Uncertainty in Long-term Water Demand Forecasting

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Sustainable Water Management | March 2016 | Providence Biltmore Hotel
Overview

Fundamental concepts of risk and uncertainty

How uncertainty enters long-term forecasts and methods for addressing uncertainty

Selected results of web survey

Closing remarks
Defining Uncertainty

The situation or state of being unsure or in doubt

Lack of confidence--recognition of the chance for error
Uncertainty stems from:

Facts in the universe that we do not possess

Inherent variability in the universe even beyond knowledge of all relevant facts

Components of Uncertainty

Knowledge uncertainty
- Lack of understanding
- Lack of facts
- Lack of data

Inherent variability
- Irreducible randomness
- Nature
- Human
Risk is an expression of the chance of an undesirable outcome as well as the degree of harm occurring due to that outcome.

\[ \text{Risk} = \text{Probability} \times \text{Consequence} \]

If a consequence has no probability of occurring there is no risk.

If there is no consequence or undesirable outcome, there is no risk.
Risk and Water Supply Planning

Risks arise from lack of information, or uncertainty, about events that have not yet occurred.

Risk associated with planning decisions commonly stems from forecasting the future.

There is often a tendency to forecast things that are both variable and uncertain as if they were fixed and certain.
Water demand forecasting

1. Investment Decisions
2. Funding Priorities
3. Revenue and Rate-setting
4. Management Policies
Risks that can be tied to long term water demand forecasts and forecast inaccuracies

Over-sizing of a system

- Unused capacity (you still have to pay for)
- Opportunity costs (environment, financial)

Under-sizing of a system

- Chronic or more frequent shortages (economic damages)
- Lost water sales
Forecasting models help us organize what we know and can measure into instruments for planning.

Water Demand Forecasting Methods
Basic Methods

- Trend extrapolation
- Unit use approaches
- Econometric models
- End use accounting
- Hybrids
- Others

(see Billings & Jones text)
Generic model structure (deterministic)

Model of water use

\[ Q = f(X) \]

The ways in which x’s affect water use

\[ f(*) \]

Factors that affect water use

\[ X \]
Model specification

The most important part of forecast model development

Reflective of:

(a) the degree of knowledge about what influences water use over time,

(b) the amount of information or skill available to derive associations among explanatory factors and water use

(c) the amount of emphasis and resources devoted to the demand forecasting process
Generic model structure (deterministic)

Model of water use: \[ Q = f(X) \]

The ways in which x’s affect water use: \[ f(*) \]

Factors that affect water use: \[ X \]
Generic model structure (uncertain)

Model of water use: \( Q = f(X) \)

The ways in which x’s affect water use: \( f(*) \)

Factors that affect water use: \( X \)

Incomplete, variable, and uncertain
Generic model structure (uncertain)

Model of water use \[ Q = f(X) \]

The ways in which x’s affect water use \[ f(*) \]

Factors that affect water use \[ X \] Imperfect

Incomplete, variable, and uncertain
Generic model structure (uncertain)

Model of water use

\[ Q = f(X) + \epsilon \]

The ways in which x’s affect water use

\[ f(*) \]

Factors that affect water use

\[ X \]

Imperfect

Incomplete, variable, and uncertain
Does your utility attempt to account for uncertainties about the future in your long term water demand forecast?

- Yes: 81.43%
- No: 15.71%
- Don't know: 2.86%
Methods for incorporating uncertainty

Qualitative methods

Rule of thumb range:

\[ Q_{\text{Predicted}} \pm z \% \]

Qualitative scenario:

\[ X_{\text{Expected}} \pm z\% \rightarrow Q_{\text{Predicted}} \pm z'\% \]
Methods for incorporating uncertainty

Quantitative scenarios

Probabilistic scenarios:

\[ X_{\text{Simulated}} \xrightarrow{\text{yields}} Q_{\text{Simulated}} \]

Key concept: We are more confident about predicting a range of possibilities than a single number!

Methods for incorporating uncertainty
Quantitative scenarios

Statistical confidence intervals:
\[
\left( \hat{Q} - t_{(1-\alpha)/2} \cdot \sqrt{s_f^2} \right) \leq Q_{Actual} \leq \left( \hat{Q} + t_{(1-\alpha)/2} \cdot \sqrt{s_f^2} \right)
\]

Where for given value(s) of X:

\[
s_f^2 = s_m^2 + \frac{s_m^2}{n} + \sum_k (X_k - \bar{X}_k)^2 + s_{\hat{\beta}_k}^2 + 2 \sum_{j<k} (X_j - \bar{X}) (X_k - \bar{X}) \text{Cov}(\hat{\beta}_j, \hat{\beta}_k)
\]

- Random error
- Sampling error
  - “Range of experience”
  - Coefficient error
Methods for incorporating uncertainty

Quantitative scenarios

Probabilistic statistical simulation:

\[ s_f^2 = s_m^2 + \frac{s_m^2}{n} + \sum_k (X_k - \overline{X}_k)^2 \]

\[ s_{\beta_k}^2 + 2 \sum_{j<k} (X_j - \overline{X}_j)(X_k - \overline{X}_k) \text{Cov}(\hat{\beta}_j, \hat{\beta}_k) \]

\[ \left( \hat{Q} - t_{(1-\alpha)/2} \sqrt{s_f^2} \right) \leq Q_{Simulated} \leq \left( \hat{Q} + t_{(1-\alpha)/2} \sqrt{s_f^2} \right) \]

Where many value(s) of \( X \) are possible.
Which of the following approaches best describes how your utility accounts for forecast uncertainty?
(57 Responses)

- Scenarios based on qualitative assumptions: 64.9%
- Broad intervals or rules of thumb about variation: 21.1%
- Statistically-based intervals: 12.3%
- None of the above: 1.8%

*Increased likelihood with system size*

>50% addressing uncertainty would like additional variables in forecast model

What would you consider to be the 3 main drivers of uncertainty about water demands over the next 20 to 30 years?

- Climate
- Economy
- Efficiency

Tendency to err on the high side (appetite for risking excess capacity)

Cost of Reliability

Risk Attitude

Foregone opportunities
What types of management methods do you use to cope with uncertainty and mitigate potential consequences?

(n=66; multiple answers possible)

- Monitor water demands and make periodic forecast adjustments
- Build facilities that can be easily expanded in the future
- Phase water supply projects into smaller increments
- Implement water efficiency programs
- Periodically restructure debt/financing
- Employ a rate stabilization fund
- Rely on emergency storage/other short term plans
- Other (please specify)

Flexible structural strategies

Financial innovations

Adaptive management of uncertainty

Coping with knowledge uncertainty

Demand monitoring
Periodic forecast updates
“When the facts change, I change my mind.” (John Maynard Keynes via Nate Silver)

Implementation of water efficiency programs

Alternative source of supply
Highly scalable risk reduction alternative
Closing remarks

• The *raison d'être* for urban water supply planning is to meet current and future demands
• The future demand for water depends on multiple factors that are uncertain
• Practical barriers exist for specifying all “known” sources of uncertainty and variability
• Understanding the array of even a few factors presents an important starting point (climate, economy, efficiency)
Closing remarks

• Resist the urge to think deterministically
  • Be more explicit about what you know and don’t know
  • Confront the role of risk in decision making

• Recognizing and developing forecasts scenarios for most impactful factors another good starting point

• Periodic monitoring of water demand and forecast performance supports anticipatory and adaptive actions—knowledge building
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Relationships of Uncertainty to Knowledge

Meta-Knowledge

- Known Knowns
- Known Unknowns
- Unknown Knowns
- Unknown Unknowns

- exploit
- explore
- find
- imagine

Knowledge

- Knowns
- Unknowns
Thanks! Questions?

For more information and project updates, visit the Water Research Foundation website:

http://www.waterrf.org/Pages/Projects.aspx?PID=4558

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Forecasting methods used by WRF 4558 survey sample.

Actual Water Demand and Past Forecasts

Source: Bruce Flory
Relationships of Uncertainty to Knowledge

Meta-Knowledge

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exploit

Known Knowns

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Meta-Knowledge

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explore

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**Relationships of Uncertainty to Knowledge**