Electronic Supplementary Material (ESI) for Energy & Environmental Science.

Desalination for a Circular Water Economy

Supplementary Information

Meagan Mauter[1,2*] and Peter Fiske[2^]

[1]Civil & Environmental Engineering, Stanford University, Stanford CA 94305.

[2]National Alliance for Water Innovation, Lawrence Berkeley National Laboratory, Berkeley CA 94720.

[*]Corresponding Author: mauter@stanford.edu

Supplementary Information file includes a description of Water Treatment Cost Calculations (Section 1), Water Distribution Cost Calculations (Section 2), and References (Section 3).

Section 1: Water Treatment Cost Calculations

$$CapEx = aQ^n \qquad (1)$$

where CapEx is the total capital cost (in $ million);
Q is the treatment flow (in m^3/day); and
a, n are cost parameters for seawater reverse osmosis.

a assumed to be 0.0046915 and n assumed to be 0.87547 (Bhojwani et al., 2019)

We then normalize this to calculate a levelized cost of water for the capital cost.

$$LCOW_{Cap} = \frac{CapEx[\frac{i(1+i)^n}{(1+i)^n-1}]}{365Q*U} \qquad (2)$$

where $LCOW_{cap}$ is the levelized cost of water due to capital recovery (in \$/m^3);
CapEx is the total capital cost (in $);
i is the discount rate (assumed to be 3%);
n is the payback period (assumed to be 75 years);
Q is the treatment flow (in m^3/d); and
U is the capacity utilization factor (assumed to be 0.9).

We then calculate the levelized cost of water for the operating expenses based on an assumed contribution to the total cost made by capital expenses.

$$LCOW_{Op} = \frac{LCOW_{Cap}}{(1-f)} \qquad (3)$$

where $LCOW_{Op}$ is the levelized cost of water due to operating expenses (in \$/m^3);
$LCOW_{Cap}$ is the levelized cost of water due to capital recovery (in \$/m^3); and
f is the fraction of total cost due to capital recovery (assumed to be 0.37 based on (Fritzmann et al., 2007).

The total levelized cost of water due to treatment is therefore:

$$LCOW_{treat} = LCOW_{cap} + LCOW_{op} \qquad (4)$$

Using the assumed values, this simplifies down to:

$$LCOW_{treat} = 0.7895Q^{-0.125} \qquad (5)$$

where $LCOW_{treat}$ is the levelized cost of water from treatment (in \$/m^3)
Q is the treatment flow (in m^3/hr)

Section 2: Water Distribution Cost Calculations

$$A = \frac{Q}{N} \qquad (6)$$

where, A is the area of the distribution network (in mi^2);
Q is the treatment flow (in m^3/hr); and
N is urban water demand (in m^3/mi^2)

N is assumed to be 79.8 m^3/mi^2, the median value from EPANET.

$$L = \frac{A}{R} \qquad (7)$$

where, L is the length of water mains in the distribution network (in mi)
A is the area of the distribution network (in mi^2); and
R is the median ratio of water main length to distribution network area (in mi)

The total capital cost is then,

$$CapEx = C_{main}\mathrm{L} \qquad (8)$$

where, *CapEx* is the capital cost for building the water network (in $)
C_{main} is the cost per mile of water main installed (in $/mi)
L is the length of water mains in the distribution network (in mi)

C_{main} is assumed to be 33 $/ft. This is calculated by assuming 15% of water pipe will be 65 $/ft with a diameter of more than 12", 20% of water pipe will be $35/ft with a diameter between 8" to 12", and 65% of water pipe will be 25 $/ft with a diameter between 4" and 6". (BCC Research, 2016) The $LCOW_{cap}$ is then calculated using Equation (2).

The operating cost for the average cubic meter of water (i.e., travelling halfway down a water main) is then:

$$LCOW_{Op} = \frac{\left[\frac{1}{2}C_{op}\sqrt{\frac{A}{\pi}}\right] * \left[\frac{i(1+i)^n}{(1+i)^n - 1}\right]}{U} \qquad (9)$$

where, $LCOW_{op}$ is the levelized cost of water for operation (in $/m^3$);
C_{op} is the operating cost per mile of pipe traveled (in $/mi);
A is the area of the water distribution network (in mi^2);
i is the discount rate (assumed to be 3%);
n is the payback period (assumed to be 75 years); and
U is the capacity utilization factor (assumed to be 0.9).

C_{op} is assumed to be 0.03 $/mi (Bartholomew and Mauter, 2016). The levelized cost of water distribution is therefore

$$LCOW_{dist} = LCOW_{cap} + LCOW_{op} \qquad (10)$$

The levelized cost of water due to distribution does not have a simplified form. The closest linear approximation is:

$$LCOW_{dist} = 0.1628 + 3x10^{-6}Q$$

where, $LCOW_{dist}$ is the levelized cost of water from treatment (in \$/m^3)
Q is the treatment flow (in m^3/hr)

and the total levelized cost of water is

$$LCOW_{total} = LCOW_{treat} + LCOW_{dist}$$

Section 3: References

1. Bartholomew, T. V. & Mauter, M. S. 2016. Multiobjective Optimization Model for Minimizing Cost and Environmental Impact in Shale Gas Water and Wastewater Management. *ACS Sustainable Chemistry & Engineering,* 4**,** 3728-3735.
2. BCC Research 2016. Special Research Study: Comparison of Water Main Pipe Installation Lenghts and Costs in North and South Carolina: Raleigh, Charlotte, and Spartanburg/Greenville. Wellesley, MA: BCC Research.
3. Bhojwani, S., Topolski, K., Mukherjee, R., Sengupta, D. & El-Halwagi, M. M. 2019. Technology Review and Data Analysis for Cost Assessment of Water Treatment Systems. *Science of the Total Environment,* 651**,** 2749-2761.
4. Fritzmann, C., Löwenberg, J., Wintgens, T. & Melin, T. 2007. State-of-the-art of reverse osmosis desalination. *Desalination,* 216**,** 1-76.