LONG-TERM TRENDS IN OFF-STREAM WATER USE IN THE UNITED STATES

Ben DZIEGIELEWSKI, Xiaoying YANG, and Tom BIK
Department of Geography, Southern Illinois University, Carbondale, Illinois 62901, USA

ABSTRACT

This paper reviews the long-term trends in off-stream water withdrawals in the United States since 1950. The principal data source used in this study is the series of national water use reports that have been prepared by the United States Geological Survey's National Water Use Information Program (NWUIP). This study provides insights into the demographic and economic factors that have influenced national withdrawals and assesses possible trends in future water use.

Keywords: water use, water withdrawals, determinants of water use, demographic variables, economic variables, long-term forecast

INTRODUCTION

Knowledge of the availability and use of water resources is essential for effective planning at national, state and local levels. Several inventories and forecasts of water resources in the United States have been conducted over the past 50 years in order to provide this critical information (Landsberg, et al., 1963; Wollman and Bonem, 1971; National Water Commission, 1973; Water Resources Council, 1968, 1978; and Brown, 2000). Researchers from diverse disciplines have described the influence of factors such as climate, price, markets, and technology on water use. These efforts have substantially improved our understanding of the role of water and other natural resources in the Nation's welfare and economic development.

In the US a unique program to estimate water use began with a 1950 report prepared by the USGS (MacKichan, 1951). This report ultimately served as a template for the nine reports that followed, which provided updates of water use estimates in 5-year increments (MacKichan, 1957; MacKichan and Kammerer, 1961; Murray, 1968; Murray and Reeves, 1972 and 1977; Solley et al., 1983, 1988, 1993, and 1998).

In 1978 Congress acknowledged the value of the program by appropriating funds to establish the National Water Use Inventory Program (NWUIP), a co-operative federal-state effort to collect and store water use data. This commitment of funds and staff time permitted the NWUIP to focus on improved quality in data collection procedures and to provide water-use information at increasingly detailed levels. Several publications provide a review of the history of the changes in the USGS water-use program (Lumia, 2000; NRC, 2002). In general, the USGS estimates of water use have focused on annual total water withdrawals, which include the extractions of both fresh water and saline water, with separate estimates of withdrawals from surface water and groundwater sources. These estimates are based upon the aggregation of point withdrawals for various water uses reported at the state level, and since 1985, also at the county level. Although the structure of the water use inventories has changed over time, in general, eight categories (or sectors) of water use are specified: public supply, commercial, industrial, irrigation, thermoelectric generation, self-supplied domestic, livestock, and mining. (Estimates of in-stream water uses are also included but these are not discussed in this paper.)

A review of the changes in estimated water withdrawals has been a routine part of the USGS inventory circulars since the second national report in 1955. In the most recent water use circular, Solley, et al. (1998, p. 63) provide a comprehensive review of the estimates collected from the entire series of water use inventories.

The analysis presented in this paper combines this summary review of USGS water-use estimates with demographic and economic data from the Census and other sources. The purpose of this paper is to provide insight into changing trends in water use, the factors that influence water use, and the changing relationship between water withdrawals and these factors. The method developed in this paper to examine the influences on past water withdrawals is also used to assess the influence of projected trends in explanatory variables on future

water withdrawals. Although strictly speaking water withdrawals and water use are not identical, these terms are used interchangeably in this paper. A more extensive analysis of trends in U.S. water use can be found in Dziegielewski et al. (2002).

TRENDS IN TOTAL WITHDRAWALS

During the 45-year period from 1950 to 1995, estimated total water withdrawals have increased from 180 billion gallons per day (bgd) to 402 bgd. The most distinctive trend of the historical changes in water withdrawals was the continuous growth of withdrawals to a peak of 440 bgd in 1980, followed by a decline and flattening out of withdrawals since that time.
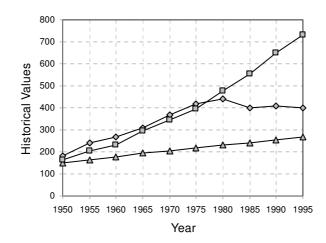

Figure 1. Historical trends in population, GDP and total water withdrawals

Changes in water use are generally linked to changes in population and economic activity. Figure 1 displays the changes in total withdrawals, total population, and economic activity as measure by the Gross Domestic Product (GDP, in the unit of $10 billion 1995 dollars) from 1950 to 1995 (unless otherwise specified, the unit of monetary variables will always be in 1995 US constant dollars throughout the article).

During the 1950-1980 period, the growth in water withdrawals corresponded well to the growth in population and GDP. However, since 1980, total withdrawals have slightly declined and leveled off despite a continuing growth in population and an accelerated growth in GDP. The incremental change in the influence of population and GDP can be discerned by expressing withdrawals as ratios. Figure 2 shows a plot of total withdrawals in gallons per capita per day, and as gallons per $10,000 of GDP. [1]

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[1] Note: Some non-traditional units are used in this paper to allow trends to be displayed on a single gragh.
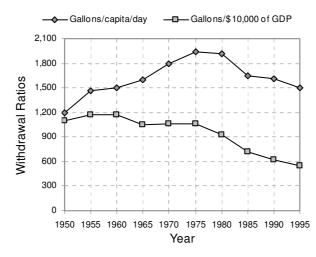
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Figure 2. Historical trends in per capita and per GDP withdrawals

Per capita withdrawals increased until 1975, but have declined since that time, with a sharp decline between 1980 and 1985. Withdrawals per $10,000 of GDP have been declining since 1955, but at an increasing rate after 1975. In 1995, withdrawals per capita and per $10,000 of GDP were, respectively, 22 percent and 49 percent lower than the 1975 peak historical values.

Total off-stream withdrawals are the sum of the withdrawals of individual water use sectors. Historical changes in withdrawals in the four major water use sectors have each contributed differently to the trends in total withdrawals. The contribution of the four major water use sectors in 1985, 1990, and 1995 are displayed in Figure 3.
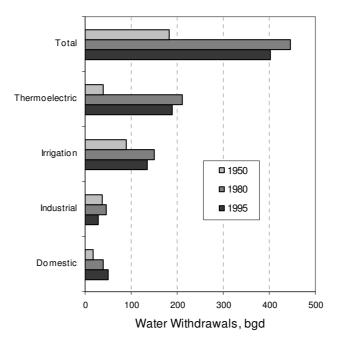

Figure 3. Sectoral composition of total withdrawals in 1950, 1980 and 1995.

In 1950, irrigation was the leading user of water, at which time it represented nearly one-half of total withdrawals. By 1980, withdrawals for thermoelectric power generation (47 percent of total) surpassed those for irrigation (34 percent). Together, thermoelectric and irrigation withdrawals accounted for 80 percent of total withdrawals in 1995. Of the four major water use sectors, only the domestic sector has increased consistently throughout the period. The historical changes in withdrawals for each of the major sectors are discussed in the following sections.

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ANALYSIS OF SECTORAL WITHDRAWALS

A simple allocation procedure was developed to investigate how water withdrawals changed in response to total population, the per capita amount of water-demanding activity, and average rate of water withdrawals per unit of that activity. This can be expressed as:

$$W_{st} = P_t \cdot c_{st} \cdot w_{st} \qquad\qquad (\textit{Equation 1})$$

where: W_{st} is total withdrawals by sector s in year t, P_t is total U.S. population in year t, c_{st} is per capita amount of production (or another related factor) that requires water, and w_{st} is withdrawal rate per unit of production.

For example, by using Equation 1, total thermoelectric withdrawals of 190 bgd in 1995 can be represented as the product of total U.S. population (267.1 million), average per capita generation of energy (27.6 kWh/capita/day), and the average rate of withdrawals per kilowatt-hour of energy produced (25.7 gallons/kWh). Because the product of c_{st} and w_{st} represent per capita water withdrawals by sector s in year t, Equation 1 can also be written as:

$$W_{st} = P_{st} \cdot q_{st} \qquad\qquad (\textit{Equation 2})$$

where q_{st} is average per capita water withdrawals. Table 1 shows the values of c, w and q for each of the major sectors of water use in 1995. The historical changes in the three quantities (i.e., c, w and q) are plotted for each major sector in Figures 4(a) to 4(d) below and discussed in the following sections.

Table 1. Total Withdrawals and Unit Parameters: 1995

Water-use Sector	Parameter/Quantity/Unit	1995 Value
Thermoelectric	Per capita energy generation, kWh/capita/day	27.6
	Unit withdrawals, gallons/kWh	25.7
	Per capita thermoelectric water use, gallons/capita/day	711.3
	Total thermoelectric withdrawals, bgd	190.0
Irrigation	Per capita acreage if irrigated area, acres/capita	0.2
	Unit withdrawals, gallons/acre/day	2314.3
	Per capita irrigation water use, gallons/capita/day	501.7
	Total irrigation withdrawals, bgd	134.0
Industrial	Per capita value added, $1,000/capita	6.4
	Unit withdrawals, gallons/$1,000 of value added	6231.1
	Per capita industrial water use, gallons/capita/day	108.9
	Total industrial withdrawals, bgd	29.1
Domestic	Per capita income, $1,000/capita	23.3
	Unit withdrawals, gallons/$1,000 income/day	7.9
	Per capita domestic water use, gallons/capita/day	183.8
	Total domestic withdrawals, bgd	49.1
All sectors	Per capita water withdrawals, gallons/capita/day	1505.1
	Total withdrawals, bgd	402.0

Thermoelectric Power Withdrawals

Thermoelectric withdrawals peaked in 1980 at 210 bgd, and have changed little since that time. Figure 4(a) shows the ratios of thermoelectric withdrawals to population and power generation during the 1950-1995 period. Between 1950 and 1975, per capita thermoelectric withdrawals were increasing very rapidly in spite of a gradual decrease in withdrawals per unit of generated power (gallons per kWh). This growth in per capita withdrawals can be attributed to the historical increases in per capita generation from 4.2 kWh per capita in 1950 to 20.8 kWh per capita in 1975. After 1980, the effect on withdrawals of increasing per capita power generation was overshadowed by declines in unit water use for generation (gallons/kWh), and total thermoelectric withdrawals began to decline. Water use per unit of thermoelectric generation has declined by nearly 60 percent since 1950, including a greater than 30 percent drop since 1980.
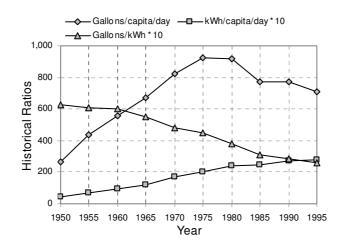
Figure 4(a) Per capita thermoelectric withdrawals and power generation and average withdrawals per kWh.

Irrigation Withdrawals

The trends in irrigation water use mirror the changes in total withdrawals, peaking at 150 bgd in 1980 then declining to approximately 135 bgd in the last three reporting periods. Before 1980, irrigation withdrawals, irrigated acreage, and population are all steadily increasing. After 1980, both irrigation withdrawals and irrigated acres level off, while population continues to increase (Figure 4(b)). Throughout this period the amount of irrigation water per irrigated acre was decreasing, while per capita irrigated acres increased consistently from 1950 to 1980, followed by a steady decrease. This caused the amount of per capita irrigation withdrawals to undergo a large decline after 1980, following the fluctuation between 1950 and 1960 and a slow increase between 1960 and 1980.
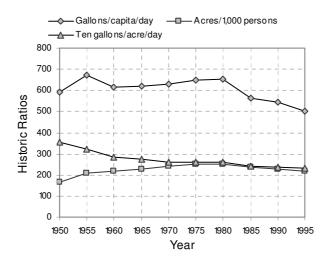

Figure 4(b). Per capita irrigation withdrawals, irrigated
acres per capita and irrigation withdrawals per irrigated acre.

Industrial Withdrawals

Total industrial withdrawals (including self-supplied, deliveries from public supplies, and mining withdrawals) increased between 1950 and 1970, but have steadily declined since that time. Compared with the other three sectors, the industrial sector has experienced considerably less variation in withdrawals. In spite of this, the value added by manufacturing, one measure of the output from the industrial sector, grew rapidly from 1950 to 1995 (Figure 4(c)). Per capita industrial withdrawals and industrial withdrawals per thousand dollars of value added declined almost continuously between 1950 and 1995. However, the per capita value added by manufacturing is generally increasing throughout the entire period.
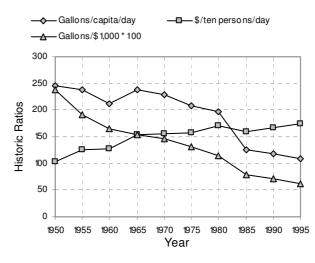
Figure 4(c). Per capita industrial withdrawals, per capita value added by
manufacturer, and industrial withdrawals per dollar value added by manufacturing.

Domestic Withdrawals

Domestic withdrawals are not exactly the same as public supply withdrawals because most public water supply systems also serve at least a few industrial, commercial, institutional and/or governmental establishments. Also, about 15 percent of households are not connected to public supply systems (1990) and have their own water supplies (Census, 1999). The domestic withdrawals discussed in this section are the combined public supply and self-supplied domestic withdrawals.
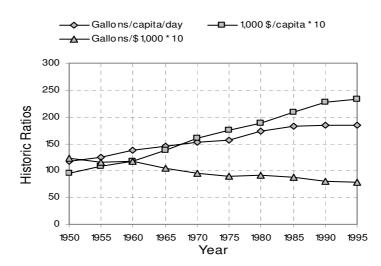

Figure 4(d). Domestic per capita use, per capita income, and income-adjusted per capita uses

Reported domestic withdrawals have increased in every reporting period, nearly tripling between 1950 and 1995, while population increased only by 77 percent. This resulted in increasing per capita withdrawals for most of the historical record, with the per capita withdrawals being noticeably flat since 1985. While per capita income (in 1995 dollars) increased steadily, water use per dollar of per capita income has generally decreased since the beginning of the USGS water use inventories (Figure 4(d)).

COMPONENTS OF HISTORICAL CHANGES

The representation of total withdrawals expressed in Equations 1 and 2 is helpful in allocating the change in withdrawals between points in time into two component changes: those related to population growth and those related to changes in per capita consumption. Also, changes that arise due to trends in technical efficiency of water use (i.e., the ratio of output to input) can be assessed. A simple heuristic procedure was

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used in order to determine the effect of each contributing factor on water withdrawals in specific sectors. The analysis of thermoelectric water use is presented below as an example of the procedure used to calculate the contribution of individual effects.

The contribution of the change in population from t_1 to t_2 on the change in withdrawals during this period can be calculated by assuming constant per capita withdrawals at the t_1 level. The effect of population change can then be estimated as:

$$e_{\Delta t}^{PG} = (P_{t_2} - P_{t_1}) \cdot q_{TE,t_1}$$ (*Equation 3*)

where, e^{PG} is the effect of population growth during period Δt (e.g., 1950 to 1980), P_{t2} is population at time t_2 (e.g.,1980), P_{t1} is population at time t_1 (e.g., 1950) and $q_{TE,t1}$ is per capita thermoelectric water withdrawals at time t_1.

Similarly, the effect of increasing per capita power generation can be calculated as:

$$e_{\Delta t}^{EGC} = (c_{TE,t2} - c_{TE,t1}) \cdot w_{TE,t1} \cdot P_{t2}$$ (*Equation 4*)

where: e^{EGC} is the effect of the increase in per capita generation of electricity during period Δt, $c_{TE,t2}$ is per capita generation at time t_2, $c_{TE,t1}$ is per capita generation at time t_1, $w_{TE,t1}$ is unit withdrawals (volume of water needed to generate 1 kWh of electricity) at time t_1, and P_{t2} is population at time t_2.

Finally, the effect of decreasing unit withdrawals per kilowatt-hour of electricity generated can be calculated as:

$$e_{\Delta t}^{UW} = (w_{TE,t2} - w_{TE,t1}) \cdot c_{TE,t2} \cdot P_{t2}$$ (*Equation 5*)

where: e^{UW} is the effect of the decrease in unit withdrawals per kilowatt-hour of generation of electricity during period Δt, $w_{TE,t2}$ is unit withdrawals per kWh at time t_2, $w_{TE,t1}$ is unit withdrawals at time t_1, $c_{TE,t2}$ is per capita generation at time t_2, and P_{t2} is population at time t_2.

The above procedure can be used to examine the components of change in the USGS estimates of national water withdrawals. As discussed above, the year 1980 seems to represent a point where the U.S. water use patterns underwent a significant change. Thus, the component of changes in historic withdrawals is analyzed in two phases: 1950-1980 and 1980-1995.

Components of change in withdrawals of major water use sectors

Thermoelectric water use sector
The factors considered to be primary influences on thermoelectric withdrawals are: population, per capita power generation, and withdrawals per kWh of power generation (Table 2). If per capita electric generation and unit withdrawals per kilowatt-hour remained constant at the 1950 level, then the increase in total population alone (from 150 million to 230 million) should have added 20.9 bgd to total thermoelectric withdrawals, and the nearly six-fold increase in per capita electric generation (from 4.2 kWh/capita/day to 23.9 kWh/capita/day) should have added 283.5 bgd to thermoelectric withdrawals. Using the constant 1950-scenario assumption, these two effects (i.e., population growth and increases in per capita electric generation) should have resulted in the total 1980 withdrawals of 344.5 bgd; a volume that is 64 percent higher than the USGS reported withdrawals of 210 bgd. The lower actual withdrawals can be attributed to decreasing unit withdrawals per kilowatt-hour of generation, which declined from 62.7 gallons/kWh in 1950 to 38.2 gallons/kWh in 1980. Applying the same approach to the changes occurring between 1980 and 1995, population growth and the increase in per capita electric generation should have increased thermoelectric withdrawals by 34.3 bgd and 37.9 bgd, respectively. However, the decline in withdrawals due to the reductions in withdrawals per unit of thermoelectric generation overwhelmed this increase, and reduced total thermoelectric withdrawals by 20.0 bgd.

Irrigation water use sector

The factors considered to influence irrigation withdrawals are: population, irrigated acreage, and withdrawals per irrigated acre (Table 2). Between 1950 and 1980, estimated irrigation withdrawals increased by 61 bgd (from 89 to 150 bgd). If irrigation withdrawals per irrigated acre had remained constant at 1950 levels, then the increase of 33 million irrigated acres from 1950 to 1980 should have added 117.5 bgd to total irrigation withdrawals, about twice the reported increase during this period. Instead, average unit irrigation withdrawals decreased by about 974 gallons/acre between 1950 and 1980, resulting in a decrease of approximately 56.5 bgd from expected withdrawals. Between 1980 and 1995, irrigated acreage varied little, and therefore contributed little to changes in irrigation withdrawals. During the same period however, irrigation water use decreased by about 272 gallons/acre, resulting in a 98 percent (15.7 bgd) decrease in irrigation withdrawals during this period.

Industrial water use sector

The factors considered to influence industrial withdrawals are: population, value added by manufacturing per capita, and water withdrawals per unit of value added by manufacturing (Table 2). If per capita value added by manufacturing and per thousand dollars of value added industrial withdrawals had remained constant at the 1950 level, the increase in total population during the 1950-1980 period should have added 19.4 bgd to industrial withdrawals. However, per capita value added by manufacturing increased by more than $2,400 (from $3,758/capita/day to $6,212/capita/day) between 1950 and 1980. The contribution from this factor alone should have added 36.8 bgd to industrial withdrawals. These two effects together should have caused an increase of 56.2 bgd during the period, about seven times the reported increase. The lower reported increase can be attributed to the decrease in value added per unit of industrial withdrawals, which contributes to a decrease of 48.2 bgd during the period. Using the same rationale, the combined contribution of population growth and the increase in per capita value added by manufacturing account for an increase of 8.7 bgd from 1980 to 1995. However, the decrease in industrial withdrawals per value added counteracted the impacts of the other two factors, and resulted in a decrease of 15.9 bgd during the period.

Table 2. Effects of Contributing Factors on Sectoral Water Withdrawals

Sector/Specific Effects	Contribution to withdrawals, bgd[a]		
	1950-1980	1980-1995	1950-1995
Total Thermoelectric change	*170.0*	*-20.0*	*150.0*
Population change (*Equation 3*)	20.9	34.3	55.2
Change in per capita generation (*Equation 4*)	283.5	37.9	321.5
Change in withdrawals per kWh (*Equation 5*)	-134.5	-92.2	-226.7
Total Irrigation change:	*61.0*	*-16.0*	*45.0*
Population change	46.6	24.5	71.1
Change in per capita irrigated acres	70.9	-24.8	46.1
Change in withdrawals per acre	-56.5	-15.7	-72.2
Total Industrial change:	*8.0*	*-15.9*	*-7.9*
Population change	19.4	7.3	26.7
Change in value added by manufac. per capita	36.8	1.4	38.2
Change in withdrawals per $ value added by manufac.	-48.2	-24.7	-72.9
Total Domestic change:	*22.0*	*9.5*	*31.5*
Population change	9.2	6.5	15.7
Change in per capita income	26.1	10.8	36.9
Change in withdrawals per $ income	-13.3	-7.8	-21.1

[a]1 billion gallons per day (bgd) = 3,785 million cubic meters (Mm^3) per day

Domestic water use sector

The factors considered to influence domestic withdrawals are: population growth, per capita income, and withdrawals per dollar of per capita income (Table 2). Between 1950 and 1980, total domestic withdrawals increased by 22.0 bgd (from 17.6 to 39.6 bgd). If per capita withdrawals remained constant at the 1950 level, population growth from 1950 to 1980 alone should have resulted in an increase of 9.2 bgd to total domestic withdrawals. However, per capita withdrawals increased by 55.7 gallons between 1950 and 1980, adding 12.8 bgd to domestic withdrawals. Between 1980 and 1995, population growth alone accounts for more than two

thirds of the 9.5 bgd increase in domestic withdrawals. The influence of per capita use declined significantly in this second period, and the contribution of both variables is approximately equal across the entire time period.

FUTURE TRENDS

The method used to review past water use trends can also be applied to project the potential future quantities of water that are likely to be used in major water use sectors. The following sections provide estimates of future water use by major sector in 2040.

Future Thermoelectric Withdrawals

Future thermoelectric withdrawals will be influenced by factors that determine the demand for electricity and changes in water withdrawals per KWh of generation. The Department of Energy (DOE) projects that total thermoelectric generation capacity will increase to 922 Gigawatts in 2020, and that thermoelectric generation will increase to 4,517 billion kWh in 2020, with an average annual growth rate of 1.8 percent (DOE, 2002). Combining this generation projection with the Census Bureau's middle-series population projections of 324,927,000 persons in 2020, the projected per capita generation would equal 38.1 KWh per capita (compared with 28.2 KWh/capita in 1995). However, since per capita generation has had a decreasing growth rate after 1980, and has leveled off after 1990, the growth rate derived from DOE projections appears to be unjustifiably high. Thus, for the following analysis, per capita generation was held constant at the 2020 value from 2020 to 2040. Using this assumption, the amount of thermoelectric generation in 2040 is estimated to be about 5,248 billion kWh. The DOE also projects changes in the compositions of generation method and fuel type in thermoelectric generation. The percentage of generation capacity using fossil steam and nuclear steam are projected to decrease from 68.1 percent and 15 percent in 2000, to 50 percent and 9.5 percent in 2020, respectively. Correspondingly, the percentage of generation capacity by internal combustion and combined cycles are projected to increase to 19.3 percent and 23.2 percent in 2020, compared with 12.0 percent and 4.7 percent in 2000 (DOE, 2002).

Another factor that is likely to influence per kWh generation withdrawals is the proportion of steam generating capacity that utilizes cooling towers and other closed-loop cooling systems. In 1995, about 30 percent of installed conventional steam generation capacity was at facilities with cooling towers (DOE, 1996). The trends in fuel switching and more water-efficient cooling suggest that thermoelectric withdrawals per kWh will continue to decrease. In 1995, national average thermoelectric withdrawal per unit of generation was 25.7 gallons/kWh. In order to estimate the quantity of future water withdrawals per unit of generation, a simple linear model was developed, regressing unit thermoelectric withdrawal on the percentage of installed conventional steam generation capacity with cooling towers (1990 and 1995 for the lower 48 states). The resulting regression coefficient was applied to the future installed conventional steam capacity in 2040, of which it was assumed that 50 percent had cooling towers. This method predicts a decrease in the national average thermoelectric withdrawal per unit of generation of 18.74 gallons/kWh. It is also reasonable to assume that the percentage of generation capacity by internal combustion will reach at least 30 percent by 2040 (compared to about 10 percent in 1995). This switch in generation type would further reduce the estimated unit thermoelectric withdrawals by another 20 percent, resulting in an expected national average unit thermoelectric withdrawals in 2040 of about 15 gallons/kWh. Combining the above generation projections with this projected unit use yields an estimate of 2040 thermoelectric withdrawals of approximately 216 bgd.

Future Irrigation Withdrawals

Future irrigation withdrawals will be influenced by factors that change the number of irrigated acres and/or the water use per irrigated acre. Although irrigation practices are more widespread than ever, with every state reporting some irrigation withdrawals, the number of irrigated acres has remained the same since 1985. In his study on U.S. freshwater withdrawals, Brown (2000) projected that U.S. irrigated acres will increase from 57.9 million acres in 1995 to 62.4 million acres in 2040, an increase of about 0.8 percent per year. Irrigation efficiency (gallons/acre) has also been steadily improving through changes in water application methods and reduction in conveyance loss. Water use per acre has declined in every reporting period since 1975 to a national average irrigation depth of about 31 inches/year in 1995. The number of acres using more efficient water methods has steadily increased, causing a corresponding reduction in conveyance losses (Dziegielewski, 2002). If the percentage of irrigation by flooding and the percentage of conveyance loss were modestly reduced to 40 percent and 10 percent (respectively), the national average irrigation depth would decrease to 23.6

inches/year. Combined with Brown's projected 2040 acreage, total irrigation withdrawals would then decrease from 134 bgd in 1995 to 110 bgd in 2040.

Future Industrial Withdrawals

The review of historical industrial withdrawals used the value added from manufacturers to estimate the relationship between water use and industrial output. Unfortunately, no reliable source of projections for the value added by manufacturers was found to be available. Another measure of industrial output, gross state product in manufacturing and mining, was therefore employed to represent this relationship. The Bureau of Economic Analysis (BEA) has published historical GSP data since 1977, as well as projections to 2045 (in millions of 1987 dollars). The average annual growth rate derived from BEA's projections were used to develop projected GSP values. The historical data (since 1977) on industrial withdrawals per unit of output (gallons per $1,000 of GSP in manufacturing and mining) reveals a continuous downward trend. If it is assumed that the annual decrease rate of 0.86 percent between 1985 and 1995 will continue to 2040, industrial withdrawals per $1,000 GSP in manufacturing and mining in 2040 should decrease to 13.8 gallons (compared with 21.0 gallons in 1995), and industrial withdrawals for 2040 would be 35 bgd.

Future Domestic Withdrawals

Future domestic withdrawals depend on both future population and per capita consumption. The Census Bureau has developed low, middle, and high series projections for the U.S. population. The middle series population projected for 2040 is 377 million. Changes in per capita withdrawals can be partly explained by changes in income. BEA per capita income projections to 2045 (in constant $1987) (BEA, 1995) were used to develop a projected value of per capita income of $34,800 dollars in 2040 (see Research Note). Historically, per-capita withdrawals per $1,000 of per capita income decrease continuously, but the rate of decrease slows after 1975, to a rate of 0.6 percent from 1975 to 1995. If this decreasing rate is applied to income-adjusted per capita withdrawals, the value would decrease from 7.9 gallons per $1,000 of per capita income in 1995 to 6.0 gallons in 2040, and the resulting per capita withdrawals would be 209 gpcd in 2040 (compared with 184 gpcd in 1995). Combining this per capita estimate with the middle series population projection yields a 2040 domestic withdrawals estimate of about 79 bgd.

SUMMARY

Table 3 compares the estimated water withdrawals by major water use sector in 1995 and the projections of withdrawals developed in this paper. Water used in thermoelectric generation dominates the estimates of current and future water use, and accounts for nearly half of projected 2040 withdrawals. This prediction may be a bit high because of the use of the continued growth rate of 0.8 percent in generation. It also demonstrates that if thermoelectric generation continues to increase at the current rate, this growth will overwhelm the impacts of increasing water use efficiency in generation.

Total irrigation withdrawals are projected to decrease by nearly 18 percent, primarily due to the expected increasing water application efficiency and reduction in conveyance loss. Industrial water demands are expected to increase only slightly in the coming years, balancing the increases due to expanding economic growth with decreases due to increased efficiency and shifts to less water intensive industries. Domestic withdrawals are the one water use sector that has been reported to have grown consistently during the time period included in the USGS inventories. This sector is projected to experience the largest increase in the quantities of water demanded in the future. Figure 5 compares the changes in the historical and projected population with those in total and sectoral withdrawals.

Table 3 Comparison of 1995 withdrawals and 2040 predictions

Water Use Category	Estimated 1995 Withdrawals (bgd)	Projected 2040 Withdrawals (bgd)	1995-2040 Change (bgd)
Thermoelectric	190	216	26 (38.4)[a]
Irrigation	134	110	-24 (-17.9)
Industrial	29	35	6 (20.7)
Domestic	49	79	30 (61.2)
Total	402	440	38 (21.1)

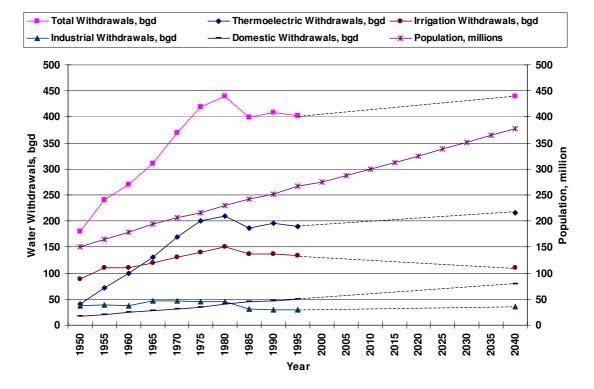(a) Percent change from 1995 to 2040 is shown in parenthesis.

Figure 5. Historical and projected withdrawals: 1950 - 2040

This study indicates that the general picture of the sectoral composition of water withdrawals will not change much in the next 40 years. Thermoelectric generation will remain the leading water user followed by irrigation, domestic, and industrial. Total withdrawals will show a 21% increase, growing at a much slower rate than before 1980. The thermoelectric and domestic sectors are expected to contribute the most to the increase in total withdrawals. The industrial sector is the only sector expected to maintain the post-1980 leveling off trend, while irrigation is the only sector that is forecast to experience a decrease in withdrawals. The simple projections presented here suggest that total withdrawals in the next 40 or so years will only increase enough to return to the previous peak water use year of 1980. However, the uncertainty of the long-term estimates presented here is readily acknowledged. Foreseeable technical changes could radically alter the water use relationship discussed here and result in dramatic differences in these projections. However, the value of the approach presented here is that it can potentially be used to quantify the weight of such changes as they become apparent.

Acknowledgements

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