Complexities of Analyzing the Water/Energy Nexus in Small Hillside Water Distribution Systems

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What is the energy penalty associated with leakage and other losses in water distribution systems?

Quantifying the water/energy nexus

The research project aims to merge the analytical methods for quantifying water loss and embedded energy to establish a new metric that quantifies the energy penalty for real water losses. A small hillside water distribution system was used as a simple case for testing the applicability and practicality of this analytical technique.

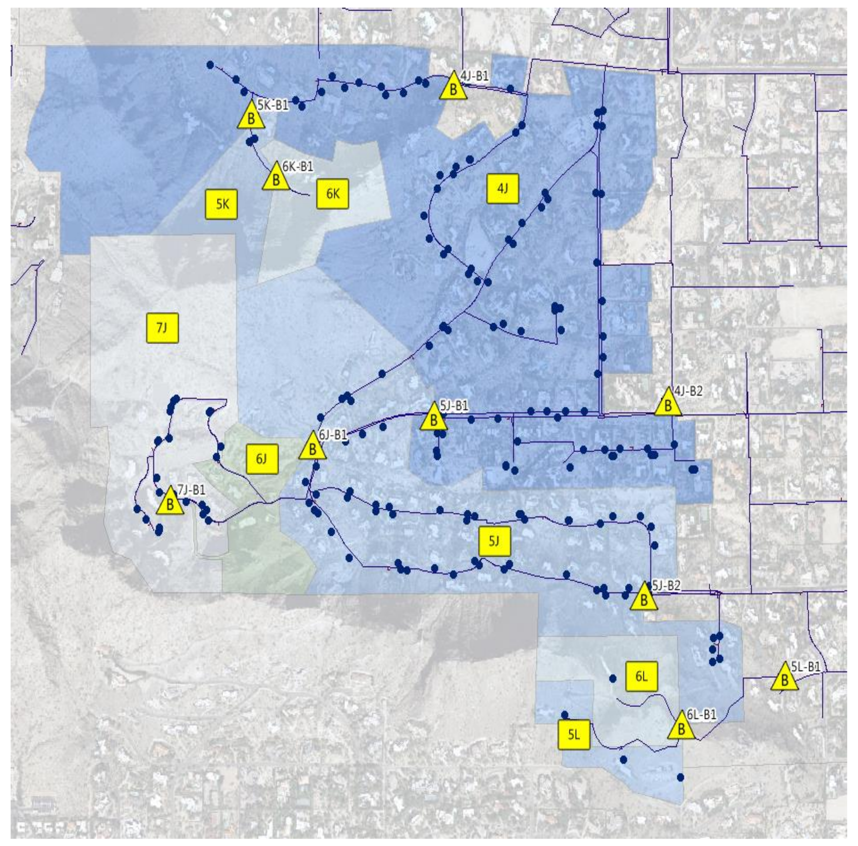
Water and energy calculations

The project involved collecting, normalizing and analyzing data pertaining water and energy use in the distribution system that serves customers along the hillside of Mummy Mountain in Paradise Valley, Arizona. Due to the change in elevation, the area is served by four major pressure zones, split into smaller zones due to geography.

Data used included:

- Customer consumption
- Volume of water pumped by booster stations, and
- Energy used at the booster stations

The data is inputted into an array of equations that relate the different zone structures.



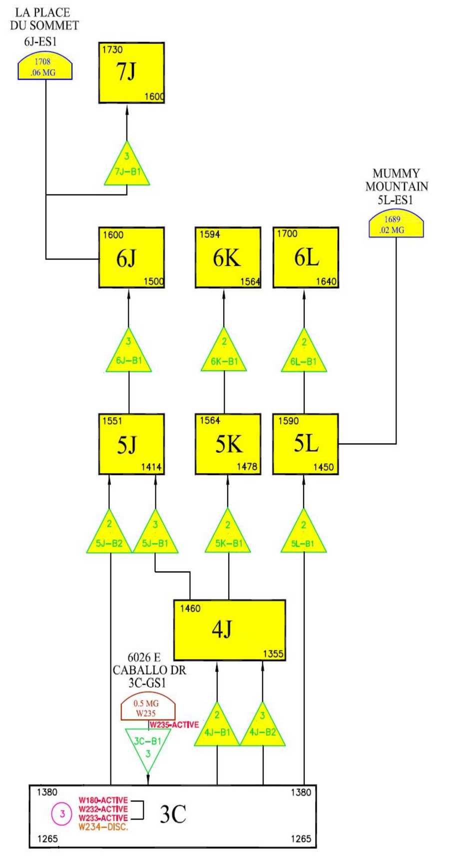


Figure 1 (left): Map of Mummy Mountain hillside area
Figure 2 (right): Schematic of zone interrelationships

Analyzing hillside water system

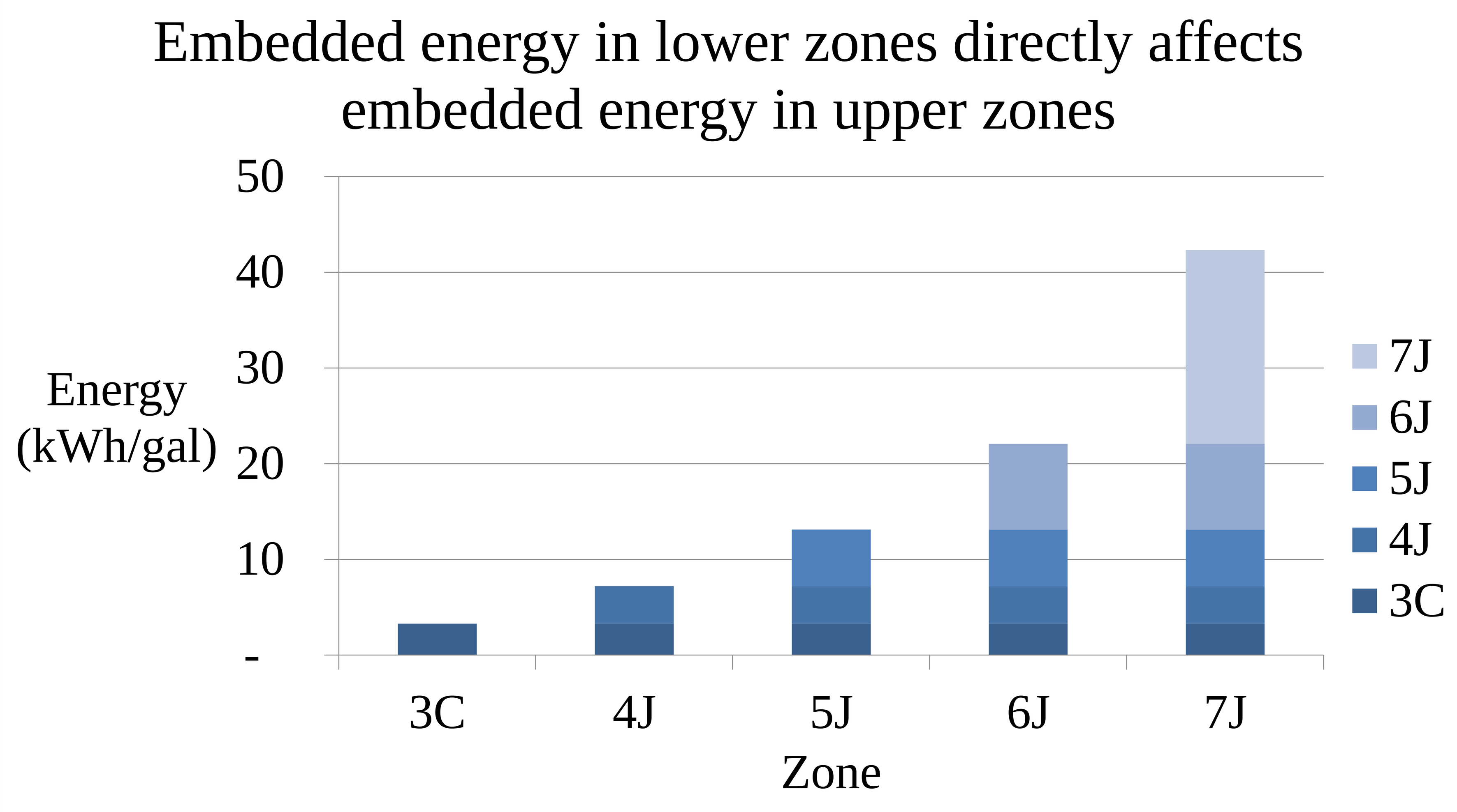


Figure 3: The embedded energy is the amount of energy traveling throughout the system. Higher zones ,which are at higher elevations, further down the system chains have cumulative embedded energy in the water.

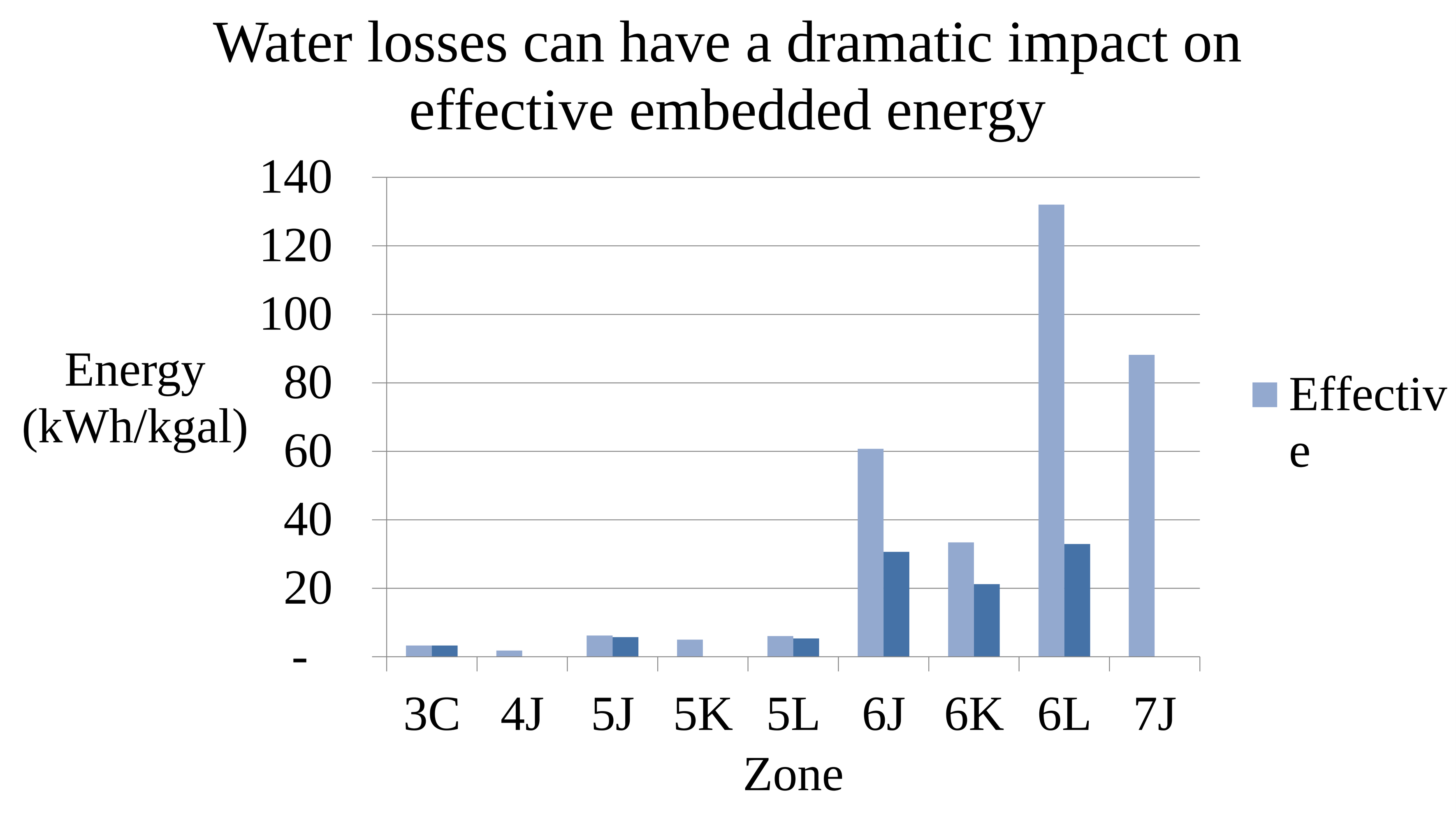


Figure 4: Comparison of Effective Embedded Energy (based on water customers receive) and Actual Embedded Energy (based on water pumped). The difference is the energy penalty due to water losses in the distribution system. It should be noted that zones 4J, 5K and 7J do not depict Actual Embedded Energy bars because of inaccurate data.

Identifying areas of energy loss

The embedded energy equation calculates the embedded energy per zone. The following calculates the embedded energy in zone "A":

$$E_A{}^{out}\left(\frac{kWh}{gal}\right) = \left[E_A{}^{in}\left(\frac{kWh}{gal}\right) + E_A{}^{added}\left(\frac{kWh}{gal}\right)\right]\left[\frac{Q_A{}^{in}(gal)}{Q_A{}^{in}(gal) + Q_A{}^{loss}(gal)}\right]$$

Where $E_A{}^{out}$: embedded energy flowing out of the zone
$E_A{}^{in}$: embedded energy flowing into the zone
$E_A{}^{added}$: embedded energy added due to pumps
$Q_A{}^{in}$: volume of water flowing into the zone
$Q_A{}^{loss}$: volume of water lost in the delivery

Energy is lost either through pumping inefficiency or through system leakage. Calculating Actual and Effective Embedded Energy will quantify both the source and severity of these losses.

Prioritizing improvement efforts

The nexus study allows the City of Phoenix Water Services Department to evaluate the economic viability of corrective measures. Based on the embedded energy chains, the utility is able to prioritize their improvement efforts and correct zones that most affect others. Improvements such as correcting pump inefficiencies and plugging system leaks will make these systems more energy efficient and environmentally sustainable.

Acknowledgements

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