Water-Energy Nexus: Moving the People or Resources?

A hypothetical consideration of addressing sustainability

D. Perrone, J. Murphy & G. Hornberger

Vanderbilt Institute for Energy and Environment

INTRODUCTION

Energy and water are inexplicably linked, yet rarely do communities collect enough of the appropriate data to understand how the connection may affect their community. The interrelated nature of these resources is even more evident when their supplies are scarce. We qualitatively describe communities that lack sufficient local water and energy resources for their demands as ***Resource Islands.***

Resource Islands

- ***Resource Islands***: Communities located considerable distances from their water and energy resources
- Ecological Definition: "Resource islands form when individual plants influence the surrounding soil to alleviate nutrient and temperature stress and foster seedling survival and growth" (Carrillo-Carcia et al 2000).
  - Definitions are similar in terms of describing a more-livable micro-environment in an otherwise inhospitable desert ecosystem.
- Example: City of Tucson located in Arizona, United States of America
  - Over 335 miles (540 km) from one of its main water sources and 200+ miles (320 km) from its power supplies (Figure 1).

Problem Statement

Geography (i.e. distance from available water and energy resources) and community size (i.e. demand) directly affect energy and water use. However, quantifying water-energy resource use is difficult to accomplish, much less comprehend, without a functional conceptual model. Current water-energy nexus models are not useful for city planning or community development as they call for data that are not typically collected by communities, inevitably using 'hypothetical' cities or data.

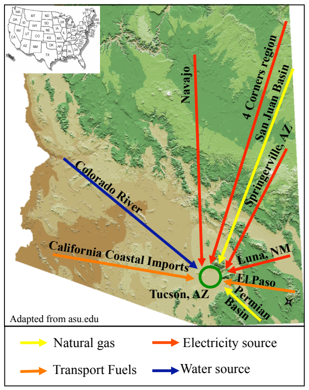

Figure 1: Tucson site map and *Resource Island* depiction.

Project Objectives

1.) To develop a model using national and regional averages of energy for water and water for energy consumption

2.) Enable communities to acquire a cursory understanding of the potential connectedness and impacts to water and energy use

3.) Indicate potential directions of energy for water and water for energy data collection

4.) Use the City of Tucson, Arizona, USA as a case study to highlight the impact of geographic location, distance from water and energy resources

Table 1: Characteristics of the City of Tucson, Arizona, USA

Location	○ 32°08'N, 110°57'W ○ Southern portion of Arizona, USA (Figure 1)
Geography	○ Basin and Range: broad desert valleys and small isolated mountain ranges ○ Groundwater aquifers are small and often isolated from adjacent basins ○ Located in the Tucson basin, a valley composed of alluvial fan sediments ○ Santa Cruz River is adjacent to the City of Tucson, currently intermittent flow controlled by wastewater discharge
Climate	○ Sun belt: Arid to semi-arid climate ○ Low annual precipitation (approximately 27cm / year) ○ Average temperature range from 52° to 85°F (11° to 30°C)
Population	○ 6.5% increase in population over the past 6 years ○ 534,685 people, current population as of 2006
Demographics & Lifestyle	○ 96% of people live within metropolitan Tucson ○ Approximately 71% of Tucson residents commute to work alone (compared to 75% U.S. nationally) ○ 3.5% use public transportation.

METHODS

Conceptual models were developed (Figures 2 & 3) and quantified according to various stages of energy and water use. Tables 2 and 3 describe the model by each stage and provide insight to the user input required for the model. Due to data constraints and difficulties defining conditions, various assumptions were made for the model (Table 4).

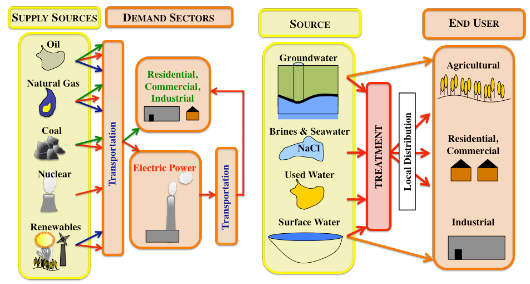

Figure 2: Water for Energy (left) and Energy for Water (right) Conceptual Diagrams

Table 2: Water for Energy Model Description

	Fuel Cycle	Transport	Electricity Production	Transmission
DESCRIPTION	Uses average water consumption for the processes needed to make the energy source consumable by users • Exploration • Extraction & mining • Recovery • Processing • Refining • Enrichment • Growing (biomass)	• Uses heat content of the transportation fuel, or pipeline efficiency, and distance to calculate the total amount of energy consumed for transport • Calculates the water for the energy consumed in transport by using the energy source's water consumption in its fuel cycle • Inherentlydeals with transport mode efficiency	• Uses average water consumption data for power plants based on their energy source and cooling technology • Calculations are dependent on technology • Cooling towers consume ~2X the water that once-through plants consume • Does not incorporate geographical variations in plant consumption	• Uses average transmission line losses and efficiencies to calculate the energy lost in transmission over distances • Assumed end user does not alter energy, so no water is used by the end user for energy consumption
USER INPUT	• Energy sources • Coal, oil, natural gas, nuclear, renewables • Amountof each source • KWh/source/yr	• Location of energy sources, electric generating plants, and community • Distance between energy sources and electric plants or community • Transport mode • Transport mode efficiency • Distance/volume fuel • Pipeline efficiency	• Energy sources • Coal, oil, natural gas, nuclear, renewables • Amountof each source • KWh/source/yr • Type of generating plant • Energy sources used • Cooling technology used	• Transmission line distance from generating facility to community • Transmission line efficiency
SOURCES	•(1994). "Water and Energy." Annual Review of Energy and the Environment **19: 267-299.**	Davis, S. C., S. W. Diegel, et al. (2009). Transportation Energy Data Book.	•Gleick, P. H. (1994). "Water and Energy." Annual Review of Energy and the Environment **19: 267-299.**	Davis, S. C., S. W. Diegel, et al. (2009). Transportation Energy Data Book.

Table 3: Energy for Water Model Description

	Source	Treatment	Local Distribution	End User
DESCRIPTION	Energy used to retrieve water from the source area and moveit to treatment facility •Surface water (conveyance) • Groundwater (pumping) • Recycled water (collection) • Desalination (movement)	Energy used to treat water to usable a standards • Potable •Recycled	Energy used to distribute potable and recycled water to end users	Energy expended in the use of water by the 'End User' (e.g. heading)
USER INPUT	• Water sources & volume / year •Elevation of source • Elevation of treatment facility •Pump efficiency	• Source of water • Size of treatment plant • Level of treatment • Or type of technology	• Average electricity used for distribution pumping • Average electricity rate	• Population of community
MODEL FRAMEWORK	• Surface water, groundwater & desalination: general horsepower equation hp=(y*Q*H)/ (550*e) Where: Y = specific weight of water Q = flow (cubic feet per second) H = total head (feet) E = pump efficiency • Recycled water: Price for pumping and electricity rate to infer average cost of collection	Energy intensity rates from published literature for water treatment depending on source, technology and quantity treated. •Surface water (e.g. SBW Consulting, Inc 2006 Municipal Water Treatment Plant Energy Baseline Study Prepared for the Pacific Gas and Electric Company, Bellevue, WA p 55)	Conversion of electricity used for local pumping to KWh/AF: Ewp = Xe/Re Where: Ewp = Energy used for pumping (KWh/AF) Xe = Average electricity costs for distribution Re = Average electricity rate	KWh per person consumption based on California energy utility reporting. Source data: California Energy Commission, 2005 California's water energy relationship Final Staff Report Prepared in Support of the 2005 IEPR Proc. (Sacramento, CA) CEC-700-2005-011-SF

Table 4: Model Assumptions

Major Model Assumptions	Justification	Implications
No significant energy efficiency technological advances for the fuel cycle & electricity generation since the 1990's	Most detailed and recent data for energy used during production are from 1994 (Gleick)	If the new technology is more efficient, like it often is, the model will over-calculate consumptive water
National and regional averages approximate local scenarios	Water and energy data is often not reported or collected and very hard to track down	Results may be higher or lower than actual
Negligible water is lost through evaporation and leaky pipes	Evaporative loss is suggested to be 2-3% (CAP) and quality of local distribution system was not taken into account	The total amount of water may be high if accounting for 'lost' water during transportation
Only the community's reported, direct water and energy demands were used	This study does not address a life cycle approach so a cradle to grave analysis was not needed	Water and energy associated with construction and maintenance of equipment (water & energy) is not accounted for
Community is considered an incorporated city	Boundaries are hard to define due to inconsistency in water and energy boundaries	Results do not include suburbs or the surrounding metropolitan area

RESULTS

Virtual water and energy resources (the amount of water used in the production of energy and the amount of energy used in the acquisition of water) were analyzed for Tucson, Arizona. Inclusion of virtual water for energy more than doubles the amount of water consumed by the City of Tucson (Figure 3). However, virtual energy used in the acquisition of water is an insignificant portion of the total energy used by the City of Tucson (Figure 4). For the case study, two scenarios were considered to address the hypothetical question of moving the people to the resources and the resources to the people for Tucson: Scenario 1 Current Conditions (i.e. moving the resources to the people) and Scenario 2 Hypothetical Conditions (i.e. moving the people to the resources) (Figures 5 and 6).

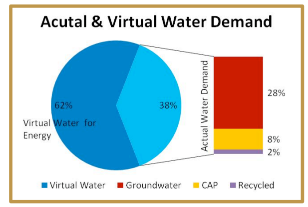

Figure 3: Tucson water demand

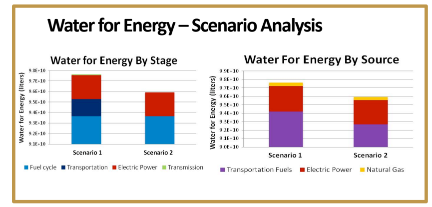

Figure 5: Tucson water for energy scenario analysis

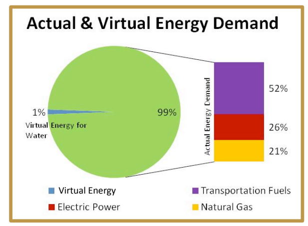

Figure 4: Tucson energy demand

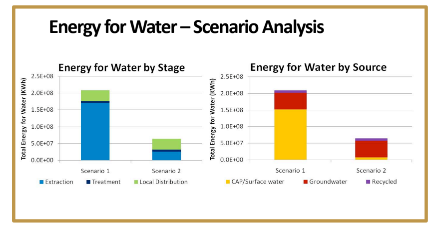

Figure 6: Tucson energy for water scenario analysis

DISCUSSION

The scenario analysis indicates that Tucson is a resource island. For virtual water and energy, transportation and extraction, respectively, are the most sensitive stages (Figure 5 and 6), confirming the reliance on distant resources to provide a more hospitable environment in an otherwise arid, resource-deprived desert. If the people were, hypothetically, moved to the resources, less water and energy would be consumed. Although the magnitude difference between scenario one and two is far greater for virtual energy, it only accounts for 1% of Tucson's total (virtual and actual) energy (Figure 4 and 6). End use is not important for water for energy considerations but it plays a significant, if not dominant, role in energy for water. Due to difficulties quantifying the end-use stage (e.g. heating water) of energy for water, this was not included in this case study. Rough estimates, however, approximated end-use virtual energy as three orders of magnitude higher than all other stages combined. International imports of energy materials were not considered in this study due to difficulty identifying source location. Including international import distances in the scenario analysis of water for energy would greatly increase the magnitude of scenario one through the transportation stage (Figure 5). Economies of scale may prove important when considering water and energy use and will be further investigated.

CONCLUSION

Although this model does not use site specific data, it has the potential to expose a community to the data collection needs of water-energy analysis. The aim is to make communities more aware of the nexus so future planning can account for the intimate relationship between water and energy resources.

ACKNOWLDGEMENTS

This work was supported by the Vanderbilt Institute for Energy and Environment. We also thank the Departments of CEE & EES for their support.