The central Arizona water-energy nexus: WaterSim 3.5.5

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Introduction

Water and energy are inextricably linked; energy is required to make (enable) use of water and water is used in the process of energy production. Tremendous amounts of energy are required to move water from source through reclamation (Cohen 2007). As a land-locked desert community Metropolitan Phoenix has narrowly defined water sources and, thus, known but unavoidable energy expenditures.

Central Arizona receives potable water from surface supplies and groundwater pumping. About 40% to 60% of the surface water is conveyed by the Central Arizona Project (CAP) aqueduct; Salt River Project (SRP) provides the balance. *The difference between surface water supply and water demand must come from groundwater pumping.*

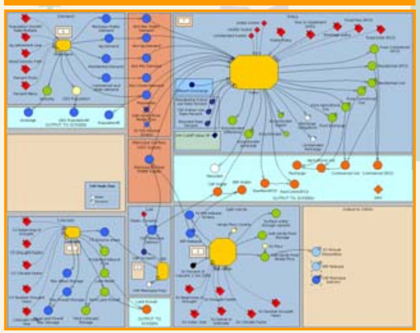
Population growth and climatic uncertainty are two driving factors that will alter the water-energy nexus for Central Arizona. The population of Maricopa Co. is expected to increase 68% by 2031 (Anonymous 2008b). General Circulation Models predict variable future climatic conditions for the SRP watershed, and thus surface water runoff, depending on the scenario used (Ellis et al. 2008). We can evaluate the interactions among population, expected runoff, and the energy requirements needed to sustain our desert community in real time using a water policy and management systems model.

Objectives

We are interested in the energy requirements associated with delivering water to Maricopa County, AZ under an uncertain future.

We examined the impacts of population growth and reduced runoff (as a consequence of climate change) on the energy needed to move CAP water, and pump groundwater, into the county in order to meet demand projected over a 25-year period. To accomplish this objective we used the DCDC WaterSim model (Figure 1) adapted for this purpose.

Figure 1. Object-oriented programming depiction of WaterSim 3.5.5



Materials and methods

We adapted the DCDC WaterSim model to incorporate a county-scale energy use module (Figure 2). Here we focus on the transport of ***CAP water from Lake Havasu to the CAP interconnect*** and on ***groundwater pumping***. Energy use was simulated over a 25-year projection period starting in 2006.

Separate and combined effects of population growth and climate change on the terawatt hours of energy used in source water conveyance were examined.

• **CAP:** We incorporated algorithms for each of the five pumping stations between Havasu and the interconnect using a generic horsepower equation:

$$hp = \frac{\gamma Q H}{550\,e} \qquad [1]$$

Where: hp = horsepower, γ = Specific weight (lbs ft^{-3}, Q = Flow (ft3 s^{-1}), H = head (ft), 550 = the rate at which work can be done for 1 hp (ft lbs s^{-1}), and *e* = pump efficiency (unitless). We converted horsepower to kW (* 0.745699872), and integrated over the year (kWh).

We parameterized and verified the model for each station using known flow amounts and energy used to move that water for each pumping station (B. Henning, personal communication, December 9, 2008).

• **Groundwater pumping:** We used equation [1] parameterized for groundwater pumping (i.e. average well depth). **Here we do not** account for the energy used to move the water from pumps into the water supply.

• **Climate Change:** The AR4 average projection (67% of current; Ellis et al. 2008) was used to estimate the altered runoff for the Salt-Verde watershed.

• **Population Growth:** The 25-year projected change in the population for Maricopa County was used (Anonymous 2008b).

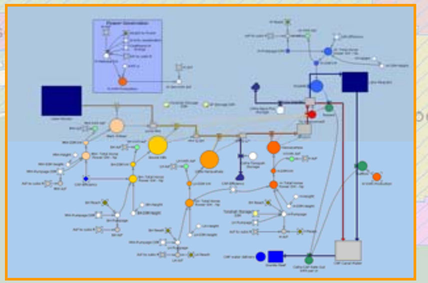


Figure 2. Object-oriented programming depiction of the CAP aqueduct pumping and storage facilities between Lake Havasu and the interconnect. The Lake Pleasant reservoir system generates electricity during release operations but requires energy during storage periods; we model net energy consumption from Waddell.

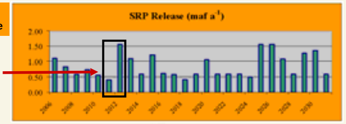
For Perspective

A 100-watt light bulb left on for 10 hours will consume one kWh of electricity. Average household energy use for common appliances (Cohen 2007), based on 10,660 kWh a^{-1} (Anonymous 2008a), and (annual %) are as follows:

- Refrigerator: 1,600 kWh a^{-1} (15%)
- Personal Computer: 384 kWh a^{-1} (3.6%)
- Color TV: 171 kWh a^{-1} (1.6%)
- Home lighting: 938 kWh a^{-1} (8.8%)
- Coffee Maker: 149 kWh a^{-1} (1.4%)
- Elec. Water Heater: 959 kWh a^{-1} (9%)
- Heating, ventilation, and cooling: 3305 to 5970 kWh a^{-1} (31% to 56%)

Results

Figure 3. SRP Annual Release



The Salt-Verde watershed exhibits high variability in annual flows.

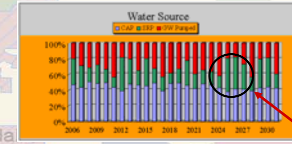


Figure 4. The relative CAP and SRP water conveyed, and groundwater pumped (%) for the projected growth in population.

SRP water is vitally important to the Valley's water budget

Figure 5. The percent change in the volume of groundwater pumped expected with the growth in population projected.

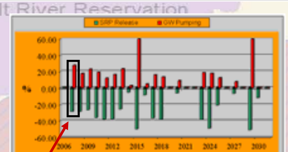


Figure 6. Climate scenario impacts on the % change in the volume of SRP water released and, thus, on groundwater pumped.

Reduced runoff under a changing climate leads to increased groundwater pumping

1 terrawatt hour = electricity for 93,800 homes!!

1 *terrawatt* hour = kWh / 10^9

Figure 7. Moving water from Lake Havasu to the CAP interconnect requires ~1,605 kWh per acre-foot. This corresponds to, roughly, 2 to 2.5 terrawatt hours of electricity each year. Energy used to pump groundwater was an order of magnitude less.

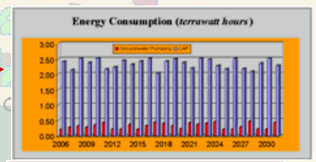
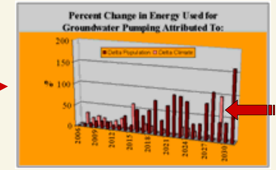


Figure 8. Groundwater pumping accounted for 7% to 18% of the total energy used to supply water to the Valley.

Figure 9. The relative impact of population growth and climate change (independently) on the energy used in groundwater pumping.



Climate impacts energy used

Conclusions

- Moving CAP water to Central Arizona requires 2 to 2.5 terawatt hours of electricity annually (Figure 7). This is equivalent to, approximately, the annual energy used in 188,000 to 235,000 Valley homes.
- The annual energy needed to pump groundwater in Maricopa County varies, depending on:
  - Inherent, annual fluctuations in surface water supplies- Salt-Verde watershed; 0.15 to 0.32 terawatt hours of electricity,
  - Population growth; 0.2 to 0.46 terawatt hours of electricity, and
  - Climate change above and beyond population growth; an additional 0.0 to 0.21 terawatt hours of electricity.
- Projected increases in population are expected to increase energy expended on groundwater pumping by ~ 30 to 150 % by 2031 (Figure 9).
- Reduced surface runoff on the Salt-Verde watershed, as a result of the change in climate projected, will increase the energy expended on groundwater pumping 0 to ~100% (Figure 9).

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For further information

Please contact ***david.a.sampson@asu.edu.***
More information on this and related projects can be obtained at http://watersim.asu.edu/Default.aspx .