



HAL
open science

Changing from Unrestricted Access to Sustainable Abstraction Management Regimes: Lessons Learnt from France and Australia

Jean-Daniel Rinaudo, Steve Barnett, Cameron Holley

► **To cite this version:**

Jean-Daniel Rinaudo, Steve Barnett, Cameron Holley. Changing from Unrestricted Access to Sustainable Abstraction Management Regimes: Lessons Learnt from France and Australia. Sustainable groundwater management: a comparative analysis of French and Australian policies and implications to other countries, pp.537-562, 2020, 10.1007/978-3-030-32766-8_27 . hal-02532185

HAL Id: hal-02532185

<https://hal.science/hal-02532185>

Submitted on 4 Apr 2020

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Chapter 27. **Changing from unrestricted access to sustainable abstraction management regimes: lessons learnt from France and Australia**

Jean-Daniel Rinaudo¹, Steve Barnett², Cameron Holley³

1. BRGM, Montpellier University, Montpellier, France.

2. Department for Environment and Water, Adelaide, South Australia, Australia

3. New South Wales University, Sydney, NSW, Australia

Corresponding author: Jd.rinaudo@brgm.fr

Abstract

This concluding chapter compares the important features of the groundwater policy and management approaches that have been implemented in France and Australia and draws lessons that may be relevant to other countries who are implementing groundwater management regimes. To support the comparison, the chapter looks at six main stages of the policy development process: 1) political awareness raising; 2) increasing the groundwater knowledge base; 3) defining and allocating water use rights; 4) defining sustainability objectives and setting extraction limits; 5) returning over allocated and overused ground-water systems to sustainable levels of extraction; and 6) enforcement policies.

Keywords : political awareness raising; groundwater knowledge base; water use rights; allocation; extraction limits; enforcement.

1 Introduction

This concluding chapter compares the important features of the groundwater policy and management approaches that have been implemented in France and Australia and draws lessons that may be relevant to other countries who are implementing groundwater management regimes. It shows that, in spite of huge climatic, environmental, socio-economic and legal differences (Figure 27. 1), there

are many similarities in the groundwater management approaches developed and implemented in France and Australia. Key differences are also highlighted. The comparative analysis is based on the case studies presented in the 26 preceding chapters. To support the comparison, the chapter looks at the main stages of the policy development process which are listed below. Jakeman et al (2016) also provides insights into this process.

- Stage 1 is the process through which groundwater management is brought on the political agenda and becomes a public policy issue.
- Stage 2 involves increasing the knowledge base and understanding of the groundwater systems, which is required to underpin the foundations of a groundwater management regime. In most of the case studies covered in this book, management has been initiated with very limited information, which later improved over several decades.
- Stage 3 consists of defining and allocating water use rights, a policy issue where France and Australia have taken very different pathways.
- Stage 4 requires the definition of sustainability objectives. This chapter compares the approaches taken in France and Australia. While the theoretical approaches apparently differ, in practice the definition of sustainability objectives results in some cases more from a negotiation with water users than a scientific objective evaluation.
- Stage 5 corresponds to the process where the State aligns water use entitlements to the extraction limits which correspond to the sustainable objectives. The comparison of the case studies covered in the book shows the diversity of strategies chosen by water managers. It also highlights the political challenges associated with this crucial stage.
- The chapter finally compares enforcement policies in Stage 6 as well as their capacity to adapt to a rapidly changing social, economic and climatic context.

The chapter concludes by summing up key insights that may be relevant for other countries and regions on the journey to develop sustainable groundwater management policies.

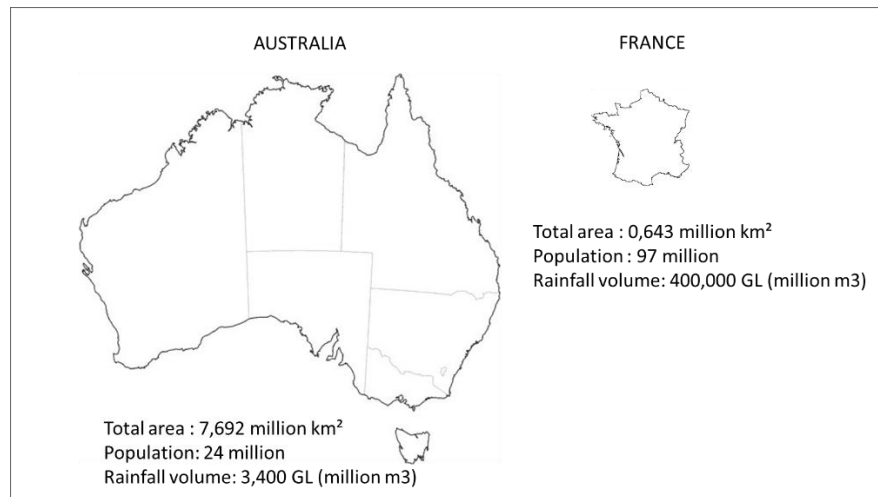


Figure 27. 1: Area, population and yearly precipitation in France and Australia.

2 Bringing groundwater management on the political agenda (stage 1)

Overall, bringing groundwater management on the political agenda, engaging stakeholders and developing dedicated policies has been a very gradual process which has developed over the last 80 years and is still evolving. One of the main reasons for this is that, in France as in Australia, political attention has long been focused on the more visible surface water resources through the construction of reservoirs and canals, and then the management of those resources through the development of sophisticated rules to allocate surface water amongst competing demands, supported by a legal framework. Meanwhile, groundwater remained unrecognized and unmanaged and was long considered a resource that could be freely accessed without controls imposed by the State.

Deep confined artesian aquifers were the first groundwater resources to be intensively exploited. From the beginning of the 19th century, the progress of drilling technologies led to the development of thousands of wells tapping these artesian aquifers for industrial uses (e.g. the Parisian Basin in France) or for agricultural purposes (e.g. the Great Artesian Basin in Australia). Although these supplies must have seemed endless, the States progressively realized after several decades that some important groundwater resources were being used beyond sustainable limits. Declining water pressure levels resulted in impacts such as loss of artesian conditions in France and the drying of springs in Australia. This raised awareness of the need to regulate groundwater extraction.

When the State finally decided to intervene through the development of groundwater laws or regulation, problems due to over-exploitation were already being experienced in some areas. For instance, when the French government passed the 1935 groundwater decree, groundwater pressure levels had already dropped significantly in deep confined aquifers of the Parisian Basin, and most wells were no longer artesian. In Australia, Interstate Conferences on Artesian Water were held between 1912 and 1928, long after pressure levels started to decline due to more than 1500 deep wells having been drilled in less than 30 years.

It is worth noting that those State interventions in both France and Australia were motivated by the desire to protect the “common good”, and were not a response to pressures exerted by third parties impacted by groundwater overdraft. In France in particular, the 1935 State decree was a response to concerns that private industries were overexploiting aquifers which would put high quality drinking water supplies for cities at risk in the future.

Between 1960 and the end of the 1980’s, improvements in drilling and pumping technology led to an exponential increase of water extraction from both deep confined aquifers and shallow unconfined aquifers. Exploitation of those resources was further accelerated by increased restriction imposed on surface water resources, which had the unintentional result of shifting the demand for extraction to nearby groundwater resources. A second wave of environmental problems ensued, including aquifer depletion, declining baseflows discharging into rivers, drying up of wetlands, seawater intrusion from the sea or from adjacent saline groundwater, etc. A significant number of stakeholders were affected by these impacts leading to a number of conflicts that compelled governments to take action and initiate the development of new regulations. In areas of over-extraction in both countries, legislation and policies were introduced to protect the resource for sustainable use into the future.

By the early 1990’s, there was widespread acceptance of the need for “ecologically sustainable development” resulting in a second wave of legislation and agreements (1992 Water law in France, 1994 CoAG Agreement in Australia) that recognized the environment needed an allocation of water and that the impacts of groundwater extraction on dependent ecosystems should be managed.

The analysis of the French and Australian policy developments shows several similarities that potentially have implications to other countries. First, based on the French and Australian experiences, it seems very unlikely that policy makers will anticipate groundwater management problems and pre-emptively establish a constraining or precautionary legal and regulatory framework. Like the management of many environmental issues, groundwater management may only appear on the political agenda once problems and conflicts emerge, because politicians and decision makers are generally reactive with awareness, funding and reform only occurring during droughts and water resource decline, which then seem to evaporate when water is plentiful or the crisis has been averted. This process, called the “hydro-logical cycle” by Wilhite (2012), is also described in the Californian and Chilean case studies presented in Chapters 25 and 26. The implication for other countries is

that their policy makers and managers should be aware of this cycle and attempt to initiate management intervention before crisis situations develop.

Because groundwater resources are hidden from view (Chapter 10), the effects of groundwater depletion are often only recognised when there are visible impacts on surface water resources and dependent ecosystems such as springs and wetlands. In response to these impacts, a management regime should include an appropriate environmental protection legislative framework which requires a proper scientific understanding of the relationships between surface and groundwater.

Perhaps a reason why it took so long to bring groundwater on the political agenda in France and Australia was the lack of understanding of important groundwater resources and their relationships with surface water resources and ecosystem. Accessing this knowledge is much easier today than it was 50 to 80 years ago. Modern societies now have access to incomparable knowledge (theoretical frameworks, data, measurement technologies, modeling capacities) as well as to a wide range of communication tools that can improve awareness raising, facilitate stakeholders' engagement and training. Bringing groundwater on the political agenda should therefore be facilitated. This however requires that public institutions invest the required resources to develop and transfer that knowledge, since private actors do not have sufficient incentives to do it.

3 Increasing the knowledge base (stage 2)

The comparison of the Australian and French case studies presented in the previous chapters of this book highlights that the development of the knowledge base needed to establish sustainable groundwater management consists of six main consecutive steps:

1. the definition of aquifer and management unit boundaries;
2. the establishment of groundwater monitoring network;
3. the development of an information system to locate and quantify groundwater extraction;
4. the development of a conceptual model describing the aquifer flow system;
5. the development of a numerical model that allows simulating alternative management approaches;
6. the identification of groundwater dependent ecosystems and assessing their water requirements

The first step consists of defining aquifers boundaries (extent and geometry) and management units, both of which are essential for the development of groundwater laws and policies (Nelson and Quevauviller 2016; Cuadrado-Quesada et al 2018). When there is no central regulator or agency to carry out this work, a methodology has to be developed and its use made mandatory to ensure that all the aquifers are

delineated in a consistent manner. This is particularly important in sedimentary basins which can contain numerous superimposed aquifer and aquitard layers which need to be grouped for efficient management, based on connectivity and common aquifer characteristics. This is a key issue in large basins that extend across several regions or states that have their own water management agency and policies (e.g. Murray Darling Basin). The same issue applies to Europe in general (and France in particular), where groundwater aquifers were delineated by numerous River Basin District Authorities. In addition to aquifer definition, it is essential to define the boundaries of management units (a unit typically covers the whole aquifer or basin extent). Finally, smaller management zones (including areas of similar hydrogeological characteristics or similar sustainability issues) can be defined within a management unit to allow for targeted management policies that may not need to apply to the whole management unit.

The second step consist in establishing groundwater monitoring networks that allow assessing long term trends in groundwater levels and quality. Long-term groundwater monitoring not only indicates whether water levels or salinities are rising or falling, but also helps determine the major drivers causing the changes (e.g. rainfall or extraction). Because of the expense for drilling new observation wells, existing privately owned wells should be used where possible. However, the French and the Australian case studies show that coordinating the data collection from existing but often heterogeneous monitoring networks is challenging, in particular where they have been developed independently over time by several different institutions for different purposes (municipal water supply, government agencies, local or regional governments, etc.).

The third step consists of locating all groundwater abstraction points and developing a database that accounts for all significant extractions. This information is not only a prerequisite for the calibration of groundwater models, but is essential for the implementation of a compliance and enforcement regime (see Stage 6 below). A State agency usually performs this task, based on existing regulations defining the need for groundwater permits or licenses. The French and Australian experiences suggest implementing a progressive approach is desirable, focusing first on the identification of abstractions points, then developing estimates of the volume of groundwater abstraction. While French law requires that all uses be metered in volume (which results in problems of meter tampering), Australia historically implemented a more pragmatic approach, accepting to use indirect measurement approaches (use estimate based on crop type and crop area). It is worth noting that the use of more sophisticated technologies such as smart volumetric meters or connected pumping flow meters may not always be efficient if the relevant agencies or regulators does not invest sufficient effort in the analysis of the huge amount of data produced by those technologies (Holley and Sinclair, 2016).

Based on the previous information, hydrogeologist can then develop a simple conceptual model of how the aquifer system works (step 4). This model describes groundwater flow directions (based on water level elevation maps), that can identify recharge and discharge areas as well as interactions with surface water. Estimates

of hydrogeological parameters (using pumping tests where possible) may allow the calculation of order of magnitude estimates of the groundwater storage volumes and recharge rates to unconfined aquifers. Any such conceptual model will almost certainly be characterized by significant uncertainty in some components. The French and Australian groundwater experience suggest that areas of uncertainty should be communicated to stakeholders, even if it undermines the argument for a reduction in extraction. Failing to provide this transparency might later result in a break down in trust between water users on the one hand (Danielle, 2011), and scientific experts and government officials on the other, which could result in significant compliance and enforcement problems in the future (Holley and Sinclair, 2012).

The fifth step consist in developing numerical groundwater models that can predict the impacts of changes in extraction, climate or land use. Numerical models are also useful to verify conceptual models as well as to highlight data gaps that require further investigation. The development of a numerical model should not be considered as an end in itself but rather as a key component of the knowledge development process. This is well illustrated in the case of Bordeaux (Chapter 12) where a numerical model has been progressively developed and continuously improved over more than five decades. The French experience also shows that the choice of a modeling technique (lumped vs fully distributed model) needs to be adapted to the resource characteristics, existing knowledge, management issue and budget constraints (Chapter 11).

The sixth and last step consists of identifying groundwater dependent ecosystems and assessing their water requirements. In France and Australia, these are frequently expressed as critical groundwater levels or the maintenance of base-flow discharge to streams. The definition of these trigger levels are based on scientific knowledge of aquatic ecosystems but also on an analysis of stakeholders' needs.

The process of increasing the knowledge and understanding of groundwater systems is ongoing and is one of 'continuous improvement' over decades. Despite this, a key message from several case studies presented in this book is that policy makers should not wait to have perfect knowledge in order to initiate groundwater management. Early intervention with minimal information can be beneficial, provided there is a commitment to refine policies over time as new knowledge is purposefully and progressively acquired (Cosens, 2018).

Another key message from Australia and France is that significant State investment is needed to develop the knowledge base. This is mainly because of the absence of direct benefits that can be derived by private users from understanding of groundwater systems. They are therefore highly unlikely to directly invest in the acquisition of such knowledge. However, the cost of groundwater knowledge production, planning and management can be recovered from users through water abstraction fees or taxes. The cost recovery principle is generally implemented in France, with the River Basin District Agencies playing a key role in levying water abstraction charges and subsidizing actors developing water resource knowledge and planning. Cost recovery explicitly for groundwater management is only carried out to a limited extent in Australia.

Last but not least, the Australian experience suggests that other non-State organisations may generate information useful for increasing the knowledge base. These include mining and petroleum companies, universities and private companies that use groundwater. The main challenge in incorporating this knowledge lies in the design of interoperable information systems, an issue which is discussed in Chapter 9.

4 Defining and allocating groundwater use rights (stage 3)

In France and Australia, as in many other countries, groundwater management fundamentally relies on water use rights (WUR), defined as legal rights to abstract a specified quantity of water from the ground. While the history of establishing those rights in France and Australia is quite similar, the evolution of their characteristics over time show interesting differences concerning:

- (i) their property status
- (ii) the conditions under which WUR are required;
- (iii) the specification of WUR;
- (iv) the procedure used to allocate WUR;
- (v) the potential to transfer those rights.

These differences are discussed in the following paragraphs.

4.1 Property status

In the beginning of the 19th century, Australian States' and French legislators adopted the "rule of capture" which gives landowners the right to take all the water they can capture from under their property. This can be explained by the fact that at that time, groundwater was then considered as a permanent resource, whose origins and movement were poorly understood by scientists, courts and governments (Margat et al, 2013). At that time, the legislators would also not consider groundwater to be an economic resource since it was not widely used because drilling and pumping technologies were still in their infancy. Groundwater was thus largely treated as a private property, maintained outside the realm of state intervention.

While this unregulated groundwater exploitation regime was not problematic during an era of limited drilling and pumping capabilities, technical advances that took place in the 1930s and 1940s lead to an increased exploitation of groundwater resources, in particular of confined artesian aquifers. As these resources were being increasingly depleted and threatening local public water supplies, French and Australian States progressively implemented a system water use rights, based on a combination of drilling permits and groundwater use licenses. In France, this first took place in 1935, with the introduction of a system of drilling permits applying to deep confined aquifers. The 1992 water law extended State control to shallow aquifers,

thereby confirming the key role of the State as guardian of all groundwater. Interestingly, the State increasingly regulated groundwater abstraction without incorporating groundwater in the public domain: it remains the property of landowners, although its exploitation became subject to permits granted by the State. In Australia, it was only in the 1970s that some States imposed a system of abstraction licenses in areas where groundwater resources were considered as at risk due to over-extraction for irrigation, while maintaining the common law rights to a certain degree in other areas where extractions were minimal. However a permit was required to drill a borehole or construct a well in all areas. Overall in Australia, the control of all waters is now vested with the State.

The progressive strengthening of State control over groundwater extraction has been observed in many other countries, whether water is considered a private or public good. However, the rule of capture still prevails in other contexts like Texas. In such locations, the State has traditionally not interfered in groundwater management and allocation (although this is beginning to change with the introduction of the Sustainable Groundwater Management Act of California, see chapter 24).

4.2 Conditions under which a WUR is required

Since defining, allocating and managing WUR requires significant human and financial resources, some States may only use this instrument in areas where groundwater resources are at risk. Where groundwater is of poor quality (e.g. highly saline) or where the resource capacity far exceeds demand, groundwater use often remains unregulated. This risk-based approach is implemented in the Australian states of South Australia and Queensland for instance. By contrast, France and other Australian states such as Victoria, have adopted a universal licensing approach where all uses must be authorized, independent of the local water demand or quality.

In both universal and risk based approaches, a number of exemptions may apply, allowing certain categories of users to abstract groundwater without holding a WUR; e.g. wells used for domestic supplies or stock watering. The same type of exemptions were reported in other countries studied in this book (Chile, California). A justification of these exemptions is that these users abstract a limited amount of groundwater¹¹⁹. At the other extreme, some activities which do not extract groundwater but which modify the recharge can be subject to the obligation to hold a licence. This is for instance the case of forest plantations in South Australia which requires a license corresponding to the quantity of precipitation intercepted by the forest. In areas of shallow watertables, the uptake of groundwater by forests also requires a licence (Avey and Harvey, 2014).

¹¹⁹ This is however not the case for mining activities which are surprisingly exempted from groundwater regulation in several Australian States despite having large extractions. However some controls may occur under mining legislation (Productivity Commission, 2018).

4.3 Specification of groundwater use rights

In France, Australia and other countries studied in this book, groundwater use rights have been defined in very diverse ways:

- (i) individual versus collective rights;
- (ii) specification in pumping flow rate, or an annual or seasonal volume;
- (iii) a nominal value (fixed over time) or as a share of the available resource which may fluctuate over time.

Individual groundwater use rights have historically been used both France and Australia. This approach was consistent with the private property status granted to groundwater in the initial policy stages. In France, this approach prevailed until the enactment of 2006 Water Law which radically reformed WUR, by establishing a collective WUR to cover all pre-existing individual rights (chapter 3). This drastic measure only applies to agricultural users in restricted areas, where all users are compelled to establish an association, which has the responsibility of crafting rules for sharing the water they are entitled to take within the collective WUR. This approach is at odds with the Australian approach which considers that water use rights should be treated as individual property which can be freely traded in a water market subject to conditions that minimise impacts on the resource, other water users and the environment. It is still too early to judge the environmental, economic and social performance of this new approach of WUR in France. However, its mere existence should help policy makers in other countries to broaden the range of options they consider when designing their own groundwater management policies.

WURs can be specified in terms of a pumping flow rate, or a volume or area over which water can be used. The simplest approach is to define WURs in the form of an area that can be irrigated. While it facilitates enforcement (the State only has to monitor the irrigated area), it does not allow for a precise limitation of groundwater abstraction, as the water use per unit of area may greatly vary depending on crops cultivated and irrigation technologies used. Most Australian States initially issued area-based licences, but these have mostly now been converted to volumetric allocations (exceptions include the Northern Territory and Western Australia; Productivity Commission 2018).

An alternative approach consists in specifying WUR in pumping flow rates (as occurred in France up until 2003, and in Chile up until now). Enforcement of such WUR only requires checking the capacity of the pump when the well / borehole is constructed and occasionally in random surveys after that. The disadvantage of this approach is that again, it does not allow for precisely controlling the volume of water extracted, as the duration during which the pump is used is not defined in the WUR. Chapter 25 highlights the problems associated with this approach in Chile.

A third approach consists in specifying water use rights as a volume that can be abstracted over a year or irrigation season. This approach theoretically allows for the better control of water abstraction, provided that volumetric meters are installed and regularly monitored (to avoid inaccuracies or tampering problems). Another

advantage of the volumetric approach is that it provides incentives for users to increase water use efficiency – because each cubic meter that can be saved can later on be used in production, or can be sold or leased if the trading of WUR is allowed.

Historically, licenses or permits granted by the French and Australian States included different conditions controlling how the WUR could be used: the location where water can be abstracted; the characteristics of the well or borehole; and the quantity of water that can be abstracted annually from that groundwater source. More recently, there has been a tendency to unbundle the different components of the rights. In France, site use and well/borehole construction approvals are managed with a system of permits granted by the State, while allocation of water is managed with a system of annual authorizations granted for agricultural purposes by Water Users' Associations in restriction zones and by the State elsewhere. Allocations are usually granted for long periods (about 15 years) without annual adjustment, but use remains subject to seasonal restrictions if groundwater levels decline below threshold levels. In some French groundwater basins, stakeholders have agreed to unbundle water access entitlements from water allocation, with the entitlements specifying a share of the available resource, while the allocation defines the specific volume of water that can be abstracted from the resource in a given year or season depending on the resource availability. Chapters 5 and 13 respectively describe how entitlements and allocation have been unbundled in the Beauce and Tarn et Garonne aquifers. The main advantage of separating entitlements from allocation is that it allows flexibility to manage resources where sustainable extraction can vary with the climate.

In Australian States, the various legislative instruments also increasingly facilitate the unbundling of existing water licenses, but the process has not yet been widely implemented due to legal and administrative complexities and the longevity of the current management plans. In those areas where it has been introduced, licensed water users are provided with an opening allocation for each category at the start of each new water use year on 1 July. This may be anywhere between zero and 100% of their full entitlement, as illustrated in Table 26. 1 below. In Australia, another motivation for unbundling WUR through the separation of water rights from a specific piece of land, was to facilitate water trading, in particular the transfer of seasonal volume of water (allocation) independently of the water access entitlement (Chapter 21).

Table 26. 1: Groundwater allocations for 2018-2019 in New South Wales.

Groundwater resource	Allocation
Eastern Recharge (NSW Great Artesian Basin)	50%
Peel alluvium	69.4%
Murrumbidgee alluvial	98.4%
All other groundwater sources	100%

4.4 Duration and transferability

Duration and transferability of WURs are two issues on which the French and Australian policies are radically different. In Australian states' legislation, water use rights (including volumetric licences and water access entitlements) and water allocations seek to approximate a personal property right¹²⁰ that in areas that have been unbundled, can be transferred independently of land. In most States, entitlements are granted in perpetuity (with the exception of Victoria and Western Australia and specific types of licenses in several states¹²¹), although the states retain the right to make changes to these entitlements.

In France, volumetric water use licenses are not considered as personal property and they cannot be transferred. Such authorizations are generally renewed annually. The State is theoretically authorized to modify or even cancel authorizations without any compensation, provided the decision is taken for the general public interest. Such changes are generally limited and in practice, most licenses can remain unchanged for decades. And in case of severe reduction, the State often offers compensation through public subsidies granted by the Water Agency to develop alternative water resources that can substitute groundwater. However, compensation is only partial and the beneficiaries have to comply with a set of environmental rules (see chapter 18).

The French and Australian views on property rights illustrate two opposing policy approaches. However between them lies a continuum where variations of each WUR approach could be applied to suit different circumstances. For instance, water use licenses (or concessions) are granted for respectively 40, 50 and 75 years in South Africa, Mexico and Spain, while they are granted in perpetuity in Chile. They are tradable in Spain and Chile, but not in the two other countries. This illustrates the challenge of striking an appropriate balance between the security needed to encourage investment and the need for flexibility to adapt to climate change, societal needs, environmental requirements and to take into account increases in understanding of groundwater systems.

¹²⁰ The characteristic of the right as property is debatable (as a matter of law). For further see, e.g. *ICM Agriculture Pty Ltd v Commonwealth* [2009] HCA 51.

¹²¹ In several States where different types of licenses coexists, WUR may not be granted in perpetuity (for instance, area-based licenses issued under the NSW Water Act of 1912).

4.5 Use priorities

An important characteristic of WUR is the existence of priorities for their allocation. In both France and Australia, environmental water requirements are given the first priority, since sustainable extraction limits are calculated in such a way that they aim to prevent severe environmental impacts from groundwater extraction. The maximum permissible volume is then shared between economic sectors, giving priority to public water supplies (although in Australia, this is not explicitly stated in legislation). In France, industrial users are generally prioritised next, with the remaining volume of water allocated to farmers. In Australia, where groundwater use for irrigation is far greater than any other demand, the remaining users are generally treated equally.

4.6 Allocation rules

France and Australia have also adopted different policy approaches to the way in which water allocations are issued to groundwater users. In France, the allocation policy has evolved over time. Before 2006, if a basin was designated as a restricted zone, existing users would receive a water use right proportional to their average past use, estimated over a reference period of 3 to 10 years depending on the local context. New applicants could only obtain a water use right if some of the historical users no longer exercised their right. The 2006 water law drastically changed this practice by requiring all potential users be given access to water resources, including within restriction zones. This was not really an issue for the drinking water sector, since there are no “new users”. In the agricultural sector, Water Users Associations were asked to craft rules allowing the entry of new water users. Although each WUA has developed different rules, the most frequent approach relies on the following main principles:

- (i) water use can be transferred to a new owner when a farmer retires and sells his farm; WUR only follows the farm if the activity planned by the new owners makes beneficial use of water; and if not, the WUR is reverted to a WUR reserve managed by the association;
- (ii) for each transfer, a portion of the right (up to 20%) is reverted to the WUR reserve;
- (iii) rights (or portions of rights) which are not used over a number of years (typically five) also return to the association reserve;
- (iv) the associations develop a rule to redistribute WUR held in reserve to farmers willing to expand their activities or to new users; the criteria used to rank competing applicants cover a number of factors - economic (added value, employment, strengthening of existing value chains), social (young applicants favored) and the environment (organic farming, crops with limited impacts favored).
- (v) This allocation decision is taken by the association only; the State only verifies that the rules do not involve any discrimination and are correctly applied in practice.

Traditionally in Australia, the allocation of groundwater depended on a case-by-case assessment of individual applications to take water. However, since the significant reform instigated by the National Water Initiative in 2004, the different States have adopted broadly similar approaches to the allocation of water rights which are usually issued in the broader context of creating a management plan and the determination of a sustainable extraction limit. Two case studies are presented in Chapter 7. In general, the following principles are applied.

- (i) Allocations are made by the State to meet the reasonable requirements of existing users.
- (ii) This is based on use during a specified qualifying period which usually extends over several years. Those who can demonstrate a financial commitment to develop water use may be considered as existing users.
- (iii) If there is no meter information available to quantify the reasonable requirements, the theoretical crop irrigation requirement can be used.
- (iv) If the volume of existing user allocations is less than the sustainable extraction limit, the State may issue new allocations using a variety of methods (by application, ballot, auction).
- (v) If the volume of existing user allocations exceeds the sustainable extraction limit, the State may reduce allocations (often through the management plan which requires extensive consultation).
- (vi) If an area is fully allocated up to the sustainable extraction limit, the entry of new water users can only occur through trading of existing allocations on the water market.

5 Defining sustainable objectives and setting extraction limits (stage 4)

France and Australia both consider the establishment of a limit for extraction to be a fundamental requirement for the long-term sustainable development of groundwater resources. Both countries generally define this limit as the level of extraction from a particular groundwater management zone which, if exceeded, would compromise key groundwater dependent ecosystems and cause adverse impacts on the productive base of the resource. Although this concept was developed and implemented between the 1990s and the 2000's by both countries, there have been some differences in how it has been applied.

5.1 French approach

In France, the transition from unrestricted access to a management regime incorporating sustainable extraction limits in groundwater basins has been a complex process that has generally been established progressively, using a methodology that involved a number of steps over a significant time frame.

- Existing extraction is first capped at the current level (with no new users allowed) in order to prevent degradation of the resource and inform water users that the resource is not unlimited and needs to be regulated. The cap can be defined as a seasonal or yearly maximum volume or a borehole extraction rate. The cap is usually based on the number of hectares of agricultural land and the type of crops that have been irrigated over a reference period.
- At catchment or groundwater basin level, Local Water Commissions (composed of representative of users, local communities and government agencies) establish monitoring networks and conduct investigations to inform the determination of a sustainable extraction limit. This often involves the construction of groundwater flow models (Chapter 11). The sustainable extraction is then specified in Local Water Management plans, which give them legal force. The extraction limit specified in the plan may differ from scientific recommendation, reflecting negotiations that take place within Local Water Commissions (Chapter 4).
 - Because of political and economic considerations, the implementation of management actions is phased in over time to give water users time to adjust their operations.

Chapters 5, 12 and 13 give examples of how this approach was followed in three groundwater basins. In France, 581 groundwater aquifers have been identified for management purposes and of these, only 10 % are considered to be in a “poor quantitative status” with sustainability issues and are consequently being managed with volumetric limits.

Australian approach

While there is little difference between Australia and France in the fundamental approach to setting extraction limits, the implementation is different. The steps generally adopted by the States for establishing a groundwater management regime are described below. It is important to note that this process has frequently been implemented pre-emptively before over-extraction has occurred.

- Like France, the extraction is capped at the current level of pumping with no new development allowed.
- The existing knowledge of the groundwater systems is assessed and additional investigations are carried out if necessary, including groundwater modelling where appropriate.
- In parallel with these investigations, agencies begin the process of preparing a groundwater management plan which involves extensive community consultation to increase their understanding of the groundwater system and to work through various management options. The preparation of the plan may take up to five years.
- The sustainable extraction limit is determined for the plan, and in the States where a universal requirement for licensing does not exist (as explained in Chapter 7), allocations for existing users are granted. The limit can be calcu-

lated a number of ways (recharge estimation, modelling the impacts of extractions or resource condition limits) and is usually expressed as an annual volume.

- If the total volume of allocations is below the extraction limit, the management plan may define how new allocations can be issued and conversely, if the total volume of allocations exceeds the extraction limit, the plan may contain a process to reduce the allocations.
- Any reduction in allocations is generally phased in over several years to give water users time to adjust.
- The management plans are generally reviewed every ten years to take into account any new understanding of the resource, changes in demand and impacts of variations in climate e.g. declining water levels due to lower rainfall.

In Australia, 288 groundwater management areas have been created. Of these, 136 have volumetric limits for extraction, with 25% of these classified as overallocated and only 2% considered to be overused (Chapter 6).

5.2 Why the difference ?

There are a number of factors which have resulted in a different style of implementing a sustainable extraction regime. The population of Australia (24 million) is much lower than France (65 million), and is highly concentrated in large cities on the coast. About 70% of Australia's groundwater extraction is for agricultural purposes which occurs in sparsely populated areas. Compared to France, there are far fewer groundwater users, less stakeholders to involve in consultation and fewer layers of bureaucracy involved in administration. In addition, there was significant investment into the investigation of major groundwater resources by the Federal and State governments during the 1970s and 80s.

This means that the transition from unrestricted access to a sustainable management regime is much less difficult in Australia than in France, and can be achieved more quickly because of the existing knowledge base and relatively small number of users. This has allowed the establishment of management regimes in many resources before over-extraction has occurred which at the time, avoided the potentially painful and difficult process of reducing allocations.

5.3 Common challenges

One of the key on-going challenges encountered by French and Australian managers was to establish criteria which can be used to define what sustainable extraction means. There are two main aspects that need to be considered when establishing these criteria. The first is of a technical nature and should be considered fundamental. Sustainable limits should be set to prevent resource depletion, salt water intru-

sion and unacceptable impacts on streamflow and ecosystems. French and Australian managers have used a number of methods to determine these ‘technical’ limits which have been covered in earlier chapters e.g. recharge estimates, groundwater modelling and groundwater level thresholds. The second aspect is the consideration of social/economic factors which requires consultation with stakeholders and groundwater users and may lead to other criteria for determining an extraction limit e.g. timing of extraction, location of new wells, critical water levels for existing well completion depths etc. (See the case of the Barossa valley in Chapter 16). The consultation process should fully explore any trade-offs that may occur if there are differences between the ‘technical’ and ‘social/economic’ limits.

The definition of such criteria is more complex concerning confined aquifers. Indeed, the volume stored in those aquifers as well as water levels (or pressure) are doomed to decrease in those aquifers, as soon as they become exploited. It may take a few years, decades or even centuries to reach a new steady state equilibrium, in which the water storage and pressure will stabilize, at a new level. Meanwhile, it is extremely difficult to assess if extraction level is excessive and endangers the aquifer or not. A possible approach then consist in assuming that a storage decrease does not endanger the sustainability of the resource if it does not result in (i) permanent and extensive dewatering of the reservoir; (ii) flow directions and patterns causing the inflow of extraneous water (inland saline or sea water); (iii) insufficient outflow into dependent ecosystems which would threaten their ecological status.

Another key challenge faced when determining extraction limits in France and Australia lies in properly accounting for groundwater – stream interactions. This requires an understanding of how the volume, timing and location of groundwater pumping will affect baseflow to streams and interactions with ecosystems such as wetlands. These are complex processes which require sophisticated management tools such as well-calibrated groundwater flow models.

Experience from France and Australia has shown that because all aquifer systems are unique with different complexity and different levels of data availability and understanding, managers should use fit for purpose hydrogeological approaches to determine extraction limits – it is not always possible or desirable to construct a well calibrated multi-layered groundwater flow model which could cost millions of dollars/euros. In some cases, a simple spread sheet analytical model using representative hydraulic parameters may suffice (Chapters 11, 14).

Finally, the authors strongly emphasise the need to engage all stakeholders and water users in the debate that leads to the definition of extraction limits, and recognise the challenges involved with this process. Where there are significant technical and scientific uncertainties, they should be explained to stakeholders. Any assumptions made should be shared and if possible, be accepted to ensure that the final outcome is supported. If the scientific approach is not transparent and understood, there is a high probability that extraction limits will be challenged.

6 Returning over allocated and overused groundwater systems to sustainable levels of extraction (stage 5)

Having gone through the four stages previously described in this chapter (political awareness, increased understanding of groundwater systems, allocated water rights and set sustainable extraction limits), one could assume the journey to a sustainable abstraction management regime was virtually complete. However as governments, decision makers and academic researchers across the globe have come to realise, it is the remaining two steps –returning overallocated systems to sustainable levels and ensuring compliance and enforcement – that are arguably the most complex and difficult groundwater management challenges. Indeed in some areas, the impacts of a new sustainable management regime on established political, economic and social interests can become so complex and difficult, that these final stages have often been hampered by sluggish progress, or remained an afterthought for policy-makers. In short, significant work is still needed to deliver on these steps.

There is no better illustration of this fact than Chapters 16 and 20 documenting Australia's attempts to return over-allocated and overused systems to sustainable levels. Challenges such as a perceived “top down” unilateral approach adopted by some state governments (Chapter 20), different criteria and interpretations of the terms “over-allocation” and “over-use”, the development of “short term” responses, and lengthy contentious debates about the economic and social trade-offs associated with re-allocating water away from agriculture to the environment, have all made it difficult to identify and evaluate the steps taken to deal with over-allocation and over-use. While some progress has been made, including in areas such as Tintinara in South Australia (Chapter 19), recent national assessments suggest there is still more work to do (Productivity Commission, 2018). Compared to Australia, France has faced far fewer challenges in this regard, partly because of the greater involvement of affected users in developing rules for the allocation reductions. Each Agricultural users' association (OUGC) has made use of the power given to them to develop their own rules, with considerable differences in the choices made by different OUGCs. Even so, experiences in places such as Poitou Marshes (Chapter 18) reveal important insights on the fragility of pathways for returning over-allocated or over-used systems to sustainable levels.

For both France and Australia, methods to reduce the permanent share/entitlement to groundwater resources typically saw the use of some form of compensation (although this was often not legally required). This included financial payments (buy back programs in Australia, Chapter 17), and infrastructure or substitution water reservoirs (Australia and France, Chapters 17 & 18), to lessen the social and economic impact of reductions. In some areas in Australia, this was often the most difficult process in the journey to sustainable groundwater management, featuring conflict, moratoriums and court challenges (Chapters 17, 20).

Temporary adjustments to account for seasonal variation in available groundwater resources (e.g. times where aquifer levels are lower), were comparatively easier to implement for unconfined aquifers which have limited or highly variable storage volumes that are controlled by rainfall variability. In Australia, adjustments to the volume that can be pumped from these types of aquifer arise from periodic changes made to the 'available resource' (which is the sustainable extraction limit). Whilst a water user's entitlement may be a permanent percentage share of the 'available resource' (e.g. 1.0 %), the 'available resource' can change periodically depending on the aquifer levels (e.g. from 20,000 ML to 15,000 ML). The water user's annual allocation will consequently reduce from 200 ML to 150 ML. If the water user requires more water, additional allocations or entitlements can be purchased through water trading. A similar approach to seasonal adjustments occurs in France. If the State imposes a reduction in allocations in a management area due to lower groundwater levels, the OUGC then decides how to share the seasonal reduction amongst their members, which may not necessarily be a universal reduction (Chapter 18).

Regardless of the implementation process, it was clear from the case studies that there are numerous disputes about the precise rules that should be used to determine a reduction in allocations. Much of this controversy arises from the fact that governments in both France and Australia are the ultimate decision makers when it comes to determining global reductions for a given management area. In contrast in places such as Chile, Texas or other locations, the State does not impose this decision, it is up to users to decide if they want to reduce allocations and how that process might occur.

Regardless of who imposes the initial reductions, tensions clearly arise as to how the reduction effort is shared among the various groups of users. This was more prominent in Australia where conflicts and tradeoffs between environment and agricultural interests occurred, as well as amongst agricultural users themselves. While some advocated universal reductions, others called for differentiated approaches, with higher reduction imposed on recent users than historical ones or giving priority to certain activities. These processes reveal diverging concepts of social justice and alternative visions of how to reconcile impacts on agricultural communities with the needs of the environment and economic efficiency.

So how should such conflicts be solved? In France, users are asked to agree on principles, define rules and then apply them at catchment or groundwater basin level. This devolved and context specific approach has arguably had some success in France, partly because farmers are given a level of agency and autonomy to decide how the cuts should be shared and what rules will be chosen to implement them. It is however too early to tell if this approach will deliver the desired outcomes. Australia aspired to a similar approach by involving communities in water planning processes. This consultative process regarding allocation reductions was sometimes a relatively smooth (e.g. Tintinara in Chapter 19), but it sometimes was not (e.g. Lower Murrumbidgee in Chapter 20), producing ongoing distrust from affected agricultural users, calls for compensation, the threat of court action and calls for improved procedural justice (Danielle, 2011).

Ultimately, the above insights from both France and Australia on possible pathways to returning overallocated groundwater systems to sustainable levels remain important for policy makers as the world continues to confront the uncertain impacts of climate change and growing demands on water from increasing population and energy use.

7 Stage 6 - Implementing a cost-effective enforcement system (stage 6)

The final stage confronting policy makers is to implement cost effective compliance and enforcement. Although the last in the policy making process laid out in this chapter, it is arguably the foundation on which all other elements within the system come to rest. If people do not comply with rules, and rule breakers are not identified and brought back into compliance, the entire system of groundwater management can be undermined, producing aggravated effects to humans, the environment and future generations (Interpol 2016; Segato et al, 2017). Yet despite the importance of compliance and enforcement, agencies or groups responsible for groundwater management have devoted comparatively little time or effort on this final stage. This is perhaps most clearly illustrated by the estimates of Interpol (2016), that suggests that not only is up to 50 % of the global water supply illegally purchased, but that there are millions of unregulated wells worldwide (including more than 20 million in Africa alone).

With global consumption of water doubling every 20 years, demand for water from agriculture projected to increase by 50%, and up to 85% more water projected to be consumed by the energy sector over the next 15 years (Segato et al, 2017), improvements in compliance and enforcement will be vital to prevent further development of illegal water use that could lead to major degradation of groundwater resources, particularly in areas of depleting surface water resources due to climate change (Brown, 2015; Interpol 2016).

As Segato et al (2017) note: “*Groundwater reserves are depleting in many places, leaving current and future generations with close to no buffer against increased climate variability, and without effective regulation and suppression of water crimes, the sustainability, long-term viability, and inclusive and equitable use of water can-not easily be achieved*”.

Notwithstanding the importance of implementing a cost-effective compliance and enforcement regime, studies of compliance and enforcement in quantitative groundwater contexts in France, Australia and indeed other parts of the world, are quite rare. Drawing on Chapters 22 and 23, at least two broad sets of insights emerge relating to : 1) common factors explaining compliance and non-compliance ; 2) common factors explaining enforcement success/problems.

7.1 Common factors explaining compliance and non-compliance

There were at least three similar drivers of compliance in both France and Australia. Firstly it was clear that compliance was facilitated by relatively strong groundwater user understanding of the core compliance requirements. This particularly related to the obligations that were required of them on their farm and in their day to day operations.

Secondly, recognising that education and information about rules and penalties can help promote compliance, both France and Australia demonstrated an important educating role by non-government professional farming organisations/industry associations. These bodies were seen to provide useful sources of information for farmers.

Thirdly, compliance and enforcement government officials in both countries also took a graduated punitive approach (Ayres and Braithwaite 1992) to interacting with farmers when a breach was suspected. This was seen to reduce risks of conflict and helped to facilitate improved compliance over time.

In terms of differences between France and Australia, one notable distinction was the different motivations for agricultural water users to follow rules. Chapter 22 found that farmers in NSW were more likely to follow rules because of their desire to do the right thing, to ensure fairness amongst other water users, because of social and peer reputation, and the perceived legitimacy of laws (e.g. protecting water resources, user rights, viability of communities and the environment). Interestingly, these motivations did not appear to be strongly echoed in France. In some areas, where the tension between government agency and farmers is maximal, it was even suggested that not following the rules may in fact lead a farmer to have a better reputation (rather than worse) with their peers. To what extent this difference can be generalised across both nations, and/or reflects different values between the two nations peoples (see e.g. World Values Survey discussed in Chapter 22) remains an open issue worth exploring.

Turning to trends in non-compliance between France and Australia, it is notable that precise levels of non-compliance were difficult to obtain in either nation. However both Chapter 22 and 23 suggest non-compliance remains a fundamental issue, including being subject to public inquiries. Even so, both countries revealed a common justification for illegal water extraction, namely economic pressure on farmers and a desire for economic advantage. Both also showed a lack of deterrence from enforcement practices (discussed below), including perceptions of a low probability of an inspection on farm or users being caught for illegal activities.

7.2 Common features of enforcement

France and Australia have undergone steady improvement in groundwater compliance and enforcement. As detailed in Chapters 22 and 23, there has been a general trend of moving away from having a diverse set of government agencies with

mandates to support agriculture development and enforce compliance. Both countries have accordingly consolidated enforcement policies and produced more structured and separate organisations (e.g. NSW Natural Resource Access Regulator).

Despite these improvements, four common challenges were identified in both countries. First and foremost were resourcing barriers, including low numbers of permanent groundwater focused staff, combined with the lack of human resources in the judicial system.

A second challenge was the uneasy relationships between government and agricultural interests. As Chapter 23 explains in France, a significant barrier to enforcement in the agricultural sector is a tendency for government to avoid areas with significant agricultural conflicts or concerns. This issue is echoed in Australia, albeit in a wider context of inquiries pointing to ineffectual processes applied to agriculture, and a wider climate of concern arising from the murder of an environmental compliance officer during a visit to a farm¹²². Third, and intertwined with this challenge, was a perception of political interference in compliance and enforcement activities, that prevented regulators from doing their job properly in France, and led to allegations of corruption and recent inquiries in Australia.

Fourth and finally, a lack of modern technology for inspection was reported to be a significant limiting factor in both nations, including metering challenges, access to data and the need for greater use of new technology like aerial drones.

Ultimately, both Chapters 22 and 23 suggest a need for regulators and water users to devote more resources and effort to build on early successes and to fix problems that becoming evident.

8 Conclusion

8.1 Similar approaches to groundwater management

The material presented in that book and summarized in this chapter was presented during a French-Australian workshop held in September 2015, bringing together 30 French and 13 Australian attendees who were all involved in groundwater management at different administrative and geographic levels. Overall, the main conclusion of that workshop was that, in spite of huge climatic, environmental, socio-economic and legal differences “*there is more that unites us than divides us*”. Essentially, the philosophy and approaches to groundwater management are very similar:

¹²² ABC. 2016. Moree shooting: Farmer Ian Turnbull jailed for 35 years for murdering environmental officer <https://www.abc.net.au/news/2016-06-23/moree-shooting-ian-turnbull-sentenced-over-murder/7535808>

- The State plays a key role in water governance, although significant differences exist concerning water users' participation and the role of water markets.
- The State and users jointly contribute to financing the human, technical and financial resources dedicated to the management of water.
- There is a hierarchy of plans generally based on surface water catchments. Planning is supported by groundwater monitoring, including the metering of extractions, and sophisticated groundwater information systems.
- There is a clear recognition of the importance of providing water for environment, in particular groundwater dependent ecosystems.
- Policies recognizes the importance of community consultation to achieve satisfactory outcomes, and the continual need to educate decision makers and users about how our groundwater systems work.
- Policy makers, managers and users recognize that science-based decision making is the basis of responsible and sustainable groundwater management. However, other factors influence actual decision making that reflect existing power relationships and political balances within society.

8.2 A different visio of water use rights

There is however a key issue on which the French and Australian philosophies diverge quite significantly: the approach to water use rights.

Australian aspires to treat water use rights on an individual and private basis. They promote the development of water markets which have proved to be very efficient tools to minimise the economic impacts of drought in the recent past. Australia is internationally recognised for the success of this approach, it has and will continue to inspire other countries.

France is promoting an alternative approach, based on common property regime. This approach is based on the creation of hybrid institutions, holding collective resource use rights, and bringing together representatives of the State and users to define management rules. These hybrid institutions are responsible for setting extraction limits that ensure the long-term sustainability of the resource and keep environmental impacts at an acceptable level. They also define how to share among members the allocation hold in common. These rules exclude any permanent individual appropriation of natural resources.

The contrast between these two approaches is an invitation for the reader to reconsider the issue of water property. Historically, there has been a systematic attempt to eradicate community ownership regimes over natural resources in the Western world following the Enclosures movement in the 17th and 18th centuries. We then witnessed the emergence of a polarized vision opposing public and private ownerships of natural resources. Private regimes have gradually become a dominant model, leading many countries to implement policies based on private individual tradable use rights. Australian water policy aspires to be a perfect illustration of that model (albeit with mixed experiences between its different states and territories).

But the French example (and similar approaches tested in New Zealand) shows that common property regime could rise like a phoenix from the ashes.

While the Australian model has been adopted by many countries (USA, Chile, Spain) and is being popularized by scholars (mainly economists) and international institutions, the French model is a rather unique experiment which is worth being considered as an alternative to the market approach by countries engaging in the development of a new groundwater allocation and management policy.

This controversial property issue should be addressed by all countries entering into groundwater management reform. A constructive debate should be organised, bringing together researchers from various disciplines (economists, lawyers, political scientist), policy makers and water resources managers. The confrontation of different points of view should help thinking outside the box and it could lead to the identification of highly innovative approaches, combining elements of two apparently exclusive models.

8.3 Common challenges

The two countries also face similar challenges, in particular related to the following technical and institutional issues:

- The development of the knowledge base is a long and costly process which should be intensively supported by the State, with a contribution from users. Uncertainty will always remain but that should not prevent policy makers and water resources managers to make decisions. A key challenge consists in understanding and modelling groundwater-surface water interaction and developing management and planning procedures that integrate both resources.
- Involvement of users in the development of groundwater water management rules and plans is more difficult than that for surface water resources, considering the hidden nature of that resource, the absence of collective infrastructure, and the fact that it has often been considered an open access resource for decades.
- Compliance is a key challenge, even in developed countries which can dedicate significant resources to enforcement policies. Countries initiating groundwater management reforms should treat this issue as a high priority, to prevent the installation of a weak social norm where deviant behaviours become the rule, and which will be extremely difficult to reverse.

To end this book, we would like to stress again the benefits of creating a dialogue between practitioners from different countries, and between practitioners and scholars. Confronting visions of experts having very diverse backgrounds helps reconsidering assumptions each take for granted for historical, legal or regulatory reasons and it is source of creativity. We hope that readers of that book will have been inspired by the cases studies presented and experiences shared in this book and that it

will help them developing innovative groundwater management approaches, adapted to the specific technical, economic, social and institutional characteristics of their context.

9 References

Avey, S. and Harvey, D., 2014. How water scientists and lawyers can work together: A ‘down under’ solution to a water resource management problem. *Journal of Water Law*, 24:45-61.

Ayres, I. and Braithwaite, J. 1992. *Responsive Regulation*. Oxford UP.

Brown VF (2017) *Water Theft and Water Smuggling*, Brookings.

Cosens B. 2018. Governing the Freshwater Commons: Lessons from Application of the Trilogy of Governance Tools in Australia and the Western United States. In: Holley C., Sinclair D. (eds) *Re-forming Water Law and Governance*. Springer, Singapore.

Cuadrado-Quesada, G. Holley, C and Gupta, J. 2018. Groundwater governance in the Anthropocene: a close look at Costa Rica. *Water Policy*. 20(3):475-489.

Daniell, KA 2011, Enhancing collaborative management in the Basin, Chapter 26. In: Connell, D, Grafton, RQ (eds) *Basin Futures: Water reform in the Murray-Darling Basin*, ANU E-Press, Canberra, pp. 413-438.

Holley, C. and Sinclair, D. 2012. Compliance and Enforcement of Water Licences in NSW: Limitations in Law, Policy and Institutions. *The Australasian Journal of Natural Resources Law and Policy*. 15:149-189

Holley, C. and Sinclair D. (2016) Regulation, Technology, and Water: “Buy-In” as a Precondition for Effective Real-Time Advanced Monitoring, Compliance, and Enforcement. *George Washington Journal of Energy & Environmental Law*. 7(1):52-66.

INTERPOL (2016) *Strategic Report: Environment, Peace and Security*, UN/Interpol;

Jakeman, A., Barreteau, O., Hunt, R., Rinaudo, JD., Ross, A. eds. 2016. *Integrated Groundwater Management: Concepts, Approaches and Challenges*. Springer.

Nelson R., Quevauviller P. (2016) Groundwater Law. In: Jakeman A.J., Barreteau O., Hunt R.J., Rinaudo JD., Ross A. (eds) *Integrated Groundwater Management*. Springer, Cham. p173-196.

Productivity Commission. 2018. *National Water Reform*. Report no. 87, Canberra.

Segato, L, W. Mattioli, N. Capello and M. Migliorini 2017. Environmental crimes in the water sector. *European Water* 60: 373-379

Wilhite, D A. 2012. Breaking the Hydro-Illogical Cycle: Changing the paradigm for drought management. *EARTH Magazine* 57(7): 71-72.