Potential approaches to the management of third-party impacts from groundwater transfers

Short title: Managing externalities from groundwater trading

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Abstract

Groundwater extraction can have varied and diffuse effects. Negative external effects may include costs imposed on other groundwater users and on surrounding ecosystems. Environmental damages are commonly not reflected in market transactions. Groundwater transfers have the potential to cause spatial redistribution, concentration, and qualitative transformation of the impacts from pumping. An economically and environmentally sound groundwater transfer scheme would ensure that marginal costs from trades do not exceed marginal benefits, accounting for all third-party impacts, including those of a non-monetary nature as well as delayed effects.

This paper proposes a menu of possible management strategies that would help preclude unacceptable impacts by restricting transfers with certain attributes, ideally ensuring that permitted transfers are at least welfare-neutral. Management tools would require that transfers limit or reduce environmental impacts, and provide for the compensation of financial impacts. Three management tools are described.

While these tools can limit impacts from a given level of extraction, they cannot substitute for sustainable overall withdrawal limits. Careful implementation of transfer limits and exchange rates, and the strategic use of management area boundaries, may enable a transfer system to restrict negative externalities mainly to monetary costs. Provision for compensation of these costs could be built in to the system.

Keywords

Water markets; institutions; externalities; wetlands; Australia.

1 Introduction

Water trading is widely viewed as a mechanism for the efficient management of water resources in cases where supplies are constrained and subject to competing demands. While water trading alone should neither be considered a panacea, nor be solely relied upon to solve large scale problems of degradation through overuse, it represents a useful and potentially effective management tool. The literature on water markets is now extensive although very much focused on surface water transfers. Readers are referred to Hartman and Seastone (1965), Vaux and Howitt (1984), Bauer (2004), and Garrick et al. (2009), and, for a definitive exposition on "the economic conception of water" underpinning water markets, to Hanemann (2006). The aims of this paper are to identify key challenges to designing an economically and environmentally robust scheme for the management of groundwater transfers, and to examine possible strategies for delivering such a scheme.

There are some basic institutional requirements for an operative program of water transfers. For one, “[m]etering of use is an essential part of a groundwater trading environment” (NRMSC 2002, p. 10). The authors acknowledge that metering, monitoring, and enforcement of groundwater use are weak or non-existent in many cases, precluding a highly effective transfer scheme. In such instances the implementation of transfers is by no means the most urgent of management considerations. There are other cases, however, in which groundwater use is more controlled. In some of these, groundwater trading occurs (or is permitted) to various extents; in others, usage may be sufficiently controlled for transfers to be feasible. Thompson et al. (2009) examine the potential for a cap-and-trade scheme to reduce the economic cost of reductions to overall extraction levels in the Nebraska Republican River Basin case. Blomquist describes groundwater management institutions in Los Angeles County, California (USA), noting that, by 1965, “water users in [the Central and West Basins] had enforceable rights to specific quantities of water, which could be (and extensively have been) transferred” (1994, p. 15). Groundwater trading in the Lower Murrumbidgee region of New South Wales, Australia, began in 1987 (Hamilton and Smithson 2010). In Goulburn-Murray Water's jurisdiction (much of the state of Victoria, Australia), transferred groundwater volumes increased “from 2.3 GL in 2005/2006 to 12.3 GL in 2008/2009” (Ridges et al. 2010, p. 1). In the ten years to 2010, trading of groundwater allocations increased “substantially from 2%–

5% to around 10%–20% of total use in some groundwater management units” in Australia's southern Murray–Darling Basin (NWC 2010, p. 96). Finally, notwithstanding its weaknesses regarding monitoring and enforcement, groundwater transfers are currently possible in the Gnangara case in Western Australia described below (Skurray et al. 2011).

While market-based (or market-like) groundwater transfers can offer benefits, they also present potential problems. In considering the implementation of market-based principles, this paper assesses some potential tools for the management of third-party impacts of groundwater transfers. The following potential problems, in particular, are addressed:

- redistribution – transfers can cause the spatial and temporal redistribution of the impacts of groundwater extraction;
- concentration – groundwater transfers can cause the spatial concentration of extraction, thus potentially concentrating and compounding its impacts at particular locations;
- transformation – impacts of groundwater extraction may differ in their nature and extent between the original and newly-transferred locations;
- uncertainty – negative effects from groundwater transfers may be uncertain.

Ideally, a management system for groundwater transfers would provide that marginal benefits of transfers are at least as great as their marginal costs, taking into account all third-party impacts including those of a non-monetary nature as well as delayed effects. Thus, important questions are:

- how could management rules ensure that all exchanges result in improved (or, at worst, constant) overall welfare?
- how closely could this ideal be approached, and by what means?
- how might a combination of sustainable extraction limits, and management tools such as transfer limits, exchange rates, and the strategic use of management area boundaries enable managers to address these problems?

The management question addressed here is not whether impacts would be acceptable. Rather the authors address the incorporation into the management system of the ideas that some impacts may be unacceptable and disallowed structurally, and that allowable impacts should be paid for within the system. A design goal is to incorporate these rules so as to ensure (within reasonable limits) that a market or transfer system could operate safely and with a minimum of administrative oversight and intervention. Users can decide whether the gains from permitted transfers outweigh the costs they are required to bear. A goal of this paper is to address methods by which this could be achieved.

1.1 Groundwater transfers

In addition to the prominence of surface water trading in the Australian policy context (e.g., Crase 2008), groundwater trading may be one appropriate management policy under conditions of water scarcity, if certain challenges can satisfactorily be met. Under conditions of groundwater scarcity, trading may offer two primary benefits:

- trading can facilitate the adjustment by groundwater users to new, lower, allocation levels; and
- by rendering more transparent the opportunity cost of a scarce resource, trading encourages users to pursue more highly valued uses of it, thus facilitating its reallocation (e.g., see Colby 1996). (This attribute has particular potential to cause the concentration mentioned earlier; highly profitable activities may exhibit much higher willingness to pay for marginal water than other users.)

The value of water in use varies across users and usage types. To different users, the value of an additional (or marginal) unit of water, or the opportunity cost of forgoing it, will vary. This heterogeneity in private valuations is the source of the willingness of “those needing additional water [to] bid supplies away from current right holders” (Colby 1996, p. 212). In this way, economic efficiency may be enhanced (as long as overall social benefit is increased by the change of use); the allocation of resources is thus seen by economists to move closer to an efficient state.

Groundwater transfers or trades are exchanges of the right to extract water, rather than of water itself. While the same is true in some surface water contexts (transfers along a given river, for example) it is true of groundwater transfers generally. In the surface water context, water can be conveyed between buyer and seller using canals, pipelines, or rivers; only in the case of downstream-to-upstream transfers along a river do the effects of reduced water levels at the buying location become a consideration. It is, however, a general consequence of groundwater transfers that the spatial distribution of groundwater extraction points would be altered. Apart from cases in which aquifers are highly transmissive, groundwater transfers can usefully be thought of as exchanges of the impacts of groundwater pumping at one location for those at another. The redistribution, concentration, and transformation of impacts due to transfers require specific attention.

Studies of groundwater transfers that examine the range of potential impact types are relatively uncommon, although several have addressed subsets of impacts. Gohar and Ward (2010), for example, are explicit that their analysis incorporates “no treatment of hydroelectric, urban, or environmental values”. Skurray et al. 2012 provide further examples.

The paper is organised as follows. The following section describes third-party impacts of groundwater extraction, introduces a case-study, and discusses socially beneficial groundwater transfers and some of their information requirements. The subsequent section describes and discusses a range of possible management approaches that could be used to limit the environmental impacts from groundwater transfers. Concluding remarks follow.

2 Third-party impacts and groundwater transfers

The wide range of impacts from groundwater extraction, and their potentially wide spatial extent, mean that their costs may be born by an equally wide range of third parties. Such impacts require management attention whether or not groundwater transfers are occurring.

Costs or benefits imposed on participants in an activity or transaction are referred to as 'private' costs and benefits. Self-imposed increases in water-table depth, for example, are private costs to the water user. Costs or benefits imposed on parties other than those directly involved are referred to as 'external' costs or benefits, or 'externalities'. Perhaps the simplest and most readily quantifiable of these external impacts are increased pumping costs imposed on neighbouring groundwater users. A neighbour of a user whose usage increases may suffer a disproportional increase in pumping costs. Increases in pumping costs have a non-linear relationship with depth to groundwater. Provencher and Burt (1993) address the pumping cost, stock, and risk externalities from the extraction of groundwater in common property situations. Brozović et al. (2010) examine the differences between spatially explicit and single-cell models for predicting the groundwater pumping-cost externality.

Environmental damages are third-party impacts in which the third party is not an individual. Further, damages suffered by non-humans are not amenable to monetary compensation. Where financial compensation is possible, it may nonetheless be practically and/or theoretically difficult to 'monetise' the relevant damages (e.g., because of high transaction costs of identifying and quantifying adverse impacts, and/or due to their inherently non-monetary nature).

Environmental impacts of excessive groundwater withdrawal include the drying of wetlands, springs, and lakes. Pumping from the Edwards Aquifer in Texas, for example, also has major impacts on spring discharges (McCarl et al. 1999). The Edwards Aquifer provides habitat for endangered species in the Comal and San Marcos springs - the largest in the southwestern U.S. - and these springs in turn provide streamflow to the Guadalupe River (Votteler 1998). Danielopol (2003) describes a wide range of anthropogenic impacts on groundwater and groundwater-dependent ecosystems (GDEs), and Brown et al. (2009) detail threats to groundwater-dependent biodiversity in Oregon. Groundwater extraction can cause the depletion of baseflow to streams and rivers, potentially threatening the reliability of surface water supplies (Sophocleous 2002) or causing the cessation of baseflow altogether and the conversion of a gaining stream to a losing stream (Evans 2007). Another impact of groundwater withdrawals on biodiversity is that on stygofauna. The Yanchep Caves, north of Perth in Western Australia, contain unique groundwater-dependent ecosystems and rely on the Gnangara groundwater system (see below). Groundwater levels at the caves have been declining since 1969 (as have water levels elsewhere in the Gnangara system) and this has “increased the stress on the cave fauna since the mid 1990s” (Yesertener 2006, p. 2). Many springs, creeks, wetlands, and caves in Australia that are at risk from declining water levels due to pumping (including the

Yanchep Caves) hold Aboriginal cultural values (e.g., see McDonald et al. 2008 regarding the Swan Coastal Plain in Western Australia). (See Grabiel (2006) for another example of impacts of groundwater extraction on native peoples.) Land subsidence is a dramatic potential effect of groundwater withdrawal from artesian aquifers. Subsidence of 9 m was recorded in California's San Joaquin Valley between 1925 and 1977. Earth fissures, and subsidence of 2.3 m, due to “large-scale withdrawal of ground water and the resultant water-level declines” in south-central Arizona were described by Schumann and Poland in 1970 (p. 300). Coastal aquifers also face the serious threat of seawater intrusion resulting from excessive groundwater extraction; the case of the Los Angeles Coastal Plain is described by Blomquist (1994) and that of the Batinah coastal area of Oman by Zekri (2008). Glennon (2007) provides additional examples of several of the impacts described here.

While not usually an effect of groundwater over-extraction itself, water quality impacts must also be considered. As extraction points draw water from deeper within aquifers, quality often naturally declines; drawdown has quality ramifications from this fact alone. The overriding concern, however, arises from the pollutants added to water during or as a result of human uses. These include pesticides and other toxins, as well as other chemicals used in agriculture, such as nitrogen fertilisers. Further, for the Gnangara case, Appleyard and Cook (2009) present evidence that groundwater withdrawals are having a direct impact on water quality, with declining water-tables contributing to groundwater acidification. Quality impacts are susceptible to uncertainty as well as to the three operations described above (redistribution, concentration, and transformation) just as are quantity impacts.

There may, of course, be increased social value to a new location of use – positive externalities – just as there might be negative ones. For example, moving extraction away from a sensitive area of high environmental value may yield external benefits that greatly outweigh the increased pumping costs to users near the new location of extraction. Transfers could therefore be used to help relieve some of the environmental issues around sensitive areas. Without transfers, usage patterns may be 'locked'. Allowing transfers to shift groundwater extraction away from environmentally sensitive areas could provide an acceptable way out of unsustainable usage patterns for both water users and managers. These transfers could be promoted by an exchange rate or other instruments, as discussed below.

External costs of present-day groundwater use can also be subject to time lags, being imposed at significantly distant future times, particularly in larger, less transmissive systems. The depletion of future groundwater stocks by present-day over-use can result in increased future pumping costs. Aquifer storage capacities can be permanently reduced, imposing substantial economic costs. (Ostrom calculated the replacement value of the storage capacity alone in the case of the West Basin aquifer in the Los Angeles area as around $3.01 billion (1990, p. 106).) Where the economic valuation of future impacts involves the use of discount rates, potentially serious future outcomes may be discounted to the extent that they have little influence on present-day decisions. (This depends greatly, of course, on the discount rate chosen.) As their prediction and, in many cases their valuation, may be considered far from trivial tasks, the limitation of some types of negative externalities may well be the prudent, precautionary choice. By restricting overall consumption to sustainable levels, inter-temporal effects can be limited, as impacts gradually dissipate due to recharge and sub-surface flows.

As the term sustainable yield may be interpreted in different ways depending upon the audience, there is a need to be explicit about the meaning and intention of the term as used in this paper. The concept of sustainable yield is used throughout the paper on the basis that this is the amount of water that can be extracted over time without “compromis[ing] key environmental assets, or ecosystem functions and the productive base of the resource” (NWI 2004, p. 29). (The National Water Initiative is defining, here, what it terms the "environmentally sustainable level of extraction" (2004, p. 29).) While the authors do not equate sustainable yield with net recharge, they recognise that the two concepts are not unrelated. Sophocleous (2005) observes that the “long-term sustainability of groundwater resources” requires that “what is taken out of the aquifer should not be more than what goes in, with provisions made for ecosystem requirements [...] thus ensuring that future generations have access to adequate amounts of clean groundwater” (p. 364). Readers are also referred to Norgaard for a wider view: “[w]hen the economy is operating below the sustainability criterion, current generations are consuming ecosystem services at a rate that is depleting natural capital. Above the sustainability criterion, investments are being made in natural capital" (2010, p. 1223). The term sustainable yield is used here as a convenient means of representing these concepts.

2.1 Case study: Gnangara groundwater system

Perth, the capital city of Western Australia, relies on the Gnangara groundwater system for a majority of its public water supply. The system supports wetlands, native flora and fauna, and a range of economic activities. The Gnangara groundwater system underlies an area of approximately 2,200 square kilometres (Department of Water (DoW) 2009). It extends from the Swan River in the south, almost to Guilderton around 90 kilometres to the north, and eastwards from the coast for roughly 40 kilometres (see Figure 5.1). It consists of several aquifer layers. The superficial aquifer (also known as the Gnangara Mound) is the source of around 70% of the groundwater extracted from the system (DoW 2009); the Mirrabooka aquifer is semi-confined, and the Leederville and Yarragadee aquifers are confined. There is a range of soil types across the area of Figure 5.1 (to some degree reflected in the existing groundwater area boundaries). At the superficial aquifer level, the areas depicted in Figure 5.1 are hydraulically connected. In the Swan groundwater area on the eastern edge of the system, the superficial aquifer is largely absent, and extraction is from the Leederville aquifer.

Estimated total withdrawal from the system was 321 gigalitres (GL) in 2009 (DoW 2009). Approximately 60% of total extraction is for self-supplied use (including irrigated agriculture) with the remaining 40% used in urban water supply (De Silva 2009). The Water Corporation's groundwater extraction – for supply to the Perth metropolitan area – increased from approximately 18 GL in 1976 to approximately 142 GL in 2008 (GCC 2009, p. 23). Current rates of per-capita water consumption in the area are "amongst the highest in the world" (Appleyard and Cook 2009, p. 587).

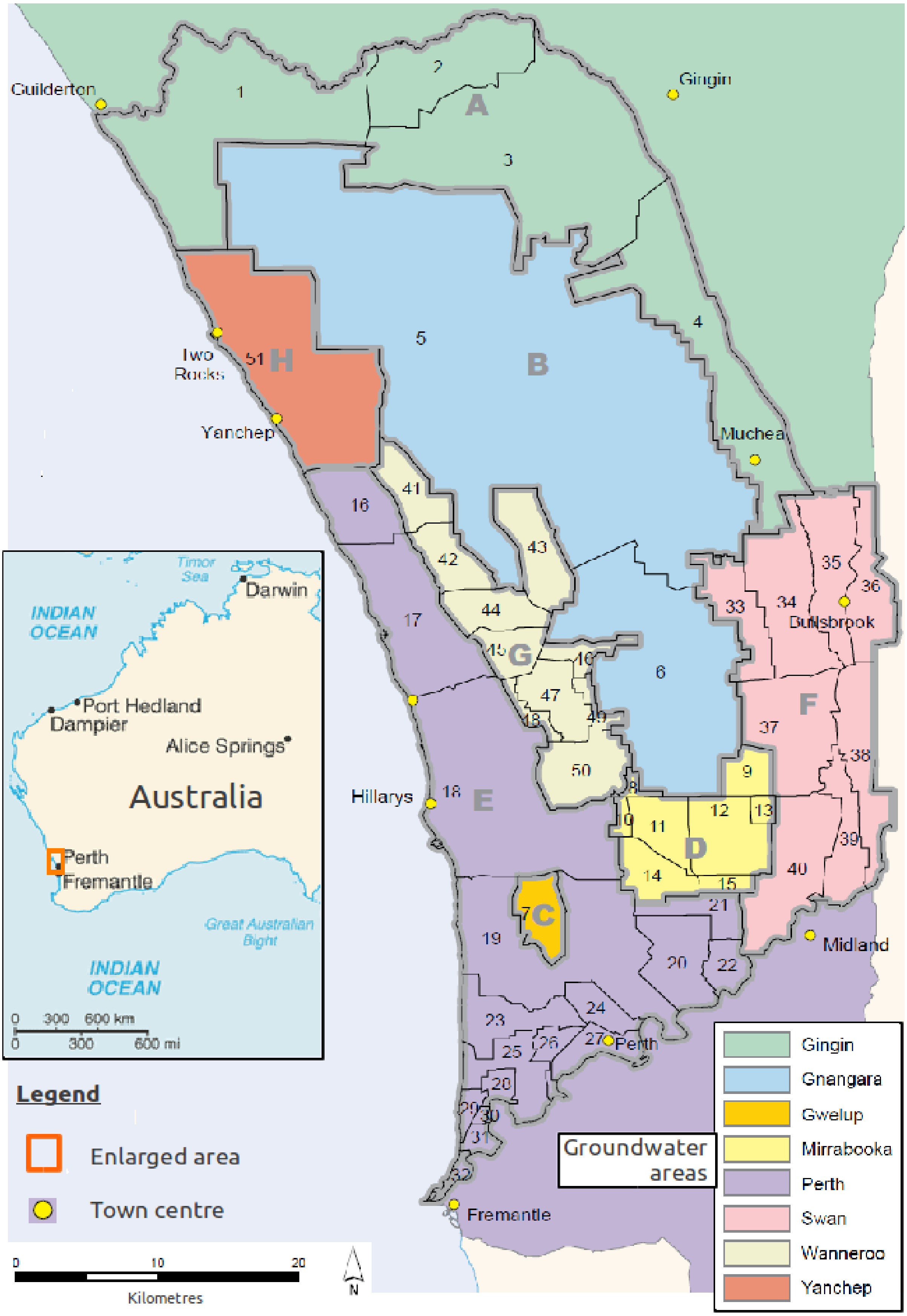

Figure 2.1: Groundwater areas and sub-areas in the Gnangara system, Western Australia. Adapted from DoW 2009, p. 40. Reproduced with permission.

The increasing withdrawals from the Gnangara system have caused water-table decline. Reduced rainfall and maturing pine plantations have also contributed. "Declining groundwater levels on the Gnangara Mound have resulted in a range of environmental impacts, including declining health and/or death of some groundwater dependent vegetation [...] peat fires, loss of aquatic species [...] and acidification of groundwater and wetlands" (DoW 2005, p. 2). Total groundwater reserves in the Gnangara system were reduced by approximately 700 GL between 1979 and 2008 (DoW 2009). In parts of the superficial aquifer, water-table drops have exceeded 4 metres (GSST 2009). At Hillarys, approximately 30 km north of the Swan River mouth, there has been subsidence of around 50mm since 1995, mainly due to increased pumping from the Yarragadee aquifer (Commander P, University of Western Australia, written communication, 2012).

The Gnangara case illustrates management failure to enforce sustainable extraction levels to reduce environmental damage. One example is Lake Mariginiup, a wetland of high conservation value in the Mariginiup sub-area (number 47 in Figure 5.1). The lake is habitat for waterbirds and supports a rich diversity of macro-invertebrates (Froend et al. 2004). The lake was denominated a zone of “high risk” to GDEs from groundwater extraction in 2005 (DoW 2005, p. 13). It is also one of the “Ministerial criteria sites” in the management agency's environmental monitoring program (DoW 2009, p. 90). Despite this, the Mariginiup sub-area is more than 776 megalitres per annum over-allocated (DoW 2009, p. 42). Rather than reduce allocations, the 2008 draft water management plan included the following "subarea specific allocation rule" for Mariginiup: “[i]n order to attenuate the effect of pumping on water table levels, new bores with allocations greater than 1500 KL/yr must be constructed to draw from the base of the superficial aquifer” (DoW 2008, p. 90). The environmentally sustainable extraction limit in this case is likely to be significantly lower than the management agency's own routinely-exceeded allocation limit for the area (4,000 megalitres/year). (Minimum water levels at Lake Mariginiup fell 0.38 m between 1995 and 2003 ; the lake has frequently been dry during summers since 1997; the "magnitude and rate of drawdown [predicted by 2013] far exceed that required to maintain a low risk of impact" (Froend et al. 2004, p. 173).) The requirement that new wells draw from the lower part of the aquifer merely delays their surface-level impacts and in no way substitutes for reduced consumption. Other wetlands across the Gnangara system are subject to similar stresses due to unsustainable extraction levels. There has been "severe decline" in mean vegetation health at Lake Nowergup (sub-area 42, Fig 1) (Malcolm 2004, p. 28). Lake Gnangara (sub-area 50) has suffered acidification and exhibits “high levels of nitrogen and symptoms of eutrophication” (Malcolm 2004, p. 59). Several GDEs have been subject to artificial water-level maintenance over extended periods (Froend 2004, Malcolm 2004).

2.2 Socially beneficial transfers

Groundwater transfers and trades have the potential to cause spatial redistribution of the impacts from pumping, and therefore require management to prevent a range of problems. Changes to the site of extraction of a given quantity of groundwater may give rise to a set of impacts at the new location that differ qualitatively or quantitatively from those at the original site of use. (Additionally, transfers between agriculture and public supply could transform and/or concentrate impacts by altering the timing of extraction; seasonal extraction for irrigation may allow some off-season aquifer recovery.) Because impacts are localised, their value (i.e., costliness) necessarily depends on the local assets and uses affected by the impacts of newly-transferred groundwater extraction. Therefore, impacts may differ in their nature and extent (and thus their value) between the original and newly-transferred locations of use. Absent the simplifying factor of very high transmissivity, surface and sub-surface heterogeneity are important considerations. They give rise to the physical distribution and the spatial heterogeneity of impacts in terms of their nature and extent. Along with the physical distance or proximity between buying and selling locations, such surface and sub-surface differences also affect the delayed nature of some impacts.

If markets were perfect, prices would automatically reflect all marginal costs and benefits (none would be external) – including those lying in the future. There would be no hydrological or environmental challenges to transfers or trading. The challenges arise from the external nature of some costs and benefits, and from the difficulties inherent in incorporating those third-party impacts into a transaction to ensure that overall social welfare is not diminished. Some impacts from groundwater transfers are likely to include damages that may be theoretically and/or practically difficult to express in monetary terms. (Techniques by which economists assign monetary values to non-monetary goods or assets are known as non-market valuation techniques. With respect to environmental impacts in particular, it is important to note that monetisation may not necessarily be helpful in situations where there may be no scope or opportunity for financial compensation of affected third-parties.) A sound groundwater transfer scheme should address unvalued (non-market) impacts, as well as financial externalities. An effective regulatory system for the market would be designed to ensure that trades whose net impacts are negative are not made, and those whose net impacts are positive or neutral can be made. In Colby's terms, markets should be “governed by policies that carefully weigh the advantages of a proposed transfer against externalities and impairment of public goods” (1996, p. 223).

One option is to attempt to incorporate external costs and benefits into the price arising in a groundwater market. The calculation of a marginal external price for inclusion in the transfer price, incorporating all external costs and benefits both environmental and financial, would be computationally burdensome and moreover in many cases practically infeasible (in part due to spatio-temporal variability of impacts). Instead, the authors propose a system of transfers in which water that is not made available under the design rules does not enter the market. In the type of system proposed here, there could potentially be a single price for available water, but the system's design rules would attach appropriate per-volume transaction fees to each transaction; these would fund the compensation of negative financial externalities. Additionally, exchange rates can be used to encourage or discourage transfers according to management goals; these are discussed later in the paper.

2.3 Information requirements for transfers

The concentration of groundwater use, its potential to impose substantial impacts on neighbouring or distant areas (depending on hydrological conditions), and the spatial transference and potential transformation of impacts, are challenges of policy design that must take into account hydrological information. (It is readily acknowledged that "ecosystem damages from groundwater depletion in large aquifer systems are driven by complex underlying biophysical processes that include nonlinear, dynamic, spatial and threshold features" (Esteban and Albiac 2011, p. 2064). Generating detailed knowledge regarding these processes is costly and time consuming. The authors propose that management could be improved in many cases by the implementation of well thought out generally applicable tools, which could be adapted in response to ongoing improvements in available knowledge.)

It is necessary to assess the likely impacts of a transfer, either intra- or inter-basin. This requires the establishment of the hydrological boundaries of the respective systems. Annual estimation of the sustainable yield may be necessary, taking into account prior rainfall recharge and water-table / aquifer responses. A refinement could be to take into account net recharge information from the preceding year, or a rolling average of a number of recent years (Skurray et al. 2012).

In contrast to meeting 'environmental water' requirements in surface water systems, ensuring that the water requirements of GDEs are met usually relates to maintenance of a water-table level, rather than to a volume of water. A certain volume of water left in a river may provide 'environmental flows', while the same approach to groundwater systems may leave water-tables too low to meet the needs of surface GDEs and/or to provide sufficient water levels in caves or baseflow to streams. This is the case for phreatophytic vegetation, for wetland flora and fauna, as well as for ecosystems dependent upon baseflow to streams. This is also the case for the groundwater-dependent stygofauna in the Yanchep Caves (Yesertener 2006) as discussed earlier. Where the attribute of concern is spring discharges or other explicitly volume-related flows, management is still likely to address the remediation of overall water levels (e.g., McCarl et al. 1999). Limiting overall extractions from a given aquifer such that ecosystem health is maintained is part of the definition of sustainable yield used in this paper. (Sophocleous (2005) makes a similar point: "[s]ustainable use of groundwater must ensure not only that the future resource is not threatened by overuse and depletion, but also that natural environments that depend on the resource are protected” (p. 352).)

Under high-transmissivity conditions, limiting extraction to the sustainable yield addresses most impacts. Impacts under conditions of lower transmissivity can also be managed by addressing water-table levels, although at a more localised level. In short, an important goal here is the delineation of spatial relationships between extraction and total cost of impacts.

One approach to determination of whether or not to allow a certain transfer is the type of case-by-case approvals process that is the status quo in the Gnangara case.

Each prospective transfer requires an application to the management agency; applicants are required to submit paperwork and to pay application fees. This is not the only option. Under the type of system proposed here, 'approvals' would be built in to the system. Assuming that the design has accounted for the compensation of financial externalities, and has disallowed transfers whose impacts are considered unacceptable, prospective buyers would be faced with a total price (including transaction fee and possibly exchange rate) which broadly reflects the social opportunity cost of the transfer. Under this type of system, it would not be necessary for the regulatory body to inspect each transaction, seeking to assess whether its benefits outweigh its costs. (In the Lower Namoi area of New South Wales, three trade areas were established, based on existing drawdown impact levels; trades were not permitted to move water to areas of higher existing impact. Temporary transfers under this system were not subject to individual assessment (Hamilton and Smithson 2010).)

3 Potential tools / approaches

In the Gnangara case, Western Australian state policy is that groundwater transfers must not result in "unacceptable" environmental or social impacts (WRC 2001, p. 4). While this policy does not provide a definition of unacceptable impacts, it does specify that trades must not cause the geographic concentration of pumping such that "unacceptable impacts are likely" (WRC 2001, p. 4). Proposed transfers in the Gnangara case are currently subject to a case-by-case review process. As well as being costly and time-consuming, this imposes significant transaction costs on potential buyers and sellers of water rights. (Boyd and Brumley note that trading rules could be based on "[a]bsolute drawdown criteria" such as "limiting drawdown to a set depth below groundwater dependent ecosystems such as wetlands" (2005, p. 409). Depending on that depth, such an approach could be highly effective; it would, however, be likely to require hydrogeological assessment on a per-transfer basis.)

The following sections describe a number of management approaches that could be used to limit the environmental impacts from groundwater transfers, while also reducing the burden of their administration and the associated transaction costs. (Accounting and compensation for negative financial externalities, discussed briefly above, is not the focus of the following sections.) These tools are suggested with the intent of reducing the administrative burden of the system relative to trade-by-trade assessment, as well as of lowering the threshold level of informational requirements for beneficial management action.

3.1 Limits on transfers and concentration

Placing proportional or volumetric limits on the water made transferable within a management area would limit the potential for concentration of extraction. Such limits could be set as a proportion of total withdrawals permitted within a management area over a given timeframe. The implementation of management tools should take account of the available information regarding each case. Purely as an illustrative example, then, limiting transferable water use to 50% of the overall annual usage volume in a given area would proportionally limit the potential scale of impacts resulting from concentration. While lacking in sophistication, this approach to limiting potential impacts from groundwater exchanges has relative simplicity of design and implementation in its favour. An alternative approach would be to use volumetric or relative transfer limits from or to particular well locations.

A further potential effect of the concentration of groundwater use may be socio-economic. Consider a large horticultural operation that buys groundwater allocations from surrounding smaller users. By not selling their allowance, a small neighbouring user incurs disproportionate but compensable increases in pumping costs, but may also suffer the loss of a particular local way of life as other affected community members move out of the area. To avoid such social impacts in the surface water context, trading limits have been used in Australia to limit inter-regional water trading. In Victoria and New South Wales, 4% annual limits on out-of-district transfer volumes were used at times between 1999 and 2009 (Commonwealth of Australia 2010). In many cases such low limits can be reached early in the water year, and can impose costs on transacting parties (Commonwealth of Australia 2010).

In cases where adjacent management areas are hydraulically connected (as are many of the areas shown in Figure 5.1) there is a potential for cross-border concentration. High-value uses located closely together, but on either side of a management boundary, could cause accumulation of pumping rights such that, at the extreme, the entire transferable volume of both management areas becomes concentrated at the two closely adjacent locations. To guard against the potential impacts of such a situation using trading limits alone would require them to be set lower than otherwise necessary, thus presenting unnecessary restrictions on other potential transfers. Using trading limits in combination with other tools, such as concentration limits or exchange rates, would be preferable in such cases. Conversely, the concentration of pumping in one corner of a hydrologically exclusive management area does not allow impacts to 'leak' across the area boundary which forms the hydraulic boundary. In this case the cone of depression extends only into the management area, removing the potential for cross-boundary concentration.

It would be undesirable to allow, for example, 90% of a large management area's allocation limit to be extracted near a GDE. This gives rise to the concept of concentration limits by distance – a form of trading limit. Rules could limit the accumulation of pumping according to distance from an environmentally sensitive area. Similar rules could be used to limit concentration near management area boundaries, addressing the problem of cross-boundary concentration. Such concentration limits would be a form of trading limit with properties that vary by location. With the goal of limiting concentration, they would effectively be spatially-varying limits on purchases.

3.2 Management areas

Restricting transfers to between hydrologically connected locations may seem appealing, as the connection allows some equalisation to take place, over time, between the impacts at different points. (Benefits may not fully offset costs, of course, for a number of reasons. Increases in pumping costs, for example, have a non-linear relationship with depth to groundwater; a neighbour of a user whose extraction increases may suffer a disproportional increase in pumping costs.) The more important connections for the discussion here, however, are those governing the propagation of impacts from sites where extraction levels have been altered by groundwater transfers (e.g., those between wells and neighbouring users, GDEs, etc.).

While there are arguments for limiting a cap-and-trade style groundwater trading scheme to hydrologically connected sites, inter-area transfers are possible. In a cap-and-trade style program, ongoing bi-directional trading between hydrologically unconnected management areas would not be allowed, because the sustainable yield of each area would form its respective cap on overall extractions. Extraction could, however, be deliberately moved from one hydrological entity to another, in order to redistribute extraction impacts. A government, for example, might seek to limit overall impacts from water use across a jurisdictional region. Impacts of pumping may be ecologically damaging at one location but not at another distant and unconnected point. Prior commitments may have been made to protect particular sites and ecosystems, such as under the Convention on Wetlands of International Importance (Ramsar Convention) for example. It may be feasible to permit the transfer of pumping rights in such a case, despite the fact that no equalising flow or common recharge exists. The management problem examined here is how management areas can best be defined so as to increase the total net benefits from transfers.

Including all hydrologically connected points within a single management area presents problems. Skurray et al. note that ”[e]stablishing a single trading area incorporating all hydrologically connected points across the Gnangara system’s 2000 km^2 area, for example, would allow the potential for unacceptable impacts due to excessive concentration of pumping. It may also increase the range of potential transformations between different types of impacts, and the scope over which these could take effect” (2012, p. 266). The range of financial impacts may also be increased by encompassing the larger number of different economic activities distributed across the management area. Conversely, a benefit would be that such a large area would give the greatest potential for water transfers and the development of a market.

In some cases the use of localised (rather than aquifer-wide) extraction limits may be required; the use of several management areas within a single aquifer system would facilitate their use. This could be beneficial where determining the sustainable yield for the system overall is difficult or precluded. Other shortcomings in available hydrogeological, environmental, and/or economic information may constitute reasons to use this approach. Uncertainties regarding transmissivity, for example, could justify the imposition of sub-aquifer-level management units. Dividing a large system up into sub-areas may facilitate monitoring and the management of local conditions.

Where a single management area is used for a large, hydrologically connected system incorporating sensitive areas, the concentration of pumping needs to be limited in different ways (such as by using exchange rates, as discussed in the following section). Whether or not dependent ecosystems are incorporated within a prospective management area is an important design consideration. One approach would be to incorporate GDEs into management areas and to use other tools to manage the potential impacts of transfers. Where this is done, the concentration of pumping near these sites could be controlled using trading / concentration limits. The establishment of 'sell-only' zones surrounding sensitive areas could lead over time to the creation of “buffers with little or no groundwater use around areas of particularly high conservation value”, as suggested by Appleyard and Cook as a shorter-term measure to reduce environmental impacts in the Gnangara case (2009, p. 587).

An alternative approach is to allow the location of GDEs to dictate the design of management area boundaries. Where boundaries exclude GDEs (and barring impacts such as subsidence and seawater intrusion) third-party effects of concentration within the area might be limited to compensable increases in pumping costs. Within areas of this type, permitted pumping could be highly concentrated at the centre (e.g., 100% of the area's extraction limit), while allowed concentration levels would decrease with increasing proximity to area boundaries. Given adequate monitoring, it would be administratively simple to keep track of the spatial distribution of extraction within a management area, and to prescribe publicly-available limits on the accumulation of pumping according to zones radiating from the centre of the management area. Buyers would be aware of these limits, and would know their eligibility to purchase additional usage rights. The environmentally sensitive area in this case lies outside area boundaries, and is protected by the radial limitations on pumping concentration in the adjacent areas. Exchange rates, discussed in the following section, could be used to effect the concentration limits.

Establishing buffer zones or separate management areas around GDEs both have the effect of distancing surface extraction points from the sensitive area. The underlying goal, however, is to provide adequate distance from the cone of depression. Impacts on sensitive areas may occur even if excessive extraction is located at some distance.

South of Perth, for example, Yarragadee aquifer monitoring data reveal that the area is affected by the cone of depression due to extraction for public supply in the Perth area, occurring some 50 km to the north. This is a case of concentrated extraction from an aquifer of large spatial extent (although not as a result of groundwater transfers), and illustrates one of the difficulties with very large management areas, discussed earlier. Management tools cannot be made to substitute for sustainable withdrawal limits overall, but can limit impacts from a given level of extraction. (Adelaide and Mount Lofty Ranges NRM Board note that "[w]hile the use of buffers delays the impacts of extraction, they do not affect the magnitude of the full impact of abstraction of underground water" (2007, p. 14). The National Water Commission makes related points: "the environmental impacts of groundwater trading should be considered in the context of overall groundwater management that seeks improved environmental outcomes by setting the sustainable yield for each aquifer" (2010, p. 96).) In general terms, avoiding such highly concentrated extraction would be more effective than seeking to provide adequate distance from so large a cone of depression.

The current management area boundaries in the Gnangara case illustrate some of these management problems. The Gnangara groundwater system is divided into a number of management areas, most in turn divided into sub-areas (see Figure 5.1). The superficial aquifer is divided into 51 sub-areas, some as little as one or two kilometres across (sub-areas 8, 10, 48, and 49 are examples). The number, size, and basis of many of these sub-areas mean that the agency's general restriction on inter-sub-area transfers greatly limits the opportunities for value-creating exchanges. This represents a significant impediment to the evolution of a market for groundwater in the area (Skurray et al. 2011). The current groundwater area boundaries are to some extent socio-economic, reflecting historical land use divisions, further limiting the potential for exchange between usage types. In 2008, the Department of Water was reviewing the Gnangara groundwater management areas "to better align with hydrogeological features" (DoW 2008, p. 2).

Within these 51 management sub-areas are a number of zones of “high risk” to GDEs from groundwater extraction, denominated by the Department of Water in 2005 (DoW 2005, p. 13). The extraction limits within the sub-areas, however, do not appear to take account of the presence of these high-risk areas, and routinely exceed environmentally sustainable levels. Froend (2004) finds that forecast drawdown at many of these sites “far exceed[s] that required to maintain a low risk of impact”; as for Lake Mariginiup discussed earlier, this finding applies to Lake Nowergup (sub-area 42, Fig 1), Lake Joondalup (48), Lake Jandabup (49), Lake Goollelal (18), and Lake Gnangara (50), as well as to Pipidinny Swamp, Lake Yonderup, Wilgarup Lake and Loch McNess (all in sub-area 51), among others. The main source of impacts in this case is excessive permitted extraction levels. Even under these conditions, however, alterations in the sub-area boundaries would improve the opportunity for transfers away from these high-risk GDEs. Alternatively, and given the current boundaries, restriction on inter-area transfers could beneficially be lifted, and replaced with management tools such as those presented here, both permitting and encouraging the environmentally beneficial redistribution of extraction.

The delineation of management area boundaries between connected surface and groundwater bodies is a management challenge in many areas. For the management of water transfers between a river and connected aquifer, the appropriate boundary should reflect the hydrological reality that extraction of water on either side of the boundary affects the resource on the other side. Moreover, pumping from two such points is to some extent drawing from the same pool. Setting the boundary somewhere further from the bank to account for this could be somewhat arbitrary. The difficulty in establishing an appropriate boundary line in such cases might be mitigated by the use of distance-based exchange rates to create a zone of gradual transition between the two management areas. Groundwater extraction points closer to the river are sharing river water to a larger extent than those further from the bank. Exchanges between groundwater and surface water users should avoid "double accounting" of water – accounting for the same water as both river flow and groundwater (Evans 2007). This could be achieved by discounting water transferred, using an appropriate exchange rate.

3.3 Exchange rates

Signatories to Australia's National Water Initiative (2004) agreed that authorities should, where necessary, “facilitate trade by [*inter alia*] providing [...] information such as the exchange rates to be applied to trades” with the goals of accounting for hydrological effects of transfers and to “reflect transfers between different classes of water sources” (p. 38).

In a water transfer using an exchange rate (or 'trading ratio') the volume transacted is converted such that a buyer may receive more or less than 100% of the volume foregone by the seller. As described earlier, the calculation of a per-transfer price that would incorporate all external costs and benefits, both environmental and financial, would be burdensome and potentially infeasible. Even where policies preclude unacceptable impacts, allowable transfers will not be equally beneficial to overall welfare; the strategies proposed in this paper would ideally generate a system in which permitted transfers are at least welfare-neutral.

Exchange rates could be used in a number of ways. Used effectively as a form of broad pricing tool, exchange rates could provide signals to market participants which would, in a perfect market, be reflected by the price itself. (Such a system may permit the evolution of an underlying or implicit equilibrium price for an unadjusted volumetric unit of water use; exchange rates would simply alter the proportion of this unadjusted volume which would be exchanged in a given case.) Exchange rates would thus effectively amount to premiums or discounts on groundwater transfers identified as having certain characteristics, without requiring management agency intervention in the price agreed between the transacting parties. They could be used to encourage or discourage transfers according to management goals.

The design of an appropriate set of exchange rates for a given context would incorporate available information regarding the hydrological relationships between extraction and environmental damage in the given case. As Colby observes, “[p]olicymakers should seek to generate, in a least cost manner, information on the externalities that accompany water transfers” (1996, p. 222). To illustrate this, consider a purchaser located further from a GDE than the seller. Using the allocated volume offered for sale as the reference point, an exchange rate in this case might be set at greater than 100%, as a means of promoting the_environmentally beneficial transfer, with the result that the buyer is permitted to extract more water than the volume foregone by the seller. The buyer is thus willing to pay more (than for_a 1:1 exchange) which in turn encourages the seller to make the exchange. Applicable rates should be determined for categories of transfer, rather than per-transaction; the rate should reflect the relative impacts of marginal extraction at the respective (buying and selling) locations. Where urgent remediation of over-extraction impacts at a sensitive location is required, the trading ratio could be high. It may be necessary, in establishing exchange rate categories, to take into account the availability of alternative sources of marginal water in the buying region.

It is possible to consider exchange rates as a means of implementing transfers across a large management area, without the use of sub-areas. This would require consideration of how to manage the potential for concentration. The issue of concentration at or near management area boundaries, for example, could be addressed by varying the exchange rate according to the buyer's position relative to the boundary. Alternatively, long-distance transfers from centrally located sellers could be discounted (by use of an exchange rate below 100%), limiting the accumulation of extraction near neighbouring management areas and/or GDEs. Short-distance transfers could be subject to less discounting, on the basis that impacts at the buying and selling locations may be similar. Short-distance transfers are also less likely to cause concentration of extraction. Transfers that would move extraction towards a GDE could be discouraged by the use of an exchange rate discount, and vice versa as described in the example above.

Establishing exchange rates on a case-by-case basis for all such potential transfers would be overly complex. One of the key objectives of this type of management system would be to simplify the determination of whether or not a particular transfer should be treated as beneficial. It would therefore be important to develop general rules, based on the available hydrological and environmental information, but employing heuristics to provide a shortcut to useful management and policy outcomes. (Boyd and Brumley propose a framework "to aid the development of groundwater trading rules". involving the ranking of impacts according to both acceptability and likelihood, resulting in a range of 3 categories of impact risk levels which would in turn dictate the stringency with which trade applications are reviewed (2005, p. 408).) Given the management goal to limit the concentration and transformation of impacts due to transfers, and the broad approach of encouraging or discouraging transfers having certain attributes, evaluating the relevant characteristics of a potential transfer, and thus its appropriate category assignment, would be the next task. A very generic and abstracted example could use ecosystem (or other forms of) stress as the primary decision criterion, with a resulting decision path similar to that shown in Figure 5.2.

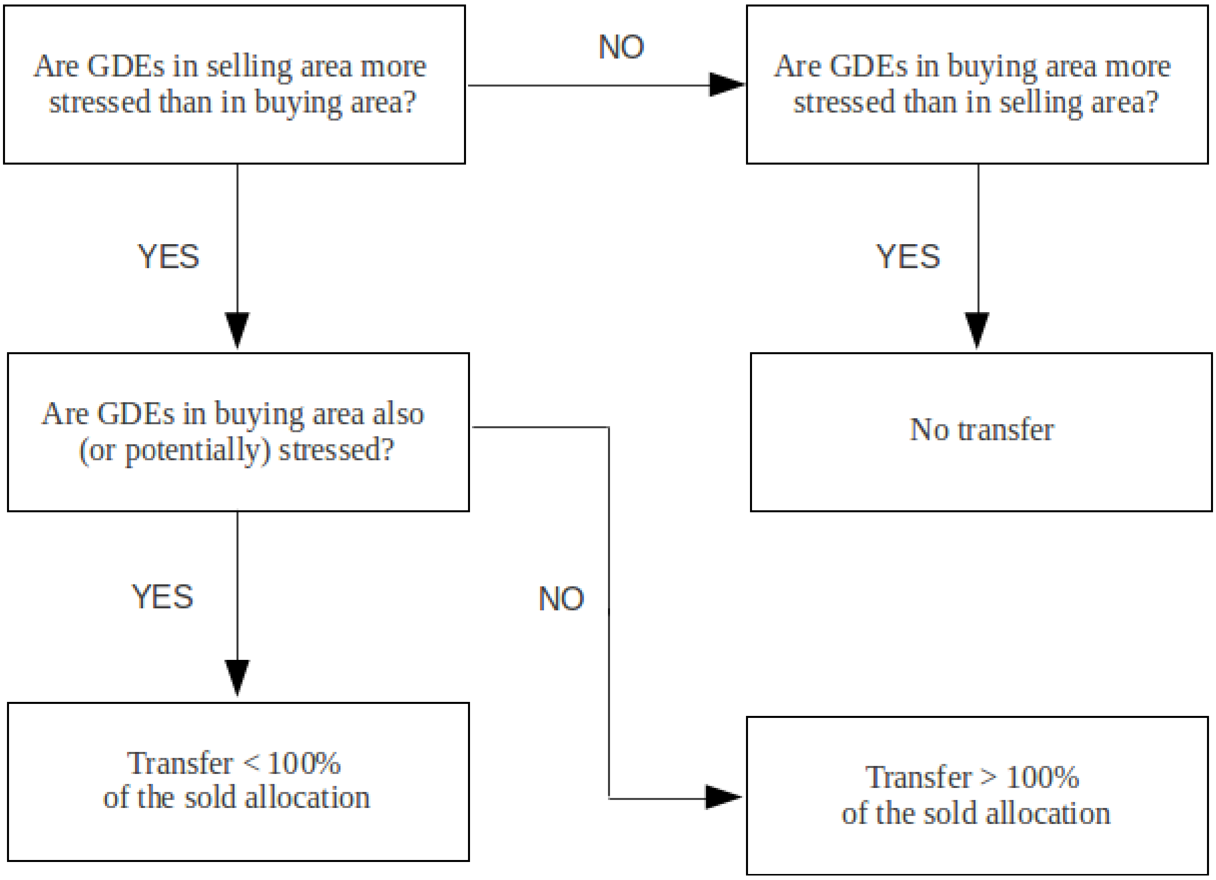

Figure 3.1: Generic partial example decision path: high-level establishment of trading ratios using ecosystem stress decision criterion.

In groundwater systems with sufficient rates of flow, the environmental effects of extractions at a buying location 'upstream' of a GDE could be more serious than those at a 'downstream' selling location, as upstream extraction intercepts water that would otherwise have flowed towards the GDE. (In delineating the high-risk zones around GDEs (mentioned earlier) the Department of Water defined a "radius of influence of pumping" which was "removed downgradient of wetlands where a steep hydraulic gradient exists, and effects from pumping should be minimal" (DoW 2005, p. 17)) Exchange rates could potentially be used in management of resulting issues of 'upstream' and 'downstream' groundwater transfers, and their respective potential external costs. Where reduction of environmental impacts is a critical issue, such upstream transfers may be prohibited or subject to strong exchange rate discounting; the reverse downstream transaction, having environmental benefits, may be promoted by a greater than 100% exchange rate.

In order to be willing to effect a transfer under the type of system proposed here, transacting parties would have to capture sufficient private value from a given exchange to outweigh any applicable exchange rate as well as the per-volume transaction fee (described earlier under *Socially beneficial transfers*), and any other transaction costs. In this way, exchanges would broadly account for the potential for environmental impacts or benefits, as well as broadly compensating for financial externalities.

4 Conclusion

A system for facilitating and managing groundwater transfers, based on sustainable extraction limits, may be one appropriate management policy under conditions of water scarcity, if_certain challenges can satisfactorily be met. This paper describes possible management strategies that would help preclude unacceptable impacts from transfers, by barring or discouraging transfers having certain attributes. The tools and strategies proposed would ideally generate a system in which permitted transfers are beneficial, or at least welfare-neutral.

Market transactions fail to include external costs, which may include financial, social, and environmental costs. The paper focuses on environmental aspects, as the authors consider these to be the more challenging issues for policy makers. They present management difficulty because the 'third party' affected is not an individual, and because of the non-monetary nature of these effects. Negative environmental externalities from groundwater transfers may also be uncertain.

An environmentally sound groundwater transfer scheme would provide that marginal costs from transfers do not exceed marginal benefits, encompassing all third-party impacts including those of a non-monetary nature as well as delayed effects. An effective system of market regulation would aim to ensure that transactions do not reduce social welfare – that only transfers whose net impacts are positive or neutral are permitted to occur.

Apart from cases where there is high transmissivity of groundwater, transfers have the potential to cause spatial redistribution, concentration, and qualitative transformation of the impacts from pumping; changes in the inter-temporal aspects of impacts can also occur. Different groundwater transfers therefore have different impacts: negative, positive, social, environmental, and financial, and therefore will have differing total benefits and costs.

The calculation of a per-transfer price that would incorporate all environmental and financial effects would be burdensome and may be practically infeasible. The authors propose the building-in of structural elements in the regulatory system, requiring that transfers limit or reduce environmental impacts and provide for the compensation of financial impacts. The paper describes three types of management tool which could be used to mitigate and manage these effects: trading and concentration limits, strategic use of management area boundaries, and exchange rates or trading ratios.

Imposing limits on the proportion of a management area's total water use that is made available for transfer would limit the potential for concentration of groundwater use. Implementing trading limits low enough to prevent all negative outcomes, however, would be restrictive. Concentration limits – a form of trading limit – could be used to restrict the accumulation of pumping according to distance from a sensitive area.

Management area boundaries could be designed to exclude environmentally sensitive areas. Where this is done, and barring other impacts of over-extraction (e.g., subsidence, seawater intrusion) third-party effects of concentration within an area might be limited to compensable increases in pumping costs. Establishing buffer zones or separate management areas around GDEs may contribute to providing adequate distance between cones of depression and sensitive areas. Larger management areas, all else being equal, increase the potential for redistribution to cause localised accumulation of pumping and impacts. Large management areas may also increase the range and scope of potential transformations from one impact type to another.

Exchange rates could function as a form of broad pricing tool. Exchange rates could be designed to have a similar effect to placing premiums or discounts on groundwater transfers identified as having certain characteristics; they could be used to encourage or discourage transfers according to management goals.

The proposed tools may be most effective when used in strategic combinations; exchange rates could be used to effect concentration limits, for example. While management tools can limit impacts from a given level of extraction, they cannot substitute for sustainable withdrawal limits overall.

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