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Mapping water availability, projected use and cost in the western United States

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Abstract

New demands for water can be satisfied through a variety of source options. In some basins surface and/or groundwater may be available through permitting with the state water management agency (termed unappropriated water), alternatively water might be purchased and transferred out of its current use to another (termed appropriated water), or non-traditional water sources can be captured and treated (e.g., wastewater). The relative availability and cost of each source are key factors in the development decision. Unfortunately, these measures are location dependent with no consistent or comparable set of data available for evaluating competing water sources. With the help of western water managers, water availability was mapped for over 1200 watersheds throughout the western US. Five water sources were individually examined, including unappropriated surface water, unappropriated groundwater, appropriated water, municipal wastewater and brackish groundwater. Also mapped was projected change in consumptive water use from 2010 to 2030. Associated costs to acquire, convey and treat the water, as necessary, for each of the five sources were estimated. These metrics were developed to support regional water planning and policy analysis with initial application to electric transmission planning in the western US.

S Online supplementary data available from stacks.iop.org/ERL/9/064009/mmedia

Keywords: water planning, water availability, water cost, western United States, projected water use

Introduction

Water is used to grow crops, power industry, generate electricity, extract minerals, raise healthy families, enhance recreation and is central to a vibrant environment. Institutions have been developed to allocate and regulate its use, while massive infrastructure projects have been constructed to capture, store, convey, treat and deliver water to hundreds of millions of users across the United States. These systems are constantly evolving to keep pace with new demands for water from growing cities, expanding industry, and energy development.

New demands for water can be satisfied through a variety of source options. Traditionally, new demands are first met with unappropriated surface or groundwater sources, as these waters are usually least expensive to develop. Unappropriated water refers to those resources whose allocation is managed by a system of water rights and which are in excess of current appropriations (Gopalakrishnan 1973). Allocation of unappropriated water to a new use simply requires authorization from the state in the form of a water right. Where unappropriated sources are limited the transfer (sale) of an existing water right might be considered as a means of satisfying new water demands. The transferred water can be made available for the new use through abandonment of the old use or through water savings achieved with improved efficiency. There is also the option of using a non-fresh source of water (e.g., municipal wastewater or brackish groundwater), which requires the added cost of water treatment.

The relative availability and cost of each source are key factors in determining which water source to develop. Availability and cost varies greatly by location, depending on such things as climate, basin hydrology, engineered infrastructure, use characteristics, legal and regulatory institutions, as well as the personal values of those living in the basin. Given these complicating factors, the spatial and temporal variability of these factors and limited supporting data, estimating water availability and cost is difficult. Past efforts have proposed metrics for surface/groundwater availability (unappropriated water) which provide a consistent basis of comparison across an extensive geographic region. Examples include the Water Stress Index, defined as the ratio of available river runoff to population in a basin (Falkenmark *et al* 1989) and the water supply stress index which considers regional trends in both water supply and demand (e.g., Averyt *et al* 2013). Roy *et al* (2005) take a similar approach except that their metric is constructed as the ratio of water withdrawal to effective precipitation. Other metrics are based on multiple criteria that are aggregated and related to some threshold of water availability/sustainable development (e.g., Roy *et al* 2012, Sovacool and Sovacool (2009), Hurd *et al* 1999). Although dated, a comprehensive analysis of US fresh water availability was conducted in 1975 as part of the Annual Water Adequacy Analysis performed as part of the Second National Water Assessment (US Water Resources Council 1978).

As traditional freshwater supplies become stressed (e.g., Averyt *et al* 2013, US Bureau of Reclamation 2013, 2010, Roy *et al* 2012, Reilly *et al* 2008) a more comprehensive view of water availability is required. Current metrics are limited to unappropriated surface and groundwater; however, other sources of water exist for which comparable metrics need to be developed. Existing metrics consider the physical availability of water; however, access to a given supply is often constrained by institutional controls like interstate compacts, treaties and water rights allocation schemes. Such considerations need to be incorporated into water availability metrics. Finally, costs differ considerably across sources, so water availability metrics need to be accompanied by estimated costs to secure, treat and convey each source of water.

The objective of this study is to estimate water availability, change in consumptive use (that water that is withdrawn from a watershed but not returned) and cost to inform water planning decisions at a regional level. Water availability and cost metrics were developed for five different sources of water including unappropriated surface water, unappropriated groundwater, appropriated water, municipal wastewater, and brackish groundwater. These metrics were mapped for over 1200 watersheds throughout the western US (states west of the 100th meridian). These basin scale estimates of water availability and cost are not intended to support siting decisions at the local scale, or to evaluate whether available water supplies are sufficient to meet growing demands; rather, their purpose is to provide a consistent and comparable measure of the relative difficulty and expense to develop the water resources in a given basin.

Methods

Availability, change in consumptive use, and cost of water were mapped for the 17-conterminous western states (see appendix for a list of states). Specifically, water availability was mapped according to five unique sources including unappropriated surface water, unappropriated groundwater, appropriated surface/groundwater, municipal wastewater, and brackish groundwater. Competing uses for the available water supply were also projected over the next 20 years. To complete the picture associated costs to acquire, convey and treat the water, as necessary, for each of the five sources was estimated.

Originally, these metrics were developed to support electric transmission planning in the western US (ERCOT 2013, WECC 2013). Specifically, these metrics were developed to aid in the regional siting of new thermoelectric generation so as to minimize impacts on water resources and lessen issues with water permitting. Nevertheless, these data are largely generalizable to other regional water development and policy analysis studies. However, it is realized that water quality requirements and related treatment costs vary by use. In order to maintain a consistent basis for comparison, all water costs assume a high level of treatment; that is, advanced treatment standards for wastewater and potable water standards for brackish groundwater.

Mapping water availability, future use and cost followed a three step process including raw data collection, translation of the data to a consistent reference system, and metric formulation. Raw data were acquired from a variety of sources. Where available, data were collected directly from the western states. In collecting the data, the study team engaged directly with state water data experts to identify and at times gain access to the data. In most cases the data came from the state's water plan that was generally available from on-line sources (see appendix for a partial list of data sources). Efforts were made to vet the collected water data with the state experts to verify the fidelity of data collected and any data conversion/translation made to render the data in a consistent and comparable format. Federally reported data were used as necessary to fill in gaps, including information derived from the US. Geological Survey (USGS), Environmental Protection Agency (EPA), Energy Information Administration, US. Department of Agriculture (USDA) and others.

This analysis made use of multiple data sets from multiple sources reported at differing geographic resolutions (e.g., point, county, watershed, state). For purposes of this analysis, a consistent reference system was required. The 8-digit Hydrologic Unit Code (HUC) watershed classification (e.g., Seaber *et al* 1987) was adopted, which resolved the 17 western states into 1208 unique hydrologic units. The 8-digit HUC was selected as it provided a physically meaningful unit relative to water supply/use and provided the highest level of detail that can be justified with the data consistently available across all 17 western states. Where a watershed was divided by a state boundary individual water availability/cost metrics were developed for each state's portion of the watershed, reflecting differences in use/policy among the states. For raw data reported in point-format, translation to the 8-digit HUC was achieved by simple aggregation/averaging. For raw data reported in polygonal-format, translation followed a simple population or areal weighting. In the case of water use data, the 1995 USGS water use reported at the 8-digit level (Solley *et al* 1995) provided the needed spatial weighting function.

The fact that the data came from multiple sources also meant that they were associated with different periods of time. In fact, the different data sets span a range of time of approximately ten years. To account for this temporal variability, efforts were made to adjust the data to current conditions. Water availability data were adjusted through the process of vetting collected data with the state water management agencies, while water cost data were adjusted to constant 2012 dollar values (see below).

There are no broadly accepted measures of water availability and cost that span the entire 17-state region. Rather, metrics needed to be developed from the raw data collected from the states and federal agencies. The challenge was to formulate water availability and cost metrics that appropriately balance the underlying complexity of the system (e.g., physical hydrology, climate, use characteristics, technology and water management institutions) with the data that were consistently available across the entire western US. To assist in striking such a balance, water availability/cost metrics were formulated with the help of subject experts. Specifically, representatives from the Western Governors' Association, Western States Water Council, USGS, and individual state water management agencies assisted in defining appropriate and informative water metrics (in total the team included 11 participants plus the author team). These metrics were developed and vetted over a two month period during 6 webinars lasting roughly 90 min each.

Below the basic framework used to estimate water availability and cost metrics is given. Details concerning the basin-by-basin calculations are beyond the scope of this paper. Rather, specifics on calculations performed by metric, water source, and HUC are available in the state specific databases associated with the project decision support system (see below).

Water availability metrics

Unappropriated surface water. States exercise full authority in matters pertaining to off-stream water use. In the western states water is managed according to the doctrine of prior appropriation, which defines a system of priority where the first to make beneficial use of water has the first right to it in times of drought (Gopalakrishnan 1973). Any new water use is allocated the most junior priority in the basin with delivery in times of drought occurring only after all water rights senior to it are fulfilled. Rights to unappropriated surface water are obtained through permitting with the state's water management agency. Although the states have different terms for such water, here it is referred to it as unappropriated surface water.

Estimating the availability of unappropriated surface water is difficult as these values depend on a number of complex factors; characteristics of the physical water supply, the water rights structure in relation to supply, interstate compacts, international treaties, and state policies. Fortunately, many western states have developed measures of unappropriated surface water availability to manage both water allocation and development within their state. Where available, these values were adopted for use in this study; specifically, state estimated unappropriated surface water values were obtained from Arizona, California, Colorado, Nevada, New Mexico, Oklahoma, Oregon, South Dakota, Texas, Utah, and Wyoming.

Where unappropriated surface water availability values were lacking we worked directly with state water managers to develop rough estimates. Efforts began by identifying basins closed to new appropriation, in such cases available unappropriated surface water was set equal to zero. In the remaining open basins, streams tend to lack regulation by interstate compacts, and flows tend to be large with respect to water use. In such cases environmental concerns are the most likely factor to constrain the permitting of new water uses. A simple (i.e., data are fully available at a HUC-8 level) and widely used environmental standard in the US (Reiser *et al* 1989) is based on studies by Tennant (1976) which found streams maintain excellent to good ecosystem function when streamflows are maintained at levels of ⩾30–60% of the annual average. For this study, a conservative threshold of 50% was adopted to define unappropriated surface water. Thus for basins where estimates were not available directly from the states, unappropriated surface water, Q_{usw}, was calculated as:

$$Q_{usw}^{j} = 0.5 * \left(Q_{p}^{j} + C^{j}\right) - C^{j} \tag{1}$$

where j designates the watershed, Q_p is gauged streamflow, and C is the total consumptive use of water upstream of the gauging point. States differed on the streamflow statistic which they preferred to use in calculating unappropriated surface water availability. The adopted streamflow ranged from the 50th percentile flow (average annual flow) to a 10th percentile flow (representative of drought conditions). Streamflow data were taken from the National Hydrography

Dataset (NHDPlus 2005) while consumptive water use data were taken directly from individual state estimates.

Unappropriated groundwater. States also exercise full authority over the allocation of groundwater resources. Determining the availability of groundwater for future development is complicated by numerous factors including the manner with which groundwater is managed (e.g., strict prior appropriation, right of capture); the physical hydrology of the basin; degree of conjunctive management between surface and groundwater resources; allowable depletions, and a variety of other issues. Except in very limited cases, the states have not broadly estimated and published data on the availability of unappropriated groundwater.

Where states have estimated unappropriated groundwater availability, these values were used. This was the case for Arizona, Oklahoma, Nevada, and South Dakota. For all other states a simple water balance approach was adopted. More sophisticated formulations were limited by the aforementioned complexities and relative lack of supporting data. Unappropriated groundwater was set equal to the difference between annual average recharge and annual groundwater pumping. Recharge rates were taken from the US Geological Survey (2003), which are derived from stream baseflow statistics, while pumping rates were taken from state data where available or from USGS (Kenny *et al* 2009) otherwise. With this approach unappropriated groundwater availability was set equal to a basin's sustainable recharge or equivalently to a condition of zero groundwater depletion. This is a conservative assumption given that western states often allow managed depletions.

To account for unique groundwater management and/or aquifer characteristics, further restrictions on unappropriated groundwater availability were introduced. Specifically, availability was set to zero in watersheds located within state defined groundwater protection zones (data acquired directly from each state). Groundwater availability was likewise set to zero in watersheds realizing significant groundwater depletions (groundwater declines exceeding 12 m of predevelopment conditions, as given by Reilly and others [2008]). Finally, groundwater availability was set equal to zero in any watershed where 10% or less of its land area is underlain by a principle aquifer (Reilly *et al* 2008).

Appropriated water. This source was defined by the quantity of water (both surface and groundwater) that could be made available by abandonment and transfer of the water right from its prior use to a new use. Short-term leases of water were not considered as the focus of the study is the availability of water for new, permanent uses (e.g., municipal expansion, electric power plant) for which a lease would not provide the needed security in water supply. Permanent transfers have traditionally involved the sale of water rights made available through abandonment of the old use or through water savings achieved through improved system efficiency.

The availability of appropriated water is strongly influenced by the price of water, as the price increases more water rights holders would be willing to sell. The price-quantity relationship dictating water availability is a complex function of the water rights priority structure, the current value (monetary, traditional) ascribed to the water by each water rights holder, community cohesion, attitudes toward development, and others. A simpler approach is justified when one recalls that the purpose of the analysis is to develop a measure that can be consistently compared across basins and water sources. To maintain consistency with the other sources we assume no 'disruptive' changes to the water rights markets in the West. In the absence of major price changes for water rights, western states project a decrease of about 5% in total irrigated agriculture over the next 20 years due to loss of land to urban development and permanent sales of water rights (see sources in the appendix). These sales are most likely from irrigated lands of low value crops.

The appropriated water availability metric was constructed based on the irrigated acreage in a given watershed that is devoted to low value agricultural production; specifically, irrigated hay and alfalfa. Data (irrigated acreage and water volume applied) were taken from the USDA's Agricultural Census (US Department of Agriculture (2007)). Appropriated water availability was further limited to 5% of the total irrigated acreage in the watershed based on projections from western states water managers. For watersheds experiencing significant groundwater depletions (see unappropriated groundwater metric above) the available appropriated water was reduced by 50%. This is to account for a portion of future water rights abandonment that is likely to be used to offset the groundwater depletion (Brown 1999).

Municipal wastewater. Non-fresh water supplies offer important opportunities for new development. Municipal wastewater is rapidly being considered as an alternative source of water for new development, particularly in arid regions. Municipal wastewater discharge data is consistently available throughout the US. The EPA publishes a pair of databases (Permit Compliance System [US EPA (2011)], and Clean Watershed Needs Survey [US EPA (2008)]) that provide information on the location, discharge, and level of treatment for most wastewater treatment plants in the US Additionally, the USGS (Kenny *et al* 2009) publishes municipal wastewater discharge values aggregated at the county level. These three sources of information were combined to provide a comprehensive view of current wastewater discharge across the West. Additionally, the projected growth in municipal wastewater discharge to 2030 was estimated (see Future Water Use section below) and added to the current discharge rates.

Not all wastewater discharge is available for future use, as a considerable fraction is currently re-used by industry, agriculture, and thermoelectric generation. Re-use estimates were determined both from the USGS (Kenny *et al* 2009) data as well as the EPA databases (as they record the point of discharge, e.g., stream, agriculture, power plant and in some cases are designated as discharging to 'reuse'). These re-use estimates were subtracted from the projected discharge values.

In western states the availability of municipal wastewater must consider return flow credits. Those municipalities that discharge to perennial streams receive return flow credits for treated wastewater. This water is not available for new development as it is already being put to use downstream. Unfortunately, there are no comprehensive data on wastewater return flow credits. In efforts to identify plants that are likely credited for their return flows, those plants that directly discharge to a perennial stream were identified (point of discharge was identified in the databases noted above as being a stream with average flow of 0.028 $m^3\ sec^{-1}$ or more). These plants were excluded as a source of available municipal wastewater.

Shallow brackish groundwater. For purposes of this analysis brackish water was defined by salinities between 1000 and10 000 ppm total dissolved solids (TDS). Additionally, the analysis was restricted to resources no deeper than 760 meters. These limits were adopted as deeper, more concentrated resources would generally be very expensive to exploit.

Estimates of brackish groundwater resources across the western US are very limited. To cover the entire study area required the use of multiple sources of information. The best quality data are state estimated volumes of brackish groundwater that are potentially developable; however, these data are only available for Texas (LBG-Guyton Associates 2003), New Mexico (Huff 2004), and Arizona (McGavock 2009). States limit appropriation of the resource by applying allowable depletion rules. In this case it was assumed that only 25% of the resource could be depleted over a 100-year period of time (annual available water was determined by multiplying estimated total volume of brackish water by 0.0025).

The next best source of data was the reported use of brackish groundwater published by the USGS (Kenny *et al* 2009). These data do not provide a direct measure of available water, simply an indication that brackish water of developable quality is present. Conservatively we assumed that double the existing use could be developed up to a maximum limit of 13.8 million cubic meters per year ($Mm^3\ yr^{-1}$). Also assumed is that the minimum quantity available was 1.4 $Mm^3\ yr^{-1}$.

Finally, if a watershed had no brackish water volume estimate or brackish water use then the presence of brackish groundwater wells was used. The USGS maintains the National Water Information System (NWIS) database which contains both historical and real-time data of groundwater well depth and quality (US Geological Survey (2011)). Where at least one brackish well existed in the dataset, the watershed's brackish water availability was set to 1.4 $Mm^3\ yr^{-1}$. To avoid including brackish water that may contribute to potable stream flow, availability was set to zero when the average depth to brackish water was less than 15 m and the salinity was less than 3000 ppm TDS.

Future consumptive water use

There are a number of water use sectors competing for the available water supplies mapped above. As with water availability, state water managers were engaged to characterize projected consumptive water use across the western US. Acquired data largely came from the state's individual water plans and other online sources (see appendix). Consumptive water use was distinguished according to current versus projected future use; withdrawal versus consumptive use; and, the source water (e.g., surface water, groundwater, wastewater, saline/brackish water). Uses were also distinguished by sector; specifically, municipal/industrial, thermoelectric, and agricultural.

Water use projections varied by state in terms of spatial resolution, target dates, and scenarios of growth. All projected future uses were mapped to an 8-digit HUC level following a strategy similar to that adopted and discussed for water availability. Projections were also uniformly adjusted to the year 2030. This was achieved through simple linear extrapolation between current use estimates and those projected at target dates beyond 2030. Where multiple growth scenarios (e.g., high, medium and low) were estimated in the individual state water plans, all data were collected; however, only the 'medium' growth projections are reported here.

Water cost metrics

Each of the five sources of water carry a very different cost associated with utilizing that particular source. The interest here was to establish a consistent and comparable measure of the cost to deliver water of potable quality to the point of use. As with water availability, costs were resolved at the 8-digit HUC level. Considered were both capital and operating and maintenance (O&M) costs. Capital costs capture the purchase of water rights as well as the construction of groundwater wells, conveyance pipelines, and water treatment facilities, as necessary. All capital costs were amortized over a 30-yr horizon and assumed a discount rate of 6%. O&M costs included expendables (e.g., chemicals, membranes), labor, waste disposal as well as the energy to lift, move and treat the water. As the utilized cost values come from a variety of sources published over a range of time, all costs are adjusted to constant 2012 dollar values based on the consumer price index. Below, specifics unique to each source are discussed.

Unappropriated surface water. No costs are assigned to unappropriated surface water. It is recognized that there are associated costs, in particular for permitting. No efforts were made to estimate permitting cost because of the difficulty and uncertainty in estimating the most important determinant, time. Given that some level of permitting is required across all five water sources this expense would do little to distinguish differences in costs, which is of primary interest here.

Unappropriated groundwater. Assumed capital costs are largely associated with the construction of groundwater wells. Drilling and construction costs were estimated following the approach outlined in Watson and others (2003). Costs were dictated both by the quantity of groundwater required and the depth to groundwater. For purposes of comparison a standard water demand of 4.4 $Mm^3\ yr^{-1}$. was assumed (based on average withdrawals for a 300 MW coal-fired power plant using recirculating cooling [see Macknick *et al* 2012]), while the depth to groundwater was taken from USGS well log data (US Geological Survey (2011)) averaged at the 8-digit HUC level. O&M costs are dominated by the electricity needed to lift the water. The price of electricity was assumed to be \$0.35 kWh^{-1}.

Appropriated water. Costs associated with this source of water result from the purchase and permanent transfer of a water right from a prior use to some new use. The price of a water right is market driven. The price fluctuates with either a change in demand for water or the number of willing participants (i.e., supply) in the market. Here we did not attempt to project how the market for water rights will fluctuate over time given the difficulty and considerable uncertainty involved in such an analysis. Rather, a fixed price was adopted based on historical trading data. This approach assumes no major changes in market forces, consistent with state projections of limited abandonment of irrigated agricultural over the next 20 years. Although this assumption can be argued, it provides the only available basis for consistent cost comparison for which a trusted set of data exists.

Water rights transfer costs utilized by this analysis were based on historic data collected by the *Water Strategist* and its predecessor the *Water Intelligence Monthly* (Water Strategist 2012). Costs were estimated by state because of the limited availability of data. Only transactions involving permanent transfers from agriculture to urban/industrial use were considered. Recorded transfers were averaged by year and by state and the average of the last 5 years used for purposes of this study.

Unfortunately the *Water Strategist* did not track water transfer data for North and South Dakota, Nebraska, Kansas and Oklahoma. Costs for these states were simply calculated as the average of the surrounding states. To respect the north to south gradient in cost (see Results section), North Dakota and Nebraska were assigned costs equal to the average of the 5 northern states while Kansas and Oklahoma were assigned values based on the average of the 7 southern states.

Municipal wastewater. Estimated costs considered expenses to lease the wastewater from the municipality, convey the water to the new point of use, and to treat the wastewater. Fees charged to lease treated wastewater from the municipality were estimated based on the initial work of the Electric Power Research Institute (EPRI 2008). Values reported in the EPRI report were verified and updated as necessary based on a review of fees published on-line. As no geospatial or plant related trends were noted in the pricing an average of the reported fees was adopted for this study, which was calculated at \$0.32 m^{-3}.

Also considered was the cost to transport the treated wastewater from the treatment plant to the point of use. Considered were both capital construction costs for a pipeline and O&M costs principally related to the electricity for pumping. Associated cost calculations were consistent with Watson and others (2003). Water conveyance costs were dictated by the distance between the treatment plant and point of use. As the distance values are currently unknown (associated with a new point of use) estimates were made as a function of land use density, defined as the ratio of developed land area to total land area in the buffer zone. Land use densities were calculated using a circular buffer area with a radius of 8.05 km around all existing treatment plants. Where more open land is available around a treatment plant (low land use density) a new water user can locate in close proximity to minimize conveyance distance. Thus, conveyance distances were estimated according to a simple rank order of land use density around each treatment plant, with low values given a conveyance distance of 1.61 km and to the highest land use density given a distance of 8.05 km.

It was assumed that all wastewater must be treated to advanced standards before it can be re-used. This conservative assumption was adopted considering both realized improvements in downstream operations (e.g., increased cycles of use, reduced scaling, improved feed quality) and the current trend of regulation toward requiring advanced treatment (EPRI 2008). Plants operating at primary or secondary treatment levels (US EPA 2008, 2011) were assumed to be upgraded to advanced standards. Capital construction costs were based on the analysis of Woods *et al* (2013), which scale according to treatment plant throughput and original level of treatment. Associated O&M costs considered expenses for electricity, chemicals and labor.

Shallow brackish groundwater. Estimated costs considered both capital and O&M costs to capture and treat the brackish groundwater. Cost calculations followed standards outlined in the Desalting Handbook for Planners (Watson *et al* 2003). Capital costs included expenses to drill and complete the necessary groundwater wells and construct a treatment plant utilizing reverse osmosis. Number of wells and treatment plant capital costs were based on the treated volume of water, which was assumed to be 4.4 $Mm^3\ yr^{-1}$. Other key design parameters included the depth of the brackish water and TDS. These data averaged at the 8-digit HUC level, were estimated from the USGS brackish groundwater well logs (US Geological Survey (2011)). O&M costs captured expenses for labor, electricity, membranes and brine disposal.

Results

Water availability

Water availability is mapped for the five unique sources of water for the 17-conterminous western states at the 8-digit HUC level in figure 1. Water availability for all five sources is mapped using the same non-linear scale and coloring.

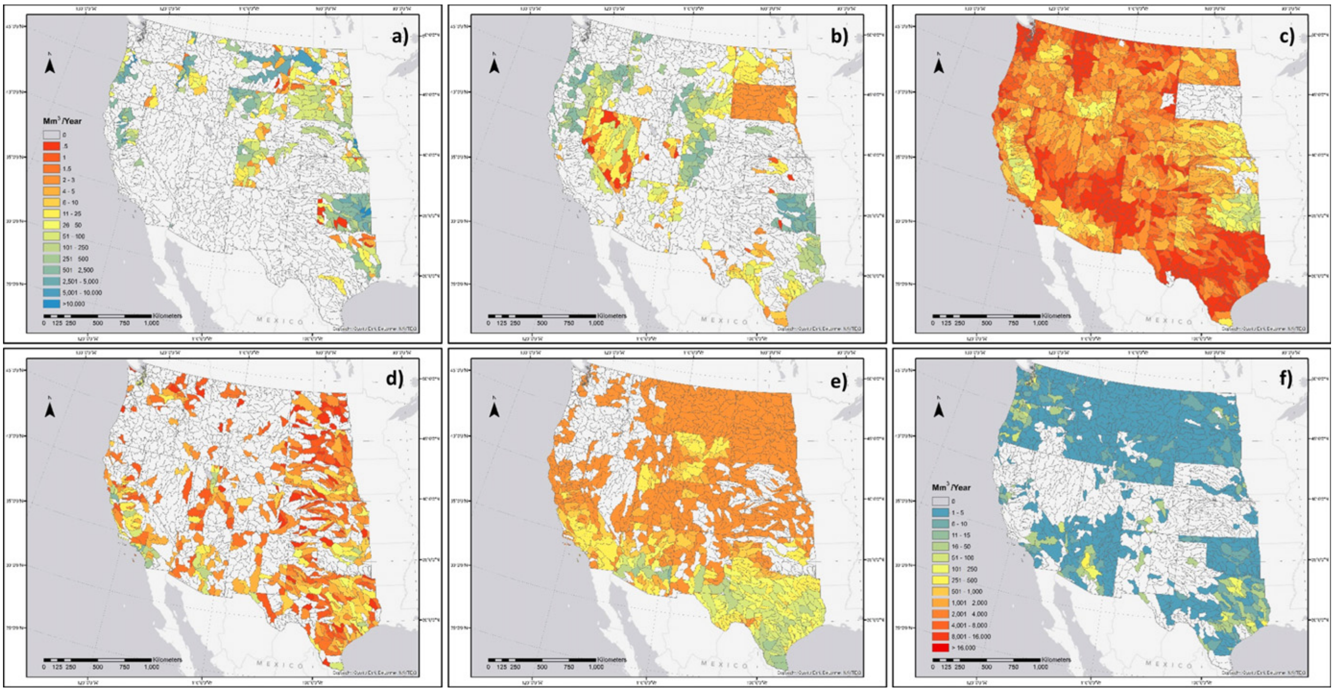

Figure 1. Water availability and projected change in consumptive use. Mapped are water availability metrics for (a) unappropriated surface water, (b) unappropriated groundwater, (c) appropriated water, (d) municipal wastewater, (e) brackish groundwater, and (f) projected change in consumptive water use between 2010 and 2030. All metrics are mapped at the 8-digit HUC level. All are mapped to a consistent non-linear color scale; however the color scheme is reversed between availability and projected change in consumptive use (e.g., warmer colors indicate limited availability or increased use).

Watersheds marked in white designate basins with no availability for that source of water (or insufficient information to suggest a reliable source in the case of brackish groundwater). A quick review of all five maps clearly reveals significant variability across the five sources of water as well as watershed-to-watershed variability for each source of water. The expressed variability is a function of the physical hydrology, water use characteristics, and water management practices unique to each watershed.

Availability of unappropriated surface water (figure 1(a)) is very limited. No unappropriated surface water is available in Arizona, New Mexico, Nevada, Utah or Washington. California, Colorado, Idaho, Kansas, Montana, Nebraska, Oregon, Texas and Wyoming register some unappropriated surface water availability; however, the scope in each is geographically limited. In contrast the majority of watersheds in the Dakotas and Oklahoma register some unappropriated surface water availability.

The availability of unappropriated groundwater (figure 1(b)) is likewise very limited. Unlike surface water, all states (except Washington) record some availability of unappropriated groundwater. The geographic footprint of available unappropriated surface water and groundwater are largely different except in the cases of Oklahoma and Western Colorado. The unappropriated groundwater availability appears notably different for Nevada and South Dakota in that there is some availability in every watershed within these states. This is because groundwater availability data were provided directly by these states, each of which makes assumptions that differ from that used for the other states.

Availability of appropriated water, both surface and groundwater, is consistently distributed throughout the West (figure 1(c)). Quantities likely to be transferred are relatively small, generally less than $3\,\mathrm{Mm^3\,yr^{-1}}$. The greatest availability corresponds to regions with heavy irrigated agriculture, including Eastern Oklahoma, Southern Arizona, Central California, Eastern Colorado, Texas Panhandle, Central Washington, and the Snake River Basin in Idaho. South Dakota registers no appropriated water availability due to policies that limit transfers out of irrigated agriculture.

Availability of municipal wastewater is sporadically distributed across the West (figure 1(d)). Availability is most uniform in the far eastern portion of the study area where the density of communities is the greatest. The highest availabilities are associated with metropolitan areas.

Brackish groundwater is available throughout much of the West except in the Northwest (figure 1(e)). The highest availabilities are noted in Arizona, New Mexico and Texas, where detailed brackish groundwater studies have been conducted. Thus mapped availability is more an indication of what is known and currently used, rather than an indication of the actual resource in the ground.

Future consumptive water use

Projected change in the consumptive use of water between 2010 and 2030 was mapped in figure 1(f). The map uses the same scale as the water availability maps (figures 1(a)–(e)),

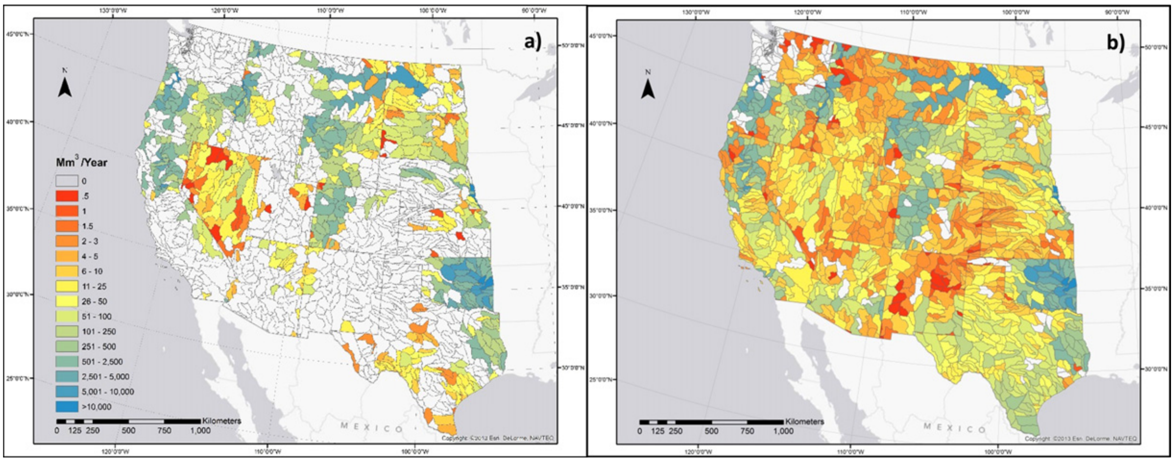

Figure 2. Water budgets constructed by aggregating available water sources and subtracting projected change in consumptive use (2010–2030). Budgets were constructed (a) considering only unappropriated water sources, and (b) all water sources.

but the color scale was reversed to distinguish watersheds with greater increase in use with warmer coloring. A noteworthy aspect of the map is the large regions with zero or decreasing projected consumptive use (white areas on the map). These are regions where the states project some level of abandonment of water permits/rights associated with agricultural irrigation combined with limited rural population growth. While the states project little growth in irrigated agriculture, increased use in the municipal and industrial sectors is expected. It follows that the largest increases projected for consumptive use are clustered around metropolitan areas. In many instances abrupt changes across state boundaries are noted, which simply reflect differences in the methods used by each state to project future water use needs.

Water budget

The difference between water availability and projected change in consumptive use provides a relative measure of the difficulty to be expected when securing a permit for a new water use. Where the projected increase in consumptive use exceeds the estimated water availability, permitting is expected to be the most difficult (assuming all other factors affecting permitting are held constant). To explore this issue, available water sources (figures 1(a)–(e)) were aggregated and the projected increase in consumptive use (figure 1(f)) subtracted to yield a simple water budget at the 8-digit HUC level across the conterminous western US. Two budgets were constructed, one that only considers unappropriated surface/groundwater sources (figure 2(a)) and a second that considers all five sources of available water (figure 2(b)). An evaluation of the unappropriated water source budget is warranted as it is generally the first source of water considered, in part because it tends to have the lowest utilization costs (see below).

When only unappropriated surface and groundwater availability are considered as potential new sources of water, results suggest difficulty with permitting should be expected throughout much of the West. This is indicated by the broad areas with negative water budget values, 61% of watersheds, where projected new consumptive use exceeds available unappropriated water (areas mapped as white in figure 2(a)). These watersheds tend to be associated with urbanized regions, containing a disproportionate 79% of the western states' population.

The picture improves considerably when all five water sources are considered (figure 2(b)). Appropriated, brackish, and municipal wastewater tend to be available in watersheds with limited or no unappropriated water supply. In fact, in only 8% of watersheds does projected new water use exceed total water availability. However, these watersheds are associated with some of the most urbanized regions accounting for 30% of the western states' population.

Water cost

Water costs associated with all sources of water except unappropriated surface water are mapped in figure 3. In order to map all four costs comparably, a non-linear color scale was used to capture the broad range in values. Note that costs were not calculated for watersheds where a particular source of water was unavailable (watersheds mapped white in figure 1).

Each water source shows some degree of watershed-to-watershed variability. This variability is masked to some extent for the brackish and wastewater maps by the large bin sizes necessitated for the scale. Variability in cost for unappropriated groundwater (figure 3(a)) largely corresponds with the average depth to groundwater. Appropriated water transfers (figure 3(b)) are seen to be more costly to the south where water supplies are most limited. Municipal wastewater costs (figure 3(c)) tend to increase as the size of the wastewater treatment plant decreases and the level of treatment increases. Brackish water costs (figure 3(d)) tend to increase as depth and TDS increases.

The most important feature of these maps is the significant variability across sources, particularly between fresh and non-fresh. Average costs for unappropriated groundwater run $\$0.09\ m^{-3}$ while appropriated water is estimated at $\$0.10\ m^{-3}$. Alternatively non-fresh supplies are considerably

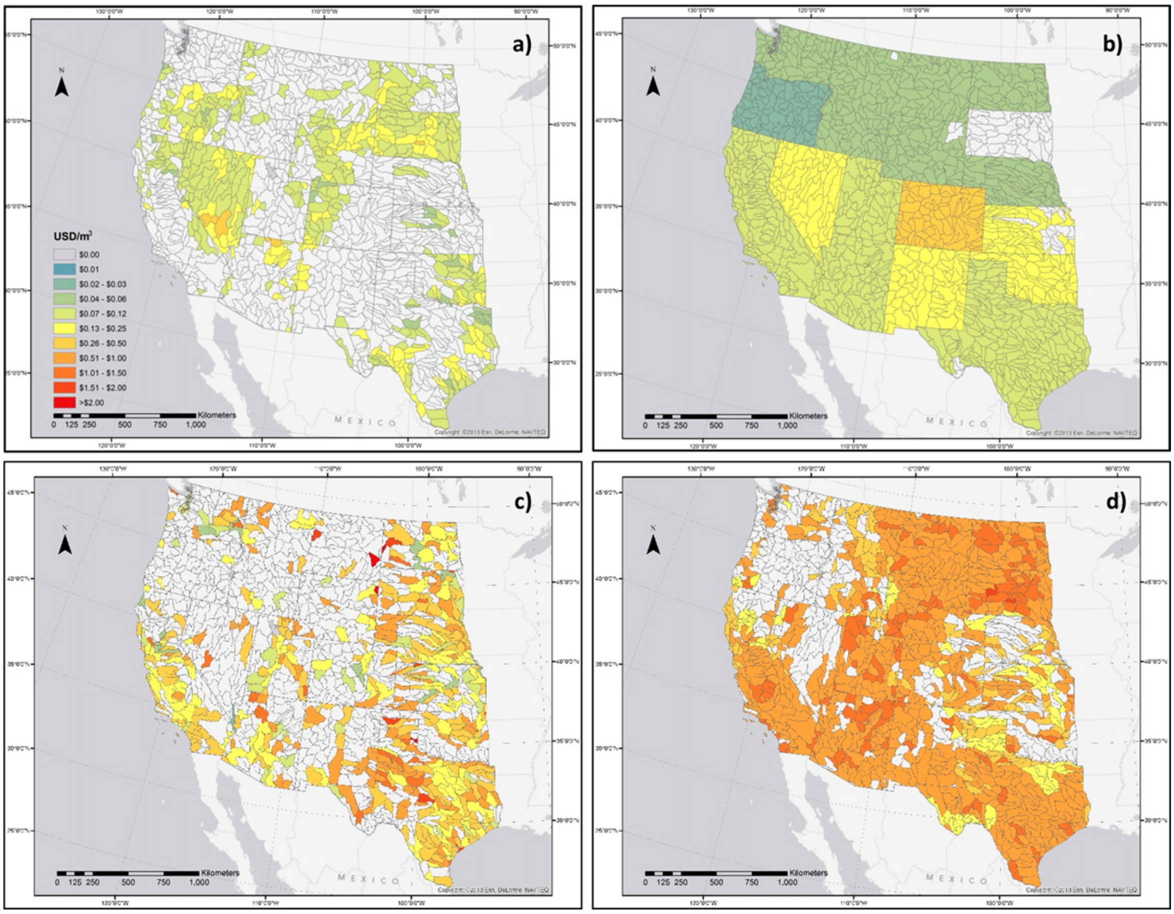

Figure 3. Water cost. Mapped are water cost metrics for (a) unappropriated groundwater, (b) appropriated water (due to data limitations estimates were developed at the state level), (c) municipal wastewater, and (d) brackish groundwater. All metrics are mapped at the 8-digit HUC level. All are mapped to a consistent non-linear color scale.

more expensive with municipal wastewater running $\$0.41\ m^{-3}$ and brackish water $\$0.58\ m^{-3}$. Historically, development has largely relied on inexpensive unappropriated water or transfers of appropriated water.

Discussion and summary

The objective of this study was to estimate water availability, new consumptive use and cost to inform water planning decisions at a regional scale. Water metrics were mapped for over 1200 watersheds throughout the 17-conterminuous states in the western US. The compiled set of water metrics is unique in four important ways. First, multiple sources of water were considered, including unappropriated surface water, unappropriated groundwater, appropriated water, municipal wastewater, and brackish groundwater. Second, water availability metrics accommodate institutional controls (e.g., water rights, administrative controls, interstate compacts) to the extent available data permitted. Third, water availability estimates were accompanied by cost estimates to access, treat and convey each unique source of water. Fourth, water metrics were developed with the direct assistance of state water managers in framing, identifying, understanding and vetting the resultant metrics.

The ultimate value of these metrics is in providing a consistent and comparable measure of the relative difficulty and expense to develop a water resource in a given watershed. By mapping the water availability metrics, important spatial trends and heterogeneity in water sources are evident. Variability in water availability is noted both within each water source as well as between sources. Where projected new consumptive water use (change in use between 2010 and 2030) exceeds estimated availability difficulty is to be expected with permitting new water projects. When only the availability of unappropriated sources of water are considered 61% of the watersheds are classified as difficult for development, which drops to 8% when all five sources are considered. These watersheds tend to be associated with urbanized regions. Estimated costs show similar spatial variability, but more important is the difference between sources where costs ranged from $\$0.09\ m^{-3}$ (appropriated water) to $\$0.58\ m^{-3}$ (brackish groundwater).

There are two important limitations concerning how this data should be interpreted. First, these basin scale estimates of water availability and cost are of insufficient detail to support siting decisions at the local scale (new water use at a specific location). Details concerning local stream flow conditions, aquifer properties, water quality, timing of flows, existing water diversions, local ordinances, etc must be carefully considered. Although developed with the help of state water managers, these availability and cost values do not guarantee such conditions persist at every point within the watershed. These values simply provide a relative measure of where water is more likely available and at what cost relative to other sources.

Second, these data cannot be interpreted as an absolute measure of whether sufficient water is available to meet projected change in consumptive water use. Not all potential sources of water are considered here; particularly, availability of sea water or produced water. Other options not considered include demand side management measures, conservation technologies, and/or construction of water storage or conveyance infrastructure. While in many cases plans are in place aimed at addressing identified short falls, there is a lack of uniform and comparable data on planned projects across the West. Additionally, project planning runs the full spectrum from conceptualization to initial construction. As such, no attempt was made to quantify 'new' sources of water.

Limiting appropriated water availability to 5% of total irrigated agriculture is an important limiting assumption in this analysis. In theory, large quantities of water are available in most all watersheds in the West if the price of water is high enough. Thus appropriated water availability values are artificially limited in this study. However, as the level of transfers grow impacts beyond the availability of water are encountered, including changes in the local economy; shifts in rural demographics; food, feed and fiber production; as well as changes to the social, cultural and traditional fabric of the community. Such dynamics are well beyond the scope of this work.

The desire of this work is that the presented data will find broad use in other policy and resource planning exercises in the western US. Toward this end, a decision support system has been developed to allow interested parties access to view, explore and download the data. The portal is developed within ArcGIS Online accessible at the following URL: http://energy.sandia.gov/?page_id=1741. Water availability, cost and use data in a tabular format can be downloaded from the site (these data are also contained in the online supplemental material for this paper, available at (stacks.iop.org/ERL/9/064009/mmedia)). Detailed spreadsheets containing all supporting data, metric calculations, and data source citations are also available for download at the site, organized by state. This site is linked to the Western States Water Council Water Data Exchange (WaDE). WaDE is a long-term project that uses a web-services-based approach to allow each state to maintain its current data systems, while allowing common datasets among the states to be mapped to a standard format thus facilitating data sharing. When fully implemented WaDE will serve up-to-date state level data, the basis of the water metrics developed here.

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Appendix

See table A1

References

Averyt K, Meldrum J, Caldwell P, Sun G, McNulty S, Huber-Lee A and Madden N 2013 Sectoral contributions to surface water stress in the coterminous United States *Environ. Res. Lett.* **8** 035046

Brown T C 1999 Past and future freshwater use in the United States: a technical document supporting the 2000 USDA Forest Service RPA assessment. Gen. Tech. Rep. RMRS-GTR-39. Fort Collins, CO: US Department of Agriculture, Forest Service, Rocky Mountain Research Station, 47 p

EPRI 2008 *Use of Alternate Water Sources for Power Plant Cooling* (Palo Alto, CA: Electric Power Research Institute) 10014935

ERCOT 2013 Long-Term Transmission Analysis 2012-2013: Final Report, Electric Reliability Council of Texas, December 2013. Available at: http://www.ercot.com/committees/other/lts/index

Falkenmark M, Lunduist J and Widstrand C 1989 Macro-scale water scarcity requires micro-scale approaches: aspects of vulnerability in semi-arid development *Nat. Resour. Forum* **13** 258–67

Gopalakrishnan C 1973 The doctrine of prior appropriation and its impact on water development: a critical survey *Am. J. Econ. Soc.* **32** 61–72

Huff G F 2004 An Overview of the Hydrogeology of Saline Ground Water in New Mexico. Water Desalination and Reuse Strategies for New Mexico, September. New Mexico Water Resources Research Institute wrri.nmsu.edu/publish/watcon/proc49/huff.pdf

Hurd B, Leary N, Jones R and Smith J 1999 Relative regional vulnerability of water resources to climate change *J. Am. Water Res. Assoc.* **35** 1399–409

Kenny R F, Barber N L, Hutson S S, Linsey K S, Lovelace J K and Maupin M A 2009 Estimated use of water in the United States in 2005 *US Geological Survey Circular* **1344** 52

LBG-Guyton Associates 2003 Brackish groundwater manual for Texas regional water planning groups: Report prepared for the Texas Water Development Board, available at: www.twdb.state.tx.us

Macknick J, Newmark R, Heath G and Hallett K C 2012 Operational water consumption and withdrawal factors for electricity generating technologies: a review of existing literature *Environ. Res. Lett.* **7** 045802

McGavock E 2009 Opportunities for desalination of brackish groundwater in Arizona, Montgomery and Associates, available at: http://www.elmontgomery.net/documents/salinityPoster.pdf

NHDPlus 2005 National Hydrography Dataset Plus, edition 1.0, US Environmental Protection Agency and the US Geological Survey http://www.horizon-systems.com/NHDPlus

Reilly T E, Dennehey K F, Alley W M and Cunningham W L 2008 Ground-water availability in the United States in 2008 *US Geological Survey Circular* **1323**

Reiser D W, Wesche T A and C Estes C 1989 Status of instream flow legislation and practice in North America *Fisheries* **14** 22–9

Roy S B, Chen L, Girvetz E H, Maurer E P, Mills W B and Grieb T M 2012 Projecting water withdrawal and supply for future decades in the US under climate change scenarios *Environ. Sci. Technol.* **46** 2545–56

Roy S B, Ricci P F, Summers K V, Chung C-F and Goldstein R A 2005 Evaluation of the sustainability of water withdrawals in the United States, 1995 to 2025 *J. Am. Water Res. Assoc.* **41** 1091–108

Seaber P R, Kapinos F P and Knapp G L 1987 Hydrologic unit maps *US Geological Survey Water-Supply Paper* **63** 2294

Solley W B, Pierce R R and Perlman H A 1995 Estimated use of water in the United States in 1995 *US Geological Survey Circular* **1200**

Sovacool B K and Sovacool K E 2009 Identifying future electricity–water tradeoffs in the United States *Energy Policy* **37** 2763–73

Tennant D L 1976 Instream flow regimens for fish, wildlife, recreation and related environmental resources *Fisheries* **1** 6–10

US Department of Agriculture 2007 The Census of Agriculture, available at: http://www.agcensus.usda.gov/

US Bureau of Reclamation 2013 Colorado River Basin Water Supply and Demand Study, available at: http://www.usbr.gov/lc/region/programs/crbstudy/finalreport/

US Bureau of Reclamation 2010 WATER 2025 Preventing Crises and Conflict in the West. Available at: http://biodiversity.ca.gov/Meetings/archive/water03/water2025.pdf

US EPA 2011 *Permit Compliance System (PCS) Database* available at www.epa.gov/enviro/facts/pcs/

US EPA 2008 *Clean Watershed Needs Survey (CWNS)* available at www.epa.gov/owm/mtb/cwns/

US Geological Survey 2003 *Estimated Mean Annual Natural Ground-Water Recharge in the Conterminous United States* available at: http://water.usgs.gov/lookup/getspatial?rech48grd

US Geological Survey 2011 *National Water Information System* available at: http://water.usgs.gov/nwis

US Water Resources Council 1978 The Nation's Water Resources: 1975-2000, Second National Water Assessment, December

Water Strategist 2012 Published by Stratecon, Inc., PO Box 963, Claremont, CA, available at www.waterstrategist.com

Watson I C, Morin O and Henthorne L 2003 *Desalting Handbook for Planners* Desalination and Water Purification Research and Development Program Report No. 72 3rd edn (Denver, CO: US Bureau of Reclamation)

WECC 2013 2013 Interconnection-Wide Plan: Plan Summary, Western Electricity Coordinating Council, September 19, 2013. Available at http://www.wecc.biz/committees/BOD/TEPPC/Pages/2013_Plans.aspx

Woods G J, Kang D, Quintanar D R, Curley E F, Davis S E, Lansey K E and Arnold R G 2013 Centralized versus decentralized wastewater reclamation in the Houghton area of Tucson, Arizona *J. Water Resour. Plann. Manage.* **139** 313–24

Table A1. Water planning documents

State	Citation	Agency	Document	Site
Arizona	Arizona Department of Water Resources (2010). Arizona Water Atlas.	Arizona Department of Water Resources	Arizona Water Atlas	http://www.azwater.gov/AzDWR/StatewidePlanning/WaterAtlas/default.htm
California	California Department of Water Resources. (2009) California Water Plan Update 2009. Bulletin 160-09. Sacramento, CA.	California Department of Water Resources	California Water Plan Update 2009	http://www.waterplan.water.ca.gov/cwpu2009/index.cfm
Colorado	Colorado Water Conservation Board. (2004) Statewide Water Supply Initiative 2004. Denver, CO.	Colorado Water Conservation Board, Colorado Department of Natural Resources	Statewide Water Supply Initiative 2004	http://cwcb.state.co.us/public-information/publications/pages/studiesreports.aspx
Colorado	Colorado Water Conservation Board. (2011) Statewide Water Supply Initiative 2010.	Colorado Water Conservation Board, Colorado Department of Natural Resources	Statewide Water Supply Initiative 2010	http://cwcb.state.co.us/water-management/water-supply-planning/pages/swsi2010.aspx
Colorado	Ivahnenko, Tamara and Flynn, J.L. 2010, Estimated withdrawals and use of water in Colorado 2005: US. Geological Survey Scientific Investigations Report 2010–5002, 61 p.	USGS in cooperation with the Colorado Water Conservation Board	Estimated Withdrawals and Use of Water in Colorado 2005	http://pubs.usgs.gov/sir/2010/5002/
Colorado	BBC Research & Consulting. Yampa Valley Water Demand Study.	US Fish and Wildlife Service	Yampa Valley Water Demand Study	http://www.crwcd.org/media/uploads/Elk_Yampa_water_demand.pdf
Idaho	Idaho Department of Water Resources.			http://www.idwr.idaho.gov/GeographicInfo/GISdata/gis_data.htm

Table A1. (Continued.)

State	Citation	Agency	Document	Site
	Idaho Geographic Information Systems Data.	Idaho Department of Water Resources		
Idaho	Idaho Department of Water Resources web page.	Idaho Department of Water Resources	No document. Information can be found here on spatial data, water supply information, groundwater levels, groundwater management, etc…	http://www.idwr.idaho.gov/
Kansas (1)	Kansas Department of Agriculture. (2010) Kansas Municipal Water Use 2010. Topeka, KS: Division of Water Resources.	Kansas Department of Agriculture, Division of Water Resources	Kansas Municipal Water Use 2010	http://www.ksda.gov/includes/document_center/dwr/Publications/2010_KS_Municipal_Water_Use.pdf
Kansas (2)	Kansas Department of Agriculture. (2010) Kansas Irrigation Water Use 2010. Topeka, KS: Division of Water Resources.	Kansas Department of Agriculture, Division of Water Resources	Kansas Irrigation Water Use 2010	http://www.ksda.gov/includes/document_center/dwr/Publications/2010_Irrigation_Water_Use.pdf
Montana	Montana Department of Natural Resources and Conservation, Water Resources Division. Montana's State Water Plan.	Montana Department of Natural Resources and Conservation, Water Resources Division	Montana's State Water Plan. There is no cohesive document but the parts can be found on the website.	http://dnrc.mt.gov/wrd/water_mgmt/montana_state_waterplan/default.asp
Nebraska* (1)	US Geological Survey. (2005) Water Use in Nebraska 2005.	US Geological Survey	Water Use in Nebraska 2005.	http://ne.water.usgs.gov/infodata/wateruse
Nebraska* (2)	Nebraska Department of Natural		NebraskaMap Geoportal contains	

Table A1. (Continued.)

State	Citation	Agency	Document	Site
	Resources.(2012) NebraskaMAP GeoPortal. Registered Groundwater Wells.	Nebraska Department of Natural Resources	geospatial data of approved groundwater wells.	http://www.nebraskamap.gov:8080/geoportal/catalog/main/home.page;jsessionid=F723792C157CBEA759B0158AD1F78CD2
Nebraska* (3)	Nebraska Department of Natural Resources. (2005) 2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies. Lincoln, NE.	Nebraska Department of Natural Resources	2006 Annual Evaluation of Availability of Hydrologically Connected Water Supplies	http://dnr.ne.gov/IWM/AnnualReport/2006_AnnualReport.pdf
Nevada	Nevada Division of Water Planning. (1999) Nevada State Water Plan. Carson City, NV.	State of Nevada Division of Water Resouces	Nevada State Water Plan	http://water.nv.gov/programs/planning/stateplan/
New Mexico	New Mexico Office of the State Engineer. (2013) Water Use by Categories 2010. Technical Report 54.	Office of the State Engineer	Water Use by Categories 2010, Technical Report 54	http://www.ose.state.nm.us/Conservation/PDF/NMWaterusebyCategoriesTech.Report54.pdf
North Dakota (1)	North Dakota State Water commission. (2012) General Water Resource MapService.	North Dakota State Water Commission	MapService is an online mapping program that contains all water permit data for the state.	http://mapservice.swc.nd.gov/
North Dakota (2)	North Dakota State Water Commission. (2009) State Water Management Plan. Bismarck, ND.	North Dakota State Water Commission	North Dakota State Water Management Plan	http://www.swc.state.nd.us/4dlink9/4dcgi/GetContentPDF/PB-1349/SWMP09Report.pdf
Oklahoma	Oklahoma Water Resources Board. (2012) Oklahoma	Oklahoma Water Resources Board	Oklahoma Comprehensive Water Plan 2012	www.owrb.ok.gov/supply/ocwp/ocwp.php

Table A1. (Continued.)

State	Citation	Agency	Document	Site
	Comprehensive Water Plan 2012. Oklahoma City, OK.			
Oregon	Oregon Water Resources Department (2009). An Introduction to Oregon's Water Laws: Water Rights in Oregon.	Oregon Water Resources Department	An Introduction to Oregon's Water Laws: Water Rights in Oregon. 'Aquabook'	http://www.oregon.gov/owrd/pages/pubs/aquabook.aspx
Oregon	Oregon Water Supply and Conservation Initiative (2008). Statewide Water Needs Assessment.	Oregon Water Resources Department	Statewide Water Needs Assessment	http://www.oregon.gov/owrd/law/docs/owsci/owrd_demand_assessment_report_final_september_2008.pdf
Oregon	Oregon Water Resources Department Webpage.	Oregon Water Resources Department	Information can be found here on surface water, groundwater, storage, etc…	http://www.oregon.gov/owrd/Pages/index.aspx
South Dakota*	Carter, Janet M. and Kathleen M. Neitzert. (2008) Estimated Use of Water in South Dakota 2005. Reston, VA: US Geological Survey. 2008–5216.	Estimated Use of Water in South Dakota 2005	Estimated Use of Water in South Dakota	http://pubs.usgs.gov/sir/2008/5216/pdf/sir2008-5216.pdf
Texas	Texas Water Development Board (2012). Water For Texas 2012 State Water Plan.	Texas Water Development Board	Water For Texas 2012 State Water Plan	http://www.twdb.state.tx.us/publications/state_water_plan/2012/2012_SWP.pdf
Utah	Utah Divison of Water Resources Webpage.	Utah Division of Water Resources	Information can be found on water use, policy, etc…	http://www.water.utah.gov/
Washington*				http://www.ecy.wa.gov/programs/wr/wrhome.html

Table A1. (Continued.)

State	Citation	Agency	Document	Site
	State of Washington Department of Ecology, Water Resources Web page.	State of Washington Department of Ecology	No document. Information can be found here on spatial data, water supply information, groundwater levels, groundwater management, etc…	
Wyoming	Wyoming Water Development Commission. (2007) Wyoming Framework Water Plan.	Wyoming Water Development Commission	The Wyoming Framework Water Plan	http://waterplan.state.wy.us/frameworkplan-index.html

*No comprehensive state water management plan