An Integrated Assessment of Water Markets: A Cross-Country Comparison

By

R. Quentin Grafton*§ [1]

Gary Libecap §

Samuel McGlennon §

Clay Landry

Bob O'Brien

*Contact author:
Crawford School of Economics & Government
Crawford Building (132)
Lennox Crossing
The Australian National University
Acton, ACT 0200
Australia

Email: Quentin.grafton@anu.edu.au
Telephone: +61-2-6125-6558

§: denotes senior authorship, which is shared equally among these authors (names are listed alphabetically). The remaining authors are listed alphabetically.

Revised 24 February 2011

Word count: 9,586 (including abstract and title page)

---

[1] R. Quentin Grafton is Chairholder, UNESCO Chair in Water Economics and Transboundary Governance, Director of the Centre for Water Economics, Environment and Policy (CWEEP) and Professor of Economics at the Crawford School, the Australian National University; Gary Libecap is Professor, Bren School of Environmental Science and Management and Economics Department, UCSB and Economics Department, Cambridge University, Research Associate, NBER, and Fellow Hoover Institution and PERC; Samuel McGlennon is a doctoral researcher at the Fenner School, the Australian National University, and a research associate at CWEEP; Clay Landry is Managing Director, WestWater Research, LLC, Boise, Idaho and Research Associate, PERC, Bozeman, Montana; and Bob O'Brien is Managing Director of Percat Water. We have benefitted from comments provided by two anonymous reviewers and Oscar Cristi, Zack Donohew, Eric Edwards, Stefan Farolfi, Lovell Jarvis, Guillermo Donoso Harris, and Robert Speed.

Abstract

The paper provides an integrated water markets framework (IWMF) to assess water markets in terms of their institutional foundations, economic efficiency, and environmental sustainability. The framework can be applied to: (1) benchmark different water markets; (2) track performance over time; and (3) identify ways in which water markets might be adjusted by informed policy makers to achieve desired goals. The IWMF is used to identify strengths and limitations of water markets in: (1) Australia's Murray-Darling Basin; (2) Chile (in particular the Limarí Valley); (3) China (in particular, the North); (4) South Africa; and (5) the western United States. The framework helps identify what water markets are currently able to contribute to integrated water resource management, what criteria underpin these markets, and which components of their performance may require further development. These findings for each market and comparisons between them provide general insights about water markets and improve water governance.

Introduction

Many parts of the world's arid and semi-arid regions face dilemmas of reduced water supplies (Ludwig and Moench 2009) and an increasing demand for water resources due to population and income growth (Falkenmark 1999). In water scarce and low-income countries, especially those with high population growth rates, the effects on the livelihoods of the poor will be dire without comprehensive efforts to address water scarcity.

To address global water challenges, there is a need for effective institutional arrangements and allocation mechanisms among competing users to mitigate and manage water scarcity. Water markets are one such institutional arrangement, intended to enhance the economic efficiency with which water resources are utilized. Our contribution is to develop, for the first time, a comprehensive and integrated framework to benchmark water markets. The framework is used to identify strengths and limitations in five water markets: Australia's Murray-Darling Basin, Chile (in particular the Limarí Valley), China (in particular, the North), South Africa, and the western United States. All these locations are semi-arid and face, to a greater or lesser extent, an expectation of reduced water availability associated with climate change. Two are in rich countries (Australia and the United States), two are in low to middle-income countries (Chile and South Africa), and one is in a poor, but rapidly developing country (China). All countries, however, differ substantially in terms of their history of water use and reform and in terms of their legal and institutional frameworks.

To provide the comparisons across different water markets we use both a qualitative and quantitative framework that provides an assessment of 19 criteria in three key categories:

institutional foundations (eight criteria), economic efficiency (six criteria), and environmental sustainability (five criteria). The framework helps identify what water markets are currently able to contribute to integrated water resource management, what criteria underpin these markets, and which components of their performance may require further development.

In the following section we describe the integrated framework and provide an overview of the five water markets. Sections three, four and five separately evaluate the five water markets, respectively, in terms of their institutional foundations, economic efficiency, and environmental sustainability. In section six we draw together key and general insights from the integrated assessment.

An Integrated Water Markets Framework

Several indicators of water scarcity, water withdrawals, water poverty or 'peak' water have been developed (Postel et al. 1996; Shiklomanov 2003; Sullivan 2002). Most of these measures are based on physical quantities of water and are not indicators of the quality of water institutions. An exception is a Water Institutions Health Index (WIHI) developed by Dinar and Saleth (2005) and Saleth and Dinar (2004) that uses 16 variables of institutional quality in three broad categories: law-related, policy-related, and organization or administration-related variables, but has only one variable directly related to water markets.

Previous reviews of water markets include Easter et al. (1998; 1999), Howe et al. (1986), Rosegrant and Binswanger (1994), among others, that provide guidance as to how markets might be improved, typically from an economic efficiency perspective. Our goal is to show how water markets can, and do, function in very different legal and institutional frameworks and what this implies in terms of efficiency and sustainability. In particular, we develop a comprehensive and integrated framework in order to generate a qualitative, ordinal rank of the institutional foundations of water markets and their performance in terms of integrated water resource management. While many of the rankings we provide are subjective, we provide evidence to support our judgments while recognizing conclusions drawn from single basins may not be fully representative.

The integrated water markets framework (IWMF) we develop is based on a four-point scale in three categories: institutional foundations, economic efficiency, and environmental sustainability. Equity considerations are included in several sub-categories, specifically: recognition of public interest; priority of use; initial allocation and reallocation; and dealing with market failures. Many of the criteria we use are qualitative measures that are derived from primary or secondary data, but some economic efficiency criteria are quantitative. The qualitative scores provide four ordinal rankings: the highest (three drops) indicates the criterion is nearly or fully operational; two drops indicates the criterion is mostly satisfied but some further development is required; one drop means the criterion is partly satisfied and substantial development is required, while the lowest ranking (X) specifies that the criterion is not operational or is missing. For some criteria insufficient information is available to provide a ranking. The integrated framework is designed to: (1) benchmark different water markets; (2) track the performance of water markets over time; and (3) identify ways in which water markets might be reformed to achieve desired goals. While correlation between criteria is possible given the interwoven challenges of water governance, we have taken care to specify and stream-line the criteria to minimize this possibility.

We apply the integrated framework to five water markets: Australia's Murray-Darling Basin, Chile (the Limarí Valley), China, South Africa, and the western United States. In the case of the US limited, local water markets have existed since the nineteenth century, while in China water trading is still very much in its infancy[2]. Chilean water rights of the Limarí Valley are, arguably, the most entrenched in terms of legal rights, but this market is small in size compared to water markets in Australia's Murray-Darling Basin that were first established in the early 1980s.

In all countries we use secondary data sources that have been supplemented by data, first-hand knowledge and experience with three of these markets (Australia, South Africa and US) and verification by water experts in China and Chile. Even in the most developed water markets, the framework shows that further development of robust water rights and governance is possible, should policy makers wish to undertake the necessary reforms.

Institutional Foundations

The IWMF uses eight criteria to assess the institutional foundations of water markets, namely: (1) Recognition of the public interest (legal and practical recognition of multiple interests in water resources); (2) Administrative capacity (sufficient administrative authority, resources and information to manage water resources effectively); (3) Well-developed horizontal and vertical linkages (robust and clear institutional relationships, both at a given level of governance and between different levels of governance); (4) Legal/administrative clarity (including definition and

[2] China's experience with water trading has to date been limited to (i) the 'administered reallocation' of water savings from channel lining, and (ii) several inter-county and inter-prefecture agreements to reallocate bulk water entitlements (Speed 2011, pers. comm.). There is, however, a directive from the 2006 State Council to develop 'a water rights transfer system' (Sun 2010, p1.).

recognition of water rights and trading rules, as well as transparent administrative actions); (5) Priority of use (provision of water for basic human needs and the existence of beneficial use requirements); (6) Initial allocation and reallocation (transparent processes for allocating water rights and reallocating as priorities evolve); (7) Dealing with market failures (recognition of third-party effects and appropriate and robust mechanisms for resolving conflict); and (8) Adaptive management of institutions (capacity for institutional adaptation). A summary of the rankings for these criteria is provided in Table 1.

Recognition of Public Interest

The public interest includes beneficiaries from water resources other than direct water users, notably the environment. In the case of Australia, water resource plans are obliged to "…establish the intended balance between environmental and consumptive use outcomes, as well as setting out terms and conditions for water access" (National Water Commission 2009a, p. 14) although in practice this does not necessarily occur (Connell and Grafton 2008). In the US, western states own water in trust for their citizens. Individuals hold *usufruct* rights to the water, subject to the requirement that the use is beneficial and reasonable and is subject to oversight by the state in monitoring applications and water transfers to ensure that they are consistent with the public interest (Gould, 1995, p. 94). The notion of 'public interest', however, is sufficiently vague to justify state intervention that has led to uncertainty regarding water rights. In South Africa the public interest in water resources is defined under its *National Water Act 1998* and the national government is held as the custodian of the public interest (Nieuwoudt and Armitage 2004, p. 2). The national government, however, has failed to prevent major pollution problems, such as acid mine drainage (Water Research Commission 2009, p. 14-17), that generate substantial external costs.

In Chile, the *1981 Water Code* specifies "…water is a natural resource for public use" (Hearne 1998: p. 142), but public interest regulation under the law is constrained by scarce resources especially with regard to third party losses or environmental services (Oscar Cristi 2011, pers. comm.). China's Constitution provides that water resources are owned by the state on behalf of the people (Speed 2010a, p. 207), and its *2002 Water Law* provides a framework for integrated water resource management and includes sections dealing with planning, conservation and pollution control (Khan and Liu 2008, p. 14). Despite the good intentions, however, comprehensive Chinese water resource planning is still in a 'developmental phase' (Liu and Speed 2010, p. 12).

Administrative Capacity

Administrative capacity refers to the capacity to enact government's stated water policies, and it is most developed in the high–income countries: Australia and the US. Due to their historical development as federalist systems, in both cases much of this capacity resides at a state level, although in the case of Australia this capacity is rapidly being developed at a federal level following passage of the *Water Act 2007*. In the US, each state has a regulatory agency to monitor whether water is held, used, and transferred consistent with the notions of beneficial use and the public interest. These agencies vary from the State Engineer in New Mexico and Utah, to the Department of Water Resources in Arizona, and to the Department of Natural Resources and special water courts in Colorado.

In South Africa, capacity in the water sector is more limited. Attempts to establish effective catchment management authorities have been stalled by the social problems generated under the previous regime (Farolfi and Rowntree 2007, p.5). Further difficulties emerge from the existing influence of regional offices of the Department of Water Affairs, which are at present the entities providing local water management. These factors combine to render the ability of the state to effectively manage and control water resources problematic (Malzbender et al. 2005, p. 2). In China, "serious questions about the state's capacity to tackle water problems" remain (Lee 2006, p. 10), although the establishment of river basin commissions for major rivers and the revision of master basin plans are promising (Speed 2011, pers. comm.). By contrast, in Chile the issue is one of more limited regulatory authority and resources for the government's water rights agency, Direccion General de Aguas (DGA).

Horizontal and Vertical Linkages

Well-developed linkages across governments and agencies are necessary to ensure effective water governance if responsibilities are shared. In Australia, cross-government agreements have formed the basis of water reform since the mid 1990s. A willingness to cooperate and cede authority to the federal government in return for financial benefits led to the *Water Act 2007* that provides for centralized Basin planning.

Within South Africa, significant inter-basin transfers — as well as across national borders with its neighbors — have necessitated functioning horizontal cooperation and numerous water agreements have been implemented (Turton et al. 2008, p. 326). The *National Water Act 1998* defines the lines of authority between governance levels, but capacity for local water management still resides largely in the regional offices of the Department of Water Affairs rather than in its catchment management authorities.

In the US water management is left primarily to the states, a practice that has led to relatively weak vertical and horizontal institutional linkages. For example, water trades may have to be approved by the relevant irrigation district board, the county where the district is found, the state regulatory body, and potentially federal agencies such as the Bureau of Reclamation. These institutional limitations complicate and obstruct water trading, leading to inconsistencies across spatial scales. In Chile, while horizontal relationships are transparent at lower levels of governance (e.g. between irrigation organizations), significant problems can exist between the DGA and the court system in dealing with water conflicts (Bauer 2004, p. 98-9). Chile does appear to have well developed vertical linkages, although this is partly attributable to the inter-connected nature of the Limarí Valley's water infrastructure (Zegarra 2008, p. 40).

China has fragmented horizontal linkages that result in diminished administrative authority and confusion (Lee 2006, p. 10; Liu and Speed 2010, p. 17; Zhou 2006, p. 5). Fractured water management systems have been identified by the World Bank (2002, p. 5) as "…the critical unsolved problem" for China's water resources, including the nine separate bureaus with water policy interests (Lee 2006, p. 10).

Legal/administrative clarity

Legal clarity over water rights is a key feature of effective water markets. In Australia, water rights are statutory rights that could, in principle, be revoked or modified without compensation. In practice governments have sought to protect the existing rights holders by purchasing water rights from willing sellers to increase environmental flows (Connell and Grafton in press).

Chile has the strongest and most broadly-defined water rights based on the Water Code of 1981 and the government must pay for the attenuation of water rights (Bauer, 1997, p. 13). Water use efficiency has increased under the system, but there remain some conflicts created over third party effects and confusion over the relative priority of consumptive and non-consumptive (mainly hydropower) rights (Brehm and Quiroz 1995, p. 15). To overcome this problem, users can register their water rights in registers, a practice that also is underway in China and South Africa.

Water rights in the US West are, typically, based on prior appropriation and diversion (Johnson et al. 1981), with diversions prioritized based on the date of the right. In certain areas water rights are not well defined, while in others the assurance of junior rights is undermined by over-allocation of the available water. There is no single or central water title office. Rights are also conditional upon varying state regulations for beneficial use, preferred uses, area of origin restrictions, and public interest/public trust doctrine mandates (Getches 1997, p.128-9). These requirements vary across states and can raise the transaction costs of transfers and lower the value of water rights.

In South Africa, addressing equity concerns – including through water management — remains the chief national priority, relegating the trading of water rights between farmers to a lower-order concern. Water rights are formally recognized and registered by the Department of Water and Environmental Affairs, and are renewable every five years (Pott et al. 2009, p. 9). Delays in registration and licensing have prevented water users in many catchments from being assured of their existing rights and impeded trade, and farmers have demonstrated a clear desire for these issues to be resolved (Speelman et al. 2010, p. 1).

Unclear property rights in China continue to cause significant problems for the management of China's water resources (Speed 2010b, p. 88). There remains a lack of transparency surrounding water allocation decisions (Lee 2006, p. 17; Zhou 2006, p. 6), and the opaque legal status of water allocation has led to implementation difficulties (Shen and Speed 2010, p. 33).

Priority of use

Priority of use refers to the provision of water for basic human needs (defined as the immediate requirements of households in terms of drinking water and sanitation) and conditions relating to beneficial use (referring to whether, and how, the water is used).

Neither Australia nor Chile has explicit provisions for beneficial use. In Australia, basic human needs are defined in terms of water supplies for communities that depend on rivers for their water supplies. Such communities have the highest order priority of access. In Chile there is a general deference to the urban water supply (Hearne 1998, p. 154), and water availability is such that the provision of basic human needs has tended not to compromise existing water markets and allocations. Increased demand, however, poses allocation challenges in areas where mining activity has been increasing (eg. Barrionuevo 2009).

The US has appropriative water rights that are conditional upon placing the water in beneficial use. Most western states define beneficial use in terms of the benefit for the appropriator, other persons, or the public with corresponding lists of what is considered beneficial use (evolving through time), but should there be extreme water shortages, domestic and municipal uses would be preferred over agricultural, industrial and in-stream uses (Trelease 1955, p. 134).

The provision of basic water services for human needs – often for free – has been a major priority of the South African government's water policies. This approach is underpinned by the *National Water Act 1998*, which aims to ensure adequate water for basic human needs, ecological and development purposes (Farolfi and Perret 2002, p. 3). Beneficial use is also an explicit consideration and is taken into account when licences are reviewed (Nieuwoudt 2000, p. 2), but transparency is lacking as to what this means in practice, and free provision of water may have incentive effects for use and management. In China basic human needs for water are provided for due to the priority given to urban and rural domestic water (Speed 2011, pers. comm.). Because of the centrally administered nature of water allocation in China, it may be that beneficial use is taken into account, but it is not clear how this is done.

Initial Allocation and Reallocation

Initial allocations of water rights can be contentious, especially if prior users of water are excluded or provided with a lower share than they had historically. Such allocations may be viewed as inequitable and can contribute to water conflicts that can jeopardize the efficient functioning of water markets.

The challenge in Australia has been to reallocate water rights from existing users to the environment in ways that are equitable and meet societal goals. To date, this has been accomplished with the purchase by the Federal Government of water rights from willing sellers funded from general tax revenues (Connell and Grafton 2008; in press). In the US, water rights in western states are largely based on the prior appropriation doctrine or 'first possession' (Getches 1997, p.74-189; Kanazawa 1998) whereby senior rights have first claim to water and junior rights holders bear more risk during drought. While there is no central registry of water rights, rights in each basin generally are well known and transferable separately or with land.

Since the passage of its *National Water Act 1998*, South Africa has been undergoing a process of compulsory licensing, following which an 'initial allocation' of water licences will occur (Water Research Commission 2009, p. 9). This process may reallocate water to other purposes, such as to previously disadvantaged individuals, without compensation, creating rights uncertainty. China's 11th five-year plan (2006-10) requires the development of a national initial allocation system (Sun 2010, p. 1), but no clear interpretation of this requirement has been provided to date. Large inter-basin transfers from the South to the North indicate that past water use does not ensure current access. In Chile's *1981 Water Code* prior users, primarily in agriculture, were allocated consumptive water rights, but also included were non-consumptive rights such as hydro-electric power generation. There is some confusion as to the priority of these two (Bauer 2004, p. 103-111). Allocation of return flows to holders of water rights, as part of the *1981 Water Code*, also may disadvantage customary downstream flow uses.

Dealing with market failures

Market failures can emerge for a variety of reasons, including third-party impacts from use, market power and an inadequate provision of public goods. Market power has yet to emerge as a significant issue, but third party impacts are important in all markets and arise when water trades impose external costs not accounted for in the water trade.

In Australia, states and irrigation districts have limits on the quantity of sales permissible in water markets so as to protect communities from reduced water diversions. These controls have had a negative effect on water transactions and the efficient functioning of water markets (Productivity Commission 2010). Conflicts over water use and tradeoffs are resolved primarily at both a basin and catchment level. Where there have been difficult tradeoffs, for example over water allocations to the environment to the detriment of irrigators, the federal government has provided substantial funding to smooth the transition.

In the US water trades are regulated by states to meet beneficial use and no harm or no injury requirements when they involve changes in location, timing and nature of use that could affect other rights holders (Getches 1997, p. 161). There can also be restrictions to limit negative pecuniary impacts of trades. The approach to conflicts in the US has primarily been one of litigation, including those under the Public Trust Doctrine, a common law notion that emphasizes the public nature of water and other natural resources (Sax, 1970; Brewer and Libecap, 2009). Because there is no compensation for rights holders who lose water under the doctrine, conflicts over water reallocation can be long lasting (Libecap, 2007, p148-51).

Chile's *1981 Water Code* does not specifically address third-party effects or environmental impacts. The World Bank considers externalities in Chile's water sector to be of potential concern, (Briscoe et al. 1998). Similar to the US, the approach to conflicts in Chile has also primarily been one of litigation. This process has proved time-consuming and costly (Briscoe 1998 et al., p. 6).

Nieuwoudt (2000, p. 8) reports that the South African *National Water Act 1998* "gives prominence to third party (environment and human) issues", although it is difficult to assess how effective these protections are in the absence of significant levels of water trading. It is clear, however, that conflicts over water are on-going. Until effective catchment management is implemented, these difficulties are unlikely to be resolved. Some stakeholder-driven water management processes have been developed by the Water Research Commission (for example, see Farolfi and Rowntree 2007).

In China, water transfers as a result of water 'savings' through lining of irrigation channels produces third-party effects which, to date, have been inadequately considered (Speed 2010b, p. 89), especially for surface-groundwater linkages and wetlands (Xie 2008, p. 76). Importantly, the third-party effects of large inter-basin transfers from South to the North (Ghassemi and White

2007, pp. 307-316) have not been fully considered nor compensated. Regarding conflicts, the *2002 Water Law* contains provisions for dispute settlement (Liu and Speed 2010, p. 9), although shortcomings in the water planning framework have allowed inconsistencies to emerge between regional and local water plans, increasing the potential for conflict in times of water shortage (Liu and Speed 2010, p. 18).

Adaptive Institutions

Australia's *Water Act 2007* was a radical shift in responsibility of water planning and management and was agreed to by all levels of government and with bi-partisan support. This suggests that, at least at the present time, Australia has the most adaptable institutions of the countries in this study, although like elsewhere political tensions affect the pace and degree of reform implementation. In Chile there have been numerous attempts since 1990 to modify Chilean water law and some changes were implemented in 2005 (Bauer 1997, p. 13; Bauer, 2008; Zegarra 2008, p. 29).

South Africa radically changed its water institutional framework with its *National Water Act 1998* that provides for decentralized control of water resources. Since its passage, the focus has been to implement the various reforms rather than embark on further institutional change. China's recent development of river commissions for its seven major basins is illustrative of adaptability, as is the *Water Law 2002* which, on paper, contains many provisions conducive to sound water management. The ability of institutions to adapt in practice, however, has lagged behind the ideals espoused in official laws and regulations. This is at least partly due to the inertia which emerges from the enormity of China's water sector: 1.1 million employees within the institutions of the Ministry of Water Resources and around 1 300 "water affairs bureaus" (Speed 2011, pers. comm.).

Within the US, institutional heterogeneity within and across states provides opportunities for learning and innovation. For instance, many water supply organizations have historically resisted water transfers (Thompson, 1993), but as the potential gain from exchange rises, irrigation districts — the largest water supply organizations — have become more responsive to trading potential (Eden et al. 2008).

Economic Efficiency

We provide three ways of quantifying the efficiency of water markets: (1) Size of the market (volume of water traded of permanent and temporary water rights as a percentage of total water rights); (2) Estimates of the annual gains ($) from water trade; and (3) Size of storages (that allows for trades over a longer duration and trades upriver). In addition, we present qualitative measures of economic efficiency: (4) Nature of water rights (the extent to which they are unbundled); (5) Breadth of market (capacity for water trading between catchments, including upstream trades, as well as inter-sectoral trading); and (6) Market price formation and availability (predictability of prices given changing water availability and accessibility of price information). These criteria are summarized in Table 2.

Size of Water Market

Chile's Limarí Valley (Hadjigeorgalis and Lillywhite 2004, p. 9) and Australia's Murray-Darling Basin (National Water Commission 2009b, p. 5) have well developed water markets in terms of the volume traded as a proportion of the entitlements available. The amount traded is over 20% in both locations, including permanent and temporary water rights, which is extraordinarily high. Data are not available across all the US West to make a similar calculation, but the amount of water traded as a proportion of total water use is much less. Nevertheless, substantial volumes of water are traded in US water markets. Between 1987 and 2008 trades by state were Texas (38,700 GL); Arizona (27,500 GL); and California (24,500 GL). These amounts are based on committed volumes where the annual amounts are projected forward for the term of the contract and discounted back at 5% (Brewer et al. 2008, p. 99). As of 2010, there have been only limited transfers of water rights in South Africa, although this may change after all rights are registered (expected by the end of 2011). Similarly, in China there are only *ad hoc* transfers that may amount to less than 0.1% of the total volumes used (derived from Speed 2010b, p. 85 and Liu and Speed 2010, p. 15).

Gains from Trade

To be able to calculate gains from trade requires data on actual transactions. These data, at best, are only partially available for China and South Africa. Calculations of the gains from trade in Chile indicate that the benefits of water markets are substantial and amount to between 8 and 32 per cent of agricultural contribution to regional GDP (Hadjigeorgalis and Lillywhite 2004, p. 9), or some $22 million annually. Australian water markets are much larger, with the total volume of trade in the Murray-Darling Basin worth over $1.8 billion in 2009 (National Water Commission 2009b) and estimated gains from trade in a dry year around $495 million (Peterson et al. 2004, p.

43). In the US West, the average annual value of water trading across 12 western states 1987-2008 was about $405 million in $2008 (Libecap, forthcoming).

Annually, the value of water transactions for all contract types and sectors varies from under $1 million in Montana and Wyoming, the two least urban western states, to near $40 million in Arizona, Colorado, Nevada, and Texas; and over $223 million in California. The high turnover in California is driven by one-year leases within agriculture and a few large multi-year leases from agriculture to urban use.

Water Storages

In regions where rainfall is not evenly spread throughout the year, water storages provide a valuable smoothing function. The more variable is the climate, the larger are the required storages. In terms of water markets, storages also provide an opportunity for trade over longer periods of time and enable trades upstream provided the transaction takes place before the water is released from upriver.

In all water markets there are substantial water storages that facilitate water trade. The ratios of total capacity of water storages to average water use range from more than 2 in Australia's Murray-Darling Basin to about 3 in Chile's Limarí Valley. The ratios vary substantially for the US West, but in one case in Colorado is 2.3. China has extensive water storages capabilities along all of its major rivers, with approximately 25 million GL of storage capacity along the Yellow River (Ministry of Water Resources 2011).

Nature of Water Rights

In the past 15 years water rights in Australia have, more or less, been separated from land rights. Although some riparian rights (stock and domestic use by farmers) still exist, essentially water rights can, in principle, be traded across catchments without also acquiring the land where the water rights were originally located (National Water Commission 2009a, p. 140-2). The water market includes two types of trade: a permanent market for the water right (that can vary in reliability across and within catchments), and a seasonal market for the actual allocations of water assigned each year to the permanent water right.

Chile has a similar system to Australia that features both permanent and contingent rights where the latter provide allocations when availability is above-average. In the Limarí Valley there are also both permanent (title) and seasonal trade, with the latter typically more prevalent (Zegarra 2008, p. 5; Hadjigeorgalis and Lillywhite 2004, p. 9; Cristi 2010). In the US west, surface water rights are based on the prior appropriation doctrine that allows water to be separated from the land and moved via canals and ditches to new locations (Getches 1997, p. 74-189; Kanazawa 1998; Johnson et al. 1981). Appropriative rights with the earliest water claims have the highest priority claim on water.

Water rights have been unbundled from land in South Africa since the passage *of National Water Act 1998* (Pott et al. 2009, p. 2) and both temporary and permanent water trading have been observed (Nieuwoudt et al. 2005, p. 1). In China, despite the *2002 Water Law*, water rights remain poorly defined at either the regional, irrigation district or farmer level (Speed 2010b, p. 88). Although water access is restricted by the requirement to hold an abstraction permit, allocations have generally not been granted at the farmer level (Shen and Speed 2010, p. 32), and land area is often used as a proxy to calculate water charges (World Bank 2002, p. 12).

Breadth of Market

The breadth of water markets is defined spatially as well as by trades across competing uses. While Australia has well developed water markets over a very large spatial area within irrigated agriculture, there have been relatively few agricultural-urban trades. This has arisen because state governments that control urban water supplies have chosen to avoid, as much as possible, the purchase of water from rural areas to protect rural livelihoods and communities. As in Australia, the agricultural sector dominates Chile's water markets (Bauer 2004, p. 88). In the Limarí Valley, there has been limited trade activity by the urban sector because of adequate urban supplies and few conveyance systems between basins (Easter et al. 1999, p. 14).

In the US West, with the exception of a few locations, the majority of water markets are localized with trading within river basins or sub-basins. Regulatory restrictions and limited conveyance infrastructure are the primary reasons markets that restrict trades. In addition, nearly every western state has laws which protect basins of origin that make it difficult to export water from one basin to another. Consequently, there is virtually no private water trading across states. The lack of conveyance infrastructure and the high capital costs of moving water also limit the geographic scope of water markets. Most short-term trades are within sector, especially within agriculture. Agriculture-to-urban transactions are dominated by longer term leases and sales, but patterns vary across the states.

In South Africa the vast majority of water trading has been within the agricultural sector (Pott et al. 2009, p. 25-6), despite demands for extra water volumes by industry. While inter-sectoral transfers from agriculture to mining would be beneficial for both parties in South Africa it could also "challenge the [equity] objectives of government" (Farolfi and Perret 2002, p. 8) and the priority of providing water to previously disadvantaged individuals (PDIs). Any inter-sectoral water trading must also wait for initial allocation of licenses to be completed (Pott et al. 2009, p. 9). China stands out as the one country where there has been substantial transfer of water from agricultural to industrial and domestic uses. However, this has occurred via measures such as lining irrigation channels rather than through a fully operational water market (Speed 2010b, pp. 85-9).

Market Price Formation and Availability

Stable price formation and the availability of market price information are indicators of a competitive and mature water market. In Australia, water prices are remarkably consistent across catchments in the southern Murray-Darling Basin (National Water Commission 2009b, p. 26-9). Where substantial differences exist it is because of differences in reliability of the water rights or whether they are permanent or seasonal water rights. Australia also has the most developed price data, with accessible state registers and a national water register due to go on line in 2011. In Chile, there is an uneven spread of pricing information in the market, which increases transaction costs (Zegarra 2008, p. 120). In the Limarí Valley, where there is more information, prices of water shares have increased due to economic development across the mining, industrial and agricultural sectors (Zegarra 2008, p. 46).

In the US West**,** markets are both local and 'thin' such that there is considerable annual fluctuation in prices across time, across jurisdictions, and among sectors. As well as reflecting limited market integration, differences in price across sectors reflect the opportunity cost of water, adjusted for water quality, conveyance, and the priority of the water right. Price dispersion is also explained by the transaction costs involved in trading (Brookshire et al. 2004; Colby et al. 1993). Price differentials can be considerable. In South Africa, price formation is stable and information is spread largely by word of mouth (Gillet et al. 2005, p. 10), with no central notice board. This has led to asymmetries in terms of price information between buyers and sellers (Nieuwoudt and Armitage 2004, p. 3).

The outlier in terms of price formation is China where water prices are regulated by the government (Liao et al. 2008, p. vi). Consequently, water prices are stable, but they do not reflect changing environmental or economic conditions. Prices for water transfers between regional governments, for instance, are determined through direct negotiation.

Environmental Sustainability

Water markets provide a mechanism for the allocation of water between competing water users and market-based consumptive uses. However, unless there is explicit consideration given to nonmarket uses or set asides/reserves for the public good, markets may not deliver on broader societal goals.

There are several preconditions for meeting environmental sustainability in water management, including adequate information of environmental needs, delivery of water to meet these needs, and an adaptive process to manage these requirements with changing conditions and circumstances. These preconditions are captured in the criteria presented in Table 3, namely: (1) Adequate scientific data to determine hydrological requirements of water-based environmental resources; (2) Adequate provisions for environmental flows; (3) Adaptive management of environmental needs, including the capacity to monitor the environment; (4) Water quality considerations in water planning and markets; and (5) Complementary catchment and Basin-wide planning and trading.

Adequate Scientific Data

Adequate scientific data is required for effective water resource planning that underpins formal water markets. The best available data are in Australia, Chile, the US, and South Africa. In the case of Australia, much of this data has been developed in the past decade in response to government programs such as the *Living Murray First Step* (Grafton and Hussey 2007), initiated to increase environmental flows. The data are 'patchy' depending on the catchment and are not always accessible even to academic researchers, but are used by water agencies for planning purposes. In the US, state and federal agencies gather and provide information regarding hydrological data on stream flows, water use, and environmental demands. Environmental requirements are project and river specific and there is no central clearinghouse. South Africa has well developed hydrological models of its major catchments and is developing 'ecological reserves' as part of its *National Water Act 1998,* forcing water planners to improve data collection and monitoring. Chile also has scientific data for management and some modeling of basins, maintained by the DGA since 2000 (Brehm and Quiroz 1995, Cristi 2010). It is not clear that China has adequate water data for environmental purposes (Shen and Speed 2010, p. 33).

Provisions for Environmental Flows

In the US all western states recognize that environmental flows are consistent with beneficial use. Quasi-government agencies and private organizations, such as Oregon Water Trust, engage in water leasing or rights acquisition for in-stream flow maintenance (Neuman 2004; Scarborough 2010). However, there is considerable debate about how much water is needed to achieve specific environmental objectives. Cost-benefit analysis is not expressly required under the *Endangered Species Act 1973* or the *Clean Water Acts* so that a weighing of opportunity costs generally does not take place in determining environmental flows. Because the 1981 Water Code in Chile does not directly address third party effects, the primary mechanism for allocating water for environmental purposes is the purchase of existing water rights, although the 2005 code does describes minimum flow requirements.

In Australia and South Africa there is federal legislation mandating provision of water for environmental and public good purposes. In the case of Australia's Murray-Darling Basin this will be implemented via a Basin-wide plan that will determine sustainable diversion limits for each catchment in 2011-12. At present, water is provided for the environment through water resource planning processes and also through the purchase of water rights by governments from willing sellers (Connell and Grafton, in press). South Africa is also developing ecological reserves of water for public good purposes that include basic human needs as well as for the environment (Farolfi and Perret 2002, p. 3), although progress to date has been slow (Pollard et al. 2009, p. 2). In China, "…water is generally not allocated to the environment in any meaningful way" (Shen and Speed 2010, p. 33), although China is in the process of amending water basin plans to account for environmental flows in at least seven of its major river basins (Speed 2010b, p. 211).

Adaptive Management of Environmental Flows

All water markets, to some extent, have elements of adaptive management to facilitate responses to shocks, such as drought, by allowing high-value uses to access water that might otherwise have been denied to them. The challenge is to ensure water markets can flexibly respond to desired public good benefits of water.

In Australia, water resource plans disproportionately favor water diversions that, typically, decline by a lesser amount than inflows in dry periods (CSIRO 2008, p. 43). As a result, in extended droughts, environmental flows can become negligible and this can generate widespread environmental degradation (Wentworth Group of Concerned Scientists 2010). A proposed Basin Plan for the Murray-Darling Basin, due to be released in 2011, will attempt to correct this fundamental failing in water planning. South Africa has also recognized the importance of adaptively managing its water resources. As a key component of the ongoing reform process, ecological reserves of water are being determined to meet environmental needs (e.g. Pollard et al. 2009, p. 17).

In the US West there is capacity for adaptive management under state and federal environmental legislation. The absence of cost-benefit analysis and reliance upon judicial injunctions under federal endangered species and water quality legislation, however, can result in protracted legal disputes. Consequently, there is potential for greater reliance upon water markets where rights holders are compensated for environmental diversions. In the case of Chile, adaptive management is in the form of proportional allocation adjustments across all water rights in response to annual variability of inflows. China's water adaptive water planning is presently in a state such that "…current approaches to defining environmental flows do not adequately account for complex relationships between flow regimes and ecosystems" (Liu and Speed 2010, p. 17).

Water Quality Considerations

Water quality is related to flows and how water is diverted and used. In all water markets some consideration is given to water quality. In the Murray-Darling Basin of Australia there are some restrictions on trade to avoid worsening salinity and the 2011-12 Basin Plan will include a water quality and salinity management plan to safeguard water quality (Murray-Darling Basin Authority 2009, p. 14). In the US, water quality is regulated by state and federal legislation and trades can be restricted due to quality concerns. This has been the case, for example, in the Sacramento Delta where rising salinity levels contribute to reduced exports of water through the State Water Project.

In Chile, China and South Africa there is evidence of major water quality problems, at least in some river basins. The Limarí Valley, however, does not appear to have major water quality problems (Hearne 1998, p. 145). In South Africa, the most damaging water quality issue is acid mine drainage that comes from both active and abandoned mines. Despite the fact that these problems have existed for many decades, they remain a major concern in key catchments. China has a daunting challenge to mitigate severe water quality problems, and although it is taking steps to resolve water pollution, enforcement remains weak and the problems are "…grave and deteriorating" (Lee 2006, p. 7).

Basin and Catchment-level Water Planning

Interlinked and compatible Basin and catchment water planning is necessary for integrated catchment management to address downstream externalities. In Australia, there will be a comprehensive Basin Plan proposed for the Murray-Darling Basin in 2011 that will specify environmental water requirements and sustainable diversions for each catchment (Murray-Darling Basin Authority 2009, p. 19).

Chile has a decentralized planning system where much of the management within basins is done locally. For example, irrigation associations and officials in the Irrigation Bureau effectively manage Limarí's water supply on a year-to-year basis (Zegarra 2008, p. 41). In the US there is partial basin-wide water management regarding environmental flows. Basins often cross multiple political jurisdictions so that differing regulations and agencies are involved, although federal quality regulations generally apply. The 18 interstate water basin compacts have had limited coordinated environmental roles, and in California the Integrated Regional Water Management Plan Program (IRWMP) has been expanded to promote water planning outside traditional political boundaries.

South Africa's *National Water Act 1998* provides for catchment-level planning for environmental and human needs through reserves. However, slow progress in creating catchment management authorities has meant that water planning remains in its infancy in most catchments. China's seven major river basins all have comprehensive water plans, although only now are these beginning to go beyond a focus on allocation to incorporate more holistic objectives such as water quality, flood control and environmental protection (Speed 2011, pers. comm.).

Water Markets: An Overview

Informal markets exist in many other countries such as India and Pakistan, as well as more formal water markets, such as in Mexico (Easter et al. 1998). Benchmarking across these water markets would help policy makers to make judgments about how they can be further developed to achieve particular goals. We contend that our integrated framework shows the important linkages between water market development, institutional constraints, and management goals. Understanding these connections is crucial to good water governance.

In closing, we provide ten key insights from the application of the integrated framework to five water markets. First, institutions matter. Thus, what may work in one water market may not necessarily be as successful in another with different institutions. Second, the design of water markets has arisen for purposes other than direct economic efficiency in terms of managing third-party impacts and equity, in the case of South Africa. Third, markets can be adapted to account for environmental sustainability without necessarily compromising economic efficiency. Fourth, markets can successfully work in small catchments, such as Chile's Limarí Valley, as well as in large basins, such as the Murray-Darling Basin. Fifth, water markets can generate substantial gains for buyers and sellers that would not otherwise occur, and these gains increase as water availability declines. Sixth, there is a need for flexibility in water markets as the benefits of consumptive and *in situ* use change, as has happened in the US West and Australia. Seventh, there must be a close connection between water markets and water planning to provide surety to holders of water rights while maintaining desired public benefits. Eighth, history matters. The path dependence of the US with its appropriative rights has been very different to that of Australia that has statutory rights. Ninth, differences in regulatory capacity (human and financial) help to explain some of the variation in the performance of water markets, such as between South Africa and Australia. Tenth, performance must match goals. Water markets should be judged not just on economic efficiency but also equity or environmental sustainability where these aims are deemed important.

References

Barrionuevo, Alexei. 2009. Chilean town withers in free market for water. *New York Times*, 14 March.

Bauer, Carl J. 2008. The Experience of Chilean Water Markets. Working paper, Arizona State University.

Bauer, Carl J. 2004. *Siren song: Chilean water law as a model for international reform*. Washington D.C.: Resources for the Future.

Bauer, Carl J. 1997. Bringing water markets down to earth: The political economy of water rights in Chile, 1976-95, *World Development* 25(5): 639-656.

Brehm, Monica Rios, and Jorge Quiroz. 1995. The market for water rights in Chile: Major issues, *World Bank technical paper no.285*. Washington D.C.: The World Bank.

Brewer, Jedidiah, and Gary D. Libecap. 2009. Property rights and the public trust doctrine in environmental protection and natural resource conservation. *The Australian Journal of Agricultural and Resource Economics* 53: 1–17.

Brewer, Jedidiah, Robert Glennon, Alan Ker, and Gary D. Libecap. 2008. Water markets in the west: prices, trading, and contractual flows. *Economic Inquiry* 46(2): 91-112.

Briscoe, John, Pablo Anguita Salas and Humberto Peña T. 1998. Managing water as an economic resource: Reflections on the Chilean experience, *Environment Department Paper no. 62,* Environmental Economics Series. Washington D.C.: The World Bank.

Brookshire, David S., Bonnie G. Colby, Mary Ewers and Philip T. Ganderton. 2004. Market prices for water in the semiarid West of the United States. *Water Resources Research* Doi: 10.1029/2003WR002846.

Colby, Bonnie G., Kristine Crandell, and David B. Bush. 1993. Water rights transactions: market values and price dispersion. *Water Resources Research* 19: 1565-1572.

Connell, Daniel, and R. Quentin Grafton. 2008. Planning for water security in the Murray-Darling Basin. *Public Policy* 3(1): 67-86.

Connell, Daniel, and R. Quentin Grafton. In press. Water reform in the Murray-Darling Basin. *Water Resources Research* doi:10.1029/2010WR009820 (in press),.

Cristi, Oscar. 2010. *Risk Analysis and Water Market Activity*. VDM Verlag Dr. Muller Aktiengesellschaft & Co. KG.

CSIRO. 2008. *Water availability in the Murray-Darling Basin*. A report to the Australian Government from the CSIRO Murray-Darling Basin Sustainable Yields Project. Canberra, CSIRO.

Dinar, Ariel, and R. Maria Saleth. 2005. Can water institutions be cured? A water institutions health index. *Water Science and Technology: Water Supply* 5(6): 17-40.

Easter, K. William, Mark W. Rosegrant, and Ariel Dinar. 1999. Formal and informal markets for water: Institutions, performance and constraints. *The World Bank Research Observer* 14(1): 99-116.

Easter, K. William, Mark W. Rosegrant, and Ariel Dinar (eds). 1998. *Markets for water: potential and performance*. Boston: Kluwer Academic Publishers.

Eden, Susanna, Robert Glennon, Alan Ker, Gary Libecap, Sharon Megdal, and Taylor Shipman, 2008. Agricultural water to municipal use: the legal and institutional context for voluntary transactions in Arizona. *The Water Report* 58: 9-20.

Falkenmark, Malin. 1999. Forward to the future: A conceptual framework for water dependence. *Ambio* 28(4): 356-361.

Farolfi, S., and K. Rowntree. 2007. Accompanying local stakeholders in negotiation processes related to water allocation through simulation models and role-playing games:

An experience from South Africa. Empowers Insight biannual magazine 2:5-7. Available online at www.project.empowers.info/page/2980.

Farolfi, S., and S. Perret. 2002. Inter-sectoral competition for water allocation in rural South Africa: Analysing a case study through a standard environmental economics approach, *Working paper 2002-23*, Department of Agricultural Economics, University of Pretoria.

Getches, David H. 1997. *Water law in a nut shell*, St. Paul: West Publishing Co.

Gould, George. A. 1995. Recent developments in the transfer of water rights. In *Water law: Trends, policies, and practice*, ed. Kathleen Marion Carr and James D. Crammond, 93–103, Chicago: American Bar Association.

Ghassemi, Fereidounm, and Ian White. 2007. *Inter-basin water transfer: Case studies from Australia, United States, Canada, China, and India.* Cambridge, England: Cambridge University Press.

Gillet, C.G., W.L. Nieuwoudt and G.R. Backeberg. 2005. Water markets in the Lower Orange River catchment of South Africa, *Agrekon* 44(3): 363-382.

Grafton, R. Quentin, and Karen Hussey. 2007. Buying back the Living Murray: At what price? *Australasian Journal of Environmental Management* 14: 74-81.

Hadjigeorgalis, Ereney, and Jay Lillywhite. 2004. The impact of institutional constraints on the Limari River Valley water market, *Water Resources Research* 40, W05501, doi:10.1029/2003WR002701.

Hearne, Robert R. 1998. Institutional and organisational arrangements for water markets in Chile. In *Markets for water: Potential and performance*, ed. K. William Easter, Mark W. Rosegrant and Ariel Dinar, 181-158. Massachusetts: Kluwer Academic Publishers.

Howe, Charles W., Dennis R. Schurmeier, and W. Douglas Shaw. 1986. Innovative approaches to water allocation: The potential for water markets. *Water resources Research* 22(4): 439-445.

Johnson, Ronald N., Micha Gisser, and Michael Werner. 1981. The definition of a surface water right and transferability. *Journal of Law and Economics* 24 (2): 273-88.

Kanazawa, Mark T. 1998. Efficiency in western water law: The development of the California doctrine, 1850-1911. *Journal of Legal Studies* 27(1): 159-185.

Khan, Haider, and Yibei Liu. 2008. Ecological economics of water in China: Towards a strategy for sustainable development. *MPRA paper no. 7705*, Munich Personal RePEc Archive. Published March 2008.

Lee, S. 2006. China's water policy challenges. *China Policy Institute discussion paper 13,* University of Nottingham.

Liao, Yongsong, Zhanyi Gao, Ziyun Bao, Qingwen Huang, Guangzhi Feng, Di Xu, Jiabin Cai, Huijing Han, and Weifeng Wu. 2008. China's water pricing reforms for irrigation: Effectiveness and impact. *CA Discussion Paper 6*. Comprehensive Assessment of water management in agriculture. Colombo: International Water Management Institute.

Libecap, Gary D., forthcoming. Water Rights and Markets in the U.S. Semi-Arid West: Efficiency and Equity Issues. In Daniel Cole and Elinor Ostrom, eds, *The Evolution of Property Rights Related to Land and Natural Resources*, Cambridge, MA: Lincoln Institute.

Libecap, Gary D. 2007. *Owens valley revisited: a reassessment of the west's first great water transfer.* Palo Alto: Stanford University Press.

Liu, Bin, and Robert Speed. 2010. Water resources management in the People's Republic of China. In *Water resources management in the People's Republic of China*, ed. Xeutao Sun, Robert Speed, and Dajun Shen. New York: Routledge.

Ludwig, Fulco and Marcus Moench. 2009. The impacts of climate change on water. In *Climate change adaptation in the water sector,* eds. Fulco Ludwig, Pavel Kabat, Henk van Schaik, and Michael van der Valk, 35-50. London: Earthscan Publishing.

Malzbender, Daniel, Jaqui Goldin, Anthony Turton, and Anton Earle. 2005. Traditional water governance and South Africa's National Water Act: Tension or cooperation? Paper presented at the international workshop African water laws: Plural legislative frameworks for rural water management in Africa, Johannesburg, South Africa, January, 26-28.

Ministry of Water Resources, China. 2011. Major Reservoir Information. Accessed from website at http://xxfb.hydroinfo.gov.cn/EN/eindex.jsp.

Murray-Darling Basin Authority. 2009. The Basin Plan: A concept statement. MDBA Publication no. 02/09, June.

National Water Commission. 2009a. *Australian water reform 2009: Second biennial assessment of progress in implementation of the National Water Initiative*. Canberra: National Water Commission.

National Water Commission. 2009b. *Australian water markets report 2008-09*. Canberra: National Water Commission.

Neuman, Janet C. 2004. The good, the bad, and the ugly: The first ten years of the Oregon water trust. *Nebraska Law Review* 83: 432-84.

Nieuwoudt, W. L., C. G. Gillet, and G. R. Backeberg. 2005. Water marketing in the Crocodile River, South Africa. *Agrekon* 44(3): 383-401.

Nieuwoudt, W. L. and R. M. Armitage. 2004. Water market transfers in South Africa: Two case studies. *Water Resources Research* 40: W09S05, doi:10.1029/2003WR002840.

Nieuwoudt, W. L. 2000. Water market institutions: Lessons from Colorado. *Agrekon* 39(1): 58-67.

Peterson, Deborah, Gavin Dwyer, David Appels, and Jane M. Fry. 2004. *Modelling water trade in the southern Murray-Darling Basin*. Productivity Commission Staff Working Paper. Melbourne, Productivity Commission.

Pollard, Sharon R., Derick du Toit, and S. Mallory Skukuza. 2009. Drawing environmental water allocations into the world of realpolitik: Emerging experiences on achieving compliance with policy in the Lowveld rivers, South Africa. Paper presented at the International Conference on Implementing Environmental Water Allocations, Port Elizabeth, February 23-26.

Postel, Sandra L., Gretchen C. Daily, and Paul R. Ehrlich. 1996. Human appropriation of renewable fresh water. *Science* 271: 785-788.

Pott, A., K. Versfeld, M. van Rooyen and A. Muir. 2009. *A scoping exercise to investigate the potential need for, and nature of, water trading in South Africa*. WRC Report No. KV 222/09. South African Water Research Commission.

Productivity Commission. 2010. *Market mechanisms for recovering water in the Murray-Darling Basin*. Melbourne, Productivity Commission.

Rosegrant, Mark, and Hans P. Binswanger. 1994. Markets in tradable water rights: Potential for efficiency gains in developing country water resource allocation. *World Development* 22: 1613-1625.

Saleth, R. Maria, and Ariel Dinar. 2004. *The institutional economics of water: A cross country analysis of institutions and performance.* Cheltenham: Edward Elgar Publishing.

Sax, Joseph. 1970. The public trust doctrine in natural resource law: effective judicial Intervention. *Michigan Law Review* 68: 471–566.

Scarborough, Brandon. 2010. *Environmental water markets: restoring streams through trade*. PERC Policy Series No. 46. Bozeman, MT: PERC.

Shen, D. and R. Speed. 2010. Water resources allocation in the People's Republic of China. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Shiklomanov, I.A.2003. World water use and water availability, In *World Water Resources at the Beginning of the 21st Century*, eds. I.A. Shiklomanov, and John C. Rodda, 369-389. Cambridge, England: Cambridge University Press.

Speed, R. 2010a. A comparison of water rights systems in China and Australia. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Speed, R. 2010b. Transferring and trading water rights in the People's Republic of China. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Speelman, S., S. Farolfi, A. Frija and G. van Huylenbroeck. 2010. Valuing improvements in the water rights system in South Africa: A contingent ranking approach. *Journal of the American Water Resources Association* 46(6): 1133-1144.

Sullivan, Caroline. 2002. Calculating a water poverty index. *World Development* 30(7): 1195-1210.

Sun, Xuetao. 2010. Introduction: The development of a water rights system in China. In *Water resources management in the People's Republic of China*, ed. Xuetao Sun, Robert Speed and Dajun Shen. New York: Routledge.

Thompson, Barton H. 1993. Institutional perspectives on water policy and markets. *California Law Review* 81: 673-764.

Trelease, Frank J. 1955. Preferences to the use of utility. *Rocky Mountain Law Review* 27: 133-60.

Turton, Anthony R., Marian J. Patrick, and Jeanette Rascher. 2008. Editorial: Setting the scene – hydropolitics and the development of the South African economy. *Water Resources Development* 24(3): 323-327.

Water Research Commission. 2009. Experts united to save abused river from extinction. *The Water Wheel* 8(1): 14-17.

Wentworth Group of Concerned Scientists in association with R.Q. Grafton, I. Kowalick, C. Miller, T. Stubbs, F. Verity and K. Walker. 2010, *Sustainable diversions in the Murray-Darling Basin: An analysis of the options for achieving a sustainable diversion limit in the Murray-Darling Basin.* Melbourne: Wentworth Group of Concerned Scientists.

World Bank. 2002. *China: Country water resources assistance strategy*. The World Bank East Asia and Pacific Region. Washington D.C.: The World Bank.

Xie, Jian. 2008. *Addressing China's water scarcity: Recommendations for selected water resource management issues*. Washington D.C.: The World Bank.

Zegarra, Eduardo. 2008. *Water markets and coordination failures: A case study from Chile*. Saarbrucken: VDM Verlag Dr. Muller Aktiengesellscharft & Co. KG.

Zhou, G. 2006. *Institutional arrangements for river basin management: A case study comparison of the United States and China.* World Bank Policy Note 37747, China Water Analytical and Advisory Assistance Program. Washington D.C.: IBRD, The World Bank.

Table 1. Institutional Foundations

	Recognition of public interest	Administrative capacity	Horizontal and vertical linkages	Legal/administrative clarity	Priority of use	Initial allocation and reallocation	Dealing with market failures	Adaptive management of institutions
Australia	💧💧	💧💧	💧💧💧	💧💧💧	💧💧💧	💧💧💧	💧💧	💧💧💧
US West	💧💧	💧💧	💧	💧	💧💧💧	💧💧	💧	💧💧
Chile	💧	💧💧	💧💧	💧💧	💧	💧💧	💧	💧
South Africa	💧💧	💧	💧	X	💧💧	(pending)	💧💧	(pending)
China	💧	💧	💧	X	💧💧	(pending)	X	💧💧

💧💧💧 Nearly or fully satisfied

💧💧 Mostly satisfied, some further development required

💧 Partly satisfied, substantial further development required

X Not satisfied/Missing/Not operational

Table 2. Economic Efficiency

	Size of market (permanent/ temporary)	Gains from trade (US$ million)	Storage (ratio of average use)	Nature of water rights	Breadth of market	Market price formation and availability
Australia	12.5/20.1 %	495	2.0	💧💧💧	💧💧	💧💧💧
US West	I	406	2.3 (Colorado)	💧💧💧	💧	💧
Chile	15/30 %	22.1	3.3	💧💧💧	💧💧	💧
South Africa	I	I	I	💧	💧	💧
China	I	I	I	X	💧💧	N/A

💧💧💧	Nearly or fully satisfied
💧💧	Mostly satisfied, some further development required
💧	Partly satisfied, substantial further development required
X	Not satisfied/Missing/Not operational
I	Inadequate info

Table 3. Environmental Sustainability

	Adequate scientific data	Adequate provisions for environmental flows	Adaptive management of environmental needs	Water quality considerations in water planning	Basin and catchment-level water planning
Australia	💧💧	(pending)	(pending)	💧	(pending)
US	💧💧	💧	💧	💧💧	💧
Chile	💧💧	💧	💧	💧	💧💧
South Africa	💧	(pending)	💧	X	💧
China	X	💧	X	💧	💧

💧💧💧	Nearly or fully satisfied
💧💧	Mostly satisfied, some further development required
💧	Partly satisfied, substantial further development required
X	Not satisfied/Missing/Not operational