Quantifying Indirect Water Impacts of Buildings' Energy Efficiency

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The issue – indirect water usage

- Most building energy use does not directly impact water.
- Yet, water impact of energy production is very large, via generation plant cooling requirements.

Courtesy of U.S. Department of Energy.
2005 total water withdrawal

Total: 149,650 Billion Gal./Year
Thermoelectric Power: 73,402 Billion Gal./Year

Data source: 2005 USGS Circular 1344.
http://pubs.usgs.gov/circ/1344/

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2005 thermoelectric power withdrawal breakout

Data source: 2005 USGS Circular 1344.  
http://pubs.usgs.gov/circ/1344/
2005 freshwater withdrawal

Total: 127,385 Billion Gal./Year
Thermoelectric Power: 52,195 Billion Gal./Year

Data source: 2005 USGS Circular 1344.
http://pubs.usgs.gov/circ/1344/
2005 freshwater consumption

Total: 37,324 Billion Gal./Year
Thermoelectric Power: 1,305 Billion Gal./Year

http://pubs.usgs.gov/circ/1344/
But why does the Department of *Energy* care about water?

- Water withdrawal constraints may impact utility operations, and restrain energy production.
  - Drought
    - Several Southeast reactors threatened by drought in 2008.
    - Browns Ferry reactor shut down briefly in 2007.
  - Hydro. Water consumed upstream may not make it through turbines downstream.
  - New baseload plants, at least in some regions, could face difficulties in securing sufficient cooling water.

- In DOE’s and society’s interest to fully capture, understand, and convey program impacts, many of which are external and cannot easily be converted into dollar terms.

- Energy efficiency efforts can significantly reduce indirect water impacts of generation, while providing increased water consumptive capacity elsewhere.
  - A CFL in a porch light avoids the consumption of ~140 gallons of water over its lifetime.
The Building Energy Analysis and Modeling System (BEAMS)

- PNNL-developed and DOE Building Technologies Program (BTP)-funded tool used to estimate impacts of buildings-related projects.
  - Lighting
  - Equipment
  - Envelope
  - Whole building

- Uses internal algorithms as well as inputs from the National Energy Modeling System (NEMS).

- Outputs
  - Energy savings
  - Required investment
  - External impacts: avoided carbon, CO, SO\(_x\), NO\(_x\), VOCs, PM10, and now H\(_2\)O withdrawal and consumption.
Enhancements to the estimation of external impacts in BEAMS

- Avoided indirect water withdrawal and consumption (tied to avoided electricity consumption).
- Mean or marginal analysis.
- “By plant” (base, intermediate, peaking) or “weighted” (aggregated across plant type) basis.
  - “By plant” method essentially a time-of-use approach, allowing specification of activity-specific avoided generation mixes.
  - “Weighted” analysis assumes efficiency activities do not shift generation plant dispatch. Generation is avoided at each plant type, using average plant-type mix.
The starting point: water coefficient development, by generation technology

<table>
<thead>
<tr>
<th>Plant Technology</th>
<th>Mean Withdrawal Factor (Gal./kWh)</th>
<th>Mean Consumption Factor (Gal./kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Steam Turbine</td>
<td>11.664</td>
<td>0.299</td>
</tr>
<tr>
<td>Combined Cycle</td>
<td>0.925</td>
<td>0.048</td>
</tr>
<tr>
<td>Combustion Turbine</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Import</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Nuclear</td>
<td>15.691</td>
<td>0.456</td>
</tr>
<tr>
<td>Oil Steam Turbine</td>
<td>14.871</td>
<td>0.11</td>
</tr>
<tr>
<td>Renewable</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

Sources: DOE/NETL-400/2008/1339 and PNNL internally-developed estimates.
## Water coefficient development, by generation plant type and year

### 2010

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Marginal Withdrawal Factor (Gal./kWh)</th>
<th>Marginal Consumption Factor (Gal./kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseload</td>
<td>11.585</td>
<td>0.309</td>
</tr>
<tr>
<td>Intermediate</td>
<td>3.411</td>
<td>0.104</td>
</tr>
<tr>
<td>Peaking</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Weighted</td>
<td>9.391</td>
<td>0.254</td>
</tr>
</tbody>
</table>

### 2030

<table>
<thead>
<tr>
<th>Plant Type</th>
<th>Marginal Withdrawal Factor (Gal./kWh)</th>
<th>Marginal Consumption Factor (Gal./kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseload</td>
<td>11.361</td>
<td>0.304</td>
</tr>
<tr>
<td>Intermediate</td>
<td>3.313</td>
<td>0.101</td>
</tr>
<tr>
<td>Peaking</td>
<td>0.004</td>
<td>0.004</td>
</tr>
<tr>
<td>Weighted</td>
<td>9.204</td>
<td>0.249</td>
</tr>
</tbody>
</table>

Sources: PNNL internally-developed estimates, employing NETL inputs.

Note: Only two selected years of the annual data are displayed here for illustration.
Factors decline slightly over time due to increasing new-plant efficiencies.
Weighted factors utilize average plant-type mix (75.2% baseload, 20.0% intermediate, 4.8% peaking).
Factors are applied to site electricity savings.
Results (weighted): water withdrawal and consumption avoided due to BTP activities

**Actual BEAMS output (Billion Gal./Year)**

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided Total Water Withdrawal</td>
<td>232</td>
<td>925</td>
<td>1,804</td>
<td>2,872</td>
<td>3,493</td>
</tr>
<tr>
<td>Avoided Total Water Consumption</td>
<td>6</td>
<td>25</td>
<td>49</td>
<td>78</td>
<td>94</td>
</tr>
</tbody>
</table>

**Using only freshwater portion of BEAMS output (Billion Gal./Year)**

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avoided Freshwater Withdrawal</td>
<td>165</td>
<td>658</td>
<td>1,283</td>
<td>2,042</td>
<td>2,484</td>
</tr>
<tr>
<td>Avoided Freshwater Consumption</td>
<td>4</td>
<td>18</td>
<td>35</td>
<td>55</td>
<td>67</td>
</tr>
</tbody>
</table>

Sources: PNNL BEAMS model outputs and USGS Circular 1344.  

Proudly Operated by Battelle Since 1965
But how much is a billion gallons of withdrawal?

Sources: BEAMS outputs; USGS, Largest Rivers in the United States; and USGS Circular 1344.
http://pubs.usgs.gov/circ/1344/
And for some perspective on avoided consumption…


▶ Avoided freshwater consumption indicated by BEAMS outputs, in terms of persons offset:

<table>
<thead>
<tr>
<th>Persons offset</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>132,286</td>
<td>529,005</td>
<td>1,031,480</td>
<td>1,641,811</td>
<td>1,997,042</td>
</tr>
</tbody>
</table>

http://www.newton.dep.anl.gov/askasci/gen01/gen01629.htm
Alternative methods of acquiring equivalent consumptive capacity

Household-level retrofits:
- Replace older toilets with 1.6 gallon/flush toilets.
- Replace older top-loading clothes washers with current Energy Star clothes washers.

| Number of retrofit households necessary to yield equivalent consumptive capacity |
|-----------------------------------------------|--------|--------|--------|--------|--------|
|                                               | 2010   | 2015   | 2020   | 2025   | 2030   |
| Households: 1.6 GPF Toilets                   | 434,537| 1,737,687| 3,388,230| 5,393,058| 6,559,929|
| Households: Energy Star Clothes Washers       | 516,582| 2,065,780| 4,027,962| 6,411,323| 7,798,511|

2030: would require at least $980 million toward toilets to yield equivalent impact.

Sources: BEAMS outputs, PNNL Save Water and Energy Education Program (SWEEP), and Energy Star criteria.
http://www.energystar.gov/index.cfm?c=clotheswash.pr_crit_clothes_washers

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“By plant” analysis example

- Avoided-generation plant mixes
  - By plant: 55.7% baseload, 35.7% intermediate, 8.6% peaking.
  - Weighted: 75.2% baseload, 20.0% intermediate, 4.8% peaking.

- In this example, “by plant” analysis yields less avoidance of water withdrawal, due to less avoided generation at water-intensive baseload plants.
Water and energy are intertwined, not only at the point of consumption (in some instances), but also at the point of generation (nearly always).

Efficiency programs can provide significant reductions in indirect water withdrawal and consumption. To the extent this is unrecognized, we may be undervaluing energy efficiency.

Analysis of efficiency impacts on generation plant dispatch is important not only for utility operation, but also for more accurate quantification of water and emissions impacts.
By 2030, BTP efficiency activities will reduce annual freshwater withdrawal and consumption by an estimated 2.48 trillion gallons and 67 billion gallons, respectively.