WOODS INSTITUTE FOR THE ENVIRONMENT STANFORD UNIVERSITY

POLICY BRIEF

09/2008

Managing Water Supply Uncertainty: Option Contracts and Short-Term Water Transfers in California

By Claire D. Tomkins, Thomas A. Weber, David L. Freyberg, James L. Sweeney, and Barton H. Thompson

Executive Summary

Climate change, population and economic growth, and new environmental management edicts are all contributors to increasing water supply uncertainty. In addition, California faces a groundwater overdrafting problem: the state has been withdrawing more water from its aquifers annually than is recharged. The deficit will have to be repaid in order for aquifers to remain viable future sources of water. Restrictions in local water supply, due to climate and regulation, and fluctuating demand create the potential for costly water shortages. Option contracts that give a water agency (a buyer) the right, but not the obligation, to purchase water at a future date offer effective risk management in the face of these shortages.

Option contracts that facilitate temporary water transfers have the potential to alleviate local water shortages and enhance economic efficiency. Efficiency gains result from the reallocation of water from lower-value to higher-value uses. There has long been interest in a water market in the state to accomplish this reallocation, and policy liberalization around water transfers has resulted in more active trading. The most active trading has been between agricultural users, with ag-urban water transfers lagging behind due to considerable market friction in the form of institutional resistance and high transaction cost. Specifically, this market friction has impeded permanent water rights transfers, which have been the predominant focus of urban agencies to date. A shift in emphasis from permanent to *temporary transfers* under option contracts could stimulate the ag-urban water market and unlock the potential to meet urban water shortfalls through transfers versus costly supply expansion. In the absence of transfers, urban supply shortages will need to be met through a combination of new water treatment/reuse facilities, additional storage, and more aggressive demand-side management programs. While unlikely to entirely offset the need for such investment, transfers do provide an alternative to costly supply augmentation and are currently more cost-effective than the energy-intensive desalination alternative.

A temporary transfers market has the additional advantage of flexibility. In the short-term, while conservation programs and alternative supplies are under development, temporary transfers can serve as a stopgap technology. In the long-term, uncertainty regarding water demand, energy prices, and future crop prices, among other variables, makes the option to transfer water between different end users valuable. In contrast, permanent water rights sales are relatively inflexible, due in large part to the high transaction cost associated with the exchange of these resource rights.

The widespread use of option agreements as a risk management tool, coordinating short-term water transfers between water agencies, will ultimately require reliable infrastructure. North-south transfers are currently restricted by pumping capacity at the Delta outtake and by environmental regulation. These restrictions limit the potential of transfers from northern California to fully meet supply shortages in Southern California. Under discussion is a proposal to invest in a peripheral canal to provide water conveyance circumventing the Delta. This infrastructure investment could make it possible to transfer larger volumes of water reliably, opening the door to a more active transfers market. o

Policy Insights

1. Temporary water transfers coupled with sound Delta infrastructure can help meet local water supply shortages

Water transfers to alleviate local supply shortages require three things: (1) reliable infrastructure, (2) a willingness to transfer water on the part of agricultural water districts (where water rights are concentrated), and (3) low transaction cost. Investment in reliable infrastructure alone will not accelerate water transfers if market friction in the form of high transaction cost and institutional resistance to trade persist. Permanent water transfers, or water right sales, are characterized by both high transaction cost (attributable to legal fees and overhead associated with protracted negotiation and environmental review, as well as possible environmental mitigation fees) and institutional resistance from farming communities whose sovereignty is threatened by the sale of water rights.

The recent advent of option contracts in the California water market suggests a way forward. An option contract gives the buyer the right, but not the obligation, to purchase water at a future date (referred to as the "exercise date") at a pre-set price. The buyer pays an upfront fee to the seller for this right. The buyer may typically elect to purchase any amount of water up to the full contract limit (referred to as "calling" or "exercising" options). Option contracts institute *temporary transfers*, as opposed to permanent transfers. Temporary transfers lower transaction cost and reduce institutional resistance. Under these temporary transfer contracts, farming communities retain control of their underlying water rights. This eliminates the recognized threat to the community's sovereignty and the livelihoods of its members. As a result, agricultural water districts are willing to enter into temporary transfer contracts. The lower transaction cost owes to a decrease in the uncertainty and complexity regarding contract negotiation and an expedited environmental review.[1] Paired with reliable infrastructure, option contracts could facilitate the transfer of larger volumes of water and ultimately serve as an integral component of water agencies' risk management strategies in the face of costly water supply shortages.

2. Temporary water transfers provide water agencies with additional flexibility

High transaction cost coupled with a long review/negotiation period precludes the use of permanent transfers (water rights sales) for short-term supply adjustments. Investment in supply expansion, including desalination and recycling, is irreversible. Temporary water transfers provide a degree of flexibility not present under either of these alternatives. This flexibility is important in view of the uncertainty surrounding a number of key value drivers:

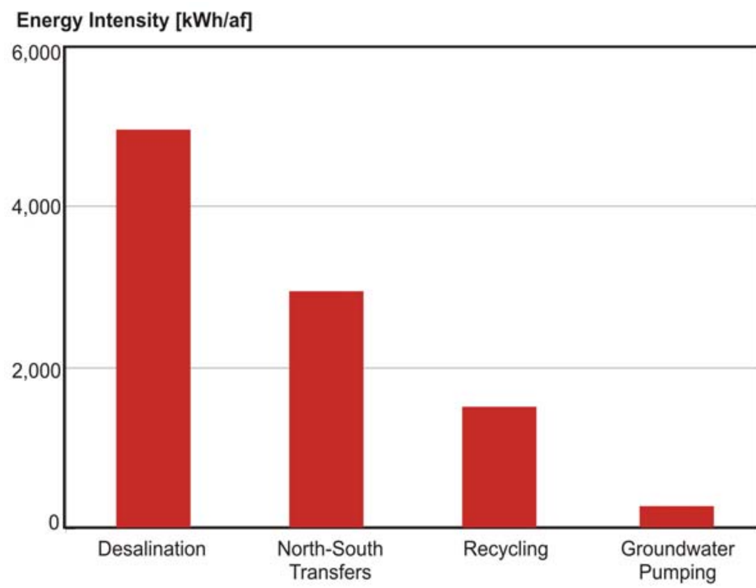
(1) Low water demand. Water demand in the short-term is driven largely by climate and population. During wet periods and when storage is replenished, water demand may be low and additional supply inessential. Water held under contract may therefore be more productively applied elsewhere. Temporary transfers, and in particular option agreements, provide the flexibility to make short-term supply adjustments. Under the option agreements, the buyer is not obligated to take the water on delivery if, for instance, demand is low relative to supply that year. Water demand in the long-term is driven by efficiency improvements (in addition to climate and population). Temporary transfers can thus serve as a stopgap technology during the transition to a higher-efficiency state.

(2) High crop prices. Recent record prices for commodities, including rice, wheat, and soybeans, demonstrate the value of flexible water transfers that allow water to reach the highest value end user *at a given point in time*. Fixed transfers arranged using low historical commodity prices as benchmarks could lead to a highly inefficient system. The unpredictability of crop prices and the possibility of global food shortages suggest the value of (1) keeping agricultural land in production and (2) retaining the ability to transfer water between agricultural users based on crop values. Flexible short-term transfer agreements aid both practices.

(3) High energy prices. The marginal cost of water conveyance depends on the price of electricity. It requires 2,900 kWh to transport an acre-foot of water from northern California to Southern California, including pumping over the Tehachapi Mountains.[2] The price of electricity for conveyance, as negotiated under Department of Water Resources contracts, has been stable over the past four years at $0.05/kWh. A rise in the price of electricity would make water supply in general, and transfers in particular, more expensive. (All water supply relies on energy as an input at some stage, from treatment to conveyance to distribution.) Desalination, which is currently more energy-intensive than water transfers, would become less attractive under a scenario of rising electricity costs. Permanent transfers that require the buyer to pay the conveyance fee may also be less attractive when rising electricity costs are taken into consideration. Temporary transfers mitigate the risk associated with both of these alternatives by providing the flexibility to (1) avoid or postpone desalination investment – or temporarily cease operations if the investment is in place and (2) avoid the upfront investment in securing a permanent transfer that may become uneconomical under rising energy costs.

3. The direct cost of a water transfer is currently lower than that of desalination

All water supply alternatives require energy as an input. The direct cost of a



Estimates of the energy requirements for pumping local groundwater depend on the depth of the water table. The estimate of 220 kWh/af is based on Knapp et al.'s (2003) data for Kern County Water Agency.[3] There is a large range of national estimates, reaching as high as 600 kWh/af. In California, coastal basins have a higher water table and require less energy to pump water than the inland basins.

Source of data: California Energy Commission (2005)

Figure 1. Energy Intensity of Water Supply Alternatives

water supply alternative is a function of the prevailing cost of electricity. The higher the energy-intensity, the higher the direct cost. The energy-intensity of north-south water transfers is currently considerably lower than that of desalination. It is higher than the energy intensity associated with recycling water in situ and with groundwater extraction.[4] The energy intensity of desalination is currently estimated at 4,900 kWh/af. Improvements in desalination technology have been increasing the cost-competitiveness of the technology. There is still considerable room for energy efficiency gains in desalination, with current technology using approximately three times the estimated minimum energy requirement for the process.[5] Improvements on this order would make desalination competitive with transfers with respect to energy intensity.

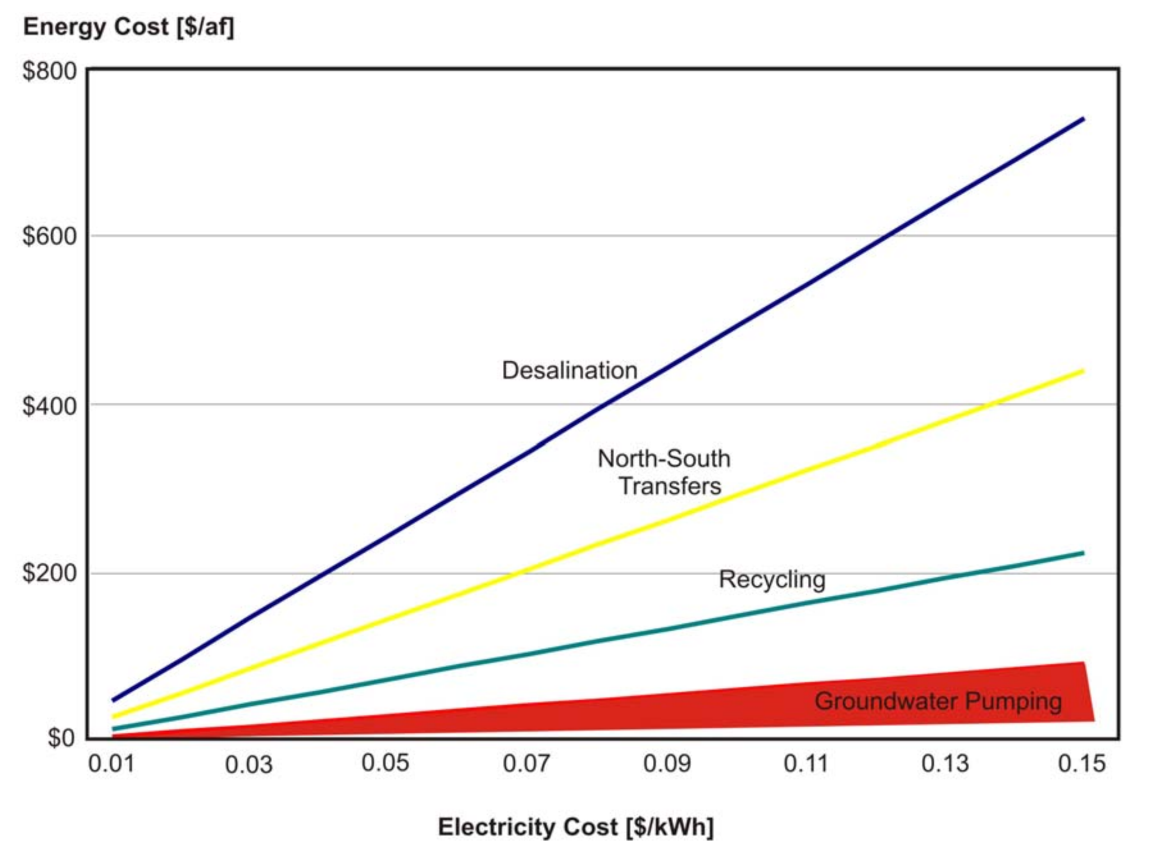
The direct cost of a water supply alternative also includes the capital cost. This cost must also be taken into consideration in the final cost-benefit calculus. There are large capital costs entailed with both desalination and recycling and reuse facilities. Capital investment is also required to expand reliance on groundwater (requiring wells and pumps, and possibly conveyance infrastructure). Further, while there is north-south conveyance infrastructure already in place, infrastructure investments would be required to move significantly larger volumes of water across, or around, the Delta to accommodate water transfers.

The indirect costs associated with water transfers include the environmental impacts of moving water across the Delta. Fish populations are adversely impacted by pumping operations. The operation of the Delta pumping plants can entrain fish, sucking them into the pumps. The powerful pumps also reverse natural flow patterns, impeding fish migration. In general, the use of the Delta as a conduit for urban water supply has effected significant change in the natural conditions, including changes in the water temperature and flows. The impact of an increase in water transfers on the Delta ecosystem is an important consideration in weighing the costs and benefits of relying on transfers to manage supply risk. The plan to build infrastructure circumventing the Delta would avoid these impacts to the Delta ecosystem but would nonetheless require an assessment of other associated environmental impacts.

Option Contracts for Water in CA

In 2003, the Metropolitan Water District of Southern California (MWD) initiated option contracting in the water market. MWD signed eleven option contracts with Sacramento Valley farmers, eventually calling options from 10 of the 11 contracts for a total delivery of over 100,000 af of water. MWD, a wholesaler of water, is the largest water intermediary in the state, supplying water to 26 member agencies in its California South Coast service area, including Los Angeles and San Diego. MWD again entered into option contracts with three Sacramento Valley irrigation districts in 2005, demonstrating the viability of repeated contracting for temporary water transfers. The 2005 options were not called, as spring rains alleviated the supply shortage. In 2008 the San Diego County Water Authority (SDCWA) entered the options market, signing contracts with Butte Water District and Sutter Extension Water District.

Option contracts for reserve capacity are common in the restructured electricity sector, where production, transmission, and distribution are unbundled. In these markets, a buyer may reserve capacity in the form of an amount of power to be generated by the seller, for distribution by the buyer, on a given day and time.[6] Bilateral option contracts serve as an important instrument for coordinating stochastic supply and demand and avoiding costly shortfalls in electricity supply. The transfer or development of local supply generation facilities to meet this demand would, in general, be extremely costly and not viable on a short-term basis.



Source of data: California Energy Commission (2005)

Figure 2. Energy Cost of Water Supply Alternatives

Analogously, option contracting in the water market permits cost-effective and timely water transfers to meet local supply shortfalls during dry periods. Without such contracts in place, mismatched supply and demand can result in costly shortages such as those experienced during mandatory rationing periods in the California drought of the early 1990s. The buyer's decision to exercise, or call, options depends on the actual realization of supply and demand at the contract exercise date. For example, a buyer would call his options if the cost of the water shortage he faced was above the exercise, or strike, price for water under the contract.

The economic gains under option contracting result from shifting water use from lower-value to higher-value applications, where the future value in use remains uncertain at the contracting date. Tomkins and Weber (2008) report sizeable social welfare gains under contracting in the option market to date.[7]

There are alternative supply technologies for meeting water shortfalls. For instance, an urban water agency could invest in desalination, water recycling, or groundwater banking (or groundwater pumping) programs. The variable direct cost associated with all four alternatives – water transfers, desalination, and groundwater extraction – is energy. North-south water transfers require on average 2,900 kWh/af of electricity, which includes the energy required to pump the water over the Tehachapi Mountains during north-south transport.[8] Groundwater extraction requires energy to pump the water from beneath the ground to the land surface. (Groundwater banking programs, in which water is actively collected and then stored in aquifers for later recovery, require additional energy in the water collection/storage phase, e.g., energy to inject the water subsurface.) Recycling water consumes energy in the extended treatment phase. Finally, the high cost of desalination is attributable to the technology's energy intensity. Figure 2 presents a comparison of the energy cost associated with provision of an acre-foot of water from the four different sources, as electricity costs vary. The current cost of electricity use for water transfers is $0.05/kWh. As desalination is the most energy intensive, its cost is also the most sensitive to increases in energy prices.

Water management agencies will likely need to pursue a range of alternatives to address statewide pressures on water supply. If per-capita water consumption were to remain constant, total urban water demand is projected to grow by 40% over the next 23 years, requiring over two million af of additional supply.[9] At the same time, DWR (2005) estimates that to correct groundwater overdrafting in the state, annual use will have to decrease by another two million af.[10] Urban water agencies that face voluntary or mandatory restrictions on groundwater use and increasing water demand will have a higher risk profile in the future. The shift in risk profiles is likely to be uneven, with water agencies in some regions facing much greater risk than others. Option contracts will be even more valuable as a risk management tool under this scenario. The more disparate the distribution of water shortage risk, the more active the option contracting market would need to be, with prices driven by the cost of local supply shortage.

California offers an interesting test bed for option contracting in the water sector. A number of water-short states and nations face similar pressures to those being confronted in California: population growth, limited new supply options, and environmental constraints. Changes in the hydrologic cycle associated with climate change often compound these problems. As a world economic leader, the policies and the actions California adopts will be of international interest.

Historical Development of Market Frictions

A formalization of the idea of water markets in California dates back over 30 years to two reports commissioned by the state legislature and the governor in the wake of the 1976-77 drought. Many of the recommendations in those reports have since been implemented. Despite the policy liberalizations, the state's water market has developed slowly.[11] The average volume of water traded annually remains less than 3% of the state's total average usage of 43 maf (9 maf in an urban setting and 34 maf in an agricultural setting).[12]

The most successful sector in terms of market development in the wake of policy liberalization has been the agriculture sector.[13] Transfers in the agricultural market increased significantly in the wake of policy reforms in the early 1990s and account for the largest percentage of water trades annually.[14] Reforms to the California Water Code and the State and

Federal water project operational guidelines have thus been effective in stimulating water transfers between agricultural users within the State Water Project and the Central Valley Water Project. Transfers from agricultural to environmental uses have also increased since the inception of the Department of Water Resources (DWR's) Environmental Water Account in 2001.[15]

Ag-urban transfer volumes have not increased at the same rate. This is surprising given clear evidence of differences in the value-in-use, with the shortage cost of water above $1,000/af in Southern California and the profit derived from an acre-foot of water applied to grow rice, for example, historically between $0-$140/af. The disparity between agricultural and urban value-in-use has long been recognized, and Water Code reforms were undertaken with the ag-urban water market in mind.

The ag-urban market was jump-started in 1991, when DWR instituted the first ever Drought Water Bank, purchasing water directly from farmers for $125/af and then reselling it to urban interests for $175/af. The Drought Water Bank was operational in 1991, 1992, and again in 1994, moving over 400,000 af the first year and close to 200,000 af the second two years. DWR has continued to operate a Dry Year Water Purchase Program, with activity in 2001, 2002, and 2003. The majority of ag-urban transfers have been coordinated by DWR. Such centralized operation has the advantage of buyer aggregation and reliable access to infrastructure, of which DWR retains control. However, it will be difficult for DWR to scale operations to meet the variable needs of the hundreds of separate water districts in California, for whom water transfers could become a strategic management tool if existing market friction were reduced.

The reasons for stalled development of the ag-urban water transfers market have their origin in the institutional structure of the state's water sector, which was designed to prevent, rather than facilitate, water transfers. The institutional structure set in place by the California legislature in the early 1900s accomplished many of its aims, primary among them to band together local water users to encourage water use for the common good. The legislature formed irrigation districts and mutual water companies that operate much like municipalities. These districts are overseen by boards, which are in turn elected by the districts' residents, with voting rights either held in proportion to land ownership or on a one-member-one-vote basis. The districts have been largely successful in promoting equitable and cooperative water use (and avoiding the "tragedy of the commons" associated with public goods). However, their formation also set the stage for future conflicts over water transfers through (1) creation of incentives and means for district members to block proposed water transfers by other members and (2) failure to establish rules for the allocation of profits from such transfers to members of the district.

Water transfers typically need to be approved – and are often negotiated – by irrigation districts.[15] If the general membership of an irrigation district does not stand to benefit financially from the transfer, then they may seek political means to block transfers. Voting rights structures differ by district in California – in some cases, each resident of the district has a vote (general membership), while in other districts voting is restricted to landowners and may also be proportional to the total value of landholdings. The Imperial Irrigation District (IID) is an example of a district in which each resident has voting power. Under the Quantification Settlement Agreement

(QSA) approved in 2003, IID agreed to transfer water to both MWD and SDCWA. The QSA was a complicated negotiation, involving Colorado River water rights, that took over five years to settle. The transfers to MWD and SDCWA met with considerable community resistance. The general membership of the irrigation district sought to block the transfers. In the case of IID, a compromise was reached only after federal involvement and the threat of reduced diversion rights for the district. The eventual compromise involved creation of a mitigation fund for the community.

Community resistance stems from perceived economic harm when farming activity decreases. Individuals whose livelihoods revolve around irrigated agriculture, including millers, marketers, fertilizer and equipment salesmen, machine salesmen and repairmen, and farm laborers, anticipate a decline in business and wages as land is idled, or taken out of production. Water right sales, or permanent transfers, are likely to result in land retirement, for instance. Permanent transfers on a large scale could therefore lead to community dissolution and widespread unemployment. Institutional resistance to water right sales is understandable in face of this prospect. Furthermore, farmers who face future redundancy may also be opposed to the sale of water rights.

Temporary transfers reduce fears of permanent land retirement, while providing an immediate infusion of cash into agricultural communities. The loss in cultivation-related income may be at least partially offset by increased expenditures on equipment upgrades and repairs, as well as non-farm-related items, in years in which payments for water sales are received. Mitigation funds have become a standard feature of transfer contracts. This can also reduce community resistance. Repeated option contracting between MWD and Sacramento Valley farmers, and the recent entrance of SDCWA into the market, suggests that temporary transfers under option contracts have been successful in reducing institutional resistance to water transfers.

High transaction is another significant market friction impeding water transfers. The IID-MWD and IID-SDCWA transfers – the largest long-term water rights transfers between urban and agricultural users to date – had associated with them millions of dollars in legal and administrative fees and upwards of $100M in environmental mitigation fees. The law requires that the parties involved in a permanent water transfer perform *due diligence*, a costly and time consuming process which involves proving that there is no harm to other parties *or* the environment. (The burden of proof is on the transacting parties to show “no harm” and *not* on the downstream parties who may claim injury.) More than one attempt to transfer permanent water rights has fallen through after years of investment in the process. Finally, the valuation of the water right itself can pose an impediment to trade. A water right is a perpetuity, with uncertainty surrounding the quality and the actual volume of the flows (depending on the seniority of the right), not to mention the actual future value-in-use. Temporary transfers have lower transaction cost than permanent, or long-term, water transfers. The temporary transfer arrangements reduce the complexity of the negotiation, the uncertainty regarding approval, and the time required for environmental review.

High transaction cost and institutional resistance are the prominent sources of market friction for water transfers. As discussed, both are ameliorated under temporary transfers. For the most part, legal impediments to water transfers have been lifted. Nonetheless, there are aspects of the institutional structure of water districts under existing statute that will likely continue to produce resistance to water transfers.[17] These issues require legislative action:

(1) Distribution of proceeds from water sales. Lacking a well-defined social norm for the distribution of proceeds between members of an irrigation district with different landholdings and seniority, the negotiation of a deal that is perceived as fair (and hence receives general buy-in) can be a costly process in terms of both time and legal fees. As the number of temporary (and permanent) transfers increases over time, the establishment of an acceptable template for transfers may help lower these costs. In some cases the institution may lack the requisite authority to handle disbursements given that the distribution of proceeds from water sales was not treated explicitly in the original charter. These are failings in institutional structure require reform.

(2) Ownership of water rights. Transfers may fail to gain support from the general membership due to disagreements about who actually owns the water right and, hence, who should receive payments from the water sale.

(3) Political power. A district's management may be unwilling to permit a transfer that will result in diminished managerial oversight. A water transfer, or sale, reduces the management's direct control of valuable water resources, from which political power is derived.

(4) Artificially low prices for water. Members who wish to purchase additional water may attempt to block access to external markets and thereby keep the interdistrict price of water (artificially) low.

Future Directions

California faces increasing water supply risk due to population and economic growth, historical overdrafting of aquifers, and climate change. The introduction of sound environmental management practices has also necessitated changes in the transfer and use of water. Under climate change, predicted temperature increase will lead to increased evapotranspirative losses during the transport and application of water. Sea level rise resulting in saltwater intrusion into coastal aquifers threatens some local supplies. Additionally, a shift in the timing of snowmelt such that it occurs earlier in the season complicates reservoir management and may result in less water available later in the season. The historical overdrafting of aquifers requires an estimated annual average reduction of two million acre-feet in pumping.[16] Overdrafting, which leads to aquifer compaction, can ultimately destroy the integrity of some of the state's aquifers, thereby eliminating an important source of water and an integral storage component in the water supply system. Finally, population and economic growth is predicted to increase demand for water (some fraction of which can be offset by efficiency measures). Option contracts can help manage the increasing supply risk by facilitating water transfers. The ability to transfer water at a profit also provides an incentive for conservation.

As discussed, the efficacy of option contracts as a water management tool is critically dependent on infrastructure. There are two important future infrastructure considerations: capacity and access. The San Diego County Water Authority currently assesses a 50% chance that they will be unable to convey water southward in a given year. As the volume of water to be transferred increases, the probability of non-conveyance also increases. Construction of a peripheral canal would increase capacity for transfers, reducing the probability of non-conveyance. Access, which is currently determined on a priority basis, versus via a bidding system, also needs to be considered. The cost of an infrastructure investment such as the peripheral canal has to be weighed against the benefits it would provide in terms of risk management in the near and long term, as well as the purported reduction in seismic vulnerability. The cost-benefit analysis should take into account the following factors: (1) pressures on the California water supply, (2) alternatives for supply augmentation in the near-term and the long-term, and (3) the uncertainty regarding future urban and agricultural water use values, as well as energy prices. For instance, an increase in future electricity prices would not only increase the cost of electricity-dependent urban treatment, such as desalination, it would also increase the cost of agricultural production, possibly leading to an even greater incentive for ag-urban transfers. o

Notes

1. Temporary water transfers are not currently subject to a full environmental review under the California Environmental Quality Act (CEQA), as are permanent transfers. This reduces the time, associated costs, and approval uncertainty, entailed with the transfer.

2. California Energy Commission (CEC) (2005), “California’s Water-Energy Relationship,” Staff Report, Sacramento, CA.

3. Knapp, K.C., Weinberg, M, Howitt, R., Poskinoff J.F. (2003) “Water Transfers, Agriculture, and Groundwater Management: A Dynamic Economic Analysis,” *Journal of Economic Management* 76:291—301.

4. The estimates in Figure 1 are for the energy-intensity of pumping groundwater from a local aquifer. The estimates do not include the additional energy required to initially store the water, e.g., the energy used by injection wells, if the groundwater is recovered as part of a groundwater banking program. Nor do they include the additional energy to transport the water if the groundwater supply is outside the demand region. The actual energy required to pump groundwater depends on both the depth of the water table and the efficiency of the pump.

5. The energy limit for reverse osmosis is estimated to be 2.85 kWh/1,000 gal. Current technologies use between 8 and 12 kWh/1,000 gal. An improvement from 8 to 2.85 would yield an energy savings of approximately 1,700 kWh/af. For a more detailed discussion, see Veerapaneni, S. (2007) “Reducing Energy Consumption for Seawater Desalination,” *American Water Works Association Journal*, 99(6):95—106.

6. Kleindorfer, P.R., Wu, D.J., Zhang, E. (2002) “Optimal Bidding and Contracting Strategies for Capital-intensive Goods,” *European Journal of Operational Research* 137(3): 657—676.

7. Tomkins, C.D., Weber, T.A. (2008) “Option Contracting in the California Water Market,” Technical Report #2008-10-09, Department of Management Science and Engineering, Stanford University, Stanford, CA.

8. CEC, ibid., p. 11. (1 MG=3.07 af)

9. Department of Water Resources (DWR) (2005), “California Water Plan,” Sacramento, CA.

10. Ibid., p. 5.

11. Hanak, E., Howitt, R. (2005) “Incremental Water Market Development: The California Water Sector 1985:2004,” *Canadian Water Resources Journal* 30(1):73—82.

12. Estimate of the annual average transfer volume of 1.2 maf in 2000 comes from Hanak, E. (2003) “Who Should Be Allowed to Sell Water in California? Third-Party Issues and the Water Market,” *Public Policy Institute of California*, San Francisco, CA. The total average water use volumes are as reported by DWR, ibid. Data from Gary Liebcap at the Donald Bren School of

Environmental Science & Management, U.C. Santa Barbara indicates an average transfer volume of 690,000 af from 2002 to 2007. The volumes transferred in a given year vary, with typically more water transferred in dry years. In 2003, the volume transferred was estimated as just over 1 maf.

13. The Central Valley Project Improvement Act of 1992 lifted many restrictions on water transfers for CVP contractors, and the Monterey Agreement of 1994 lifted restrictions on transfers by SWP contractors.

14. Hanak, ibid., p. 16.

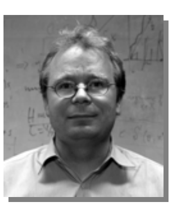
15. The Environmental Water Account was originally under the auspices of CALFED. DWR assumed responsibility after the CALFED program disbanded.

16. Farmers then have an opportunity to “subscribe” to a transfer.

17. A comprehensive review of institutions in the water sector is provided in Thompson, B.H. (1993) “Institutional Perspective on Water Policy and Markets,” *California Law Review* 81:671—764.

Authors

Claire D. Tomkins recently completed her PhD in Management Science and Engineering at Stanford. Her doctoral thesis is entitled “Pricing and Allocation of Water Resources.”
ctomkins@stanford.edu



Thomas A. Weber is an Assistant Professor of Management Science and Engineering at Stanford University. His research is concerned with the economics of information and uncertainty.
webert@stanford.edu

David L. Freyberg is an Associate Professor of Civil and Environmental Engineering, member of the Environmental Fluid Mechanics and Hydrology program, and a Woods Institute for the Environment Fellow by courtesy at Stanford.
freyberg@stanford.edu

James L. Sweeney is a Professor of Management Science and Engineering and Director of the Precourt Institute for Energy Efficiency and a Senior Fellow at the Stanford Institute for Economic Policy Research and the Hoover Institution.
jim.sweeney@stanford.edu

Barton H. Thompson is the Robert E. Paradise Professor of Natural Resources Law and the current director of the Woods Institute for the Environment at Stanford University.
buzzt@stanford.edu

Acknowledgements

The authors are grateful to the numerous individuals in the California water community who shared their expertise and their data, including Bob Campbell and Gordon Hess at SDCWA, Steve Hirsch at MWD, Tim Quinn at the Association of California Water Agencies, Paul Mendoza at the DWR, Ellen Hanak at the Public Policy Institute of California, and Gary Liebcap at U.C. Santa Cruz. Funding for this research was in part provided by Woods Institute EVP grant 1094280-1-WAKAB.