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Defining property rights to surface water in complex regulated river systems: generalising the capacity sharing concept

Neal Hughes
Australian Bureau of Agricultural and Resource Economics

Abstract

It is commonly noted that Australian water rights, specifically those prevailing within the Murray-Darling Basin, represent a significant departure from hydrological reality (see for example Young and McColl 2009). Where water rights depart from the physical realities of water supply networks, water use and water trade decisions may result in external effects and associated allocative inefficiency. This paper examines how a more exclusive set of water property rights based around the concept of capacity sharing (Dudley and Musgrave 1988) might be defined and implemented in complex regulated river systems. In particular, the paper considers how the capacity sharing concept might be generalised to accommodate complex water supply systems (e.g. with multiple storages and or unregulated river flows) and large regulated river basins (e.g. with multiple connected water supply systems).

Previous research on water storage rights and capacity sharing (Hughes 2009, Brennan 2008) focused extensively on intertemporal efficiency. In this paper the focus is primarily on spatial efficiency, in particular the potential to improve efficiency by incorporating a more accurate representation of water supply networks into water property rights. The paper also considers some of the challenges that may be associated with implementing such a system of water property rights, including distributional consequences, transaction costs and aspects of 'jointness' in the delivery and consumption of water.

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1 Introduction

Well-defined property rights to water are necessary if decentralised markets are to achieve an efficient allocation of available water resources across time and space. In particular, water property rights need to be exclusive—all of the costs and benefits associated with these rights should accrue solely to their holder. Non-exclusivities can arise where water property rights fail to accurately reflect the physical realities of water supply systems. Where water property rights are non-exclusive, water use and water trade decisions result in external effects and associated allocative inefficiency. It is commonly noted that Australian water rights, specifically those prevailing within the Murray-Darling Basin, represent a significant departure from hydrological reality (Young and McColl 2009).

For some years now the Murray-Darling basin has been in the grip of an extended dry period involving record low inflows and storage levels. Understandably, researchers, policy-makers and water users alike have been heavily focused on pressing issues associated with adaptation of productive and environmental systems to persistent drought conditions. However, increases in water scarcity also greatly increase the importance of property rights reform. Property rights reform remains one area of policy which, in the long run, has the potential to yield significant improvements in the efficiency of water allocation, of benefit to all water users, both environmental and agricultural.

There exists an extensive body of literature which documents the various ways in which existing property rights fail to accurately reflect physical realities and attempts to estimate the potential costs involved. There has perhaps been less focus placed on the design of alternative water property rights structures. The aim of this paper is not to highlight any new issues of property right misspecification, but rather to consider how a particular property rights framework, based on the concept of capacity sharing, might be employed to address at least some of these previously acknowledged issues.

Capacity sharing is a system of water property rights originally proposed by Dudley and Musgrave (1988). Capacity sharing results in water property rights which, relative to traditional rights, more accurately reflect the reality of water supply systems—variable inflows, constrained storage and delivery capacity and losses in the storage and delivery of water. A capacity sharing based approach may, in addition to improving intertemporal efficiency (Hughes and Goesch 2009a), achieve improvements in the spatial allocation of water, since capacity sharing effectively embodies the concept of source tagging (Beare et al. 2005, Heaney et al. 2006).

A common argument against the capacity sharing approach is that it may not be feasible in more complex river systems. This paper considers in detail how the capacity sharing concept might be generalised to suit complex water supply systems (e.g. with multiple storages and/or unregulated river flows) and in large regulated river basins (e.g. with multiple connected water supply systems). Some of the advantages and the practical challenges that may be associated with implementing a capacity sharing based property rights framework in complex regulated river systems are highlighted.

The paper also considers some alternatives (or complements) to a decentralised market based approach to water allocation, including approaches closer to that typically observed in practice, involving a mix of market and non-market allocation mechanisms, and so called ‘smart markets’ where water markets are effectively embedded within a central computer model.

2 A brief literature review

Many researchers have highlighted the multitude of areas in which the prevailing entitlement framework lacks 'hydrological integrity', and leads to externalities and economic inefficiency. Many of these issues have been noted, if not addressed, by governments (see the National Water Initiative (NWC 2004)). It is useful to consider briefly some of the important contributions made in the Australian context.

Randall (1981) presented an initial proposal for a system of transferable water entitlements for Australia. Randall (1981) acknowledged the inadequacy of simple water entitlements with respect to issues of return flows, in-stream values and potential external effects arising from trade in water between locations. Randall (1981) foreshadowed that augmentation of the entitlement system, in the case of return flows, and/or government regulatory oversight, in the case of in-stream values and trade, might be required.

Young and McColl (2003a, 2003b, 2005, 2008a, 2009) have published extensively on water property rights issues. For example, Young and McColl (2009), focused in detail on the exclusion of water intercepting activities from the entitlement framework, such as farm dams, plantation forestry and salinity interception schemes. Young and McColl (2008a, 2008b) have also advocated an inflow sharing approach to water property rights, where users (agricultural and the environment) are allocated shares of inflow, as an alternative to the approach of enforcing a cap on agricultural water use. The approach outlined by Young and McColl (2008a, 2008b) appears to have a number of similarities with the concept of capacity sharing as proposed by Dudley and Musgrave (1988).

A number of researchers have considered the inadequacies of property rights with regard to water storage (intertemporal transfer or carryover) (Brennan 2008; Alaouze 1991; Dudley 1988; Dudley and Musgrave 1988; Hughes and Goesch 2009a). The contribution of Dudley (1988) to the area of water property rights reform, specifically the concept of capacity sharing, is considered in more detail in the following section.

Brennan (1999, 2006 and 2008) has also contributed extensively to the literature on water property rights reform. In addition to the issue of water storage rights (Brennan 2007), Brennan (1999 and 2006) has considered a range of other property rights issues including the inadequacies of water property rights with respect to return flows and delivery constraints.

ABARE has undertaken a significant amount of research in the area of water property rights, including issues such as: return flows (Heaney and Beare 2001), ground water-surface water connectivity (Goesch and Hafi 2006) and environmental externalities (Beare and Heaney 2002). In particular, Heaney et al. (2006) considered the external effects that arise when incomplete water property rights are traded between different locations. Heaney et al. (2006) made note of the incomplete treatment of delivery constraints and delivery losses. The analysis of Heaney et al. (2006) follows Randall (1983) by focusing in detail on the concepts of exclusiveness and rivalry. More recently, ABARE has undertaken research in the area of storage management and capacity sharing, including an evaluation of the capacity sharing schemes introduced in southern Queensland (Hughes and Goesch 2009b).

There has also been a significant amount of research employing economic modelling techniques to estimate the potential efficiency costs of property rights misspecification, for example Brennan (2008), Dudley (1988) and Hughes and Goesch (2009a), in the area of storage rights / intertemporal efficiency. Of particular relevance to this paper is modelling of the costs of delivery loss socialisation (see for example Hafi et al. 2001).

In this paper, the focus is primarily on the allocation of water via markets—the property rights approach. However, it is worth noting that a number of researchers have emphasised the difficulties of a private property rights approach to water allocation (Quiggin 1988; Quiggin 2001; Crase et al. 2004; Bell and Quiggin 2008).

Among other issues, researchers have noted the difficulty of developing exclusive and non-attenuated water rights and the potential for large transaction costs in these markets, while also emphasising the importance of government involvement and common property arrangements in water allocation. As noted by Quiggin (2001) and Bell and Quiggin (2008), in practice, achieving an efficient allocation of water is likely to involve an interacting mix of public and private (and market and non-market) mechanisms. Such a mixed approach to water allocation is briefly considered later in the paper.

3 Water property rights reform: some principles

It is useful to consider some general principles of water property rights reform; specifically, principles which are expected to determine the evolution of water property rights over time, in keeping with theory of Demsetz (1967). Two key principles are outlined below. The first principle is:

Any marginal increase in the hydrological realism of water rights will increase the efficiency of water resource allocation, assuming constant transaction costs.

That is, increasing exclusiveness (internalising externalities) will be beneficial where doing so involves no additional costs. The key point is that incremental improvements in water rights may be beneficial even where property rights remain substantial simplifications of reality. Property rights may be viewed as existing along a spectrum of realism, ranging from existing property rights up to the boundary of scientific understanding of hydrological systems. In practice, water rights (in any region of context) are likely to remain a significant distance from reality and scientific understanding.

As an example, consider the case of storage losses. The marginal losses associated with storing additional water in shared storage will vary significantly depending on the aggregate storage level and the prevailing weather conditions. However, a system that applies average losses based on historical averages may still generate efficiency improvements. Refining the system by adopting storage losses that vary with the storage level and the seasonal conditions may then yield further efficiency improvements, such as the approach adopted in the St George and MacIntyre Brook irrigation schemes in Queensland (Hughes and Goesch 2009b).

To this point any potential costs associated with adopting more realistic, and possibly more complex, systems of water property rights have been ignored. Water property rights reforms are likely to involve establishment costs, particularly from a water regulators perspective. Reforms may also lead to ongoing costs, such as increased transaction costs associated with trading water rights or making water use and storage decisions, although in practice the effect of water property rights reform on transaction costs can be ambiguous. The second key principle is:

Water property rights reforms should continue so long as the marginal benefits outweigh the marginal costs.

This is essentially the idea of Demsetz (1967) who states, ‘property rights develop to internalize externalities when the gains of internalization become larger than the costs’ (Demsetz 1967, p. 340). Implicit in this principle is the idea that reforms in water property rights are likely to involve diminishing marginal returns. The closer water property rights are to reality, the smaller the marginal efficiency gains of further reforms. At the same time, the marginal costs may increase as property rights move closer to the boundary of scientific understanding, implying there exists some optimum level of property right realism.

Many have argued (see Young and McColl 2009) that the prevailing approach to water property rights in Australia is unlikely to embody an ideal hydrological realism. In general, ideal hydrological realism would be expected to increase over time as water scarcity increases and as the scientific understanding of hydrological systems improves.

A number of anecdotal examples support the idea that water property rights may evolve according to the above principle. For example, the recent expansion of carryover rights, including their introduction into Victoria, has occurred largely in response to the dryer conditions, which have significantly increased the benefits of storage flexibility. A further example is the introduction of capacity sharing in St George, where the benefits of internalising storage capacity constraints and storage losses are especially high given the system's highly constrained storage capacity and extremely high storage losses.

4 Capacity sharing

Capacity sharing is a system of water property rights originally proposed by Dudley and Musgrave (1988). Capacity sharing involves the definition of explicit storage capacity rights, inflow rights and the internalisation of marginal storage and delivery losses. Capacity sharing can be considered as a system of property rights which more accurately reflects hydrological realities. Traditional rights often inadequately reflect storage capacity constraints and storage and delivery losses, and often impose artificial constraints on the intertemporal transfer of water. Under capacity sharing, property rights are assigned to all water resources, with the environment holding identical water rights to all other water users (e.g. shares of storage, inflows and losses).

Capacity sharing remains an approach with relatively limited implementation at the end user level in Australia or internationally. However, capacity sharing has been successfully implemented in two irrigation schemes in southern Queensland, at St George and MacIntyre Brook. A detailed investigation of these capacity sharing schemes was recently undertaken by Hughes and Goesch (2009b). There has also been some interest shown in the concept in South Africa. The South African Water Commission has undertaken significant research on the topic, initially with the assistance of Dudley (see Viljoen, Dudley, Gakpo and Mahlaha 2004; Leclar 2004; Pott et al. 2005 and Pott et al. 2009). Despite the research interest, there has so far been little interest from water regulators in implementing a capacity sharing system there (G Backeberg, 2009, pers. comm.) However, there have been reports of a successful small-scale implementation in Zimbabwe (Doertenbach 1998).

Hughes and Goesch (2009a) considered capacity sharing, focusing on the issue of intertemporal efficiency of water use. They outlined the conditions under which a decentralised approach to storage management, such as carryover rights or capacity sharing, will result in a more efficient intertemporal allocation of water than a centralised approach. Hughes and Goesch (2009a) also outlined why a capacity sharing approach, having a more accurate representation of hydrological constraints, might be preferred to the carryover right approach.

A capacity sharing based approach may, in addition to improving intertemporal efficiency, achieve improvements in the spatial allocation of water. For example, capacity sharing effectively embodies the concept of source tagging, where rights to water are defined at the source (i.e. storage), which has the potential to remove a number of external effects and inefficiencies associated with water trade between different locations. Defining water rights at the source may also facilitate the internalisation of marginal water delivery losses.

While the term capacity sharing specifically refers to the allocation of storage capacity rights, the essence of the concept is more general: defining water property rights that reflect physical realities. Rather than being viewed as a special system for allocating water, capacity sharing can be more simply viewed as a bundle of water property right reforms; the incorporation of a range of physical constraints (and the removal of some artificial ones). In this paper, some effort is made to emphasise water property rights reform in general, rather than the adoption of a specific water rights system. In practice, property rights reform occurs along a continuum and no specific property rights system should necessarily be considered the optimal or final destination for reform.

While capacity sharing is often considered in the context of relatively simple water supply systems, with single storages and no tributary flows, there has been at least some consideration of issues associated with more complex systems. For example Dudley briefly considers issues such as multiple storages and tributary flows (see Dudley 1990a, 1990b and 1992b), while more recent research in South Africa has focused on the issue of unregulated flows (Pott et al. 2005 and Pott et al. 2009).

5 Regulated river systems: the surface water network

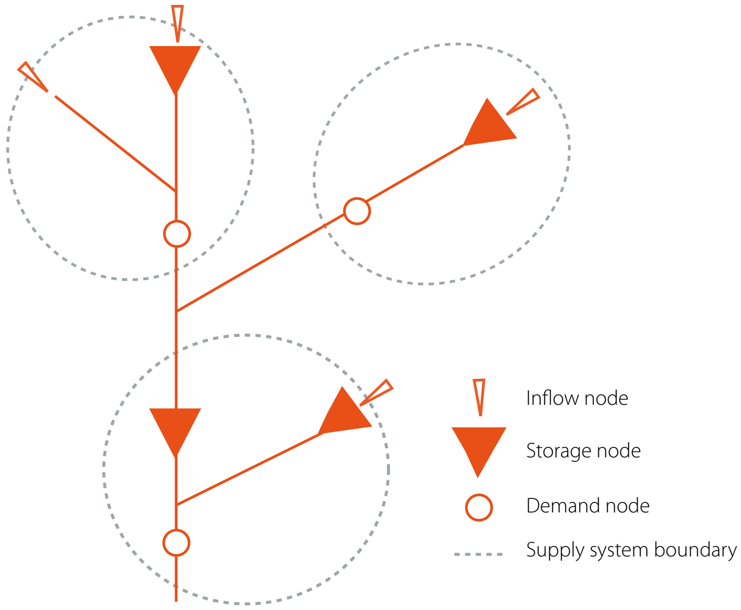
As previously discussed, it is unlikely that all features of hydrological reality can be expected to be included within the property rights framework. In this paper a simplified version of a regulated river system is considered: the surface water network. The surface water network is assumed to include storages, regulated rivers, distribution networks (pipes and channels) and major unregulated tributaries, with a range of water users connected at various points along this network.

The surface water network is an abstract concept representing a relatively well understood subset of the total hydrological system. For a number of specific points (or nodes) across the network, reliable information on the quantity of water resources and the network capacity is available. In between these points, approximations can be made of capacity constraints and delivery losses. This paper considers how water property rights can be designed to exploit this information.

This representation of a water network ignores a number of key features of hydrological reality, in particular surface-ground water connectivity and catchment management (run-off intercepting land use activities). A more realistic set of water rights would accurately reflect these features. The exclusive emphasis on the surface water network is made for simplicity, and because the surface water network is likely to be among the easiest (lowest cost) hydrological features to fully incorporate within water property rights, given existing scientific knowledge, water metering and water accounting systems.

Figure 1 provides an example of a hypothetical surface water network. For simplicity it is assumed that the branches are streams (e.g. one directional) and that water flows in a downward direction. The dotted lines indicate the boundaries of specific water supply systems, where water supply systems are defined as major water using areas and their water sources. This is an artificial distinction, but is relevant for policy, as it is the scale over which water plans and water entitlements are typically defined. The Murray-Darling Basin is an

1 A surface water network



example of a large regulated river system and the Murrumbidgee region is an example of one of its water supply systems. The demand nodes can be interpreted generally and could, for example, be irrigation areas, farms, environmental assets or even salt interception schemes.

For the purposes of designing property rights to water, the definition of the surface water network is likely to require a further degree of approximation. For example, it may be optimal to exclude some water users from a defined network/property rights framework where they are taking relatively insignificant volumes. Further, an explicit representation of some less significant tributaries may not be required; for example, tributaries that contribute negligible flows (which can be excluded), or tributaries located well upstream of significant water users (which can be aggregated with other flows). Decisions over the appropriate level of approximation should take into account the associated costs and benefits.

Further, not all aspects of water delivery systems (e.g. streams, irrigation channels and pipes) need to be explicitly included in the defined network, and in turn water property rights. In between network nodes, for example between water source nodes and demand nodes, all that is required is an approximation of the marginal delivery losses and the marginal delivery constraints, rather than an explicit representation of every channel, stream or pipe involved.

Two further complications in defining the boundaries of the surface water network include return flows, where a proportion of consumed water makes its way back into the water network, and in-stream environmental values, where the delivery (or non-delivery) of water over the network has environmental implications. For simplicity it is initially assumed that return flows are unmeasurable and therefore excluded from the property rights framework. For now it is also assumed that there are no values, environmental or otherwise, attached to water in the delivery system.

6 Delivery losses

It is necessary to consider the issue of delivery losses in more detail. Delivery losses can include seepage, evaporation and flooding. At any given point in the water network, losses will depend on prevailing weather conditions, the nature and capacity of the delivery infrastructure (streams, channels, pipes etc.) and the volume of water delivered. While some delivery losses may return to the surface water network, these potential return flows are ignored for now.

2 Stylised total, average and marginal delivery losses

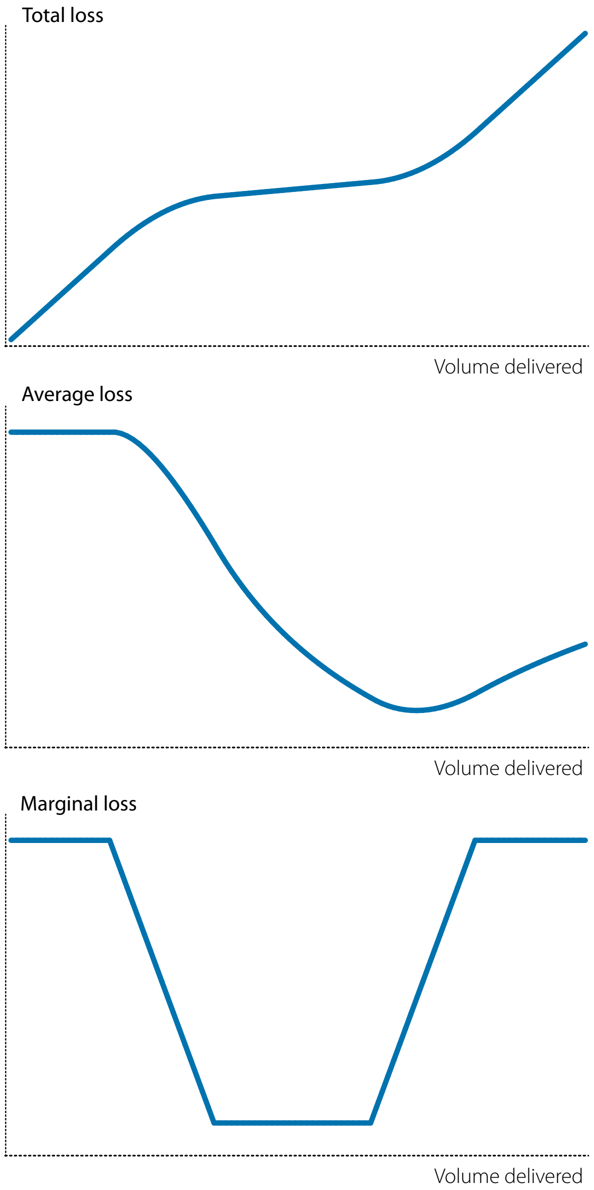


Figure 2 presents a stylised diagram of total, average and marginal delivery losses between two nodes on a water network. At low levels of flow, marginal losses may be high, and as the volume of water delivered increases marginal losses are likely to decline. For example, Griffin (2006) demonstrates that marginal evaporation and seepage losses, in trapezoidal shaped channels, are inversely proportional to the square root of the volume delivered. As the volume of water delivered nears the capacity constraint, marginal losses are likely to increase, and will reach one at the point of the constraint.

Where marginal losses are variable, individual user deliveries may have a significant effect on the marginal delivery losses applying to all other water deliveries. This 'jointness' of delivery losses is symptomatic of the non-rival nature of water delivery infrastructure. As noted by Beare and Newby (2005), water delivery channels represent congestible goods, which are non-rival below the point of congestion. This jointness presents a challenge in designing exclusive user level water property rights, potentially necessitating complimentary non-property rights approaches. For example, the occurrence of high initial marginal losses may provide rationale for a water authority to manage a share of water resources in order to maintain a minimum flow level for the benefit of all water users. In contrast, maximum delivery capacity constraints (being rival), are relatively amendable to inclusion within the water property rights framework.

Water users should only be made accountable for marginal delivery losses. Where marginal delivery losses are significantly positive and (approximately locally) constant there may be a case for applying an adjustment (loss factor) to user water orders. Assuming constant positive marginal losses along a branch of the network, marginal delivery losses will increase linearly with distance from the source. In practice, the treatment of delivery losses is likely to involve a degree of approximation, given limits to hydrological knowledge and possible transaction costs.

Although not considered in detail here, a similar argument can be made for the case of storage losses (Hughes and Goesch 2009a). Where marginal storage losses are (approximately locally) constant, specific storage loss adjustments can be relatively easily applied. Marginal storage losses are less likely to vary substantially in the short run, given that individual water users' influence on aggregate storage volumes is likely to be small, unlike in the delivery system where in some cases one water user may contribute to a significant portion of system flow.

It is outside the scope of this paper to examine to what extent delivery losses in real world systems are marginal or whether marginal losses are constant. In the remainder of the paper, for simplicity, we make the assumption that marginal delivery losses and storage losses are constant, which includes the special case where marginal losses are zero.

7 Complex water supply systems

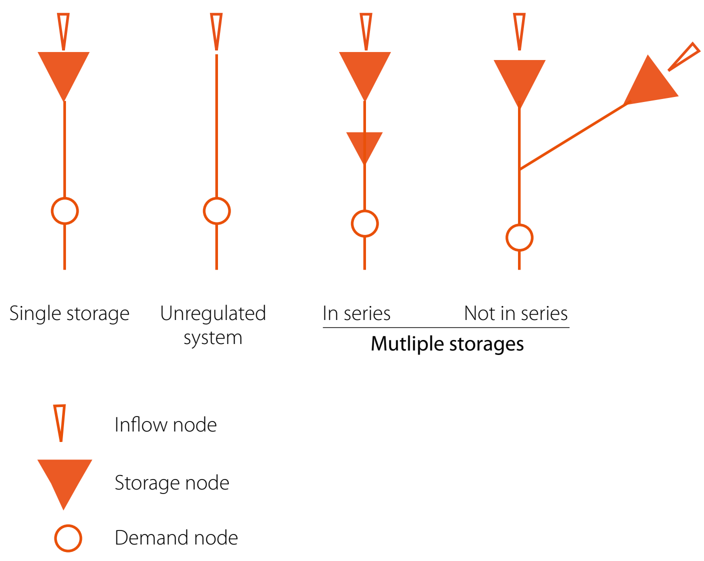
This section considers how a water property rights framework based on the concept of capacity sharing might be applied to a range of different classes of water supply systems. The water supply system is considered in isolation from the broader surface water network, with issues related to management of multiple connected supply systems, including inter-regional water trade, being discussed later.

Single storage

The single storage system is the class of system usually envisaged when capacity sharing is being proposed. In such a system, each water user is allocated a right to a share of the storage, a share of inflows into the storage and a share of any relevant delivery capacity constraints. Marginal storage and delivery losses are applied to stored water and delivered water, respectively. Within the system, water trade involves trade in water at the point of storage (e.g. temporary trade), trade in shares of storage and inflow (e.g. permanent trade), and trade in shares of delivery capacity.

While in figure 3 a single water demand node is shown, in reality there are likely to be multiple water users spatially distributed along the network. To reflect this, delivery constraints and marginal delivery losses should vary with water user location. In practice there may be a degree of approximation/aggregation, where groups of water users are treated as a single demand node facing identical marginal losses and delivery constraints. Such an approach is adopted in St George and MacIntyre Brook in Queensland where a series of zones are defined within the irrigation areas, with higher delivery loss factors applying in zones further from the source (Hughes and Goesch 2009).

3 A range of water supply systems



Unregulated system

The principles outlined above can be transferred adequately to the case of an unregulated water supply system. Pott et al. (2005) and Pott et al. (2009) considered extending the concept of capacity sharing to systems dominated by unregulated flows, referring to this approach as fractional water allocation and capacity sharing (FCA-CS).

In an unregulated system, each user would be allocated a right to a share of system inflow at a defined point and a share of marginal delivery losses. The defined source node would potentially be a stream gauge, upstream of all the significant water users. Such a system could operate over various time scales depending on the variability of the system. Under a continuous system, the maximum pumping/diversion rate for each user would be defined by each user's share of total stream flow, less marginal delivery losses. Under a discrete time system (e.g. hourly, daily etc.), a limit of water use per unit of time would be similarly defined. Under this approach to property rights, the water resources of the system are fully allocated but never over allocated. In particular, the water available to users located near the bottom of the system would be independent of the actions of users at the top of the system. Under this approach, water trade (i.e. temporary trade) would involve trading shares of system inflows at the point of the source node, such that there would be no external effects associated with water trade between different users within the system.

Multiple storages, in series

As noted by Dudley (1990), the case of multiple storages in series, with no significant water users or tributary flows in between, can be adequately approximated as a single storage system. This is the approach taken in Queensland where the major storages, in both St George and MacIntyre Brook, and a number of smaller downstream weirs are aggregated and treated as a single conceptual storage. Water users are allocated a share of this total system storage capacity. The operation of the multiple storage system (transfers of water between storages, to minimise losses for example) would then remain the responsibility of the water management authority.

Multiple storages, not in series

Systems with multiple storages not in series will likely require the definition of separate storage rights. The important distinction is the extent to which the inflows into the storages are independent and imperfectly correlated. For example, the case where multiple storages are in series, but the downstream storage receives significant inflows from an independent tributary, may also require definition of separate property rights.

Consider the multiple storage (not in series) system in figure 3. Water users would be allocated a right to a share of storage capacity in each of the storages and a right to the inflows in each storage. In effect, each user would have two separate water accounts and, therefore, two sources from which water could be obtained. Separate delivery losses, storage losses and delivery capacity constraints would also be defined, specific to the storage/source.

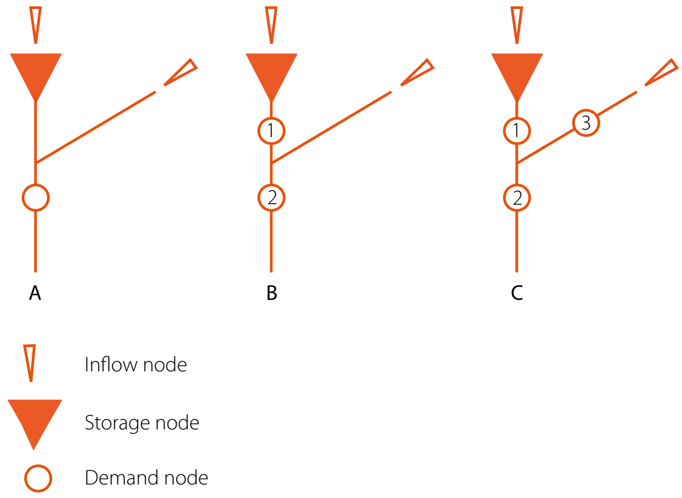
Under such an approach, water users would be collectively responsible for the management of the multiple storage system, including determining distribution of total storage reserves across the two storages and taking into account differences in losses and expected future inflows. Water trade would involve two separate commodities: water in storage 1 and water in storage 2. Given all water users have access to both storages, the market prices of these two commodities would be similar, although they could diverge as a result of differences in storage losses, delivery losses or delivery constraints.

Dudley (1990) suggested that, where the multiple storages have similar characteristics and highly correlated inflows (so no diversification benefits exist), users could each be allocated a share of only one of the storages. However, this suggestion was made in the context of urban water; in the context of rural water systems used primarily for irrigation, this approach is unlikely to be appropriate. This is because rural systems typically involve greater intertemporal variation in water use and storage levels, and greater heterogeneity in water user reliability preferences.

Tributary flows

Figure 4 displays some examples of water supply systems with tributary flows. The same property rights principles discussed above can equally be applied to these types of systems. In system A in figure 4, water users would be allocated a right to a share of storage capacity, a share of inflows into the storage, and a share of flows from the tributary (at a defined source node). As with the case of multiple storages, each of these water sources would also have specific delivery loss factors and delivery constraints.

4 Water supply systems with significant tributaries

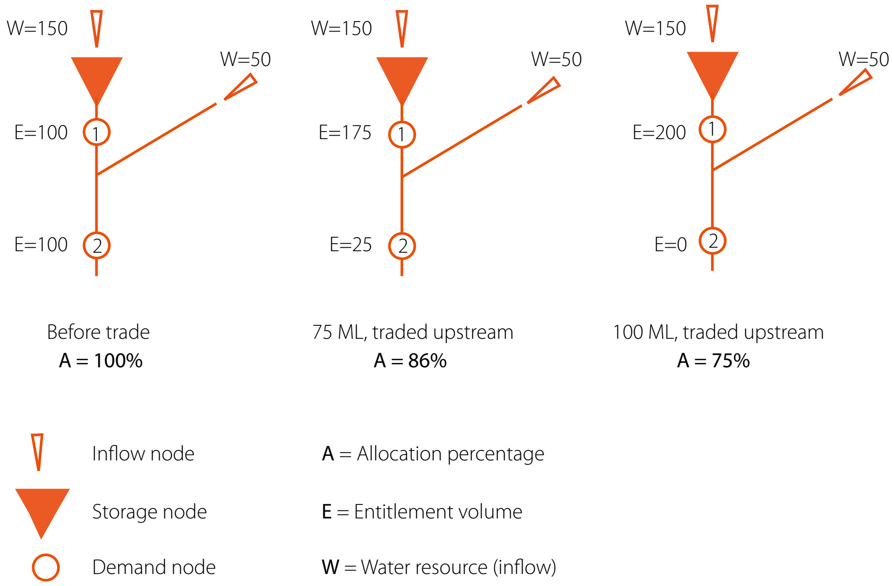


In system B, users at demand node 1 are located upstream of the confluence and so cannot take delivery of water in the unregulated tributary. Water users in this location would be allocated rights in the storage but not to unregulated tributary flows. While tributary flows would be entirely allocated to users at node 2, significant trade in water at the point of storage could still occur between the two demand nodes. This type of property rights framework, by embodying the concept of source tagging, would help to address the external effects that can be associated with water trade in systems with significant tributary flows. This is an issue that has been noted previously by Heaney et al. (2006) and Beare et al. (2005).

A simple static analysis of this situation is shown in figure 5. It is assumed that a single class of water entitlement is defined and water allocation and entitlement trade within the system is unrestricted. Problems arise where significant volumes of water entitlements (or allocations) are traded upstream of the tributary, from node 2 to node 1, specifically where users at node 2 trade more than their effective share of water in storage. Since it is not physically possible to deliver all of this water to users at node 1, a reduction in water allocations for all users becomes necessary. Under these conditions, even those water users who are not directly engaged in water trade may be adversely affected. In contrast, under the property right framework outlined above, users at node 2 could only trade their share of water that is physically in storage to users at node 1.

The property rights framework could equally be applied to systems such as C in figure 4, where there is significant water use occurring on the tributary itself. As discussed in Brennan (2006), physical network constraints prevent direct trade in water between node 1 and node 3. These constraints are embedded within the proposed property rights framework: only nodes that share a hydrological connection can engage in water trade (nodes 1 and 2 can trade water in storage, nodes 2 and 3 can trade in tributary flows). However, as discussed in Brennan (2006), nodes 1 and 3 can, subject to water availability at each source node, engage in an indirect form of trade through trade with node 2.

5 Upstream trade in a system with unregulated flows



SunWater pers. comm. (2008) have proposed a simple approximate approach for dealing with tributary flows, which involves adjusting (increasing) delivery loss factors to reflect availability of tributary flows which supplement storage releases. However, such an approach would only be appropriate where tributary flows are relatively small and constant over time.

General property rights framework

The property rights framework outlined above can be applied more generally for any water supply system involving multiple regulated and unregulated water sources, multiple water demand nodes and multiple delivery capacity constraints. Consider the general water supply system of n water sources, with m less than n regulated water sources, i water demand nodes and d relevant delivery capacity constraints. The key parameters involved in defining and managing (i.e. water accounting) this water property rights system are listed below:

$f_{i,n}\ ,\ 0 \le f_{i,n} \le 1\ ,\ \sum_i f_{i,n} = 1\ \forall\ n$ — User i share of flow in source n

$s_{i,m}\ ,\ 0 \le s_{i,m} \le 1\ ,\ \sum_i s_{i,m} = 1\ \forall\ m$ — User i share of storage capacity in storage m

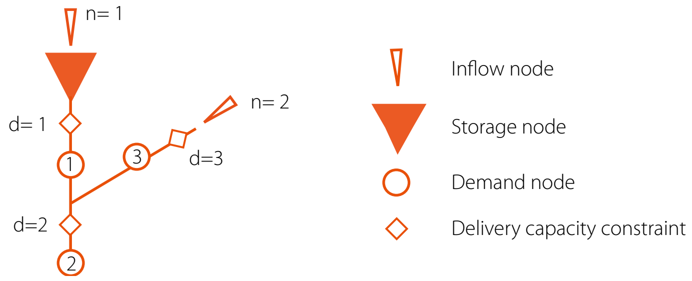
$c_{i,d}\ ,\ 0 \le c_{i,n} \le 1\ ,\ \sum_i c_{i,d} = 1\ \forall\ d$ — User i share of delivery capacity constraint d

$dlf_{i,n}\ ,\ 0 \le dl_{i,n} \le 1$ — User i delivery loss factor for source n

$ic_{d,n}\ ,\ ic = 1\ or\ 0$ — Indicator variable = 1, if water source n, connected to capacity constraint d

An example of this framework is shown in table 1 for the system illustrated in figure 6.

6 Example water supply system



1 Hypothetical parameter values for system C

f	i=1	i=2	i=3
n=1	0.5	0.5	0
n=2	0	0.5	0.5

dlf	i=1	i=2	i=3
n=1	0.2	0.3	1
n=2	1	0.2	0.1

s	i=1	i=2	i=3
m=1	0.5	0.5	0

c	i=1	i=2	i=3
d=1	0.5	0.5	0
d=2	0	1	0
d=3	0	0.5	0.5

ic	n=1	n=2
d=1	1	0
d=2	1	1
d=3	0	1

Note: Shaded cells are fixed hydrological constraints, non-shaded can vary with trade

The above parameters are specified for a fixed point in time. In practice, storage, flow shares and delivery constraint shares may change over time as a result of trade between users. Further delivery loss factors may be specified in a state dependent way (dependent on prevailing weather conditions etc.). The indicator variable *ic* is necessary in systems with tributary flows because multiple water sources may delivery water through the same delivery constraint.

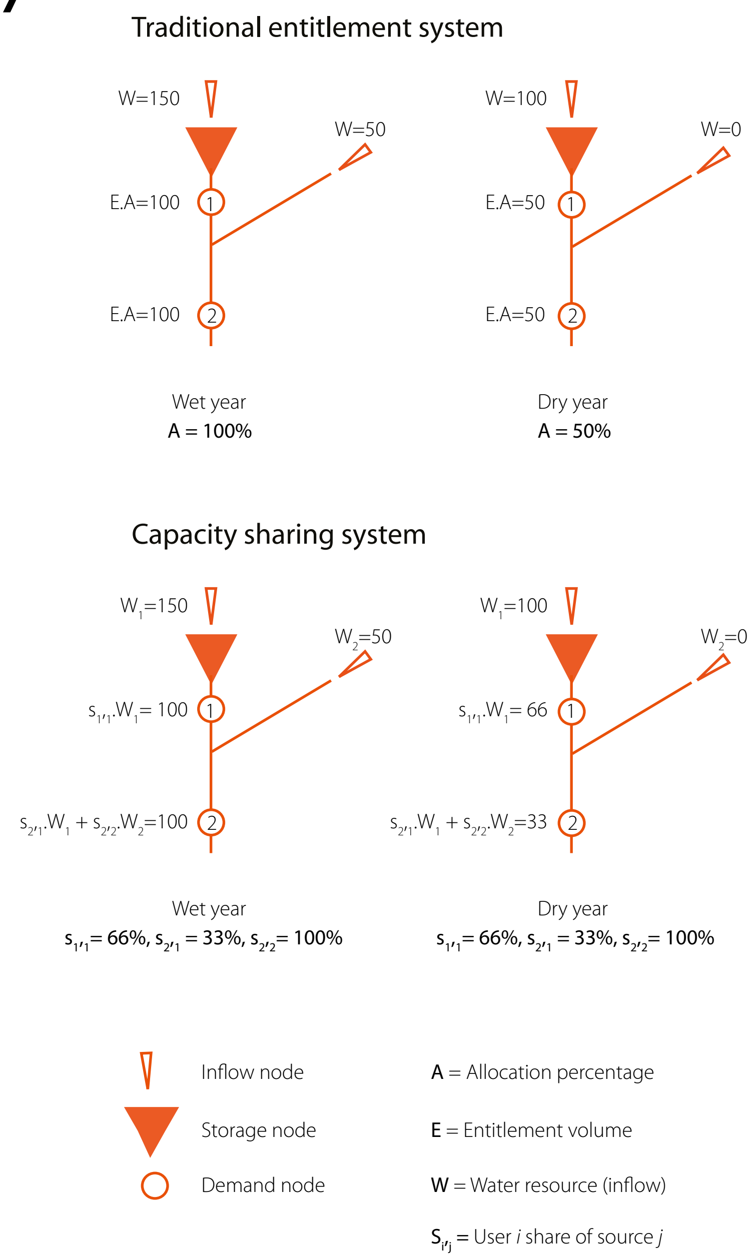
Implementation issues

Implementation of capacity sharing involves a range of practical challenges; many of these are discussed at length in Hughes and Goesch (2009a, 2009b). Some of the challenges specifically associated with complex water supply systems are discussed below.

One important issue is the initialisation of shares: the process of converting existing water entitlements into shares of various water sources. Ideally, newly created bundles of water source shares will provide relatively equivalent claims to water as previous user entitlements. It is important to emphasise that this is a distributional issue and not an efficiency issue. In single storage systems, with a single water entitlement class, this process is less challenging. For example, as in St George and MacIntyre Brook, water users can be allocated a share of system storage and inflows equal to their share of total entitlement volume. However, even in these systems the introduction of marginal delivery losses has the potential to induce some distributional effects, as was observed in MacIntyre Brook (Hughes and Goesch 2009b).

The initialisation process is likely to be more difficult in complicated systems with multiple water sources. In particular, the process is likely to be challenging in systems where different users have access to different subsets of the available water sources. A static example is given in figure 7. Under a capacity sharing system (without trade), user water availability levels can, at best, only match those achieved under the entitlement system in one of the two states. Any (hydrologically feasible) allocation of water between the two users can be achieved as a result of trade, so there are no efficiency implications, but there are distributional implications.

7 The initialisation of property rights in complex supply systems



This simple static framework does not necessarily tell the complete story. For example, where users have the ability to maintain varying levels of storage reserves, this would provide more flexibility, which would potentially allow previous entitlement outcomes to be matched more closely. While a dynamic analysis of the above scenario remains a subject for future research, the point remains that the initialisation of shares is likely to be a more difficult task in complex systems.

One area in which complex systems may involve some additional cost is information or decision-making burdens being shifted to water users. Traditionally, in systems with multiple water sources, much of the decision-making complexity is centrally managed and hidden from water users. Under the approach proposed above water users may be required to actively manage multiple water sources, which could involve some additional information, learning and decision-making costs. In particular, irrigators would need to be able to obtain and interpret information on expected inflows and expected losses for multiple water sources. In contrast, in simple systems capacity sharing is less likely to impose significant additional information costs. For example, Hughes and Goesch (2009b) found no evidence that the adoption of capacity sharing exposed irrigators at St George or MacIntyre Brook to any significant time or information costs.

The potential for information and decision-making costs raises the implementing capacity sharing at an aggregated level, such as the water utility level, water demand node level or for smaller groups of irrigators, which is a possibility regularly put forward by Dudley (Dudley 1992). For example, groups of water users in a similar location with similar water needs could potentially manage a large capacity share cooperatively, or alternatively appoint a manager on their behalf. The appropriate aggregation would then depend, among other things, on relative information costs. As noted by Dudley (1992) it is in this sense that capacity sharing is consistent with the concept of common property as advocated by Quiggin (1988).

Another issue to consider is the effect of this type of property rights system on transaction costs of water trade. It might be argued that with a greater number of different types of water rights there would be more transactions and greater transaction costs. However, as Hughes and Goesch (2009a) noted, greater flexibility to manage water and storage resources may actually act to limit seasonal trade requirements. Further, it might be argued that the incorporation of hydrological constraints into the property rights framework could lower transaction costs. By reducing the potential for external effects associated with trade, less government oversight may be required, which may act to streamline trading processes.

Finally, there is the issue of the timing of water delivery. In regulated systems users would be required to order water, which could operate (as in Queensland) on a daily time scale (Hughes and Goesch 2009b). In an unregulated system, users could potentially extract their share of source inflow in real time (i.e. there need not be a time delay applied), as long as sufficient water is present. In highly variable systems or in times of high water scarcity there might be a case for implementing a system of time delays (for both regulated and unregulated sources), where water extraction would be delayed by the approximate time it takes water to be delivered between source and demand nodes.

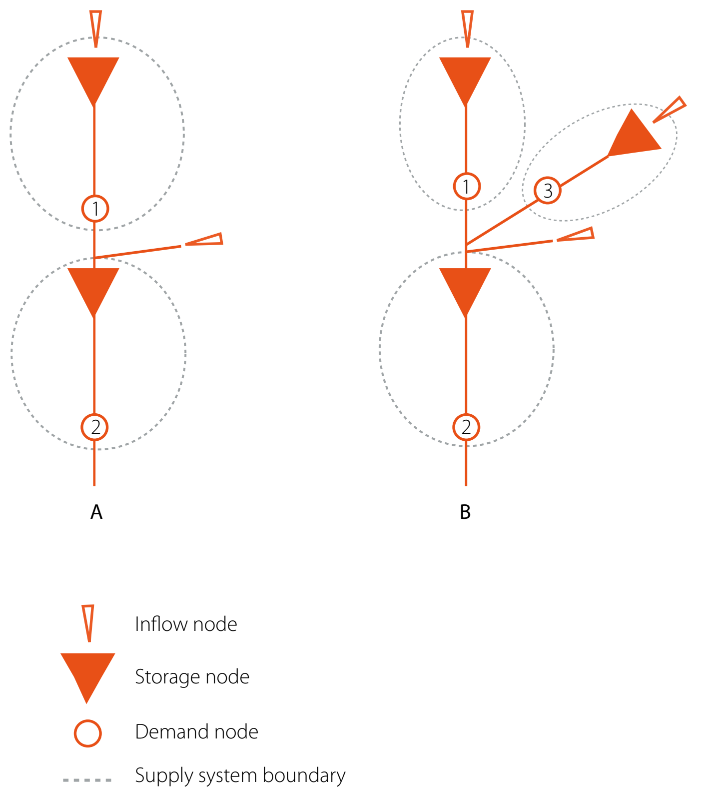
8 Multiple connected water supply systems

So far in this paper individual water supply systems have been considered in isolation from the broader surface water network. Where multiple water supply systems share a hydrological connection this introduces a number of important issues including inter-system water trade and the potential dependency of downstream systems.

Distribution of water resources across connected water supply systems

Water supply systems (such as system 2 in network A of figure 8) may have varying degrees of dependence on upstream systems for inflows. Some systems may receive a large proportion of inflows from independent tributaries, while others may be almost exclusively dependent on receiving outflows from upstream systems. The introduction of capacity sharing based property rights may have significant implications for dependent systems. The South Australian portion of the Murray River is one example of a highly dependent supply system.

8 Multiple connected water supply systems



Under the approach outlined in the previous section, all water resources in a system are fully allocated: no water resources are left for downstream systems. In practice, even a fully allocated system will have some outflows, as a result of return flows, minimum flow requirements or any unallocated tributary flows. A more advanced approach would involve defining explicit rights to these return flows (this is discussed in more detail later). Regardless, a capacity sharing approach to property rights has the potential to advantage upstream systems at the expense of downstream dependent systems.

A potential solution to this problem is to allocate water users in downstream systems rights to inflows in upstream systems. Under a pure capacity sharing approach, individual users in the downstream region would be allocated individual shares of inflows (and potentially storage) in the upstream system in addition to their rights in their own system. A more pragmatic approach would involve defining an aggregate upstream water account that could potentially be held by the water authority responsible for the downstream system. The majority of the inflows into this account could be released into the downstream system. These releases would then be treated as part of the inflows into the downstream system and shared according to downstream water users' inflow shares.

An implication of a capacity sharing approach (pure or pragmatic) is that, following initialisation, any (hydrologically feasible) allocation of water across systems could follow as a result of trade. For example, if delivery losses were especially high in downstream systems, substantial amounts of water could potentially be traded to upstream systems. Ideally, water property rights would adequately reflect in-stream values, such that any environmental implications of trading large volumes of water upstream would be internalised.

The sharing of water resources along the Murray between the states can be considered, at an aggregate level, as an example of a similar capacity sharing arrangement, where effectively South Australia (the downstream dependent system) has a right to a share of flow in the upstream system.

Inter-system water trade

Consider the systems illustrated in figure 8 and assume that within each water supply system, capacity sharing based property rights to water are defined. For network A, downstream trade involves users in system 2 purchasing water at the point of storage in system 1. Unlike within system trade, between system trade involves a change in the stored location of water, which requires physical delivery. Water purchased by users in system 2 must be physically released from storage and delivered downstream. This water can then be credited to the balance of the users' storage accounts, subject to delivery constraints and marginal delivery losses.

This process of adjustment would likely involve net batch processing. Releases would be made on a daily or weekly basis, rather than every time a trade occurs. Net trade volumes would be calculated and appropriate transfers would be made. To avoid double counting there will be a need to ensure that water transferred downstream as a result of trade is not included as part of inflows and is credited only to water purchasers. Also, as long as sufficient water is available in the downstream system, the crediting of user water accounts need not wait for the physical transfer of water from the upstream system.

While water cannot physically be transferred upstream, a form of upstream water trade can be facilitated either through offsetting downstream trades or through trading upstream rights, which allows for net upstream trade. For example, in the pragmatic upstream account approach, where water is traded upstream from system 2 to system 1, the upstream account would be debited and this water would be credited to the purchasing users in system 1. The selling users in system 2 would have their water accounts debited by the same volume, less an adjustment for delivery losses. This water would then be treated as an inflow and shared among system 2 users. Under many conditions, the pragmatic approach would operate as efficiently as a pure approach. Under either approach there is an effective upper bound on upstream trade, which is the point where all upstream water is fully allocated to upstream users.

Similar approaches to inter-system water trade could be applied in more complex configurations such as system B in figure 8, where system 1 could have an account in both upstream systems (1 and 3). This is similar to the case discussed in the previous section. Direct water trade between systems 1 and 3 would not be possible although both systems could engage in trade with system 2.

Regulation of connected water supply systems

Traditional approaches to water management within the Murray-Darling Basin have involved the imposition of limits on the volume of consumptive (e.g. agricultural, industrial and urban) water use or diversions in each supply system, such as the current Basin cap on diversions or the proposed sustainable diversion limits (SDLs). However, a capacity sharing approach to property rights could potentially render limits on water use unnecessary. Under capacity sharing, all users including both environmental and agricultural water users are allocated equivalent rights to water (e.g. shares of inflows and storage). If more water for the environment is desired, this can be achieved within the property rights framework.

A capacity sharing approach potentially offers greater flexibility than a system of use limits. Under capacity sharing, the allocation of water across users, specifically across agricultural and environmental users, can vary across time, across states of nature and across location (potentially as a result of market transactions). A water use limit might be viewed as defining an informal, and therefore non-tradable, environmental water right such that the allocation between the environment and agricultural users is necessarily fixed, at least for the duration of the limit. In practice, centralised setting of long-term volumetric limits is a challenging task involving enormous information requirements. An advantage of a capacity sharing approach is that it may provide greater flexibility for adjustment over time, in response to changes in conditions and the arrival of new information.

In addition, setting a volumetric limit (even a state dependent one) remains a challenging exercise in the presence of extreme variability over seasonal water availability. As noted by Young and McColl (2008a, 2008b), defining agricultural and environmental water rights as proportional shares of available water resources is likely to be a more robust approach in the face of extreme variability and long run climate changes.

However, there may remain some legitimate concerns about abandoning systems of volumetric limits. First, there are a number of aspects of real world hydrological systems that are not incorporated into this proposed property rights approach. These include environmental externalities from water use (e.g. salinity) or in-stream environmental values which might justify the imposition of a limit on water use in a given region. Volumetric limits might then be viewed as a second best approach when property rights are non-exclusive. Second, volumetric limits might be preferred where they can be more easily implemented, at a lower cost and over a shorter time frame, than a major reform of water rights.

Implementation issues

As discussed, one of the more significant implementation issues is the initialisation of user shares. In the context of multiple connected supply systems, a number of more 'macro' level share allocation decisions become apparent. First, there is the initial distribution of water rights across connected supply systems which involves determining the appropriate size of the upstream water accounts. An acceptable transition will likely require that the existing distribution of water across systems, as defined by existing volumetric limits and state sharing agreements, is at least approximately maintained. Similarly, determining the environmental share of water resources that will satisfy the stats quo is likely to be complicated given that current environmental allocations are defined by a range of interacting local, state and federal rules and policies.

Another practical issue will be managing water accounting between water supply systems. Implementing a capacity sharing approach to water rights in each system, and to trade between systems, will require consistent water accounting frameworks in each system and some form of linkage and reconciliation between systems. Ideally, a single water accounting system would be developed for the entire regulated river system across all jurisdictions, which would record water flows and use in each system and transactions (trades) between systems.

9 Some complications: relaxing the assumptions

The property rights framework presented in this paper excludes a range of potentially relevant hydrological realities. The focus has deliberately been placed on incorporating those aspects of hydrological systems that are relatively well understood. However, it is worth considering how some other important hydrological realities might be incorporated into even more advanced approaches to water rights.

Return flows

The proposed property rights framework does not explicitly include return flows, where a proportion of consumed water makes its way back into the water network. Return flows may also impose negative water quality effects (e.g. salinity), although this is not considered here.

Return flows may be of value to downstream water users in the same supply system or could form part of the inflow into downstream supply systems. However, where return flows are not internalised, water users have an incentive to reduce them, potentially to inefficiently low levels, especially for example through investments in water use efficiency where these are subsidised by governments.

Including return flows under a capacity sharing framework might involve allocating water users a right to their return flows at the point of the next downstream source node. For example, a water user in system 1 in figure 8 would have the right to a volume of water in storage in system 2, equivalent to their return flow volume adjusted for delivery losses between their demand node and the downstream storage. This water could then be sold to users in system 2, such that the value of return flows are internalised. There would, however, be some important distributional implications associated with the initial allocation of return flow rights, given that in many cases downstream users currently have implicit rights to upstream return flows.

In-stream values

So far the surface water network has been viewed as an abstract mechanism for water transportation. Within this simplified reality, environmental values are limited to specific environmental assets (located at defined demand nodes) which use water to achieve environmental benefits. In practice, the network itself is an integral part of an environmental system and all water delivery decisions, whether by agricultural, urban or environmental users, have some environmental implications.

Under a capacity sharing property rights framework, an environmental manager could actively manage their share of resources to achieve in-stream environmental benefits. The inclusion of return flow rights could potentially assist an environmental manager to do this. For example, an environmental manager could release water for in-stream value and then receive an inflow credit in the next downstream region, such that the cost of achieving in-stream benefits is limited to the delivery losses between the two source nodes and any water price differential. Equivalently, an environmental manager could subsidise trade into downstream systems to indirectly increase in-stream flows.

However, effectively incorporating the indirect environmental implications (positive and negative) associated with the movement of all non-environmental water over the network is likely to prove difficult in practice. The effect of any individual user on the environmental health of the delivery network is likely to be complex, dependent on both prevailing conditions and the actions of all other users. This issue is another example of 'jointness' in water delivery, which may be difficult to address through decentralised property rights systems.

Given the potential limitations on a property rights approach, additional regulations might be required. The simplest regulatory approach is the imposition of a minimum flow requirement. A minimum flow requirement, in addition to addressing environmental objectives, may also be of value in facilitating water delivery (lowering marginal delivery losses). For example, under a capacity sharing framework, the environmental manager (or the water utility) could have a right to the initial system inflows necessary to satisfy minimum flow requirements, while other water users would have a right to a share of the inflows in excess of this amount. Other more flexible approaches to in-stream flow requirements have also been proposed; for example, Murphy et al. (2009) consider a range of approaches including the possibility of a tradable minimum flow requirement right.

Groundwater and water intercepting land use activities

As previously discussed, two other important features are groundwater (and surface-groundwater connectivity) and run-off intercepting land use activities, such as forestry, farm dams etc. These two features are not discussed here except to note that a necessary prerequisite for their inclusion is adequate scientific knowledge and on the ground information (e.g. metering of ground water use and monitoring of land use activities).

10 Alternatives to a decentralised property rights approach

When water property rights are well-defined (exclusive), decentralised markets transactions are likely to achieve an efficient allocation of water. However, as has been discussed, there may be some practical constraints to the adoption of more well-defined water rights.

First, given the limits of scientific understanding, limitations on water information (e.g. stream gauging and user metering) and the costs of obtaining this information there may be a need for some approximation in the definition of water property rights. Second, is the issue of 'jointness' in water delivery, storage and use. As discussed, water storages and water delivery systems are congestible goods, which are non-rival below the point of congestion. While capacity sharing based property rights can significantly improve the exclusiveness of rights, some aspects of jointness may remain, including variation of marginal delivery losses (and to a lesser extent storage losses), internal spills (Hughes and Goesch 2009a, 2009b) and in-stream values. Further, there may also be concerns that, even with a well-defined (exclusive) set of water property rights, the transaction costs in these markets would be too high for an efficient allocation of water to be achieved.

Given these limitations, in practice, a mixed approach to water allocation is likely to be required, involving a range of government regulation and potentially common property approaches (Quiggin 2001) to compliment market based allocation. Another approach that may also act to address some of the limitations of decentralised markets is the 'smart markets' approach. Both of these approaches are considered further below.

A mixed approach

The present approach to water allocation in the Murray-Darling Basin can be viewed as an example of a mixed approach. User level water property rights exist, but are incompletely defined (non-exclusive). Markets play an important role in allocation but are supplemented by a range of government regulations. Among a range of initiatives, governments exert an influence over water allocation through management of storages and restriction on water trades. As noted by Bell and Quiggin (2008), in addition to specific regulations, governments have an important 'meta governance' role in facilitating the operation of property right and market systems.

It is worth considering the issue of trade restrictions in more detail. In the case of water trade, governments place a range of restrictions on trade between locations (e.g. between defined trading zones) including total bans, volumetric limits or simply discretionary approval of individual trades. Such an approach may involve governments rejecting approval of water trades between locations where the external effects on other users are deemed to be above some threshold level. While a prescriptive regulatory approach to trade approvals may be justified where property rights are non-exclusive, such an approach is likely to involve some efficiency cost. Where possible (and cost effective), internalising some of the external effects associated with water trade between locations, through improved property rights, may offer some efficiency benefits.

Regardless of any future reforms of water property rights, the allocation of water will likely require substantial government involvement both through regulation and 'meta governance'. However, reforms to water property rights, such as capacity sharing, may lessen the need for some types of government intervention especially related to the intertemporal management storages and trade restrictions.

'Smart markets'

'Smart markets' (McCabe et al. 1989, 1991) are an approach commonly applied to the allocation of electricity and natural gas. The smart markets approach involves the development of a large central optimisation model that contains all of the constraints of a given network: all of the demand and source nodes, the branches between them and their associated capacities and losses. Also embedded within this model would be the preferences of market participants: willingness to pay and willingness to accept schedules of users, periodically submitted to the model. The model can then be solved at regular intervals for the optimal market clearing outcomes. A smart markets approach is used to manage the Australian National Electricity Market (NEM) at a wholesale level.

A centralised smart market approach might be advocated where transaction costs are deemed prohibitively high because of the complexity of the physical network constraints. Another potential advantage of such an approach is that, since physical constraints and market outcomes are modelled simultaneously, it may be more suited to dealing with some of the aspects of 'jointness' in water delivery which are more difficult to incorporate within decentralised property rights. While there has been limited consideration of applying the smart market approach to water to date, such an approach has been advocated in Australia by Biggar (2008). In the United States there has been some research on the feasibility of smart markets for water, including some experimental studies (see Murphy et al. 2000, 2009). The smart markets approach remains a potential subject for future research.

11 Conclusions

Achieving an efficient allocation of water through decentralised markets requires well-defined water property rights which accurately reflect the physical realities of water supply systems. In this paper, a more realistic and therefore more exclusive water property rights system is proposed, based on the concept of capacity sharing, as advocated by Dudley and Musgrave (1988). The concept of capacity sharing should be viewed simply, as the embodiment of the idea that water rights should reflect physical realities. Capacity sharing is essentially 'unbundling' taken to its logical conclusion where distinct water, storage and delivery rights are defined.

A common argument against the capacity sharing approach is that it may not be feasible in more complex river systems. However, the general concepts of capacity sharing are not specific to simple systems and can be generalised to more complex systems with multiple storages, tributary flows and multiple water user locations. A capacity sharing approach, by embodying the concept of source tagging, has a lot to offer in complex water supply systems, in maximising allocative efficiency and minimising external effects associated with water trade.

While complex water supply systems do not place any significant barriers on the design of more exclusive water property rights systems, they do introduce a range of practical implementation issues. In particular, the initialisation process, which is the conversion of existing water entitlements into shares of flow in various water sources, is likely to be more challenging. Further, a capacity sharing approach to water rights could, in more complex systems, impose a greater decision-making burden on water users, relative to existing approaches.

Regardless of the complexity of supply systems, there are some aspects of water use and delivery that remain, because of their 'joint' nature, less amenable to inclusion in private property rights, such as delivery losses, in-stream values and internal spills. These aspects of jointness represent a significant challenge for decentralised systems of water property rights in general. An alternative to decentralised markets, is the 'smart markets' approach, although there is still much research to be done on applying these techniques to water.

Property rights reform remains one of the few long-term policy options for improving the social values derived from water resources. As water scarcity continues to increase and as scientific knowledge, water metering and accounting improve, more precise approaches to water property rights, such as capacity sharing, are likely to become increasingly attractive.

References

Alaouze, C 1991, 'Intertemporal water transfers and drought', *Australian Economic Papers*, Vol. 30(56), pp. 114-127.

Beare, S and Heaney, A 2002, 'Externalities and water trading in the Murray-Darling Basin Australia', ABARE conference paper 02.19 delivered at the Australian Conference of Economists, Adelaide, September.

Beare, S and Newby, J 2005, 'Incomplete markets, excluded goods and natural resource management', Annual Conference of the Australian Agricultural and Resource Economics Society, 9-11 February, Coffs Harbour.

Beare, S, Goesch, T, Bosch, C and Gooday, P 2005, *Water rights and trade: the role of exchange rates and tagging*, unpublished ABARE eReport, January.

Bell, S and Quiggin, J 2008, 'The limits of markets: the politics of water management in rural Australia', *Environmental politics*, Vol 17, no. 5, pp. 712-729.

Biggar, D (Australian Competition and Consumer Commission) 2008, 'Integrating water network physical limits into water trading, lessons from liberalized electricity markets', Monash University, Water trading - Future Directions forum, 18 November. URL: http://www.law.monash.edu.au/regstudies/water.trading.forum.biggar.pdf

Brennan, D 2006, 'Water policy reform in Australia: lessons from the Victorian seasonal water market', *Australian Journal of Agricultural and Resource Economics*, Vol. 60, pp. 403-423.

Brennan, D 2008, 'Missing markets for storage and the potential economic cost of expanding the spatial scope of water trade', *The Australian Journal of Agricultural and Resource Economics*, Vol. 52, No. 4, pp. 471-485.

Brennan, D and Scoccimarro, M 1999, 'Issues in defining property rights to improve Australian water markets', *The Australian Journal of Agricultural and Resource Economics*, Vol 43, pp. 69-89.

Crase, L, Pagan, P and Dollery, B 2004, 'Water markets as a vehicle for reforming water resource allocation in the Murray-Darling Basin of Australia', *Water resources research*, Vol. 40.

Demsetz, H 1967, 'Toward a theory of property rights', *The American Economic Review*, Vol 57, No. 2, Papers and proceedings of the 79th annual meeting of the American Economic Association, pp. 347-359.

Doertenbach, D 1998, 'Practical experiences with capacity sharing in the Mazowe river catchment', Zimbabwe, Mazowe Valley Catchment Development. Unpublished paper. Email: waterman@africaonline.co.zw

Dudley, N 1988, 'A single decision maker approach to irrigation reservoir and farm management decision making', *Water Resources Research*, Vol 24, No. 5, pp. 633-640.

Dudley, N 1990a, 'Urban capacity sharing: an innovative property right for maturing water economies', *Natural Resources Journal*, Vol. 30, No. 3, pp. 381-402.

Dudley, N 1990b, 'Alternative institutional arrangements for water supply probabilities and transfers', in Transferability of water entitlements seminar and workshop, University of New England Centre for Water Policy Research.

Dudley, N 1992a, 'Water allocation by markets, common property and capacity sharing: companions or competitors?', *Natural Resources Journal*, Vol. 32, pp. 757-778.

Dudley, N and Musgrave, W 1988, 'Capacity sharing of Water Reservoirs', *Water Resources Research*, Vol 24, pp. 649-658.

Goesch, T and Hafi, A 2006, *Conjunctive Water Management – Economic Issues and Policy Options*, ABARE research report 06.19, prepared for the Natural Resource Management Division, Australian Government Department of Agriculture, Fisheries and Forestry, Canberra, November.

Griffin, R 2006, 'Achieving water use efficiency in irrigation districts', *Journal of water resources planning and management*, Vol 132, No. 6, pp. 434-442.

Hafi, A, Klijn, N and Kemp, A 2001, 'Efficient pricing and allocation of irrigation water: a model of the Murrumbidgee irrigation area', 45th Annual Conference of the Australian Agricultural and Resource Economics Society, Adelaide 23-25 January.

Heaney, A and Beare, S 2001, 'Water trade and irrigation, defining property rights to return flows', *Australian commodities*, vol. 8 no. 2, pp. 339-48.

Heaney, A, Dwyer, G, Beare, S, Peterson, D and Pechey, L 2006, 'Third party effects of water trading and potential policy responses', *The Australian Journal of Agricultural and Resource Economics*, Vol. 50. pp 277-293.

Hughes, N and Goesch, T 2009a, *Management of irrigation water storages: carryover rights and capacity sharing*, ABARE research report 09.10.

Hughes, N and Goesch, T 2009b, *Capacity sharing in the St George and MacIntyre Brook irrigation schemes in southern Queensland*, ABARE research report 09.12.

Lecler, N 2004, 'Fractional water allocation and capacity sharing/water banking', *Proceedings of the South African Sugar Technologists' Association*, Vol. 78, pp. 245–250.

Murphy, J, Dinar, A, Howitt, R, Rassenti, S and Smith, V 2000, 'The Design of "Smart" Water Market Institutions Using Laboratory Experiments', *Environmental and Resource Economics* 17: 375-394, 2000.

Murphy, J, Dinar, A, Howitt, R, Rassenti, S, Smith, V and Weinberg, M 2009, 'The design of water markets when instream flows have value', *Journal of Environmental Management*, Vol. 90, pp. 1089-1096.

NWC 2004, *Intergovernmental agreement on a national water initiative*, URL: http://www.nwc.gov.au/resources/documents/Intergovernmental-Agreement-on-a-national-water-initiative.pdf

Pott, A, Hallowes, J, Backeberg, G and Dockel, M 2009, 'The challenge of water conservation and water demand management for irrigated agriculture in South Africa', *Water International*, Vol. 34, pp. 313-324.

Pott, A, Hallowes, J, Mtshali, S, Mbokazi, S, van Rooyen, M, Clulow, A and Everson, C 2005, *The development of a computerised system for auditing real time or historical water use from large reservoirs in order to promote the efficiency of water use*, Water Research Commission, Report No. 1300/1/05, Pretoria, South Africa.

Quiggin, J 1988, 'Private and common property rights in the economics of the environment', *Journal of economic issues*, Vol. 22, No. 4, pp. 1071-1087.

Quiggin, J 2001, 'Environmental economics and the Murray-Darling river system', *The Australian Journal of Agricultural and Resource Economics,* Vol 45, No. 1, pp. 67-94.

Randall, A 1981, 'Property entitlements and pricing polices for a maturing water economy', *The Australian Journal of agricultural Economics*, Vol. 25, No. 3, pp. 195-220.

Randall, A 1983, 'The problem of market failure', *Natural Resources Journal*, Vol 23, pp. 131- 148.

Viljoen, M, Dudley, N, Gakpo, E and Mahlaha, J 2004, E*ffective local management of water resources with reference to the Middle Orange River*, Water Research Commission, Report No. 1134/1/04, Pretoria, South Africa.

Young, M and McColl, J 2003a, 'Robust reform. The case for a new water entitlement system for Australia', *Australian Economic Review*, Vol 36, No. 2, pp. 225-34.

Young, M and McColl, J 2003b, 'Robust separation: A search for a generic framework to simplify registration and trading of interests in natural resources', *Agricultural Science* Vol 15, No. 1, pp. 17-22.

Young, M and McColl, J 2005, 'Defining tradable water entitlements and allocations: A robust system', Canadian *Water Resources Journal*, Vol 30, No 1. pp. 65-72.

Young, M and McColl, J 2008, *A Future-Proofed Basin*, The University of Adelaide, Adelaide.

Young, M and McColl, J 2008b, 'A sustainable cap: what might it look like?', *Droplet No. 12*, http://www.myoung.net.au/water/droplets/Droplet_12_Sustainable_Cap.doc

Young, M and McColl, J 2009, 'Double trouble: the importance of accounting for defining water entitlements consistent with hydrological realities', *The Australian Journal of Agricultural and Resource Economics*, Vol. 53, Issue 1, pp. 19-35.