Universities Council on Water Resources
Water Resources Update, Issue 126, Pages 94-99, November 2003

Water Sustainability in the United States and Cooling Water Requirements for Power Generation

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On a national scale, U.S. water use data collected at five-year intervals by the USGS from 1950 to the present shows that since about 1980 freshwater withdrawals have leveled off, even as population and gross domestic product have continued to increase (Gleick 2002). However, national data are of limited use in an analysis of long-term water sustainability because the aggregation of data can mask changes in demand and potential scarcities that occur at more localized scales. This factor is especially important in the United States because of the climatic variability and the differing rates of growth in various regions. To address the issue of long-term water sustainability across different geographic regions, we conducted a national-scale study at the greatest resolution possible given available data and with a special focus on identifying areas likely to have limited water availability as well as increased electricity demands. Data pertaining to water use were collected and organized at the same spatial resolution, that of counties across the continental United States (3,114 counties in the lower 48 states). The USGS was the primary source of the water withdrawal data (USGS 2002). These were supplemented by data on climate from the Climate Prediction Center of the National Oceanic and Atmospheric Administration (NOAA), on population from the US Census Bureau, on electricity generation from the Department of Energy, and on agricultural activity and land use from the US Department of Agriculture. Using these data, we developed several metrics to characterize water use, including the volume of water withdrawn in a county compared to the available precipitation (defined as the difference between precipitation and potential evapotranspiration in months where the term is greater than zero), the percent of water withdrawn by various sectors of the economy, the contribution of groundwater withdrawal, the stored-water requirements for the driest months of the year, and the rates of water withdrawal for domestic use, thermoelectric cooling, and irrigation. As an example, a map of the total freshwater withdrawal from surfacewater and groundwater sources as a percentage of available precipitation is shown in Figure 1. Areas where this ratio is greater than 100 (i.e., where more water is used than is locally renewed through precipitation) are indicative of basins using other water sources transported by natural rivers or man-made flow structures. In some cases, a ratio greater than 100 may also indicate unsustainable groundwater withdrawal. Areas where this ratio is high are concentrated in the western United States, most notably in the southwestern regions. Maps of other metrics are presented in EPRI (2003).

Projected water withdrawals for the year 2025 were calculated using current data and assuming a “business-as-usual” scenario, where the rates of water use for per capita domestic use and power generation per megawatt-hour remain at their 1995 values. Total withdrawals for other sectors of the economy (agricultural, commercial, and industrial) are assumed to remain at their current levels, broadly in line with available data for the past two decades. However, the expected increases in population and power generation lead to substantially increased water withdrawals for these sectors. To evaluate domestic water demand in 2025, we estimate that the population in each county will exhibit the same

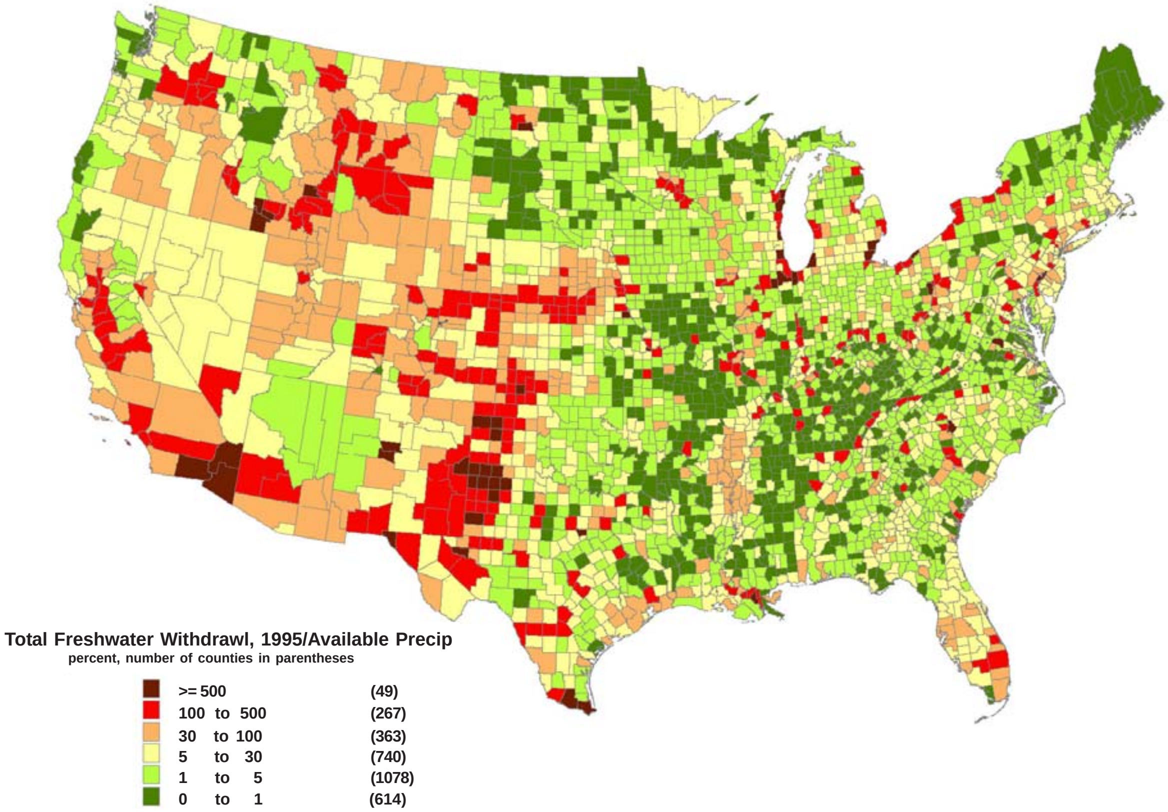

Figure 1. Total freshwater withdrawal in 1995 as a percent of available precipitation. Higher values of this ratio, are indicative of the extent of water resources development in an area. Values higher than 100, are indicative of imports from other regions.

decadal rate of growth that it did over 1990-2000. The forecast growth of electricity generation over 2000-2025, reported at the census division level, was obtained from the Energy Information Administration (EIA 2003). More spatially resolved data were not available for these forecasts. For the purpose of estimating the power generation in 2025 at the county level using the EIA forecasts and 1995 county-level data on electricity generation, we made four assumptions: (i) we applied the actual change from 1995-2000, reported at the state level to all counties within a state that had any form of power generation (hydroelectric or thermal), (ii) we then applied the forecast percent increase in generation from 2000-2025 to all counties within a census division that had any form of power generation (hydroelectric or thermal), (iii) counties that have no generation at present, were not allocated any new generation, and (iv) all new generation was assumed to be thermoelectric. These assumptions are known to have limits and, if additional data become available, may be revised in future studies or in more localized evaluations of water requirements. Our estimates of fresh water use for power generation are conservative to the extent that new power generation relies more on closed cycle cooling than generation in the past; that degraded waters (e.g., saline, produced, and sewage effluent water) are used for cooling; and that renewable energy sources (e.g., solar and wind) meet some of the increased electricity demand. The total population and thermoelectric power generation estimated for 2025 is shown in Figures 2 and 3 respectively. A key inference from these figures, in comparison with Figure 1, is that some of the fastest growth in population and power generation is expected to occur in places where the water resources are already highly developed (i.e., a large fraction of available water is withdrawn for human use).

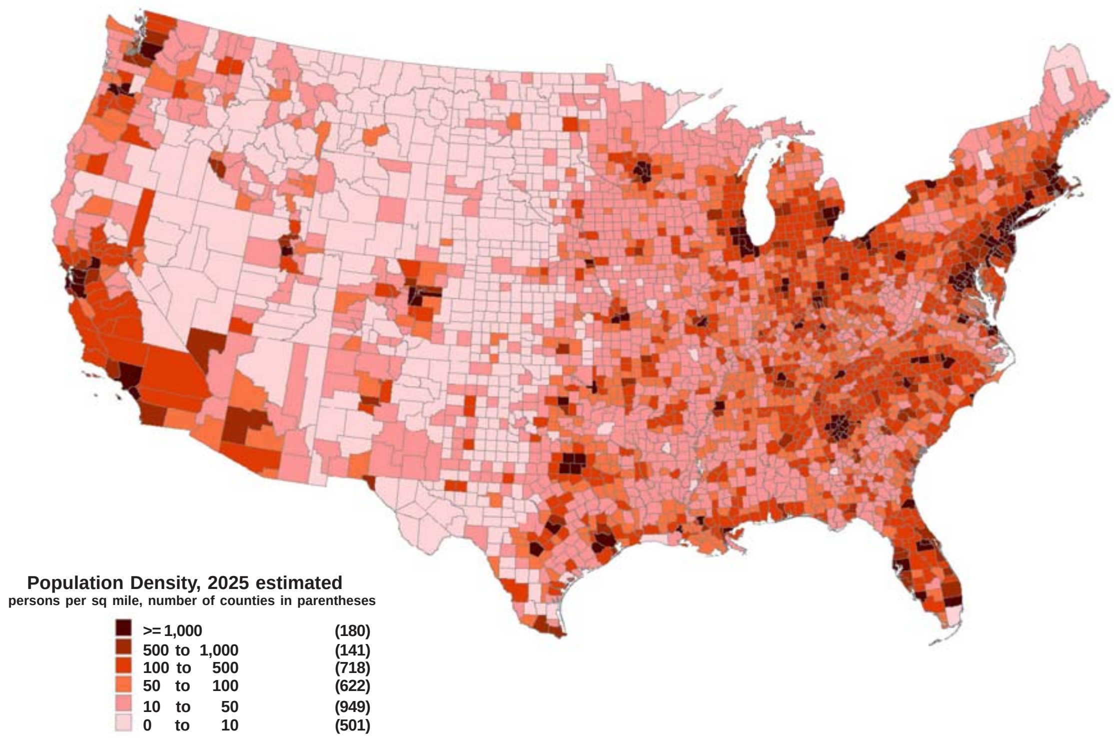

Figure 2. Projected population density of the United States for 2025.

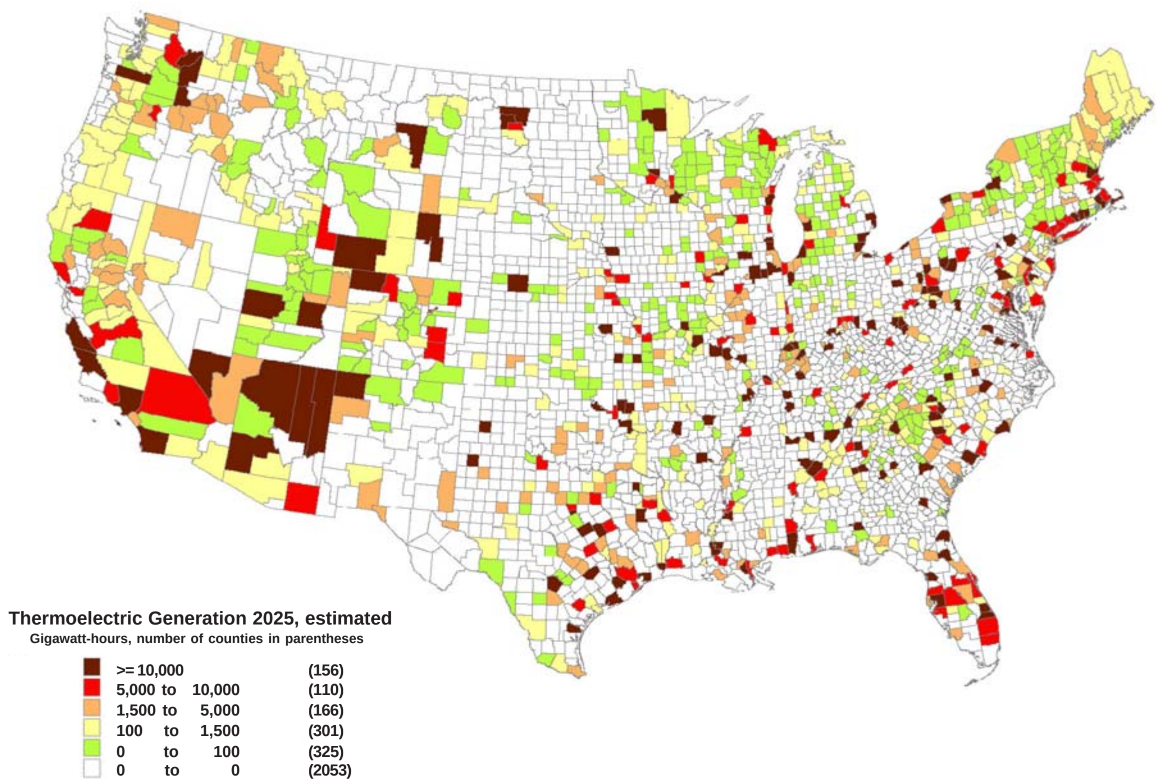

Figure 3. Projected thermoelectric generation for 2025 for the US, based on the census division forecasts.

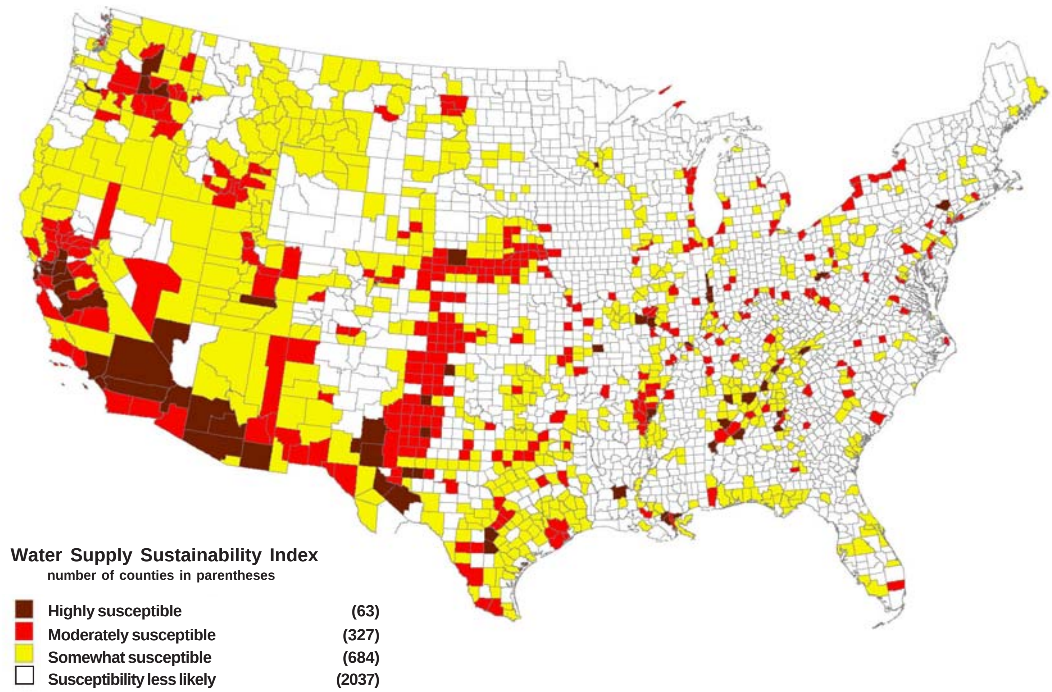

Figure 4. Water Supply Sustainability Index.

Indices of Water Supply Sustainability

Based on our evaluation of data summarized above, we propose two summary indices that can be used to identify regions where water sustainability issues have the potential to become a concern and where cooling water supplies may be limited. Maps of these indices provide a rapid snapshot of water sustainability in the United States and identify regions having water supply concerns that would be suitable for further evaluation using more detailed data and modeling. The first index we propose is the Water Supply Sustainability Index, which evaluates water supply constraints based on metrics representing six different types of criteria. The criteria, shown in bold, and the quantitative metrics considered are:

- **Extent of development of available renewable water:** Greater than 25%
- **Sustainable groundwater use:** Ratio of groundwater withdrawal to available precipitation is greater than 50%
- **Environmental regulatory limits on freshwater withdrawals:** Presence of two or more endangered aquatic species
- **Susceptibility to drought:** Difference between water withdrawal during the three driest months of the year (July, August, September) and available precipitation is greater than 10 inches, where the lowest 3-year average rolling precipitation, based on data from 1934-2002 is considered
- **Growth of Water Use:** Business as usual requirements to 2025 increase current freshwater w**ithdrawal by more than 20%**
- **New requirements for storage or withdrawal from storage:** Summer deficit (difference between withdrawal and available precipitation in an average year) increases more than 1 inch over 1995-2025

If any two of the criteria are met in a county, it is considered to be *somewhat susceptible* to water suppply shortages, if 3 of the criteria are met, the county is *moderately susceptible*, and if 4 or more of the criteria are met, the county is *highly susceptible*. The Water Supply Sustainability Index is mapped in Figure 4. Areas that are susceptible to water supply constraints are concentrated in the southwestern regions of the United States, notably California, Nevada, Arizona, and New Mexico. Other susceptible regions are located in Washington,

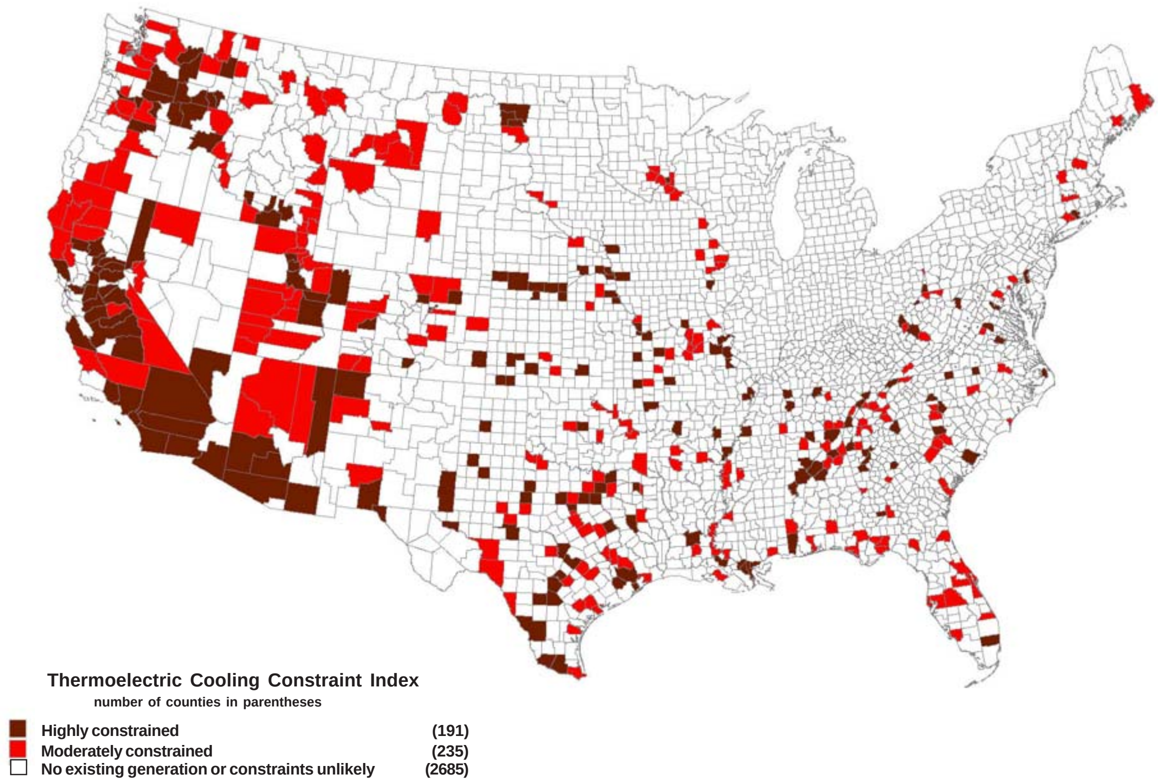

Figure 5. Thermoelectric Cooling Constraint Index.

Idaho, Texas, Alabama, Georgia, Louisiana, and Florida.

Based on the above, we also propose a Thermoelectric Cooling Water Supply Limitation Index and identify areas as *moderately constrained* if the Water Supply Sustainability Index score is two and the 2025 electricity generation is anticipated to increase by more than 50%, as *highly constrained* if the Water Supply Sustainability Index score is three or more, and the 2025 electricity generation is forecast to increase by more than 50%. The Thermoelectric Cooling Water Supply Limitation Index is mapped in Figure 5. Areas where the cooling water supply is likely to be limited occur in Arizona, Utah, Texas, Louisiana, Georgia, Alabama, Florida, and all of the Pacific Coast states. The composite indices presented in this work can be compared with two recent large-scale assessments of water sustainability (Hurd et al. 1999 and DOI 2003). The Hurd et al. study was conducted at the 4-digit HUC watershed level that divides the continental United States into 120 watersheds. Using a mix of data (e.g., level of water resources development, natural variability in streamflow, fraction of precipitation lost to evapotranspiration, groundwater depletion, consumptive use of water by the industrial sector, and an integer index representing institutional flexibility), Hurd et al. identified several regions in the western United States (California, Nevada, Arizona, Utah, Colorado, New Mexico, Kansas and Texas) as having water supply constraints. However, this study did not consider future growth trends of population and electricity generation. Furthermore, the county-level data that we have presented provides a more spatially detailed view of water supply constraints. In particular, the relatively high demands caused by metropolitan areas show up clearly in the county-level maps but not at the 4-digit HUC watershed level in the Hurd et al. study. The US DOI (2003) study identified areas in the western United States that were ranked according to their potential for water supply conflicts. Several of the areas identified in that study are common with areas that we have identified as having supply constraints in Figure 1, such as southern Arizona, eastern Washington, California's Central Valley, etc. However, the DOI study did not provide any quantitative information on how these areas were identified, and it did not identify water supply limitations from the perspective of thermoelectric cooling.

Conclusions

This study constitutes a small step toward developing a comprehensive assessment of the state of the nation's water sustainability and the possible impacts on power generation. Although we have developed maps of water sustainability using the best available information today, this information could be significantly enhanced in the future. Information is especially needed in three areas: instream use requirements to maintain optimal habitat and beneficial uses; water storage and available withdrawal capacity from an infrastructure perspective; and, finally, more temporally detailed patterns of water use. Instream flow requirements were last comprehensively assessed nationally at the level of water resources regions in the late 1970's (WRC, 1978). These data need to be updated, and estimates provided at a greater spatial resolution. Renewable water storage (in snowpack, surface water reservoirs or lakes, and groundwater) and the means to access them are a critical component of maintaining supply during the dry months of the year, but this information is not cataloged nationally. The USGS reports annual data on withdrawal, although it is widely known that water shortages are most keenly felt in the dry months. Future versions of the water use database should consider the inclusion of more temporal detail on water use so that deficits in the driest months can be computed more accurately. From the standpoint of thermoelectric generation, this study found that many power plants will have to be located in water-short areas and that a comprehensive evaluation of the tradeoffs associated with using minimal water is needed.

Acknowledgments

The work described above was supported by the Electric Power Research Institute, Palo Alto California. Huug van den Dool of NOAA provided national data on precipitation and estimates of potential evapotranspiration. Chih-Fang Chung prepared all maps in the paper.

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