that transition will almost certainly be conflictual and political, it is not necessarily a quest for an optimal allocation system. We do not propose a particular allocation system, let alone an optimal one. The water allocation literature is rich with optimization models. In practice, however, diversity of allocation rules is the norm and optimality the exception. Instead of an optimization scenario, users of an open-access groundwater resource that is already overexploited or degraded may need suggestions for proceeding from the status quo toward something different. Our recommendations therefore focus on the transition itself.

2.3.1 Examples of transitions away from open access

Thanks to the work of many researchers in recent years, there are numerous examples of the transition from open access to groundwater allocation. Some appear in subsequent chapters of this book. In this section we draw upon six previously published case studies for most of our illustrations:

- the Gakunen Council for Coordinated Groundwater Pumping (CCGP), in Japan (Endo, 2019; Jinno & Sato, 2011);
- the Pioneer Valley groundwater basin, in Australia (Queensland 2016, 2019; Thomann *et al.*, 2020); and,
- in the US, the Main San Gabriel groundwater basin in California (Main San Gabriel Basin Watermaster 2020; Steed, 2010), the Sheridan 6 Local Enhanced Management Area (LEMA) in Kansas (Peck *et al.*, 2019), and the Central Platte and Upper Republican Natural Resources Districts (NRDs) in Nebraska (Hiatt & Zellmer, 2018; Hoffman & Zellmer, 2013).

Table 2.1 relates these cases to our recommendations regarding the transition process.

Table 2.1 Six groundwater allocation cases.

	Central Platte NRD	Gakunen CCGP	Main San Gabriel Basin	Pioneer Valley	Sheridan 6 LEMA	Upper Republican NRD
Measure and report extractions	×	×	×	×	×	×
Buyouts	×	×			×	×
Establish and maintain incentives	×	×		×	×	×
Involve as many users as possible	×	×	×		×	×
Allow carry-over			×		×	×
Make production tradeable			×		×	×
Allocations as shares			×	×		×
Set an initial cap	×	×	×	×	×	×
Data on basin conditions updated regularly and transparently and cap adjusted as needed	×	×	×	×	×	×

2.3.2 Recommended considerations for the transition process

From these examples and other contributions to the natural resource management literature, we have identified several factors that may contribute positively to transitions from open access to groundwater allocations. Our recommendations are intended as helpful observations organized in a sequence that we believe to be beneficial. We emphasize that what follows is not a recipe and the recommendations should be considered and applied according to the specific conditions and dynamics of each basin.

2.3.2.1 Measure and report extractions

There may be exceptional circumstances where users are measuring and reporting their withdrawals from an open-access groundwater resource, but typically where there are no allocations or limits there is also no reporting of groundwater use. Transitioning away from open access may begin with developing some means of measuring and reporting pumping (Bruns & Meinzen-Dick, 2005; Evans & Dillon, 2018; Hoffman & Zellmer, 2013; Thomann *et al.*, 2020). The information generated by monitoring and reporting is essential for subsequent steps in allocation development and for monitoring compliance with whatever future allocation system is worked out (Babbitt *et al.*, 2018).

In addition, the act of measuring and reporting raises users' own awareness of their individual and collective use of the resource and this alone can have beneficial impacts (Syme *et al.*, 1999). Sharing the information – being aware of their own use and knowing others will see it – is sometimes associated with a drop in withdrawals; in other words, the reporting may be as important as the measurement (Ostrom, 2005).

In the six cases we listed above, measurement and reporting were early features of the transition process. In some instances, this step began with users simply reporting their own estimated use; subsequently, provisions for the metering of wells were added to assure more consistent and accurate measurement. All six cases now feature measurement and reporting of extractions (see Table 2.1). Other cases reported in the literature reinforce the importance of this step in the transition to allocations (Rittenhouse, 2018; Singh & Zaragosa-Watkins, 2018).

Larger jurisdictions can play a catalytic role (requiring or incentivizing the initiation of measurement and reporting), a reinforcing role (making measurement and reporting a condition for state recognition of users' allocations), or both. As remote-sensing technology has become more familiar and accurate, larger jurisdictions may support its adoption as an alternative to metering large numbers of spatially dispersed agricultural wells.[2] For a transition from open access to allocations, beginning to measure and report is more important than what method is used – methods can be refined over time but getting started is the key consideration.

2.3.2.2 Developing allocations takes time; in an emergency, consider buyouts

The transition away from open access will entail tensions and dilemmas. Transition is unlikely to begin until a groundwater basin is showing signs of trouble and developing and implementing an allocation system can take a long time, during which degradation will continue. That time is necessary because building cooperation and trust 'can be the difference between successful and unsuccessful groundwater management' (Babbitt *et al.*, 2018). Patience is required and typically a system of allocations will be assembled in stages rather than all at once (Bruns, 2005).

Fortunately, due to characteristics noted in Section 2.2, changes in groundwater conditions tend to be slower than for surface water. If open-access overexploitation has occurred at high rates or for long periods, however, conditions may have worsened to the point of an emergency (e.g., failing wells, water quality impairment) by the time the allocation development process gets underway. Even in

---

[2] See https://blogs.edf.org/growingreturns/2021/10/21/measuring-water-california-delta-openet/ for a description of such a system, OpenET. Starting in January 2022, California will allow farmers to use OpenET to report their annual water use in the San Francisco-San Joaquin Delta, which supplies water to 25 million people and 3 million acres of Central Valley farmland in that US state.

these circumstances there is an alternative to rushing an allocation system into place. We recommend that users and other policymakers consider buyouts as a short-term measure to address emergency conditions and provide the needed breathing space for the allocation development process to continue in a deliberate fashion.

In agricultural settings, buyouts would typically take the form of compensation for temporarily fallowing or permanently retiring irrigated land, which may mean shifting to dryland farming. Buyouts can produce prompt reductions in pumping. There may be constructive roles for larger jurisdictions, such as assisting with technical analyses to target lands for buyouts or providing funds for the buyouts (EDF, 2021). Smart implementation of buyouts should target irrigated land with comparatively lower-value production relative to water use and consider whether alternative land use benefits are possible. We do not endorse buyouts as a panacea but they may be used selectively and constructively to remediate dire groundwater problems quickly and allow a considered transition to allocations to proceed.

Buyouts have been used in most of the six basins summarized in Table 2.1. We highlight here the Gakunen case in Japan where a buyout scheme was devised to target seawater intrusion. Pumpers away from the intruded area subsidized an alternative water source for the pumpers overlying the intruded area so they could cease pumping, thereby allowing groundwater levels to recover and arrest further inland movement of seawater (Endo, 2019). There are many other examples in the literature of buyouts being used in overdrafted groundwater basins (e.g., Rittenhouse, 2018; Rosenberg, 2020a,b; Ross and Martinez-Santos, 2010; Singh and Zaragosa-Watkins, 2018).

2.3.2.3 Establish and maintain incentives to complete the transition

Given the time necessary to develop groundwater allocations, it is helpful to establish some motivation to complete the process, that is, some negative consequence users will experience if the transition is not made. Otherwise, the open-access status quo may persist despite deteriorating conditions, and users may abandon or undermine the transition process once it becomes difficult, as it inevitably will.

Here too, constructive roles may be played by larger jurisdictions. A threat of intervention if users and others at the local level do not develop an allocation system or fail to show progress within a specified time frame can be highly motivating (Molle and Closas, 2020a; Rouillard *et al*. 2021). Groundwater users might prefer no governance to local governance, but they will normally prefer local to external governance. Another source of motivation can come from neighboring users or jurisdictions. It is rare for a groundwater basin to be completely isolated: commonly there is inflow from or outflow to adjacent water sources. To the extent that groundwater overuse in one basin affects adjacent ones, the threat of intervention initiated by neighbors can provide incentives to develop an allocation system. Droughts, especially severe or multi-year ones, sometimes provide impetus to initiate or complete a transition away from open access and may trigger threats of intervention from larger or neighboring jurisdictions.

Although the details vary, all six of our comparative cases involved some motivation or incentive to keep the transition process moving. In both the Central Platte and Upper Republican cases, interstate compacts govern rivers that are either fed or depleted by the groundwater supply conditions. In Pioneer Valley there is the threat of intervention by a larger jurisdiction: the State of Queensland possesses authority to take over if basin-level efforts fail and the State audits basin-level performance every five years. In the Main San Gabriel Basin there was no threat of state intervention, but there was a prospect of litigation from downstream users who depended on the basin's outflow.

2.3.2.4 Involve as many users as possible

As stated in the Organization for Economic Co-operation and Development (OECD) report: 'A clear and transparent process should be in place to facilitate stakeholder engagement in the determination of a sustainable exploitation strategy and other key allocation decisions' (OECD, 2017). There are understandable temptations to 'streamline' the process in order to reduce the transaction costs and time associated with allocation development. In practice, however, those measures often entail excluding subsets of users or other stakeholders – for example, just negotiating allocations among the largest users or just negotiating allocations for one sector.

As mentioned earlier, the allocation development process need not and should not be rushed. An allocation system should be designed for duration; shortcuts to the transition process run the risk of neglecting issues or interests in ways that generate problems during or after implementation. Even common shortcuts such as excluding small users should be reconsidered. Involvement is a form of recognition, a way of being taken seriously (Bruns, 2005). In many groundwater basins, small users have the most at stake – their reliance on groundwater may be nearly total. Excluding them from the transition process may equate to excluding the voices, concerns, and ideas of users for whom the groundwater resource is most essential.

Although an inclusive process cannot guarantee that an allocation system will achieve consensus acceptance, trouble-free implementation, and smooth adaptation over time, excluding users or other stakeholders raises the chances of opposition, resistance, and rigidity. Involving as many users as possible is a means of incorporating the most information into the allocation system design in the present and allowing some flexibility in the future. Leaving individuals or interests out of the process may appear expedient in the short term but prove a poor bargain later.

Of course, involvement can occur in a variety of ways. Large numbers of users may have to be represented (Evans & Dillon, 2018), and local or regional governmental or non-governmental bodies may have to represent some interests or groups (as occurred in the Main San Gabriel Basin case). In the cases we compared (Table 2.1), involvement took myriad forms as one would expect: agricultural water users were directly involved in the design and implementation of allocations in Sheridan 6, for example, and users' representatives negotiated the allocation arrangements in the Main San Gabriel Basin.

2.3.2.5 *Allow carry-over pumping or multi-year allocations*

For many and probably most users, any proposed movement away from the status quo, even in the name of reform or sustainability, prompts worry. Most users will expect to end up worse off and will weigh prospective losses more heavily than gains. Accordingly, we see setting a cap – which some readers might have expected to come next – as better tackled after users are assured of some control over their post-cap circumstances and we therefore discuss carry-over and transferability options ahead of cap setting.

One way to provide some assurance of control and flexibility under a cap is through provisions for carrying over unused pumping from one period to the next. Although users will be concerned that their new allocation under the cap will be insufficient, there is some advantage in knowing that if one is able to make do with the assigned allocation – or even with a little less in some years – underutilization in period one can leave a little cushion in period two. Multi-year allocations are another means to this end. Users who receive an allocation that can be used over a period of years are similarly assured that reduced usage in one year can be available if needed in a subsequent year.

One of the most destructive dynamics in the use of any common-pool resource is the 'use it or lose it' calculus by which users strive to extract whatever they can in the present for fear that consumption foregone today will be foreclosed tomorrow. The prospects for successful adoption and continuation of an allocation system are enhanced by replacing the use-it-or-lose-it mindset with an assurance that forbearance does not equate to forfeit. In agricultural settings in particular, users may value knowing that pumping less in a year when precipitation or surface water is good allows one to save that unused pumping in case the next year offers less precipitation.

Reasonable constraints may be placed on carry-over allowances, for example, limiting how much unused pumping can be carried over from one period to the next or how much stored carryover water can be withdrawn in any subsequent period. Such precautions can mitigate negative effects from harmful rises or drops in groundwater levels (Hiatt & Zellmer, 2018). In practice, carry-over provisions and multi-year allocations are often accompanied by such limits but still provide users some control over their use and some incentive to exercise restraint in the present without jeopardizing the future. In most of the cases we have compared (see Table 2.1), either carry-over or multi-year allocations are in place subject to some rules. In the Sheridan 6 Local Enhanced Management Area (LEMA) in Kansas, for instance, with the assistance and support of the state's Chief Engineer, pumpers negotiated a multi-year allocation arrangement in which carry-over of unused pumping was both allowed and limited (Peck *et al.*, 2019). In the first five years of operation under those allocations, the target reduction of groundwater use was 20% and irrigators exceeded that goal by achieving an overall reduction of 23% and therefore had carry-over water available for the next five-year period.

2.3.2.6 Make production tradeable

Transferability of water allocations is recommended widely in the water resource management literature. Most such recommendations identify transferability as something to be added on to an allocation system after a cap on pumping has been put in place and allocations have been assigned to users. For example, the OECD states: 'Once the elements of a robust allocation scheme are in place, allowing water entitlement holders to trade, lease or transfer water entitlements can improve efficiency in allocation and resource use' (OECD, 2017).

As with carry-over provisions, and for similar reasons, we recommend that users be assured of transferability even before a cap is set and allocations made. Putting transferability assurances into place ahead of the assignment of a cap and allocations can facilitate the transition process: users will know that if they need more water than they were allocated they may be able to acquire some from another user and if they are able to use less than their allocation, they may be able to monetize the savings or exchange water transferred in one period for access to a comparable amount later. In combination with carry-over provisions, transferability gives groundwater users more control over their situation in the future which may reduce their anxiety about and resistance to the adoption and implementation of an allocation system.

Incorporating transferability into the transition process does not have to mean full development of a water market. That can come later if desired. The key is to get from open access to allocation by lowering water users' apprehension. Actual transfers may be relatively rare, especially at first, and 'large investments in developing formal registries, building capacity to scrutinize potential third-party impacts, and other costly measures, may not be justified by the potential level of transfers' (Bruns, 2005).

Our rationale for making allocations transferable is therefore different from the rationales found in the water resource literature of the past half-century or so. Those arguments were offered mainly on the grounds of economic efficiency (allowing those with higher-valued uses of water to bid some away from those with lower-valued uses) and adaptive management (allowing the initial assignment of allocations to be adjusted marginally through transfers as water resource conditions and/or valuations change). Both rationales are sound and important, but our argument for transferability is as an aid to getting an allocation system into place.

As with carry-over, transfers may be subject to limitations. In most of the cases we reviewed where transfers of allocations are allowed (see Table 2.1), there are constraints to account for potential impacts of shifting the location and intensity of pumping within a groundwater basin or for other purposes. In the Upper Republican Natural Resources District in Nebraska, for example, transfers are subject to approval by the district's board of directors and are limited to nearby lands (less than 6 miles or approximately 8 km away) (Hiatt & Zellmer, 2018).

2.3.2.7 Develop allocations as shares rather than fixed quantities

Providing assurance that no current users will be shut out can address users' anticipation about an allocation system's effects. This can be achieved by assigning users shares in the total amount of allowed pumping rather than assigning them fixed quantities of allowed pumping. Many users would prefer the certainty of a fixed quantity, but in an already overdrawn basin they also rationally anticipate there will be a cap someday and it will mean limitations on pumping. In such a scenario, fixed-quantity allocations for all users and reductions in total pumping necessarily collide. Those who anticipate negative impacts can be expected to resist and try to undermine the allocation arrangement. Young (2014) and Young and McColl (2003, 2009) have advocated allocating pumping shares for precisely this reason.

Share assignments are also more easily adjustable when a cap on total pumping is adjusted downward or upward based on groundwater conditions. This latter advantage is emphasized by Young (2014) and others, for example, Bruns (2005), Burchi (2018), Evans and Dillon (2018), and OECD (2017). Share allocations may therefore benefit both the transition process itself and the implementation of the resulting allocation system. Assigning shares is no panacea, however, and location-specific factors may require adjustment if some water users or uses are more flexible than others (Meinzen-Dick & Bruns, 2000).

Among our cases (Table 2.1), shares have not been as common as fixed quantities thus far. We draw attention here in particular to Pioneer Valley in Australia, a country that is a leader in the shift toward share-based allocations (Burchi, 2018). Each groundwater user in Pioneer Valley possesses a pumping license that nominally assigns a volumetric quantity of allowed pumping, but each year the basin administrator announces an adjustment percentage to be applied to each user's licensed quantity based on groundwater conditions in the basin. The application of an annual percentage to each user's allocation effectively transforms the volumetric allocations into relative shares. In Nebraska's Upper Republican Natural Resource District, each irrigated acre is allocated a specific number of inches of groundwater that can be pumped, and this allocation is adjusted every five years based on water availability, Republican River Compact compliance, and how much water is reasonably needed (Hiatt & Zellmer, 2018). The adjustable five-year allocation essentially mimics a shares-based system with allocations adjusted through time based on changing conditions. In California, the Main San Gabriel Basin was the first adjudicated groundwater basin to assign shares (Blomquist, 1992) and other basins followed that lead in subsequent allocation transitions.

2.3.2.8 Set an initial cap

At this point we turn to establishing an initial limit on total pumping, that is, the initial cap. Presumably the cap will be set below the aggregate amount of current extractions; otherwise there is little point in transitioning away from the status quo. The initial cap (and subsequent revisions to it) should also account for non-agricultural uses that may need to be protected, such as groundwater availability for drinking water and sanitation and for ecological needs.

On the other hand, there are reasons why the initial cap does not have to be at an ideal level for permanent sustainability. First, that level may not be known yet, and there are sound arguments for managing adaptively as more becomes known about groundwater conditions and how they (and the users) respond to the initial limitation. Second, groundwater resources generally have more buffering capacity than surface water resources and are more amenable to a phased approach. Third, as noted, we presume and recommend that if groundwater conditions are in crisis some emergency measures should be taken; in the absence of that, there should be at least some time for adjustment toward a sustainable path.

Our view is that (a) getting an initial cap in place is an important element of developing and implementing allocations, but (b) the initial cap need not be the final cap, and therefore (c) establishing the initial cap does not have to wait until everything is known and everyone has agreed on what the final cap should be. In some of the cases we have compared for this chapter, initial pumping limits have been put in place and then adjusted – typically downward – once groundwater users have been assigned their allocations and the allocation system has begun operation (see Table 2.1). In Kansas, the agricultural pumpers who established the Sheridan 6 LEMA agreed in 2012 to set their initial cap at 20 percent below their estimated aggregate pumping, with a multi-year allocation of 55 inches of irrigation water per acre for the initial five-year period. This was a substantial reduction from the status quo, but the farmers also were aware that it was still probably too high and would have to be adjusted (Peck *et al*., 2019). It was nonetheless an important starting place.

2.3.2.9 Update data on groundwater use and basin conditions frequently and transparently and use this data to adapt production limits periodically as needed, until what is perceived to be sustainable is reached

Once an initial cap is established and allocations assigned, it is vital that groundwater users and basin managers understand how the allocation system is operating and what effects it is having. Credible monitoring and reporting undergird sustainable management arrangements (Evans & Dillon, 2018). Data on groundwater use are essential to establish confidence that users are complying – which reinforces users' future compliance – or to identify non-compliance so it can be addressed quickly before it erodes trust. Data on groundwater conditions are equally essential to determine the allocation system's effects, although conditions may take a while to show results because groundwater can respond more slowly. These data can be used to adjust production limits over time until desired conditions are maintained.

There is no uniform recommendation regarding how frequently updates should occur. Technological advancement has certainly made it possible to communicate data faster than in the past, when annual reports might have been regarded as frequent enough. Annual updates on usage may still be sufficient and are the norm among the cases we have compared for this chapter. The Natural Resources Districts in Nebraska and the court-appointed watermaster in the Main San Gabriel Basin issue publicly available annual reports, which include data not only for the current year but also showing how usage and conditions have changed over time.

In regard to adjustments, production limits have been adapted over time in the cases we have compared for this chapter (see Table 2.1). We draw particular attention to the Upper Republican Natural Resources District in Nebraska, where pumpers' initial allocations in 1978–1979 were 20 inches of groundwater per year for irrigation (100 inches over five years). By 2013–2017, the five-year allocation had been adjusted downward to 65 inches or an average of 13 inches per year – a drop of more than one-third compared with the initial allocation (Hiatt & Zellmer, 2018). The politics of groundwater allocation has not prevented even this substantial adjustment; the allocations are made by the District's elected board of directors, most of whose constituents are the agricultural users receiving those allocations. Transparent, credible data on groundwater use and basin conditions, combined with the external pressure of an interstate agreement governing the river to which the groundwater resource is connected, have made reduced allocations acceptable even if they are unwelcome.

2.4 CONCLUSIONS: CONTEXT AND VARIATION IN GROUNDWATER ALLOCATION DEVELOPMENT

In any location, allocations will reflect basin characteristics and conditions, uses, preferences and priorities, and the historical, cultural, and political contexts of land and water use. Groundwater allocations also will and should reflect how groundwater and its use in that location interact with surface water and surface water use. The configuration of these conditions, characteristics, and contexts is unlikely to be the same from one location to another. Accordingly, we fully expect the transition from open access to groundwater allocations to proceed differently and produce different results in each groundwater basin.

The importance of contextual influence also means that there is and can be no blueprint or recipe for the transition to allocations or the resulting allocation system. The recommended considerations in Section 2.3 are intended only as suggested ways that a transition process may be facilitated, based upon our recognition of (a) the opportunities and challenges associated with groundwater and its allocation,

(b) the inherently and unavoidably conflictual and political nature of the transition to groundwater allocations, and (c) some lessons and illustrations drawn from places where the transition has been made.

Observing that the transition process and resulting allocation system will vary from place to place is, in our view, an empirical statement. It is not a normative argument that local allocation systems will automatically be efficient, equitable, and effective. There are no panaceas, and that includes local management itself (Boelens *et al.*, 2005; Molle & Closas 2020b; Ostrom, 2005). The importance of local variation derives from the significance of context rather than from a faith that local arrangements will always or inherently be best. Sustainable groundwater management is a complex endeavor, and on balance the development of allocations is better undertaken with careful regard for contextual factors (Boelens *et al.*, 2005; Daigneault *et al.*, 2017), which include not only physical conditions but social and historical ones, such as what users perceive to be fair and legitimate (Bruns & Meinzen-Dick, 2005; Hammond Wagner & Niles, 2020). Water 'scarcity and competition are not standard problems for which universally valid solutions can be formulated' (Boelens *et al.*, 2005; see also Ostrom, 2005).

Although allocation development is context-specific, larger-scale jurisdictions such as national and regional governments can fulfill valuable roles to enable and encourage the transition process. They can aid in the development and availability of technical information about water resources, provide financial or other assistance for emergency actions such as buyouts if needed, and adjust water resource policies, property law, or other rules to remove impediments to flexibility-enhancing practices such as carry-over or multi-year allocations, transferability, and allocations of shares. Within such a policy environment, efforts at the groundwater basin level to transition to allocations will face better prospects for success. Larger jurisdictions can also support transition processes by providing institutional arrangements that facilitate conflict resolution and equitable access to participation.

There is no reason to expect that transitions from open access to allocations will be easy, quick, or inexpensive, or will be successful upon first attempt. Diversity in allocation systems is neither unexpected nor undesirable, and policymakers may need to resist temptations to impose or induce uniformity in the name of harmonization. Similarly, there is no reason to expect transitions away from open access will result in optimal allocation systems as defined by modelers or other researchers. The transition process itself is more important and offers water users a more sustainable, enduring pathway than the open-access alternative. Further, a transition away from open access sets the stage for other water management improvements (transfers, conjunctive management, etc.) to follow.

REFERENCES

Babbitt C., Gibson K., Sellers S., Brozovic N., Saracino A., Hayden A., Hall M. and Zellmer S. (2018). Summary of lessons learned with implications for SGMA implementation. In: The Future of Groundwater in California: Lessons in Sustainable Management from Across the West, Report. Environmental Defense Fund, New York, USA, 15–18.

Bierkens M. F. P. and Wada Y. (2019). Non-renewable groundwater Use and groundwater depletion: a review. *Environmental Research Letters*, **14**, 1–44.

Blomquist W. (1992). Dividing the Waters: Governing Groundwater in Southern California. ICS Press, San Francisco, USA.

Blomquist W. (2020). Beneath the surface: complexities and groundwater policy-making, *Oxford Review of Economic Policy*, **36**(1), 154–170. https://doi.org/10.1093/oxrep/grz033

Blomquist W. and Schlager E. (2005). Political pitfalls of integrated watershed management. *Society and Natural Resources*, **18**(2), 101–117. https://doi.org/10.1080/08941920590894435

Blomquist W., Schlager E. and Heikkila T. (2004). Common Waters, Diverging Streams: Linking Institutions to Water Management in Arizona, California, and Colorado. Resources for the Future, Washington, DC.

Boelens R., Zwarteveen M. and Roth D. (2005). Legal complexity in the analysis of water rights and water resources management. In: Liquid Relations: Contested Water Rights and Legal Complexity, D. Roth, R. Boelens and M. Zwarteveen (eds.), Rutgers University Press, New Brunswick, USA, pp. 1–20.

Bruns B. (2005). Routes to water rights. In: Liquid Relations: Contested Water Rights and Legal Complexity, D. Roth, R. Boelens and M. Zwartveen (eds.), Rutgers University Press, New Brunswick, NJ, USA, pp. 215–236.

Bruns B. R. and Meinzen-Dick R. (2005). Frameworks for water rights: an overview of institutional options. In: Water Rights Reform: Lessons for Institutional Design, B. R. Bruns, C. Ringler and R. Meinzen-Dick (eds.), International Food Policy Research Institute, Washington DC, USA, pp. 3–25.

Burchi S. (2018). Legal principles and legal frameworks related to groundwater. In: Advances in Groundwater Governance, K. G. Villholth, E. Lopez-Gunn, K. I. Conti, A. Garrido and J. Van der Gun (eds.), CRC Press, Boca Raton, USA, pp. 119–136.

Condon L. E., Atchley A. L. and Maxwell R. M. (2020). Evapotranspiration depletes groundwater under warming over the contiguous United States. *Nature Communications*, **11**, 1–8 https://doi.org/10.1038/s41467-020-14688-0

Daigneault A., Greenhalgh S. and Samarasinghe O. (2017). Equitably slicing the pie: water policy and allocation. *Ecological Economics*, **131**, 449–459. https://doi.org/10.1016/j.ecolecon.2016.09.020

Endo T. (2019). A fifty-year experience of groundwater governance: the case study of Gakunan council for coordinated groundwater pumping, Fuji city, Shizuoko prefecture, Japan. *Water*, **11**(12), 2479. https://doi.org/10.3390/w11122479

Environmental Defense Fund (EDF). (2021). Advancing Strategic Land Repurposing and Groundwater Sustainability in California: A Guide for Developing Regional Strategies to Create Multiple Benefits, EDF, San Francisco, USA.

Evans R. S. and Dillon P. (2018). Linking groundwater and surface water: conjunctive water management. In: Advances in Groundwater Governance, K. G. Villholth, E. Lopez-Gunn, K. I. Conti, A. Garrido and J. Van der Gun (eds.), CRC Press, Boca Raton, USA, pp. 329–351.

Famiglietti J. S. (2014). The global groundwater crisis. *Nature Climate Change*, **4**, pp. 945–948. https://doi.org/10.1038/nclimate2425

Foster S. S. D. and Chilton P. J. (2003). Groundwater: The processes and global significance of aquifer degradation. *The Royal Society*, **358**, 1957–1972.

Garner E., McGlothlin R., Szeptycki L., Babbitt C. and Kincaid V. (2020). The sustainable groundwater management Act and the common law of groundwater rights—finding a consistent path forward for groundwater allocation. *UCLA Journal of Environmental Law & Policy*, **38**(2), 163–215. https://doi.org/10.5070/L5382050109

Gorelick S. M. and Zheng C. (2015). Global change and the groundwater management challenge. *Water Resources Research*, **51**, 3031–3051. https://doi.org/10.1002/2014WR016825

Government of Queensland, Department of Natural Resources and Mines. (2016). Pioneer Valley Water Resource Operations Plan.

Government of Queensland, Department of Natural Resources, Mines and Energy. (2019). Minister's Performance Assessment Report, Water Plan (Pioneer Valley) 2002.

Hammond Wagner C. R. and Niles M. T. (2020). What is fair in groundwater allocation? Distributive and procedural fairness perceptions of California's sustainable groundwater management Act. *Society and Natural Resources*, **33**(12), 1508–1529. https://doi.org/10.1080/08941920.2020.1752339

Hiatt J. and Zellmer S. (2018). Case study 6/Nebraska – upper republican natural resources district. In: The Future of Groundwater in California: Lessons in Sustainable Management from Across the West, C. Babbitt (ed.), Environmental Defense Fund, New York, USA, pp. 72–80.

Hoffman C. and Zellmer S. (2013). Assessing institutional ability to support adaptive, integrated water resources management. *Nebraska Law Review*, **91**(4), 805–863.

Jarvis W. T. (2014). Contesting Hidden Waters: Conflict Resolution for Groundwater and Aquifers. Routledge, London, UK.

Jinno K. and Sato K. (2011). Groundwater resources management in Japan. In: Groundwater Management Practices, A. N. Findikakis and K. Sato (eds.) CRC Press, Leiden, The Netherlands, pp. 17–31.

Lall U., Josset L. and Russo T. (2020). A snapshot of the world's groundwater challenges. *Annual Review of Environment and Resources*, **45**, 171–194. https://doi.org/10.1146/annurev-environ-102017-025800

Lebel L., Garden P. and Imamura M. (2005). The politics of scale, position, and place in the governance of water resources in the Mekong region. *Ecology and Society*, **10**(2), 18. https://doi.org/10.5751/ES-01543-100218

Main San Gabriel Basin Watermaster. (2020). 2019–2020 Annual Report. Azusa, USA.

Mechlem K. (2012). Legal and Institutional Frameworks. Groundwater Governance: A Global Framework for Action, Thematic Paper 6, GEF, FAO, UNESCO-IHP, IAH, and the World Bank, Rome, Italy.

Meinzen-Dick R. S. and Bruns B. R. (2000). Negotiating water rights: introduction. In: Negotiating Water Rights, B. R. Bruns and R. S. Meinzen-Dick (eds.), Vistaar Publications, New Delhi, India, pp. 23–55.

Moench M. (2004). Ground water: the challenge of monitoring and management. In: The World's Water, 2004–2005, P. Gleick (ed.), Island Press, Washington, DC, USA, pp. 79–100. Washington, DC.

Molle F. and Closas A. (2020a). Co-management of groundwater: a review. *WIREs Water*, **7**(1), e1394.

Molle F. and Closas A. (2020b). Why is state-centered groundwater governance largely ineffective? *WIREs Water*, **7**(1), e1395.

Molle F. and Closas A. (2020c). Groundwater licensing and its challenges. *Hydrogeology Journal*, **28**(6), 1961–1974. https://doi.org/10.1007/s10040-020-02179-x

OECD. (2017). Groundwater Allocation: Managing Growing Pressures on Quantity and Quality. OECD Studies on Water. OECD Publishing, Paris, France.

Ostrom E. (2005). Understanding Institutional Diversity. Princeton University Press, Princeton, USA.

Peck J. C., Illgner R., Wiley J. and Crittenden Owen C. (2019). Groundwater management: the movement toward local, community-based, voluntary programs. *Kansas Journal of Law and Public Policy*, **29**(1), 1–49.

Rinaudo J.-D., Moreau C. and Garin P. (2016). Social justice and groundwater allocation in agriculture: a case study. In: Integrated Groundwater Management: Concepts, Approaches and Challenges, A. J. Jakeman, O. Barreteau, R. J. Hunt, J.-D. Rinaudo and A. Ross (eds.), Springer, Cham, Switzerland, pp. 273–293.

Rittenhouse K. (2018). Case study 5/Colorado – Rio Grande water conservation district (subdistrict No. 1). In: The Future of Groundwater in California: Lessons in Sustainable Management from Across the West, C. Babbitt (ed.), Environmental Defense Fund, New York, USA, pp. 62–71.

Rosenberg A. (2020a). Incentives to Retire Water Rights Have Reduced Stress on the High Plains Aquifer. United States Department of Agriculture, Economic Research Service, Washington, DC.

Rosenberg A. B. (2020b). Targeting of water right retirement programs: evidence from Kansas. *American Journal of Agricultural Economics*, **102**(5), 1425–1447. https://doi.org/10.1111/ajae.12102

Ross A. and Martinez-Santos P. (2010). The challenge of groundwater governance: case studies from Spain and Australia. *Regional Environmental Change*, **10**, 299–310. https://doi.org/10.1007/s10113-009-0086-8

Rouillard J., Babbitt C., Pulido-Velazquez M. and Rinaudo J.-D. (2021). Transitioning out of open access: a closer look at institutions for management of groundwater rights in France, California, and Spain. *Water Resources Research*, **57**(4), e2020WR028951. https://doi.org/10.1029/2020WR028951

Singh K. and Zaragosa-Watkins M. (2018). Case study 8/Texas – Edwards aquifer authority. In: The Future of Groundwater in California: Lessons in Sustainable Management from Across the West, C. Babbitt (ed.), Environmental Defense Fund, New York, USA, pp. 93–105.

Steed B. C. (2010). Natural Forces, Human Choices: An Over Time Study of Responses to Biophysical and Human Induced Disturbance in Los Angeles, California Groundwater Governance. Ph.D. thesis, Indiana University, Bloomington, USA.

Syme G. J., Nancarrow B. E. and McCreddin J. A. (1999). Defining the components of fairness in the allocation of water to environmental and human uses. *Journal of Environmental Management*, **57**(1), 51–70. https://doi.org/10.1006/jema.1999.0282

Theesfeld I. (2010). Institutional challenges for national groundwater governance: policies and issues. *Ground Water*, **48**(1), 131–142. https://doi.org/10.1111/j.1745-6584.2009.00624.x

Thomann J. A., Werner A. D., Irvine D. J. and Currell M. J. (2020). Adaptive management in groundwater management: a review of theory and application. *Journal of Hydrology*, **586**, 124871. https://doi.org/10.1016/j.jhydrol.2020.124871

Young M. D. (2014). Designing water abstraction regimes for an ever-changing and ever-varying future. *Agricultural Water Management*, **145**, 32–38.

Young M. D. and McColl J. C. (2003). Robust reform: the case for a new water entitlement system for Australia. *Australian Economic Review*, **36**(2), 225–234.

Young M. D. and McColl J. C. (2009). Double trouble: the importance of accounting for and defining water entitlements consistent with hydrological realities. *Australian Journal of Agricultural and Resource Economics*, **53**(1), 19–35.