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LLNL-TR-431862

Estimated Water Flows in 2005: United States

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May 13, 2010

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Abstract

A flow chart depicting water use in the United States has been constructed from publicly available data and estimates of water use patterns. Approximately 410,500 million gallons per day of water are managed for use in farming, power production, residential, commercial and industrial applications. Water is obtained from four major resource classes: fresh surface-water, saline (ocean) surface-water, fresh groundwater and saline (brackish) groundwater. Water that is not consumed or evaporated during its use is returned to surface bodies of water. The flow chart serves as a compact "visual atlas" that contributes to a comprehensive "systems view" of national water resources, use and disposition.

Introduction

Lawrence Livermore National Lab (LLNL) has published flow charts (also referred to as "Sankey Diagrams") of important national commodities since the early 1970s. The most widely recognized of these charts is the U.S. energy flow chart (Livermore, 2009) , however, Livermore has also published charts depicting carbon (or carbon dioxide potential) flow and water flow at the national level as well as energy, carbon and water flows at the international, state, municipal and organizational (eg. Air Force) level. Flow charts are valuable as single-page references that contain quantitative data about resource, commodity and byproduct flows in a graphical form that also conveys structural information about the system that manages those flows.

LLNL produced flow charts depicting water use in the U.S. from 1995 and 2000 data. Data on water use is compiled by the U.S. Geological Survey (USGS) every five years, and is released between 3 and 4 years after the data collection year. Data for 2005 (Kenny et. al., 2009) were released in October of 2009.

Water use data is notoriously hard to compile. Accounting policies vary between different water management districts and water use is not metered in the same way that higher-priced commodities are sold. Quantifying water use by location and sector requires substantial estimation.

Water disposition is even more difficult to quantify. While the quality of wastewater discharge is measured regularly for environmental purposes, the total quantity of wastewater is not carefully monitored, especially when that wastewater already meets environmental regulations for discharge.

Nonetheless, this report attempts to depict the approximate relative scale of water withdrawal and consumption for various sectors of the economy.

Water is procured for economic benefit from four classes of resource: fresh surface-water, saline (ocean) surface-water, fresh groundwater and saline (brackish) groundwater. Fresh surface-water, from lakes and rivers, is used at large scale in every sector of the economy. Saline surface water, primarily ocean water, is mostly used for once-through thermoelectric cooling, although some ocean water is used for industrial cooling and a small but growing amount of ocean water is being desalinated for public consumption. Significant quantities of fresh groundwater are used in irrigation, and fresh groundwater plays an important role in both public supply as well as self-supplied domestic water consumption. Brackish groundwater is the most difficult resource to use, and is primarily used in the mining sector and for power production (often in geothermal power plants).

Per the most recent USGS water use report, the water economy is broken down into seven use sectors: Domestic, Industrial, Mining, Aquaculture, Livestock, Irrigation and Thermoelectric Cooling. Public Supply, the management of quality-controlled water networks, plays an intermediate role between water resources and end use. Commercial water is not directly specified, but the USGS mentions that Public Supply supports commercial and some light industrial operations. For that purpose, the commercial and industrial sectors have been combined in this analysis.

The 2005 USGS report does not describe the disposition of water that has been used by various sectors of the economy. Nonetheless, this analysis attempts to quantify the amount of water consumed by each economic sector, and of the water not consumed, the amount of water returned to surface fresh-water bodies and the amount discharged to the ocean. Those quantities are estimated as described in the "Analysis" section. Water can be consumed (chemically broken down or incorporated into a product) or evaporated from a sector. The majority of consumed/evaporated water eventually rejoins the global hydrologic cycle, but cannot be assumed to be reintroduced to the surface waters of the United States. Water that is discharged to surface bodies (lakes or streams) may be available for re-use, depending on its quality, temperature and location. Water that is discharged to the ocean is no longer available for any purpose except those that use saline surface-water.

Estimated U.S. Water Flow in 2005: 410,500 Million Gallons/Day

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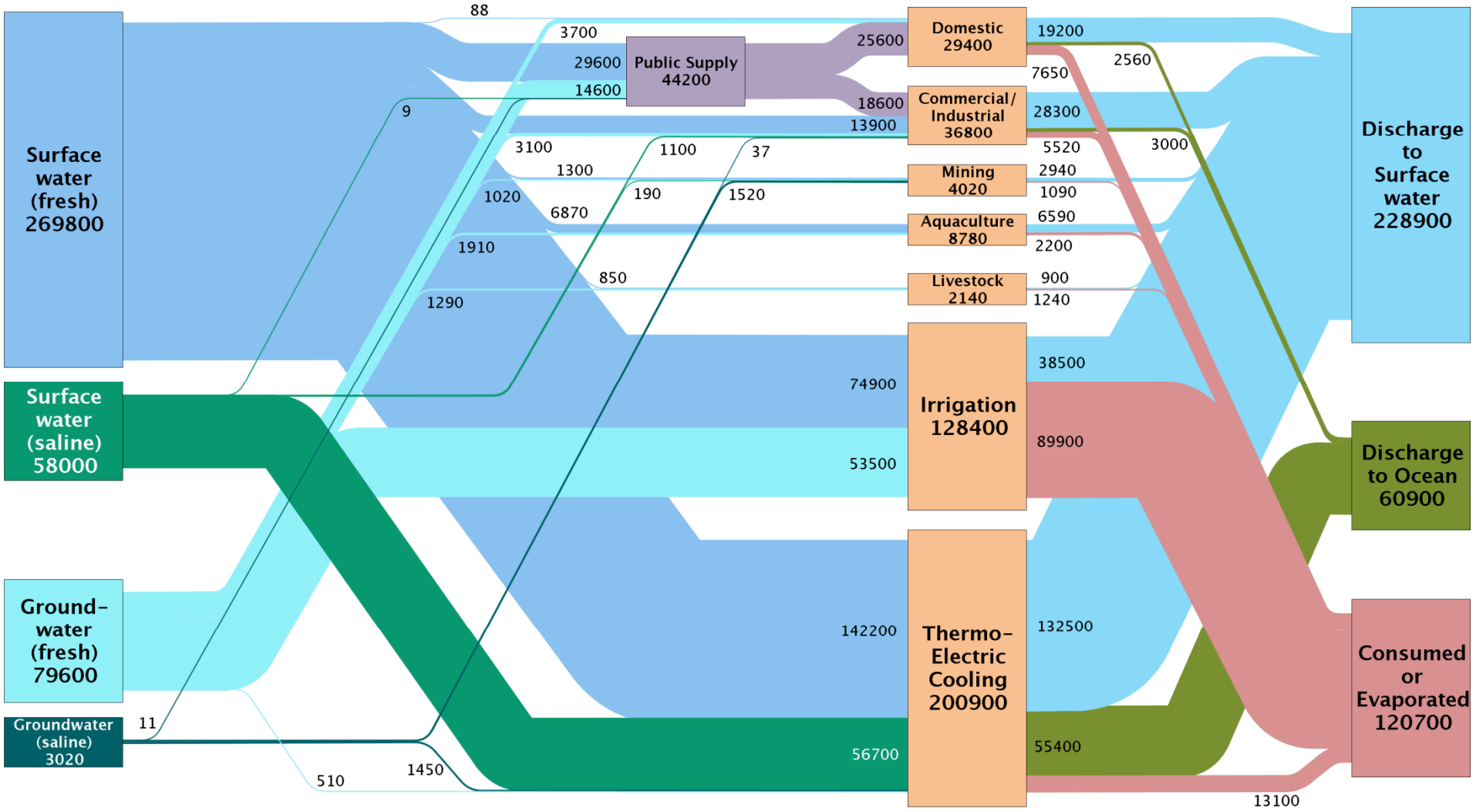

Source: LLNL 2010. Data is based on USGS Circular 1344, October 2009. If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. . Public Supply deliveries to Commercial/Industrial are assumed to be the portion of Public Supply not delivered to the Domestic sector. Those deliveries include commercial and municipal water use as well as municipal water losses. Water consumption and discharge fractions for each sector are estimated from previous years and other literature references. Totals may not equal sum of flows due to independent rounding. LLNL-TR-431862

Analysis

Fundamental to this analysis is the assumption that water use can accurately be traced from resource to distribution network to sectoral use to disposition. There are fairly large uncertainties with respect to the actual amount of water withdrawn, consumed and returned; and there are many instances where water disposed-of as "return flow" is immediately withdrawn by another user. Such arrangements can make water accounting difficult, and the USGS is to be commended for its extraordinary effort in collecting sparsely- and inconsistently-recorded data. Assembly of this water flow chart represents a small step in a very long chain of analysis that collapses the cyclic nature of the nation's water infrastructure into a conceptually linear series of unit operations. Unless stated otherwise, all data in this analysis comes from the USGS Water Use report for 2005 (Kenny et. al, 2009). Where water flows have been calculated, please see the "data dictionary" in the appendix to this report for the USGS definitions of reported flows.

Flows of water on the flow chart were calculated as follows:

Withdrawals:
USGS reports directly the total withdrawals from each of the four available water resources: Fresh surface-water, saline surface-water, fresh groundwater and saline groundwater.

Public Supply:
Public Supply represents the municipally managed distribution network for water. This network obtains its water from all four water resources, but uses very little saline water (desalination of seawater and groundwater for municipal use is growing rapidly, but still represents less than 0.05% of public supply). The public supply delivers water to the domestic and commercial/industrial sectors.

USGS reports directly the total water withdrawn from each resource for public supply.

USGS reports directly the water delivered to the domestic sector from public supply. USGS does not report directly how the remainder of public supply is apportioned. In this analysis, it is assumed that all water withdrawn for public supply that is not delivered to the domestic sector is delivered to the commercial/industrial sector. For the purposes of this analysis, the commercial sector includes commercial and light industrial entities, municipalities, golf courses, conveyance lossand "own use" by the public supply sector.

```
PublicSupply->CommInd = PS-Wtotl - DO-PSDel
```

Domestic

USGS reports directly the withdrawals of fresh surface-water and groundwater by the domestic sector. These withdrawals comprise privately owned water resources (primarily individual wells), generally in areas not served by public supply. There are no reported direct uses of saline water in the domestic sector.

USGS also reports directly the deliveries of public supplied water to the domestic sector.

USGS no longer reports the disposition of domestic water. This analysis assumes that the fraction of withdrawn water consumed by the domestic sector has not changed substantially from its value as reported in 1995: 26%. (Solley et. al., 1999)

```
Domestic->Consumed = 0.26 * Domestic
```

The remainder of domestic water is returned to the surface or ocean. It is difficult to find comprehensive data on national wastewater discharge to the ocean. However, it is estimated that 1.35 billion gallons per day (Heal the Ocean, 2010) are discharged by municipal wastewater treatment in California. This quantity represents approximately 20% of California's public supply. It is also estimated that approximately 50% of all Americans live within 50 miles of the coast (Crossett et. al, 2004). Using California as a proxy for the fractions of total near-costal population which is served by ocean discharge (and acknowledging that this is a very rough estimate), it is assume that 20% (ocean discharge) of 50% (coastal population) of public supply is discharged into the ocean. In other words, at the national level, 10% of publicly supplied water (domestic AND commercial/industrial) is discharged to ocean.

```
Domestic->Ocean = DO-PSDel * 0.10
```

Any domestic water not consumed or discharged to the ocean is returned to surface waters.

```
Domestic->SurfaceReturn =
      Domestic – (Domestic->Consumed + Domestic->Ocean)
```

Commercial/Industrial

USGS reports directly the withdrawals of all four water resources by the industrial sector.

Because the latest edition of Circular 1344 does not describe commercial water use, this analysis combines commercial and industrial water uses. The total use by the commercial/industrial sector therefore includes the total industrial withdrawal plus the portion of public supply that is not delivered to domestic consumers.

```
CommInd = IN-Wtotl + PS-Wtotl - DO-PSDel
```

USGS no longer reports the disposition of water by the commercial and industrial sectors. In 1995, the fractions of withdrawn water consumed by the commercial and industrial sectors were reported to be 14% and 15% respectively. In this analysis, we assume that the composite commercial/industrial water consumption fraction is 15%. (Solley et. al., 1999)

```
CommInd->Consumed = CommInd * 0.15
```

The disposition (ocean or fresh) of water returned from the commercial and industrial sectors is calculated as follows: similar to the residential sector, it is assumed that 10% of public supply deliveries to the commercial/industrial sector are returned to municipalities that discharge water into the ocean. Additionally, it is assumed that 1.5% of the saline surface withdrawals are lost to consumption or evaporation, and the remaining 98.5% are returned to the ocean.

```
CommInd->Ocean =
      (PublicSupply->CommInd * 0.10) + (IN-WSWSa * 0.985)
```

The remainder of commercial/industrial water is returned to bodies of freshwater.

```
CommInd->SurfaceReturn =
      CommInd – (CommInd->Consumed + CommInd->Ocean)
```

Mining

USGS reports directly the withdrawals of all four water resources by the mining sector. The mining sector does not take deliveries from public supplies.

In 1995, USGS estimated that 27% of water use in mining was consumptive (Solley et. al., 1999), and that the remainder was returned to surface bodies. This analysis assumes that no water is returned from the mining sector to the ocean.

```
Mining->Consumed = 0.27 * Mining

Mining->SurfaceReturn = Mining – Mining->Consumed
```

Aquaculture

USGS reports directly the withdrawals of fresh surface-water and fresh groundwater for use in aquaculture. No saline water use is reported for aquaculture.

Consumptive use of water in aquaculture can account for 20% to 55% of withdrawn water (Boyd et. al., 2008). This analysis assumes that on average, 25% of water used in aquaculture is consumed. It is assumed that no aquaculture freshwater is returned directly to the ocean.

```
Aquaculture->Consumed = 0.25 * Aquaculture

Aquaculture->SurfaceReturn =
      Aquaculture – Aquaculture->Consumed
```

Livestock

USGS reports directly the withdrawals of fresh surface-water and fresh groundwater for use by livestock. No saline water use is reported by livestock.

In 1995, it was estimated that 58% of livestock water use was consumptive (Solley et. al., 1999). That estimate is reused here. It is assumed that no livestock water is returned to the ocean.

```
Livestock->Consumed = 0.58 * Livestock

Livestock->SurfaceReturn = Livestock – Livestock->Consumed
```

Irrigation

USGS reports directly the withdrawals of fresh surface-water and fresh groundwater for use in irrigation. No saline water use is reported by irrigation.

In 1995, it was estimated that 61% of irrigation water use was consumptive, 20% was returned and 19% was lost in conveyance (Solley et. al., 1999). It is unclear whether conveyance losses should be accounted for as return flow (if the "lost" water remains in the watershed or if it evaporates). For this analysis, we assume that some progress has been made in irrigation efficiency (increasing the consumptive fraction in irrigation) and that some conveyance losses can be considered to be consumptive. The total consumptive fraction for irrigation is assumed to be 70%. It is assumed that no irrigation water is returned to the ocean.

```
Irrigation->Consumed = 0.70 * Irrigation

Irrigation->SurfaceReturn = Irrigation – Irrigation->Consumed
```

Thermoelectric Cooling

USGS reports directly the withdrawals of all four water resources for use in thermoelectric cooling. The thermoelectric sector does not take deliveries from public supplies.

USGS reports separately the quantities of each water resource withdrawn for once-through and recirculating power plants. The consumptive fraction of water use for once-through power plants is generally very low and assumed to be 1.5%. Power plants cooled with ocean water are generally of once-through cooling designs, and it is assumed that 98.5% of saline surface-water used in thermoelectric cooling is returned to the ocean while the remainder is consumed. The consumptive fraction of water use for recirculating power plants can be between 60% and 99% and is assumed here to be 75%. The remainder of all water withdrawn by the thermoelectric sector is returned to the surface.

```
Thermoelectric->Ocean = 0.985 * PO-WSWSa

Thermoelectric->Consumed =
0.75 * PC-WTotl + (PO-WSWSa – Thermoelectric->Ocean)

Thermoelectric->SurfaceReturn =
      Thermoelectric –
      (Thermoelectric->Ocean + Thermoelectric->Consumed)
```

Conclusion

The flow chart described in this report is a compact depiction of the national water use data contained in the USGS report on water use in the United States in 2005. This diagram is available at:

http://flowcharts.llnl.gov

References

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Appendix: Selections from Data Dictionary
(reproduced from excel file available at http://water.usgs.gov/watuse/data/2005/)

PS-WGWFr	Public Supply, groundwater withdrawals, fresh, in Mgal/d
PS-WGWSa	Public Supply, groundwater withdrawals, saline, in Mgal/d
PS-WGWTo	Public Supply, groundwater withdrawals, total, in Mgal/d
PS-WSWFr	Public Supply, surface-water withdrawals, fresh, in Mgal/d
PS-WSWSa	Public Supply, surface-water withdrawals, saline, in Mgal/d
PS-WSWTo	Public Supply, surface-water withdrawals, total, in Mgal/d
PS-WFrTo	Public Supply, total withdrawals, fresh, in Mgal/d
PS-WSaTo	Public Supply, total withdrawals, saline, in Mgal/d
PS-Wtotl	Public Supply, total withdrawals, total (fresh+saline), in Mgal/d
DO-WGWFr	Domestic, self-supplied groundwater withdrawals, fresh, in Mgal/d
DO-WSWFr	Domestic, self-supplied surface-water withdrawals, fresh, in Mgal/d
DO-WFrTo	Domestic, total self-supplied withdrawals, fresh, in Mgal/d
DO-PSDel	Domestic, deliveries from Public Supply, in Mgal/d
DO-TOTAL	Domestic, total use (withdrawals + deliveries)
IN-WGWFr	Industrial, self-supplied groundwater withdrawals, fresh, in Mgal/d
IN-WGWSa	Industrial, self-supplied groundwater withdrawals, saline, in Mgal/d
IN-WGWTo	Industrial, self-supplied groundwater withdrawals, total, in Mgal/d
IN-WSWFr	Industrial, self-supplied surface-water withdrawals, fresh, in Mgal/d
IN-WSWSa	Industrial, self-supplied surface-water withdrawals, saline, in Mgal/d
IN-WSWTo	Industrial, self-supplied surface-water withdrawals, total, in Mgal/d
IN-WFrTo	Industrial, self-supplied total withdrawals, fresh, in Mgal/d
IN-WSaTo	Industrial, self-supplied total withdrawals, saline, in Mgal/d
IN-Wtotl	Industrial, self-supplied total withdrawals, total (fresh+saline), in Mgal/d
IR-WGWFr	Irrigation, groundwater withdrawals, fresh, in Mgal/d
IR-WSWFr	Irrigation, surface-water withdrawals, fresh, in Mgal/d
IR-WFrTo	Irrigation, total withdrawals, fresh, in Mgal/d
IC-WGWFr	Irrigation-Crop, groundwater withdrawals, fresh, in Mgal/d
IC-WSWFr	Irrigation-Crop, surface-water withdrawals, fresh, in Mgal/d
IC-WFrTo	Irrigation-Crop, total withdrawals, fresh, in Mgal/d
IC-IrSpr	Irrigation-Crop, acres irrigated, sprinkler, in thousands
IC-IrMic	Irrigation-Crop, acres irrigated, microirrigation, in thousands
IC-IrSur	Irrigation-Crop, acres irrigated, surface (flood), in thousands
IC-IrTot	Irrigation-Crop, acres irrigated, total, in thousands
LS-WGWFr	Livestock, groundwater withdrawals, fresh, in Mgal/d
LS-WSWFr	Livestock, surface-water withdrawals, fresh, in Mgal/d
LS-WFrTo	Livestock, total withdrawals, fresh, in Mgal/d
LA-WGWFr	Aquaculture, groundwater withdrawals, fresh, in Mgal/d
LA-WSWFr	Aquaculture, surface-water withdrawals, fresh, in Mgal/d
LA-WFrTo	Aquaculture, total withdrawals, fresh, in Mgal/d
MI-WGWFr	Mining, groundwater withdrawals, fresh, in Mgal/d
MI-WGWSa	Mining, groundwater withdrawals, saline, in Mgal/d
MI-WGWTo	Mining, groundwater withdrawals, total, in Mgal/d
MI-WSWFr	Mining, surface-water withdrawals, fresh, in Mgal/d
MI-WSWSa	Mining, surface-water withdrawals, saline, in Mgal/d
MI-WSWTo	Mining, surface-water withdrawals, total, in Mgal/d
MI-WFrTo	Mining, total withdrawals, fresh, in Mgal/d
MI-WSaTo	Mining, total withdrawals, saline, in Mgal/d
MI-Wtotl	Mining, total withdrawals, total (fresh+saline), in Mgal/d
PT-WGWFr	Thermoelectric, groundwater withdrawals, fresh, in Mgal/d
PT-WGWSa	Thermoelectric, groundwater withdrawals, saline, in Mgal/d
PT-WGWTo	Thermoelectric, groundwater withdrawals, total, in Mgal/d
PT-WSWFr	Thermoelectric, surface-water withdrawals, fresh, in Mgal/d
PT-WSWSa	Thermoelectric, surface-water withdrawals, saline, in Mgal/d
PT-WSWTo	Thermoelectric, surface-water withdrawals, total, in Mgal/d

PT-WFrTo	Thermoelectric, total withdrawals, fresh, in Mgal/d
PT-WSaTo	Thermoelectric, total withdrawals, saline, in Mgal/d
PT-Wtotl	Thermoelectric, total withdrawals, total (fresh+saline), in Mgal/d
PT-Power	Thermoelectric, power generated, in gigawatt-hours
PO-WGWFr	Thermoelectric once-through, groundwater withdrawals, fresh, in Mgal/d
PO-WGWSa	Thermoelectric once-through, groundwater withdrawals, saline, in Mgal/d
PO-WGWTo	Thermoelectric once-through, groundwater withdrawals, total, in Mgal/d
PO-WSWFr	Thermoelectric once-through, surface-water withdrawals, fresh, in Mgal/d
PO-WSWSa	Thermoelectric once-through, surface-water withdrawals, saline, in Mgal/d
PO-WSWTo	Thermoelectric once-through, surface-water withdrawals, total, in Mgal/d
PO-WFrTo	Thermoelectric once-through, total withdrawals, fresh, in Mgal/d
PO-WSaTo	Thermoelectric once-through, total withdrawals, saline, in Mgal/d
PO-WTotl	Thermoelectric once-through, total withdrawals, total, in Mgal/d
PO-Power	Thermoelectric once-through, power generated, in gigawatt-hours
PC-WGWFr	Thermoelectric recirculation, groundwater withdrawals, fresh, in Mgal/d
PC-WGWSa	Thermoelectric recirculation, groundwater withdrawals, saline, in Mgal/d
PC-WGWTo	Thermoelectric recirculation, groundwater withdrawals, total, in Mgal/d
PC-WSWFr	Thermoelectric recirculation, surface-water withdrawals, fresh, in Mgal/d
PC-WSWSa	Thermoelectric recirculation, surface-water withdrawals, saline, in Mgal/d
PC-WSWTo	Thermoelectric recirculation, surface-water withdrawals, total, in Mgal/d
PC-WFrTo	Thermoelectric recirculation, total withdrawals, fresh, in Mgal/d
PC-WSaTo	Thermoelectric recirculation, total withdrawals, saline, in Mgal/d
PC-WTotl	Thermoelectric recirculation, total withdrawals, total (fresh+saline), in Mgal/d
TO-WGWFr	Total groundwater withdrawals, fresh, in Mgal/d
TO-WGWSa	Total groundwater withdrawals, saline, in Mgal/d
TO-WGWTo	Total groundwater withdrawals, total (fresh+saline), in Mgal/d
TO-WSWFr	Total surface-water withdrawals, fresh, in Mgal/d
TO-WSWSa	Total surface-water withdrawals, saline, in Mgal/d
TO-WSWTo	Total surface-water withdrawals, total (fresh+saline), in Mgal/d
TO-WFrTo	Total withdrawals, fresh, in Mgal/d
TO-WSaTo	Total withdrawals, saline, in Mgal/d
TO-WTotl	Total withdrawals, total (fresh+saline), in Mgal/d