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 reusable 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 consumption (Cohen 2007). As a land-locked desert community Metropolitain Phoenix has narrowly defined water sources and, thus, known but unknowable energy expenditures.

Central Arizona receives potable water from surface supplies and groundwater pumping. About 40% to 80% of the surface water is conveyed by the Central Arizona Project (CAP) aqueduct, and the Salt River Project (SRP) provides the balance. The difference between surface water supply and water demand must come from groundwater pumping.

Population growth and climate 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 climate 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 current demand 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. We see a number of uncertain factors:

• 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• Population growth; 0.2 to 0.46 terawatt hours of electricity• Climate change: 0.0 to 0.21 terawatt hours of electricity• Projected increases in population are expected to increase energy expenditure 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).

Materials and methods
We adopted 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 emphasized over a 25-year projection period starting in 2006.

Separate and combined effects of population growth and climate change on the transportation hours of energy used in surface 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:

\[ \text{HP} = \frac{\text{Q} \times \text{H}}{\text{η}} \]  

Where: \( \text{HP} \) = horsepower, \( \text{Q} \) = specific weight (lbs ft\(^{-3}\)), \( \text{H} \) = head (ft), \( \text{η} \) = head at which near and above 1.4 kg (3 lb), and \( \text{η} \) = pump efficiency (25%).

We parameterized and verified the model for each station using known flow amounts and energy requirements 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 ARA 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).

Results

For Perspective
A 100-watt light bulb left on for 10 hours will consume 1 kWh of electricity. Average household energy use for common appliances (Cohen 2007), based on 10,600 kWh/a (Anonymous 2008a), and annual % are as follows:

- Refrigerator: 1,084 kWh/a (15%)
- Personal Computer: 364 kWh/a (4.6%)
- Color TV: 115 kWh/a (1.6%)
- Home lighting: 10,606 kWh/a (100%)
- Coffee Maker: 149 kWh/a (1.8%)
- Dish-Water Heater: 914 kWh/a (11.2%)
- Heating, ventilation, and cooling: 1,901 kWh/a (17.9%)

• The relative annual hours of electricity used in generating electricity for 1,605 kWh from the CAP interconnect requires ~1,605 kWh per acre-foot. This corresponds to, roughly, 2 to 3 terawatt hours of electricity each year. Energy used to pump groundwater was in magnitude less.

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

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• Population growth; 0.2 to 0.46 terawatt hours of electricity• Climate change: 0.0 to 0.21 terawatt hours of electricity• Projected increases in population are expected to increase energy expenditure 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, is expected to increase the energy expended on groundwater pumping 0 to ~100% (Figure 9).

Literature cited

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