CHOICES
The magazine of food, farm, and resource issues
3rd Quarter 2012 • 27(3)

A publication of the
Agricultural & Applied
Economics Association

Drought Issues in Semi-arid and Arid Environments

Kurt A. Schwabe and Jeffery D. Connor

JEL Classification: Q1, Q2, Q3, Q5
Key Words: Demand-Side Management; Drought; Wastewater Reuse; Water Conservation; Water Scarcity

Drought is a common occurrence in arid and semi-arid (ASA) regions, with regions such as Australia's Murray-Darling River Basin (MDB, Figure 1) experiencing significant droughts once every ten years on average. Climate projections for many ASA regions suggest a future with increased aridity, longer periods without precipitation, and more frequent and intense meteorological drought (Seagar, et al. 2007). Recent drought events and climate analyses indicate such change already may be occurring. Over the past four decades, warm season duration, as measured by warm periods without sizable rainfall, has increased by approximately 3.5% in the Southwestern United States, and by 6.4%—15 days—within California and Nevada (Groisman and Knight, 2008), while the period from the late 1990s through 2009 is considered the driest on record in southeastern Australia. With rising water demands due to population growth, the frequency and degree to which the supply of water falls short of its demand will increases as well.

Figure 1: Map of the Murray-Darling River Basin

The impacts of sustained drought in ASA regions can be broad, with low priority water rights holders, notably the environment and groundwater systems, often suffering severely. There are numerous examples of how drought affects the natural environment through impacts on biotic communities, habitat availability, and ecosystem function, resilience, and services (Schwabe, et al. 2012). Similarly, the added reliance on aquifers during drought often results in overdraft, degradation of groundwater and groundwater dependent ecosystems, and land subsidence (Galloway, et al. 1998).

Not surprisingly, water intensive industries can be significantly impacted, namely agriculture and hydro-electric power. The 2009 drought, for instance, is estimated to have led to the fallowing of 285,000 acres, the loss of nearly 10,000 jobs, and $340 million in lost revenue in California's San Joaquin Valley (Howitt, MacEwan, and Medellin-Azuara, 2011), and a 20% reduction in the value of irrigated agriculture in Australia's MDB (Kirby, et al. 2012). In Spain, the estimated impacts from the 2004-05 drought include agricultural production losses of US$670 million, and reduced hydro-electric production that resulted in losses of US$123 million (Schwabe, et al. 2012).

While the impacts of drought can be far-reaching and impact energy, recreation, municipalities, industry, and residential households, analyses of drought show significant variability in the magnitude of the impacts—there are examples in which the impacts are severe and examples in which the impacts are minor (Wilhite, 1993; Lord, et al. 1995). What we learn about the impacts of drought from analyzing past events and model predictions is that the impacts, not surprisingly, vary over the time and location of the drought. Other factors influencing severity of impact include the vulnerability of the hydrologic system, the level of exposure, and the ability of agents and institutions to respond, mitigate, and adapt to the drought. In this article, we focus on examples of how agents and agencies, particularly in the southwestern United States and Australia, have responded to drought in ASA regions, identify past successes and concerns, and highlight opportunities for future advances.

Drought Adaptation and Mitigation in Semi-Arid and Arid Regions.

Consider three general categories for addressing and reducing the impacts of drought including: (1) modifying the impact of the meteorological event on the available supply of water (supply-side approaches), (2) reducing exposure and vulnerability to drought through demand-side adaptation/mitigation (demand-side approaches), and (3) increasing the ability of agents, sectors, and regions to respond, mitigate, and adapt to drought through institutional changes.

Supply-Side Approaches.

One of the most effective approaches to reduce drought impacts has been the development of water storage and conveyance infrastructure. Development of these structures modifies the distribution of water within and across years and space, and allows low-valued water to be used for high-valued purposes at some later date. Australia's MDB, for instance, has developed enough storage capacity in its dams to supply nearly three years' worth of water (Schwabe, et al. 2012), whereas the federal reservoirs of Lake Mead and Lake Powell can store nearly four times the mean annual flow of the Colorado River (Lord, et al. 1995).

Governments are increasingly considering aquifers as storage, likely in response to environmental concerns and the limited availability of well-suited and low-cost surface water storage opportunities. The use of aquifers as storage, referred to as conjunctive management, is not surprising given the abundant natural storage capacity of aquifers relative to the development of surface water systems in most regions. In California, for instance, where more than 65 water agencies engage in some form of conjunctive management, underground aquifers offer between four to 30 times more storage capacity than do existing surface reservoirs (Hanak, et al. 2011). This additional storage may become increasingly useful to help California adapt to the reduction in the free natural storage provided by the Sierra Nevada snowpack. This snowpack, which currently provides storage equal to approximately 50% of all major man-made storage in California, is predicted to decline as climate warms. Precipitation will increasingly fall as rain rather than snow resulting in earlier springtime runoff in volumes greater than current storage capacity can handle, with the excess flowing out of the basin.

Equally important to storage is the ability to move water around. Many countries with geographically variable rainfall and significant ASA regions transfer large amounts of water from rain-abundant basins to rain-scarce basins. Annual interbasin transfers in Australia's MDB, for example, average approximately a million acre-feet (maf), whereas the California State Water Project, which includes the 444 mile-long California Aqueduct (Figure 2), annually moves 1.4 to 4.0 maf of water from northern California to the Central Valley and southern California. In times of drought, though, it can be important to move water in low-value water areas to high-value water areas, often within the same basin. During the 2009 drought, for instance, approximately 0.5 maf of water was transferred within California's San Joaquin Valley, an adjustment estimated to have reduced the localized impact of drought significantly (Howitt, MacEwan, and Medellin-Azuara, 2011). The lesson

Figure 2: Map of the California Aqueduct

here is that when substantial basin-level variation exists with respect to water usage and value, there may be large returns from allowing intrabasin transfers that likely result in less third-party effects and have lower conveyance and evaporative losses relative to interbasin transfers.

Two other approaches that can extend water supplies in anticipation of drought include wastewater recycling, including storm water capture, and desalinization. The potential benefits of recycling and capture programs include access to a locally reliable source and less reliance on water imports, increases in drinking water supplies, and greater water supply portfolio diversity. Recycled wastewater and storm water capture serves as a replacement for water allocated to river and stream ecosystem restoration, and more recently have been increasingly used as the replenishment source in place of imported water for conjunctive use management.

Traditionally, recycled wastewater and storm water have been used to generate gray water for irrigation and industrial uses. For instance, Adelaide, Australia now receives about 20% of its water supply from recycled wastewater which is used primarily for irrigating horticultural and vegetable crops and green space. More recently, though, treatment processes have been added so that the recycled water can meet drinking water standards. This water, in both California and Australia, typically is injected into groundwater or recharge basins for a period of time before it can be extracted and used as a drinking water source, a procedure called indirect potable reuse (IPR). Southern California agencies, for example, have embraced recycled wastewater as part of their water portfolio as evidenced by the Orange County Water District's Groundwater Replenishment System (GRS). Since 2008, the GRS, the largest IPR project in the world, has produced nearly 0.273 maf of high-quality water that exceeds all state and federal drinking water standards (Dunivin, Patel, and Clark, 2011). The treated water is injected into recharge basins where it improves groundwater quality and, ultimately, provides drinking water to nearly 600,000 people.

Advances in reverse osmosis technology, coupled with water agencies' desire for a more reliable water supply, has resulted in a push for more desalinization plants. As of 2010, nearly 13,000 industrial-scale desalinization plants existed worldwide. Spain, for example, has nearly 700 ocean desalinization plants along its Mediterranean Coast (Schwabe, et al. 2012), while Australia recently built plants in Adelaide, Perth, Sydney, and Melbourne, with designs for a large plant in Victoria. In California, desalinization is an evolving alternative with 17 proposed ocean desalinization facilities along its coast, including the recently approved Carlsbad plant just north of San Diego which would be the western hemisphere's largest ocean desalinization plant.

Significant concerns exist with ocean desalinization, though, especially surrounding energy use, air emissions, and impacts on marine species and ecosystems from both the intake of water and discharge of brine. From an energy and cost perspective, for instance, new desalinization in major Australian cities is typically supplying water at two to three times more cost per unit of water supply than older surface and groundwater supply sources, with a two- to four-fold increase in energy intensity (Kenway, et al. 2010). The proposed Carlsbad plant in Southern California, meanwhile, which was approved by the state in 2009 and would produce 56,000 acre-feet annually, now faces two hurdles, not completely unexpected: will it be able to sell the water at a competitive price to local water agencies, and will there be additional environmental restrictions on its intake of ocean water? Less controversial is the desalinization of brackish groundwater since it can be locally produced at a lower cost than ocean desalinization and does not need to be near a coast. In contrast, there are other approaches which include measures such as improved outdoor water use practices that can save both money and reduce energy use in water supply.

Demand-Side Approaches.

Historically, the drivers behind reducing water use during, or in anticipation of, drought have been water use restrictions, opportunistic programs promoting water conservation—for example, rebates for water efficient indoor appliances, subsidies for irrigation—and, more recently, water pricing. The agricultural sector, which accounts for over 75% of the water use in many ASA regions, has responded to these drivers with adaptation and mitigation strategies that include deficit irrigation, irrigation efficiency improvements, the intermittent fallowing of low-valued crops, and changing to the production of less water-intensive crops. For example, in a survey of grower responses to the 1987-92 drought in California, Zilberman and colleagues found that within the agricultural rich yet arid regions of the Central Valley, sprinkler and drip irrigation adoption increased significantly in place of furrow and border irrigation; in addition to some fallowing, cotton and alfalfa cultivation was reduced in favor of tomatoes and other higher-valued vegetable crops (Zilberman, et al. 1998). In addition to increases in water-use efficiency, these drivers have led to increases in economic efficiency as water has moved from low to higher valued crops thereby raising the value per unit of irrigated water. During Australia's recent Millennium Drought, for instance, the gross value of irrigated agriculture per unit of irrigated water in Australia's MDB increased by 241%, though part of this productivity improvement may be a long-term trend rather than a specific response to drought (Kirby, et al. 2012).

Significant per capita reductions in residential water use have also occurred, mostly through the adoption of water conserving indoor appliances, including high-efficiency washers, toilets, and shower heads. From 1995 to 2005, for instance, average per capita urban water use in California decreased by approximately 25% (Hanak, et al. 2011). While such measures have helped to reduce water scarcity and, consequently, the vulnerability of any particular region to drought, there seems to be significant opportunities for further reduction through improvements in landscape irrigation and design. Not surprisingly, then, a major focus of many water agencies in ASA regions is on improvements in urban outdoor water use, which accounts for over one half the water use in most ASA cities. California's water agencies, for instance, have been mandated to reduce their water use by 20% by 2020, which certainly seems possible when compared to urban water use in other countries. As noted by Hanak and colleagues, urban water use in California averages 201 gallons per capita per day (gpcd), whereas in Australia's major cities water use is between 80 to 130 gpcd, and in Israel and Spain it is 84 gpcd and 76 gpcd, respectively (Hanak, et al. 2011).

From an economic perspective, drought impacts will be largely a function of an economy's reliance on water. Reliance can be reduced through efficiency gains, but also by changes in the composition of economic activity. California is a prime example of this, with an agricultural sector that is currently responsible for approximately 75% of the state's water use yet contributes less than 3% to its GDP and labor force. Interestingly, as the proportional value of agriculture to the entire economy decreases, the relative value of water in nonconsumptive uses increases over time. As a result, the cost of drought to economic activities that use water non-consumptively is now often greater than the costs to economic activities that use water consumptively, such as irrigation. For example, Lord and colleagues found that more than 50% of the damages from an extreme drought in the Colorado River arise from losses in hydropower opportunity, decreases in water quality, and lost tourism (Lord, et al. 1995).

Implications from Past and Recent Successes.

Historically, the main response to water scarcity and drought in many ASA regions was to build more surface water storage. Looking forward, opportunities for increased surface water storage appear to be quite limited. Significant future opportunities to adapt and mitigate drought likely involve further institutional developments that (1) increase the opportunities to allocate water more efficiently across space and time through the use of water markets and water banks, and (2) promote cooperation within and across water catchment areas and among diverse water use interests.

Water markets and water banks provide regions and countries with an efficient mechanism for allocating water to its highest valued consumptive uses dynamically with changing conditions. The presence of well-functioning temporary and permanent water markets in Australia, which arguably has the most sophisticated and advanced water markets globally, has reduced the impacts of drought significantly. From 2007 to 2010, nearly one third of all water in the MDB has been traded and this is estimated to have reduced the economic impact of drought on the irrigation economy by 50%. The ability to bank water across seasons has recently been introduced to irrigators in the MDB with estimated gains in agricultural productivity near 12% in one case study (Hughes, 2009). While water banks are not abundant in the southwest United States, they do exist and have been shown to help reduce drought. For example, California Emergency Drought Bank established in the early 1990s is estimated to have reduced the damages of drought by $104 million (Easter, Rosegrant, and Dinar, 1998).

An important reform necessary in many contexts to facilitate wide spread water markets and banking involves improved monitoring and metering of surface and groundwater extractions with property rights consistently defined in volumetric terms. Such actions would provide more accurate price signals of the scarcity value of water which, in turn, can promote more efficient water use. More accurate monitoring and metering is critical to governments who use water markets to cost-effectively provide for the environment. Water trusts and government entities in the Pacific Northwest and Australia, for example, are buying or leasing water through markets and achieving better environmental outcomes at less opportunity cost to consumptive uses (Garrick, et al. 2012). Improvements that will further develop water markets to better manage drought include: infrastructure improvements to allow more flexible inter-basin trading, and streamlining the approval process for trades through mechanisms such as zone-based trading ratios or preapproved trades that identify and account for third-party effects (Hanak, et al. 2011).

Finally, one of the great challenges in effectively addressing drought is that many diverse and geographically dispersed interests are involved. As outlined above, opportunities exist to reduce the impacts of drought through the reallocation of water across space and time via inter- and intrabasin transfers, water banking, and from greater storage through aquifer use. Experience shows, however, that the benefits are less often realized when coordinated actions across state, national, and catchment borders are required, and when cooperation across diverse water use interests such as irrigation and the environment are required. Institutions that facilitate information sharing and involve representation from key stakeholders can, however, significantly improve prospects for cooperative, multiparty adaptations to drought. Spain has some of the best examples of information systems, information sharing, and negotiation processes that facilitate drought mitigation. This involves both quantitative analysis of measures that minimize drought impacts using integrated river basin models to monitor drought risk and the effects of specific mitigation strategies, and the sharing of this information with drought management committees comprised of diverse stakeholders from key economic and environmental water interests.

For More Information

Dunivin, W., Patel, M., and Clark, J. (2011, August). Expanding Orange County's Groundwater Replenishment System. *Water, Environment, and Technology*, 56-59.

Easter, K., Rosegrant, M., and Dinar, A. (1998). *Markets for Water: Potential and Performance.* Boston, MA: Kluwer Academic Publications.

Galloway, D., Hudnut, K., Ingebritsen, S., Phillip, S., Peltzer, G., Rogez, F., and Rosen, P. (1998). Detection of aquifer system compaction and land subsidence using interferometric synthetic aperture radar, Antelope Valley, Mojave Desert, California. *Water Resources Research, 34*, 2573–85.

Garrick, D., Bark, R., Connor, J., and Banerjee, O. (2012). Environmental water governance in federal rivers: the opportunities and limits of the subsidiarity principle in Australia's River Murray. *Water Policy*, In-press.

Groisman, P., and Knight, R. (2008). Prolonged dry episodes over the conterminous United States: new tendencies emerging during the last 40 years. *Journal of Climate*, 21, 1850–1862.

Hanak, E., Lund, J., Dinar, A., Gray, B., Howitt, R., Mount, J., Moyle, P., and Thompson, B. (2011). *Managing California's Water: From Conflict to Reconciliation.* San Francisco, CA: Public Policy Institute of California.

Howitt, R., MacEwan, D., and Medellin-Azuara, J. (2011). Drought, Jobs, and Controversy: Revisiting 2009. University of California Giannini Foundation. Available online: http://giannini.ucop.edu/media/are-update/files/articles/V14N6_1.pdf

Hughes, N. (2009). *Management of irrigation water storages: carryover rights and capacity sharing.* Presented at the Australian Agricultural and Resource Economics Society Meetings 2009, Cairns, Australia. Available online: http://ageconsearch.umn.edu/bitstream/47642/2/Hughes.pdf

Kenway, S., Priestly, A., Cook, S., Seo, S., Inman, M., Gregory, A., and Hall, M. (2008). Energy use in the provision and consumption of urban water in Australia and New Zealand. CSIRO Water for a Healthy Country National Research Flagship. Available online: http://www.csiro.au/files/files/pntk.pdf

Kirby, M., Connor, J., Bark, R., Qureshi, E., and Keyworth, S. (2012). *The economic impact of water reductions during the Millennium Drought in the Murray-Darling Basin.* Presented at the Australian Agricultural and Resource Economics Society Annual Conference 2012, Freemantle, Australia. Available online: http://ageconsearch.umn.edu/bitstream/124490/2/2012AC%20Kirby%20CP%20of%20Poster2.pdf

Lord, W., Booker, J., Gretches, D., Harding, B., Kenney, D., and Young, R. (1995). Managing the Colorado River in a Severe Sustained Drought: An Evaluation of Institutional Options. *Water Resources Bulletin*, 31(5), 939-944.

Schwabe, K., Albiac. J., Connor, J., Hassan, R., and Meza-Gonzalez, L. (2012). *Drought in Semi-Arid and Arid Environments: A Multi-Disciplinary and Cross-Country Perspective.* Dordrecht, The Netherlands: Springer Publishing.

Seager, R., Ting, M., Held, I., Kushnir, Y., Lu, J., Vecchi, G., Huang, H., Harnik, N., Leetmaa, A., Lau, N. Li, C., Velez, J., and Naik, N. (2007). Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America. *Science, 316,* 1181.

Wilhite, D. (1993). *Drought Assessment, Management, and Planning: Theory and Case Studies.* Boston, MA: Kluwer Academic Publishers.

Zilberman, D., Dinar, A., MacDougall, N., Khanna, M., Brown, C., and Castillo, F. (1998). *Private and Institutional Adaption to Water Scarcity during the California Drought, 1987-1992.* Washington, DC: U.S. Department of Agriculture, Economic Research Service, Staff Paper No. 9802.

Kurt A. Schwabe (kurt.schwabe@ucr.edu) is Associate Professor of Environmental Economics and Policy, and Associate Director, Water Science and Policy Center, University of California-Riverside, Riverside, California. Jeffery D. Connor (jeff.connor@csiro.au) is a Senior Research Scientist and Environmental Economist at the Ecosystem Sciences Division, Commonwealth Scientific and Industrial Research Organization, Adelaide, South Australia.