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Estimating and Incorporating Trends in Water Efficiency into Water Demand Forecasts for New York City

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Historic Demand Context

- 1942-1944: Roosevelt-Hillview West Branch-Skaneateles Rondout-West Branch Tunnels placed into emergency service.

Historical Events:
- 1939-1945: World War II
- 1950-1953: Korean War
- 1955-1975: Vietnam War
- 2003-2011: War in Iraq, Operation Iraqi Freedom
New York City Water Consumption and Population

Water Distributed, MGD

Estimated Population

- Water Distributed
- Estimated Population

Estimated Population

Quarterly Billing

Toilet Rebates/Replacement

Metering
Demand Forecast Circa 1970

~ 1,000 – 1,100 MGD likely to be realized

~ 1,800 – 1,900 MGD Forecasted
“Incremental enhancements” that use output of specific empirical analyses to scale per capita (gpcd) estimates

Empirical analyses
- Long-term time trends in water use
- Impacts of weather and seasonality of NYC water use
- Residual variability

Output of empirical analyses provide forecast factors
- Independent variables (X)
- Elasticities ($\beta$’s) that relate changes in X to changes in forecasted consumption
Why this general approach?

- Combination of schedule and data constraints
- Incrementally builds on recent efforts
- Can mimic features of econometric model in relatively short time frame
- Chance to introduce and use some elements of a more useful future framework
Change in General Forecast Model

\[(Total \, Water \, Use)_F =\]

\[Base \, Water \, Use \; + \; (\Delta Population_F \; \ast \; 75 \, gpcd)\]

\[Population_F \; \ast \; \left(\prod_{n=1}^{N} \left(\frac{X_{n,F}}{X_{n,B}}\right)^{\beta_n} \ast \left(k_{F,\text{Res}} \ast \bar{gpcd}_{\text{Res}} + k_{F,\text{Other}} \ast \bar{gpcd}_{\text{Other}}\right) \ast (1 \pm V_F)\right)\]
Demand Forecast Factor Model Elements

\[ \text{(Total Water Use)}_F = \text{Population}_F \times \left( \prod_{n=1}^{N} \left( \frac{X_{n,F}}{X_{n,B}} \right)^{\beta_n} \right) \times (k_{F,Res} \times \overline{\text{gpcd}}_{Res} + k_{F,Other} \times \overline{\text{gpcd}}_{Other}) \times (1 \pm V_F) \]

Assumptions regarding efficiency

Assumptions regarding weather and climate

Per capita use split between residential and other

Total population and not change in population

Assumptions regarding residual scenario forecast variance
Derivation of “Efficiency Factor”

- Residential sectors dominate total water consumption in NYC.
- Efficiency of toilets fixtures chosen as an indicator of general overall trends in efficiency.
- Efficiency factor based on difference between:
  - Baseline estimated average flow rate (i.e., flush volume) for existing residential toilets.
  - Future estimated average flush volumes over the forecast horizon.
- Efficiency factor constructed as a ratio: factor moves proportionally with change in average flow rate assumptions.
Key Data Sources

- MapPLUTO—tax appraiser database
- U.S. Census
  - American Community Survey (ACS)
  - American Housing Survey (AHS)
- U.S. EPA National Water Savings Model
- Various literature
Derivation of “Efficiency Factor”

To estimate average baseline flush volumes:

- Establish fixture counts
- Estimate initial vintage of fixtures
- Apply assumptions on mechanical efficiency and useful life

Use of MapPLUTO database

- Residential units by year built
- Alteration date
- Assumed maximum alteration date as “effective” year built (where applicable)
- Found nice agreement between ACS and MapPluto for number of housing units
• SF has higher proportion of units built prior to 1980
  - 83% (SF) vs. 66% (MF)

• Collectively, citywide unit distribution looks like MF
  - Prior to 1980 = 67%
  - 1980 to 1994 = 17%
  - 1994 to present = 16%
Derivation of “Efficiency Factor”

- Estimated historical **fixtures** by (effective) year built
  - MapPluto provided estimates of housing units
  - Needed assumptions to estimate number of toilet fixtures
  - Census AHS (2003) bathrooms per housing unit
  - Assumed average number of toilets per unit for single-family and multifamily residential sectors

<table>
<thead>
<tr>
<th>Bathroom Type</th>
<th>Single-Family</th>
<th>Multifamily</th>
<th>SF % of Total</th>
<th>MF % of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>15,400</td>
<td>45,800</td>
<td>25%</td>
<td>75%</td>
</tr>
<tr>
<td>1</td>
<td>290,800</td>
<td>2,385,000</td>
<td>11%</td>
<td>89%</td>
</tr>
<tr>
<td>1.5</td>
<td>286,700</td>
<td>305,700</td>
<td>48%</td>
<td>52%</td>
</tr>
<tr>
<td>2+</td>
<td>731,500</td>
<td>332,200</td>
<td>69%</td>
<td>31%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weighted Average Toilets per Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sector</td>
</tr>
<tr>
<td>----------------------</td>
</tr>
<tr>
<td>Single-Family</td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>Multifamily</td>
</tr>
<tr>
<td></td>
</tr>
</tbody>
</table>
Derivation of “Efficiency Factor”

- Assigned mechanical efficiency assumptions to fixture vintages
  - <1980 = low-efficiency (5.0 gpf)
  - 1980-1993 = medium efficiency (3.5 gpf)
  - 1994 and later = current standard (1.6 gpf)

- Assigned proportion of 1994 and later vintage to high-efficiency (1.28 gpf)
  - U.S. EPA National Water Savings Model
  - Assumptions for passive replacement to 1.28 gpf (2001 – 2011)
Future market share will reflect increasing market for high-efficiency products.

Derivation of “Efficiency Factor”

◆ Accounted for historical DEP toilet rebates/change-outs
  ▪ Ability to match rebate database to MapPluto
  ▪ Toilets rebated by year built
  ▪ DEP rebates/change-outs assumed at current standard

◆ Useful life assumption for residential toilets tied to natural replacement
  ▪ Compared estimates of flush volumes and saturation rates under 30-year and 25-year useful life with Residential End Use Study estimates
  ▪ Developed natural replacement rate based on 30 year useful life
Estimation of Base-Year Average Flush Volumes

- **NYCDEP Toilet Rebates (Parcel)**
  - **Toilet Rebates by Year Built**

- **MapPluto (Parcel)**
  - **Year Built**
  - **SF/MF Housing Units**

- **Census AHS (MSA)**
  - **SF/MF Average Bathrooms/Unit**

- **SF/MF Toilets by Year Built**

- **SF/MF Toilets by Year Built (Post Rebate)**
  - Pre-1983 = 5.0 gpf
  - 1983-1994 = 3.5 gpf
  - Post-1994 = 1.6 gpf

- **Natural Replacement**

- **Fixtures Replaced**
  - 1983-1994 = 3.5 gpf
  - Post-1994 = 1.6 gpf
  - Post-2000 = 1.28 gpf

- **Estimate Existing 5.0, 3.5, 1.6, 1.28 gpf Toilets for 2011**

- **Weighted Average Flow Rate**

**Efficiency factor denominator**
Replacement of Fixtures and Changes in Efficiency

Building Age/Initial Flush Volume Assumptions

- Pre-1983: 5.0 gpf
- 1983-1994: 3.5 gpf
- Post-1994: 1.6 gpf

Shifts into higher efficiency

Replacement Time/GPF Assumptions

- Pre-1983: 5.0 gpf
- 1983-1994: 3.5 gpf
- Post-1994: 1.6 gpf
- Post-2000: 1.28 gpf

SF/MF Toilets by Year Built
## Housing Unit and Fixture Estimates by Building Age and Efficiency Class

<table>
<thead>
<tr>
<th>Sector</th>
<th>Building Age Cohort</th>
<th>Efficiency Class (GPF)</th>
<th>MapPluto Housing Units</th>
<th>AHS 2003 Toilets / Unit</th>
<th>Total Toilets (Pre-Rebate)</th>
<th>Rebated Toilets</th>
<th>Total Toilets (Post-Rebate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>Pre-1983</td>
<td>5</td>
<td>274,670</td>
<td>1.78</td>
<td>488,321</td>
<td>54,964</td>
<td>433,357</td>
</tr>
<tr>
<td>SF</td>
<td>1983-1994</td>
<td>3.5</td>
<td>19,121</td>
<td>1.78</td>
<td>33,994</td>
<td>4,006</td>
<td>29,988</td>
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<tr>
<td>SF</td>
<td>Post-1994</td>
<td>1.6</td>
<td>31,736</td>
<td>1.78</td>
<td>56,422</td>
<td>2,130</td>
<td>54,292</td>
</tr>
<tr>
<td></td>
<td><strong>Total (2011)</strong></td>
<td></td>
<td><strong>325,527</strong></td>
<td><strong>1.78</strong></td>
<td><strong>578,737</strong></td>
<td><strong>61,100</strong></td>
<td><strong>517,637</strong></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>Building Age Cohort</th>
<th>Efficiency Class (GPF)</th>
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<th>Rebated Toilets</th>
<th>Total Toilets (Post-Rebate)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF</td>
<td>Pre-1983</td>
<td>5</td>
<td>2,089,322</td>
<td>1.21</td>
<td>2,530,216</td>
<td>879,268</td>
<td>1,650,948</td>
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<tr>
<td>MF</td>
<td>1983-1994</td>
<td>3.5</td>
<td>462,925</td>
<td>1.21</td>
<td>560,613</td>
<td>181,700</td>
<td>378,913</td>
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<tr>
<td>MF</td>
<td>Post-1994</td>
<td>1.6</td>
<td>509,930</td>
<td>1.21</td>
<td>617,537</td>
<td>64,670</td>
<td>552,867</td>
</tr>
<tr>
<td></td>
<td><strong>Total (2011)</strong></td>
<td></td>
<td><strong>3,062,177</strong></td>
<td><strong>1.21</strong></td>
<td><strong>3,708,365</strong></td>
<td><strong>1,125,638</strong></td>
<td><strong>2,582,727</strong></td>
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</tbody>
</table>
### Fixtures Remaining and Estimated Average Flow Rate

<table>
<thead>
<tr>
<th>Sector</th>
<th>Building Age Cohort</th>
<th>Efficiency Class (GPF)</th>
<th>Total Toilets (Pre-Rebate)</th>
<th>Remaining Toilets</th>
<th>Distribution</th>
<th>Weighted Average Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>SF</td>
<td>Pre-1983</td>
<td>5</td>
<td>488,321</td>
<td>148,504</td>
<td>0.26</td>
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<tr>
<td>SF</td>
<td>1983-1994</td>
<td>3.5</td>
<td>33,994</td>
<td>97,378</td>
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</tr>
<tr>
<td>SF</td>
<td>Post-1994</td>
<td>1.6</td>
<td>56,422</td>
<td>327,557</td>
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<tr>
<td>SF</td>
<td>HE</td>
<td>1.28</td>
<td>-</td>
<td>5,298</td>
<td>0.01</td>
<td></td>
</tr>
<tr>
<td>SF</td>
<td>Total</td>
<td></td>
<td>578,737</td>
<td>578,737</td>
<td>1.00</td>
<td><strong>2.79</strong></td>
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</table>

<table>
<thead>
<tr>
<th>Sector</th>
<th>Building Age Cohort</th>
<th>Efficiency Class (GPF)</th>
<th>Total Toilets (Pre-Rebate)</th>
<th>Remaining Toilets</th>
<th>Distribution</th>
<th>Weighted Average Flow Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>MF</td>
<td>Pre-1983</td>
<td>5</td>
<td>2,530,216</td>
<td>399,765</td>
<td>0.11</td>
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<tr>
<td>MF</td>
<td>1983-1994</td>
<td>3.5</td>
<td>560,613</td>
<td>611,783</td>
<td>0.16</td>
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<tr>
<td>MF</td>
<td>Post-1994</td>
<td>1.6</td>
<td>617,537</td>
<td>2,656,724</td>
<td>0.72</td>
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<tr>
<td>MF</td>
<td>HE</td>
<td>1.28</td>
<td>-</td>
<td>40,094</td>
<td>0.01</td>
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</tr>
<tr>
<td>MF</td>
<td>Total</td>
<td></td>
<td>3,708,365</td>
<td>3,708,365</td>
<td>1.00</td>
<td><strong>2.28</strong></td>
</tr>
</tbody>
</table>
Annual In-City Water Production and Estimated Average Toilet Flow Rates

In-City Demand (MGD)  Estimated Residential Average Flow Rate (gpf)

Development of Fixture Projections

◆ New housing units (2012 – 2040)
  ▪ AHS fixtures per SF/MF housing unit held constant

◆ Existing housing units (2012 – 2040)
  ▪ Continuation of passive fixture replacement (30-year useful life)

◆ National Water Savings model assumptions for future proportion of 1.28 gpf toilets
  ▪ Fixed proportion of new and passively replaced fixtures in each forecast year

◆ Deducted planned DEP rebates/change-outs from low-efficiency inventory remaining in 2014/2015
 Calculation of Efficiency Factor

◆ Future toilet flush volumes
  - Weighted average flush volume across all existing efficiencies

◆ Efficiency (aka $k$-) factor
  - Baseline average residential toilet flush volume of 2.35 gpf serves as denominator of factor

\[
k = \frac{\text{Future average flush volume}}{2.35}
\]

<table>
<thead>
<tr>
<th>Year</th>
<th>Weighted Average Flush Volume</th>
<th>Raw k-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2011</td>
<td>2.35</td>
<td>1.00</td>
</tr>
<tr>
<td>2012</td>
<td>2.32</td>
<td>0.99</td>
</tr>
<tr>
<td>2013</td>
<td>2.29</td>
<td>0.98</td>
</tr>
<tr>
<td>2014</td>
<td>2.21</td>
<td>0.94</td>
</tr>
<tr>
<td>2015</td>
<td>2.15</td>
<td>0.91</td>
</tr>
<tr>
<td>2016</td>
<td>2.12</td>
<td>0.91</td>
</tr>
<tr>
<td>2017</td>
<td>2.10</td>
<td>0.90</td>
</tr>
<tr>
<td>2018</td>
<td>2.08</td>
<td>0.89</td>
</tr>
<tr>
<td>2019</td>
<td>2.07</td>
<td>0.88</td>
</tr>
<tr>
<td>2020</td>
<td>2.05</td>
<td>0.87</td>
</tr>
<tr>
<td>2021</td>
<td>2.03</td>
<td>0.86</td>
</tr>
<tr>
<td>2022</td>
<td>2.01</td>
<td>0.86</td>
</tr>
<tr>
<td>2023</td>
<td>1.99</td>
<td>0.85</td>
</tr>
<tr>
<td>2024</td>
<td>1.97</td>
<td>0.84</td>
</tr>
<tr>
<td>2025</td>
<td>1.96</td>
<td>0.83</td>
</tr>
<tr>
<td>2026</td>
<td>1.94</td>
<td>0.83</td>
</tr>
<tr>
<td>2027</td>
<td>1.92</td>
<td>0.82</td>
</tr>
<tr>
<td>2028</td>
<td>1.90</td>
<td>0.81</td>
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<tr>
<td>2029</td>
<td>1.89</td>
<td>0.81</td>
</tr>
<tr>
<td>2030</td>
<td>1.87</td>
<td>0.80</td>
</tr>
<tr>
<td>2031</td>
<td>1.86</td>
<td>0.79</td>
</tr>
<tr>
<td>2032</td>
<td>1.84</td>
<td>0.79</td>
</tr>
<tr>
<td>2033</td>
<td>1.83</td>
<td>0.78</td>
</tr>
<tr>
<td>2034</td>
<td>1.82</td>
<td>0.78</td>
</tr>
<tr>
<td>2035</td>
<td>1.80</td>
<td>0.77</td>
</tr>
<tr>
<td>2036</td>
<td>1.79</td>
<td>0.77</td>
</tr>
<tr>
<td>2037</td>
<td>1.78</td>
<td>0.76</td>
</tr>
<tr>
<td>2038</td>
<td>1.77</td>
<td>0.76</td>
</tr>
<tr>
<td>2039</td>
<td>1.77</td>
<td>0.75</td>
</tr>
<tr>
<td>2040</td>
<td>1.76</td>
<td>0.75</td>
</tr>
</tbody>
</table>
Application of Efficiency Factor

◆ Concern over applying residential toilet end use efficiency to total gpcd estimates

- Split of total gpcd into residential and other reduces impact by construction
- Can apply different efficiency (or other) rates to other gpcd component
- Built the model to permit scaling of efficiency effects
  - Ability to raise efficiency factor by an exponent (similar to elasticity)
  - Can reduce the value of residential efficiency factors to reflect lesser efficiency potential associated with other end uses
Historical and Forecast In-City Demand
(MGD; forecasts assume historical normal weather)

Million Gallons per Day (MGD)
Historical and Forecast In-City Demand (MGD; forecasts assume historical normal weather)

- Historical In-City MGD
- Without Additional Efficiency Scenario
Historical and Forecast In-City Demand
(MGD; forecasts assume historical normal weather)

Million Gallons per Day (MGD)

- Historical In-City MGD
- With Additional Efficiency Scenario 1
- Without Additional Efficiency Scenario
Historical and Forecast In-City Demand

(MGD; forecasts assume historical normal weather)

- Historical In-City MGD
- With Additional Efficiency Scenario 1
- With Additional Efficiency Scenario 2
- Without Additional Efficiency Scenario
Comparison of Without Additional Efficiency Scenario with 2 With Efficiency Scenarios (In-City MGD, Normal Weather)

<table>
<thead>
<tr>
<th>Year</th>
<th>Without k-factor effects</th>
<th>k-factor ^ 0.68</th>
<th>Raw k-factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>2015</td>
<td>1,057.0</td>
<td>1,020.5</td>
<td>1,004.0</td>
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<tr>
<td>2020</td>
<td>1,076.6</td>
<td>1,021.5</td>
<td>997.3</td>
</tr>
<tr>
<td>2025</td>
<td>1,103.9</td>
<td>1,030.8</td>
<td>999.3</td>
</tr>
<tr>
<td>2030</td>
<td>1,138.2</td>
<td>1,047.0</td>
<td>1,008.5</td>
</tr>
<tr>
<td>2035</td>
<td>1,173.0</td>
<td>1,065.8</td>
<td>1,021.3</td>
</tr>
<tr>
<td>2040</td>
<td>1,188.7</td>
<td>1,070.8</td>
<td>1,022.4</td>
</tr>
</tbody>
</table>
Historical and Forecast In-City Demand
(MGD; forecasts assume historical normal weather)

Historical In-City MGD
Without Additional Efficiency Scenario
Historical and Forecast In-City Demand
(MGD; forecasts assume historical normal weather)

Historical In-City MGD
With Additional Efficiency Scenario 1
Without Additional Efficiency Scenario
Historical and Forecast In-City Demand
(MGD; forecasts assume historical normal weather)

- Historical In-City MGD
- With Additional Efficiency Scenario 1
- With Additional Efficiency Scenario 2
- Without Additional Efficiency Scenario
Summary

- DEP’s previous water demand forecasting model has been enhanced on multiple fronts.
- The model now explicitly recognizes prospective impacts of future water efficiency.
- Derivation of the efficiency forecast factor required extensive use and linkage among data sources.
- All embedded assumptions can be varied to construct alternative scenarios.
- Updated forecast considered more likely to reflect recent trends.
Future Areas of Improvement

- Forecast model still relies on population as primary driver and is essentially still a per capita model
- Much of the underlying structure of demands still hidden
  - Underlying sectoral water use patterns not explicit
  - Geographical differences completely tied to differences in population
  - Per capita usage rates and efficiency factors established at City level and may not be reflective of local trends
- Continue to build spatially and sectorally disaggregate water use database
  - Estimate effects of additional variables
  - Refine water efficiency assumptions
Questions?

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