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American Water Works Association

SUSTAINABLE Water Management Conference

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

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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.

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Risk

$$Risk = Probability \times Consequence$$

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.

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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

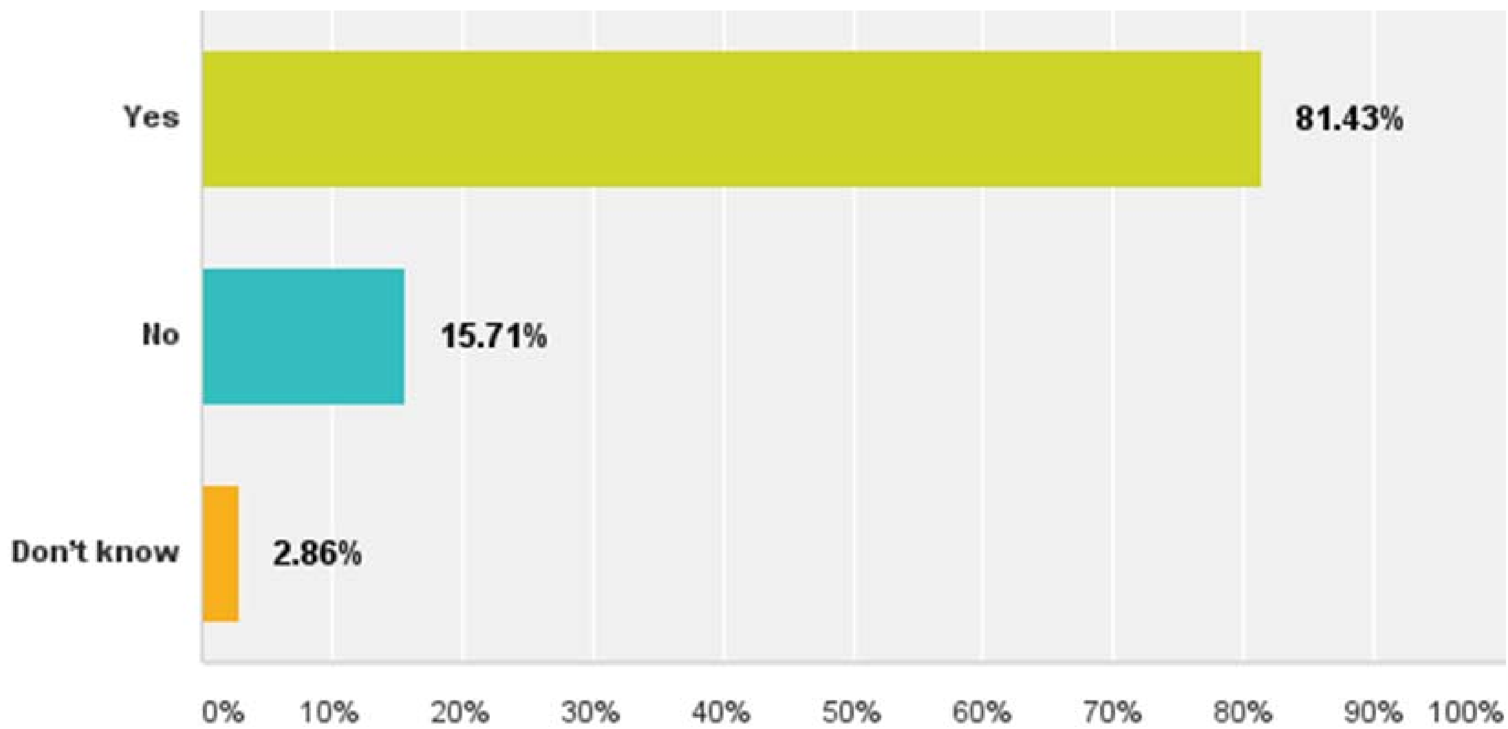
Generic model structure (uncertain)

Model of water use	$Q = f(X)$	
The ways in which x's affect water use	$f(*)$	Imperfect
Factors that affect water use	X	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	$f(*)$	Imperfect
Factors that affect water use	X	Incomplete, variable, and uncertain

Does your utility attempt to account for uncertainties about the future in your long term water demand forecast?



Methods for incorporating uncertainty

Qualitative methods

Rule of thumb range:

$$Q_{Predicted} \pm z\,\%$$

Qualitative scenario:

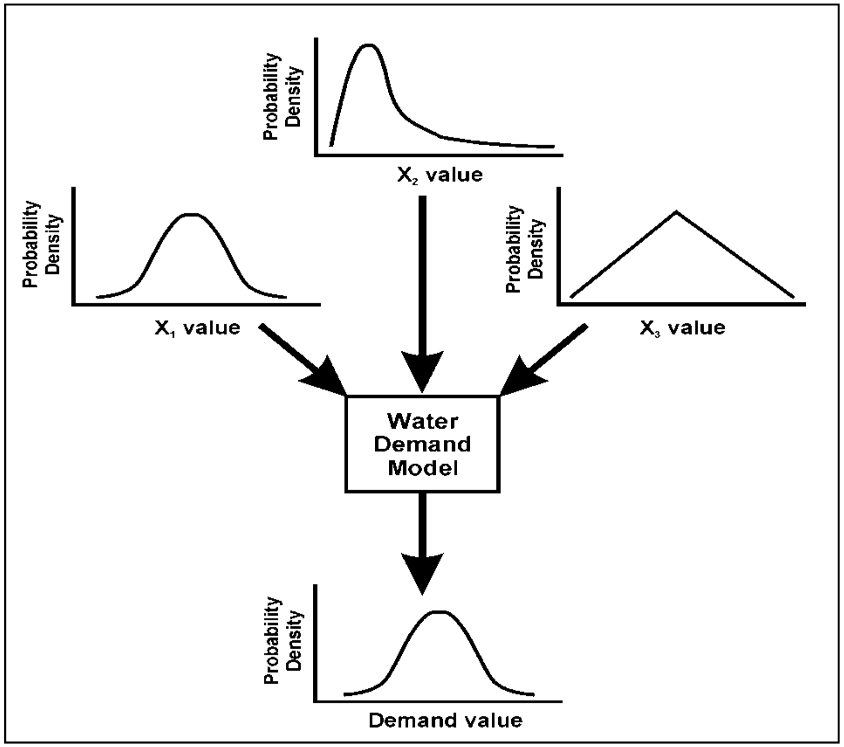
$$X_{Expected} \pm z\% \xrightarrow{\text{yields}} Q_{Predicted} \pm z'\%$$

Methods for incorporating uncertainty

Quantitative scenarios

Probabilistic scenarios:

$$X_{Simulated} \xrightarrow{\text{yields}} Q_{Simulated}$$



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

Source: Kiefer, J.C., Yoe, C., Clayton, J.M., and J.C. Leonard. [N.d.]. *Uncertainty in Long-Term Water Demand Forecasts: A Primer on Concepts and Review of Water Industry Practices.* Denver, Colo.: Water Research Foundation, forthcoming.

Methods for incorporating uncertainty

Quantitative scenarios

Statistical confidence intervals:

$$\left(\hat{Q} - t_{(1-\propto)/2} * \sqrt{s_f^2}\right) \leq Q_{Actual} \leq \left(\hat{Q} + t_{(1-\propto)/2} * \sqrt{s_f^2}\right)$$

Where for given value(s) of X:

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

Random error

Sampling error

- "Range of experience"
- Coefficient error

Methods for incorporating uncertainty

Quantitative scenarios

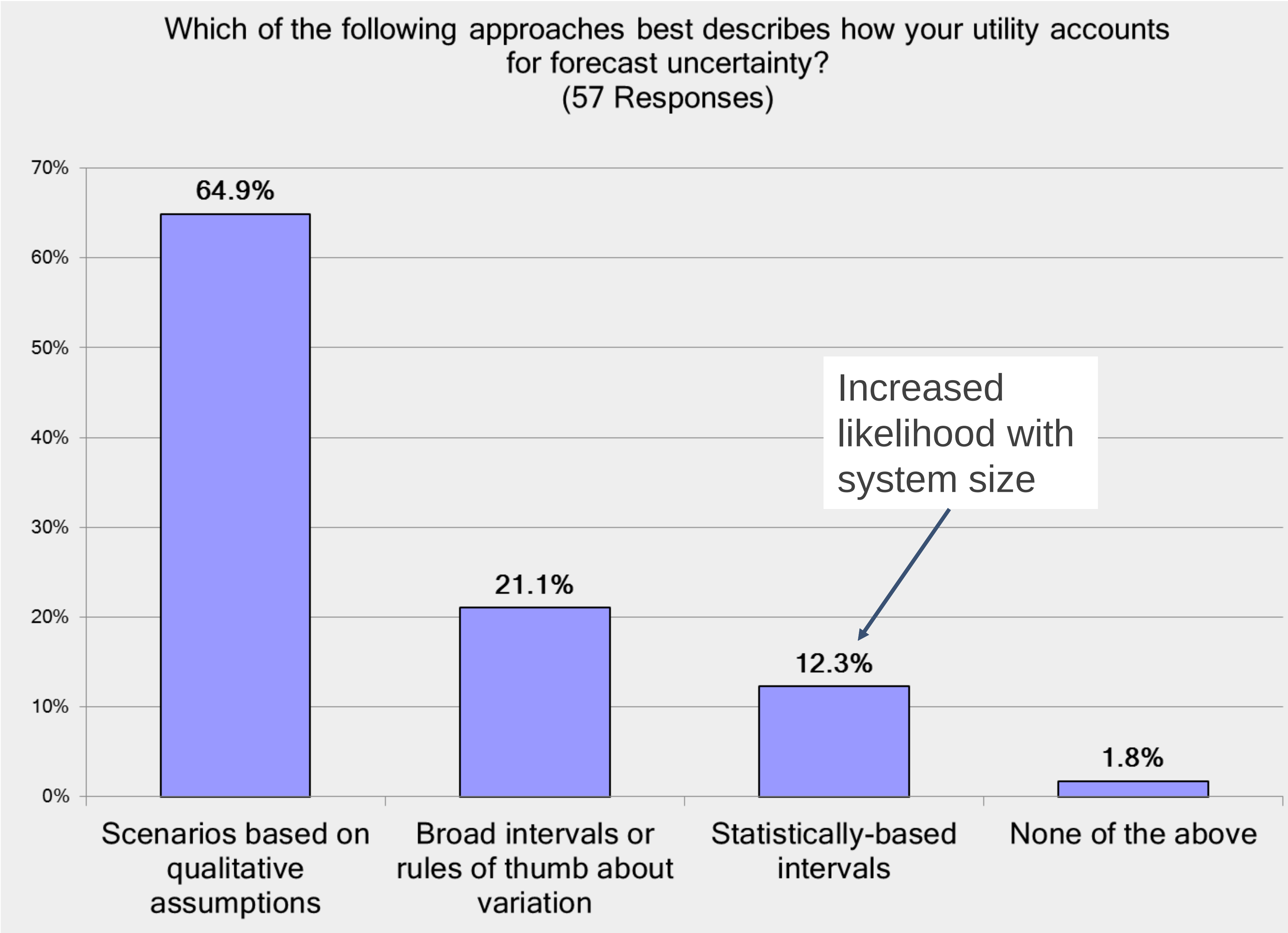
Probabilistic statistical simulation:

$X_{Simulated}$

Where many value(s) of X are possible

$$s_f^2 = s_m^2 + \frac{s_m^2}{n} + \sum_k (X_k - \overline{X_k})^2 \; s_{\hat{\beta}_k}^2 + 2 \sum_{j<k} (X_j - \overline{X_j})(X_k - \overline{X_k}) \, Cov(\hat{\beta}_j, \hat{\beta}_k)$$

$$\left(\hat{Q} - t_{(1-\propto)/2} * \sqrt{s_f^2}\right) \le Q_{Simulated} \le \left(\hat{Q} + t_{(1-\propto)/2} * \sqrt{s_f^2}\right)$$



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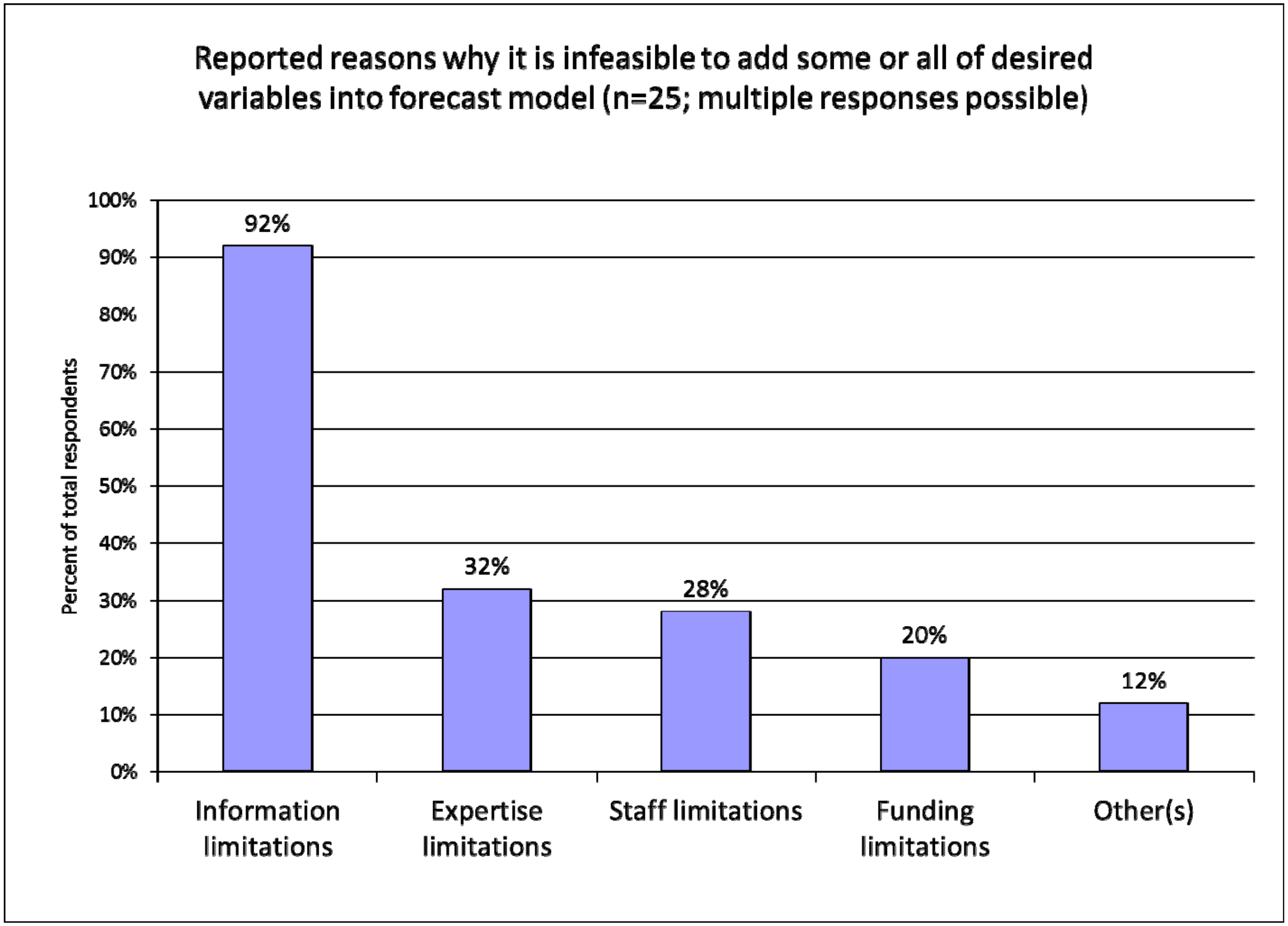
>50% addressing uncertainty would like additional variables in forecast model



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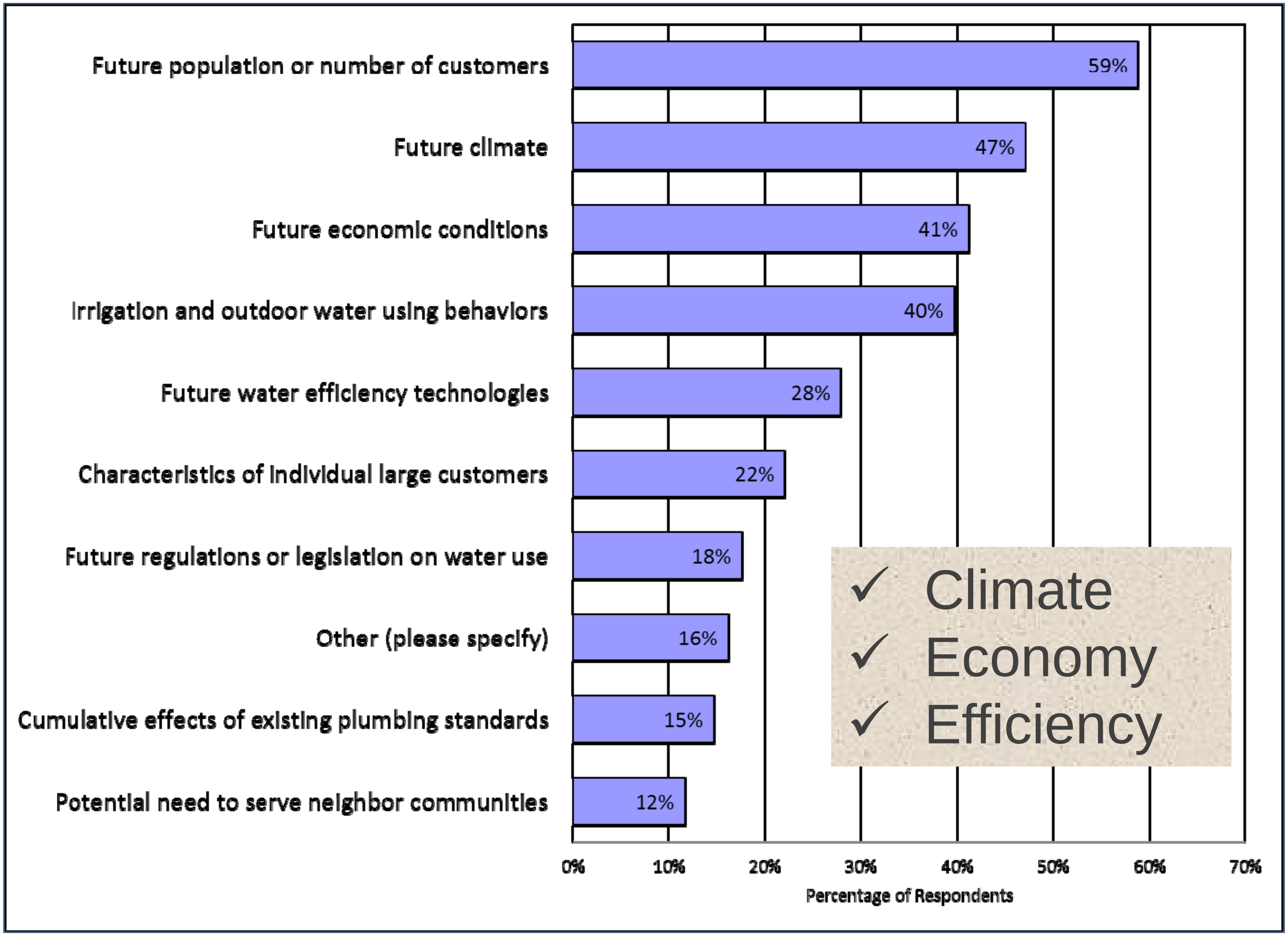
What would you consider to be the 3 main drivers of uncertainty about water demands over the next 20 to 30 years?



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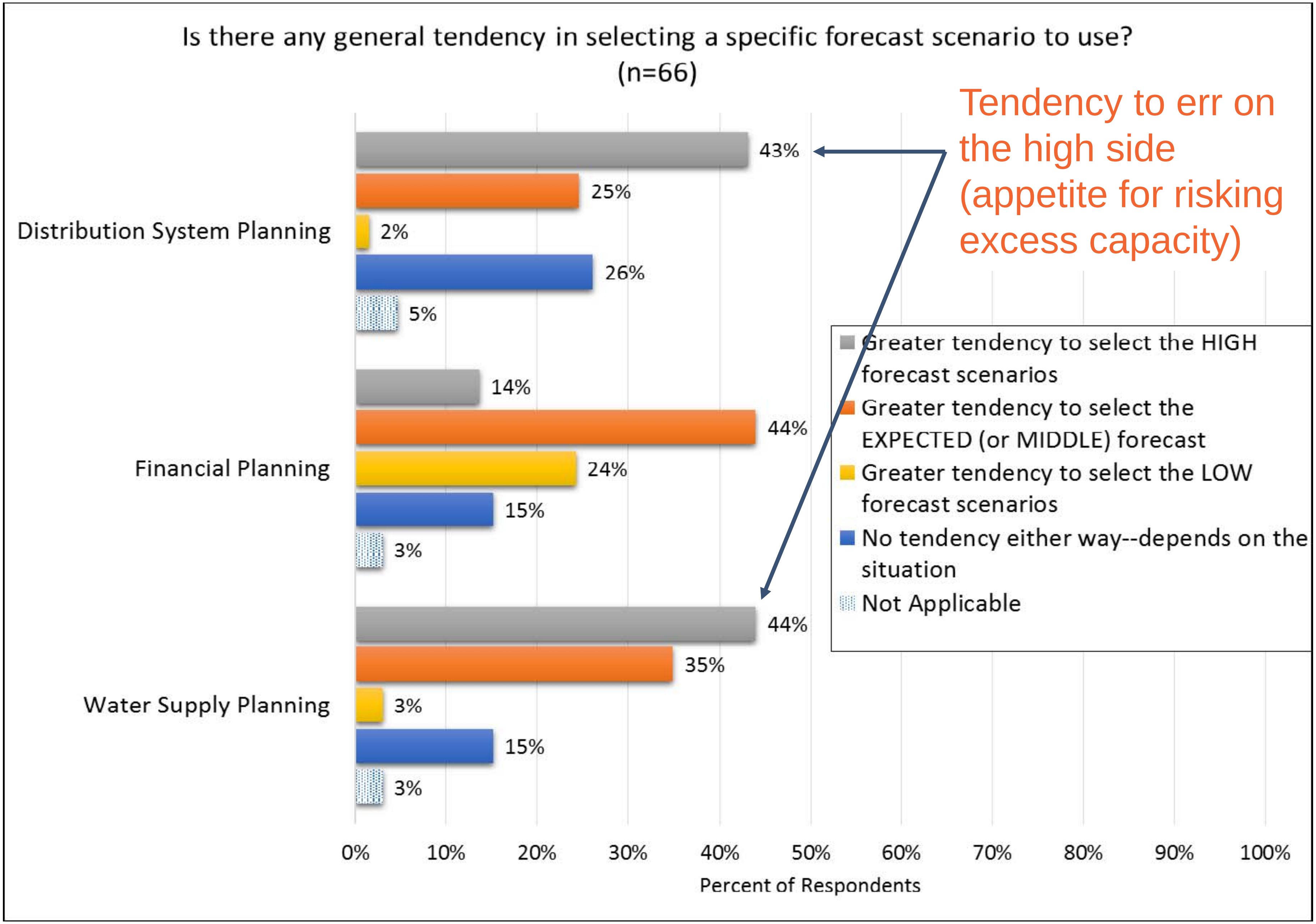

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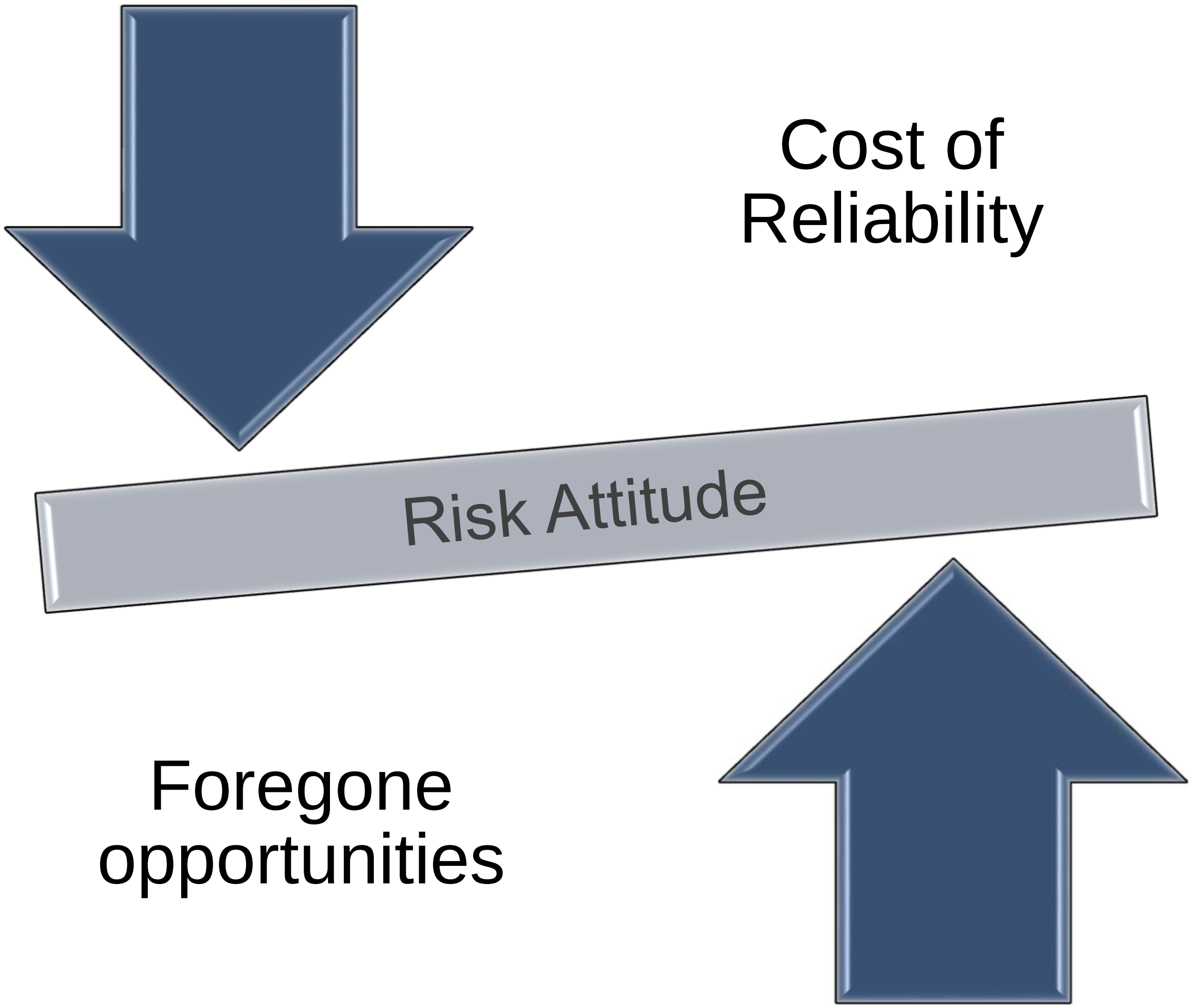
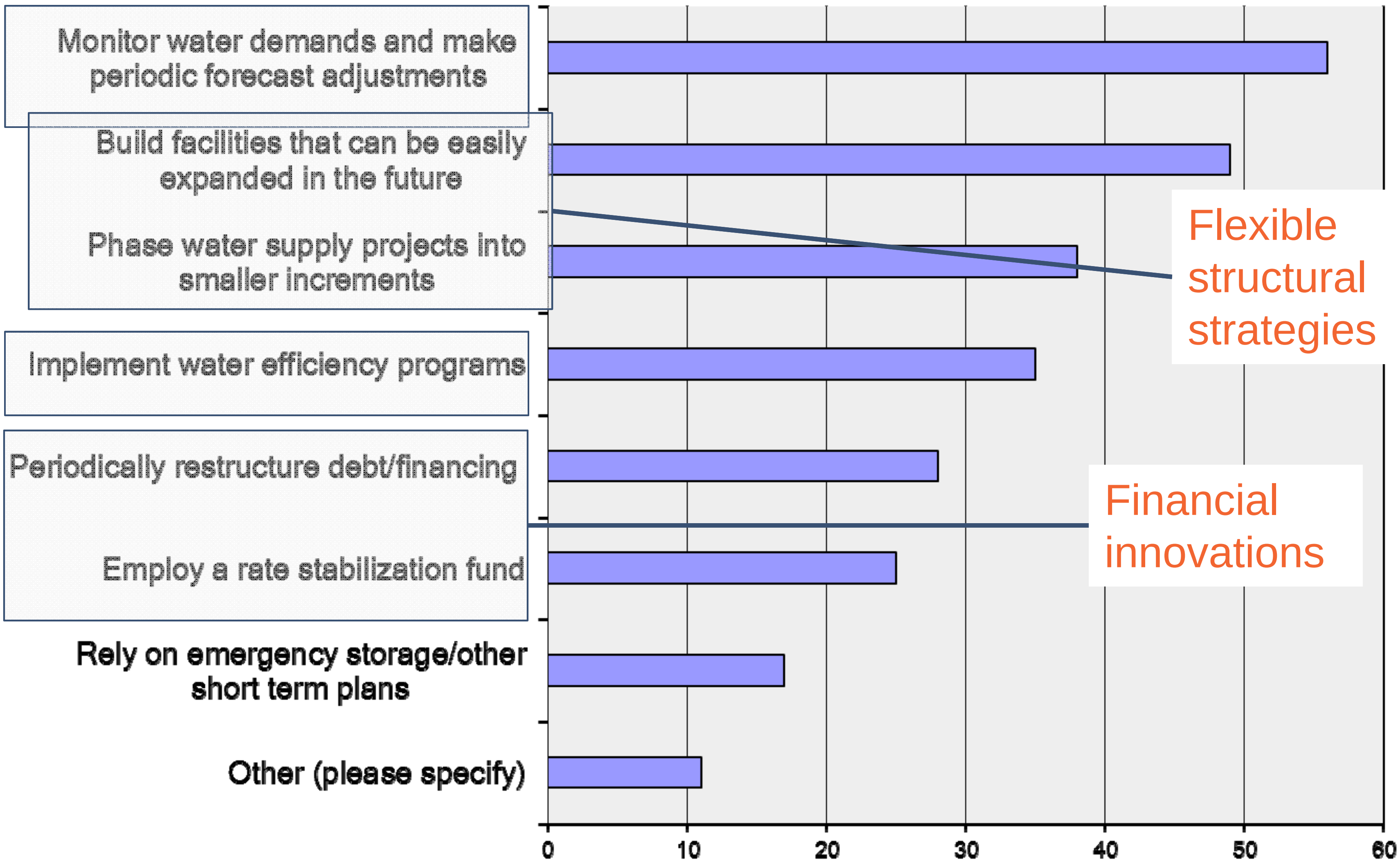


Cost of Reliability
Risk Attitude
Foregone opportunities

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

(n=66; multiple answers possible)



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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

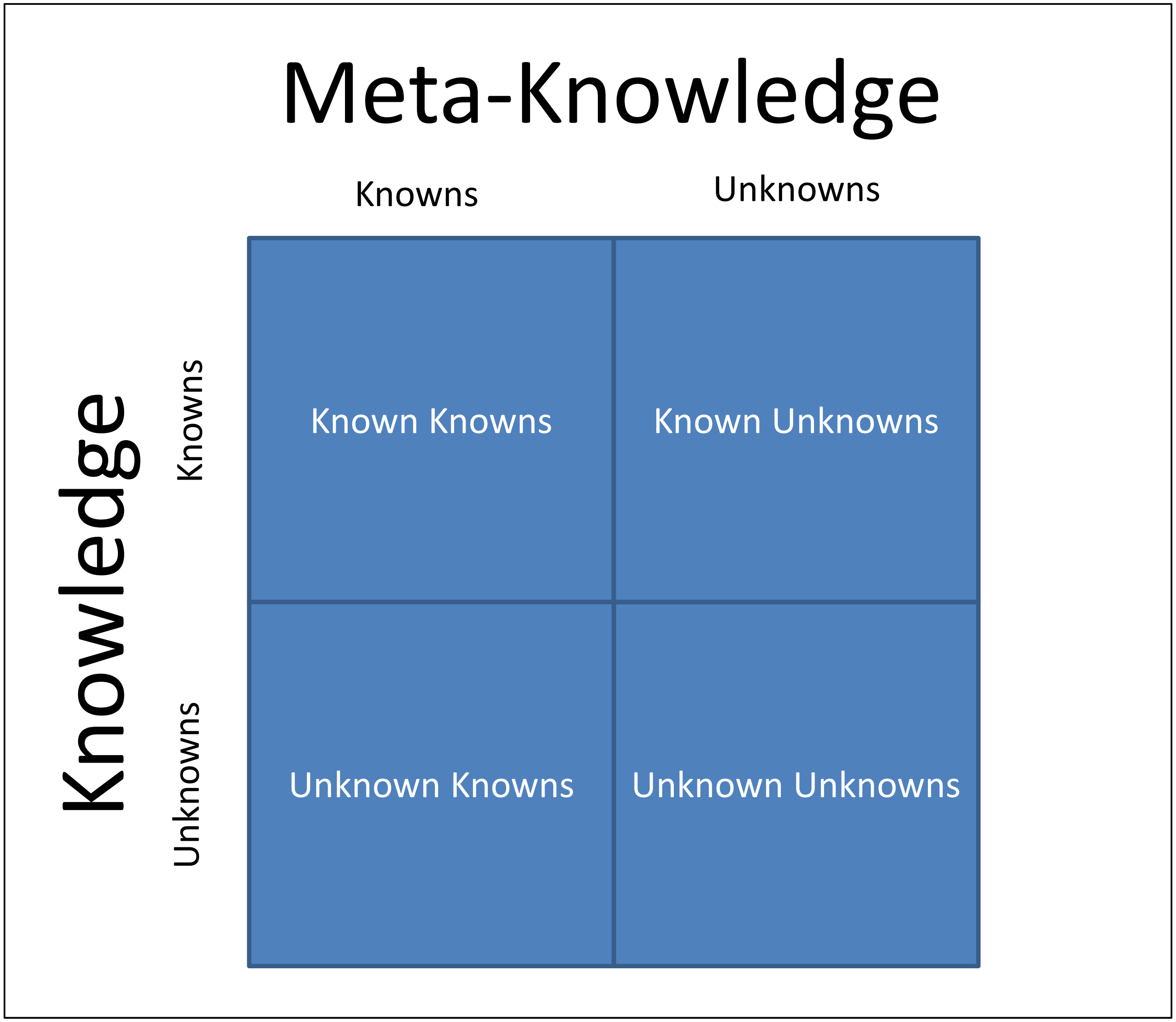
- The *raison d'être* for urban water supply planning is to meet current and future demands
- The future demand for water depends on multiple factors that are uncertain
- Practical barriers exist for specifying all “known” sources of uncertainty and variability
- Understanding the array of even a few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

Closing remarks

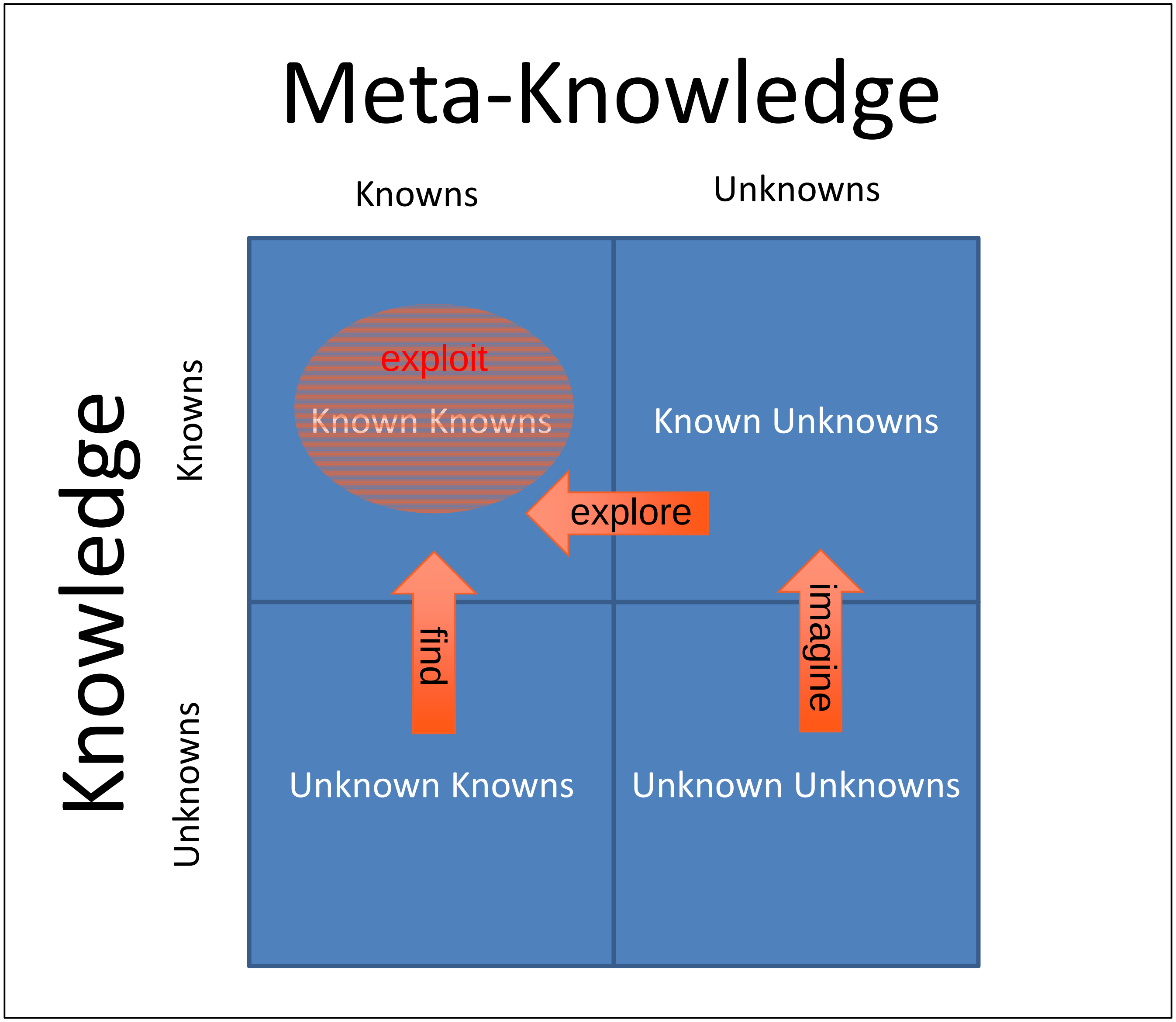
- Resist the urge to think deterministically
  - Be more explicit about what you know and don’t know
  - Confront the role of risk in decision making

- 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



Relationships of Uncertainty to Knowledge


Meta-Knowledge
Knowns
Unknowns
Knowledge
Knowns
Unknowns
exploit
Known Knowns
Known Unknowns
explore
find
imagine
Unknown Knowns
Unknown 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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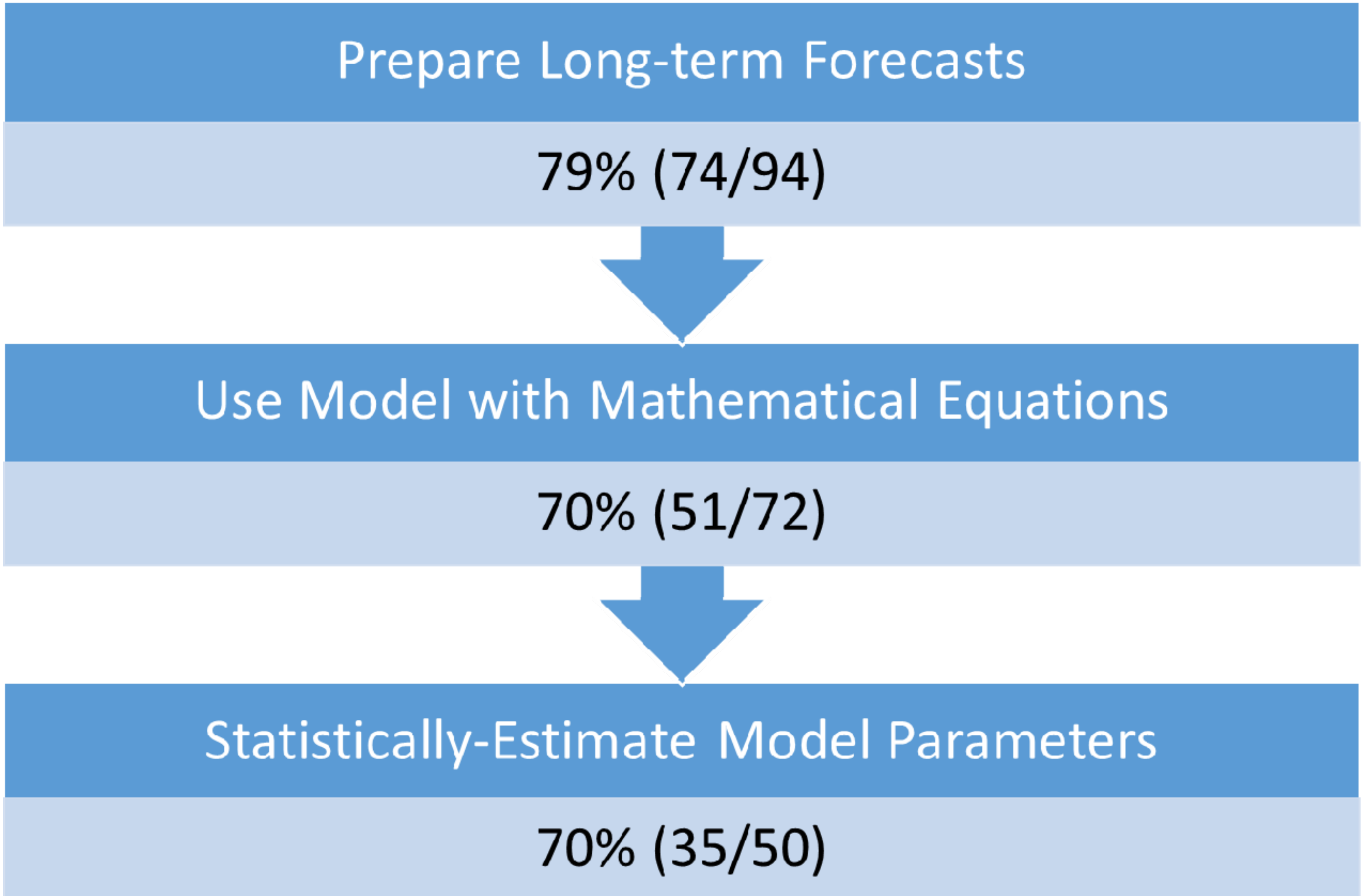

Forecasting methods used by WRF 4558 survey sample.

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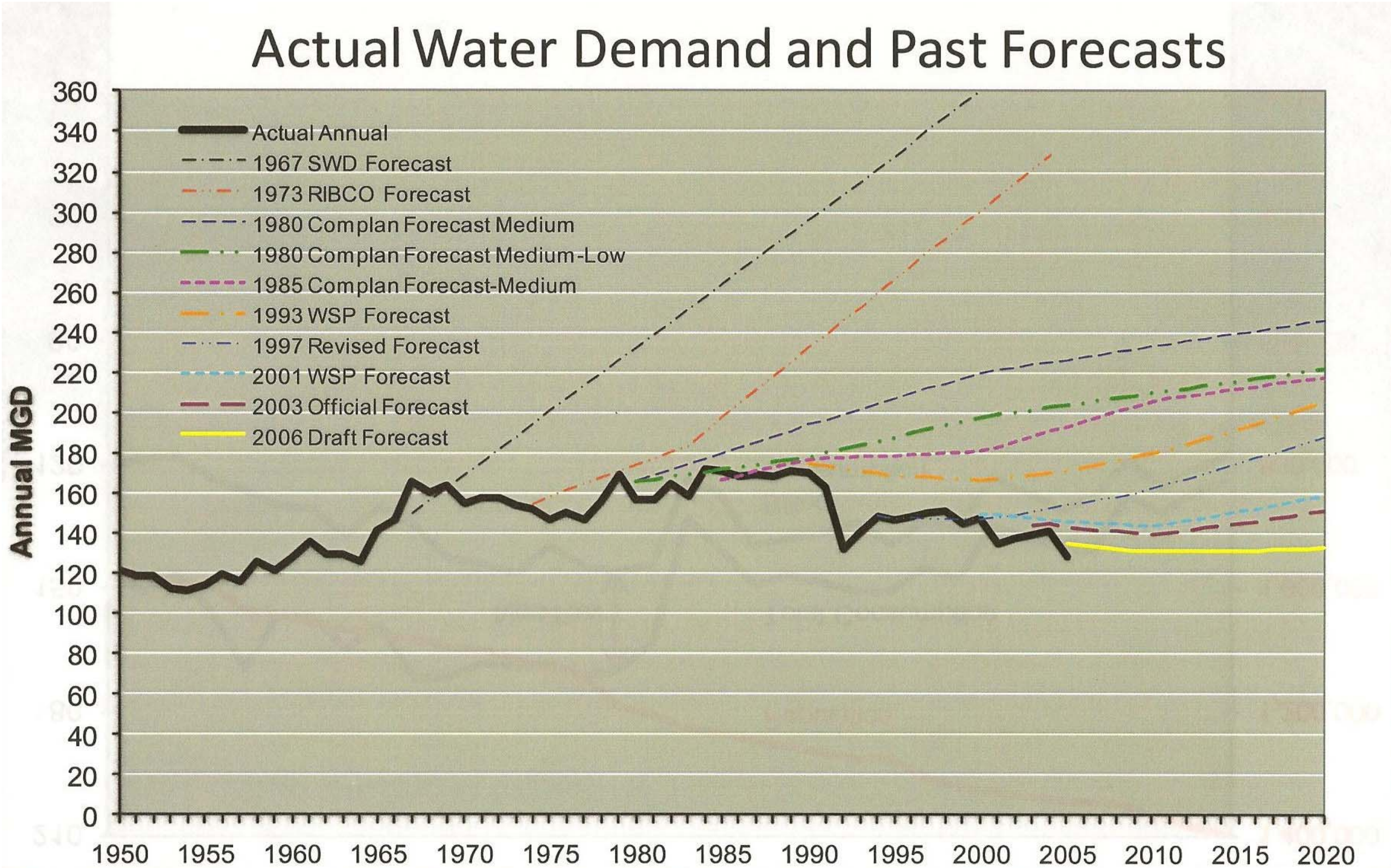
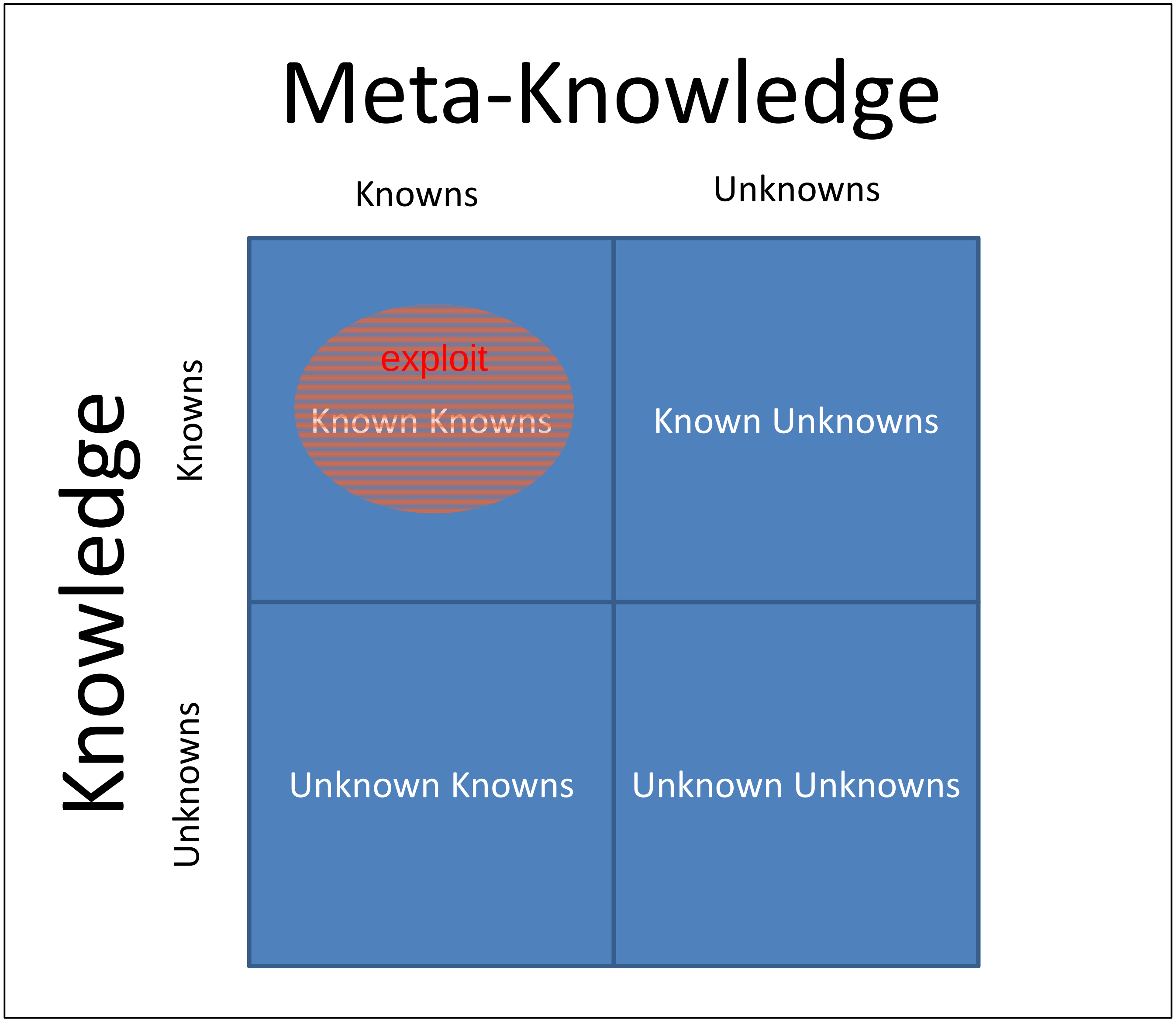


Source: Bruce Flory



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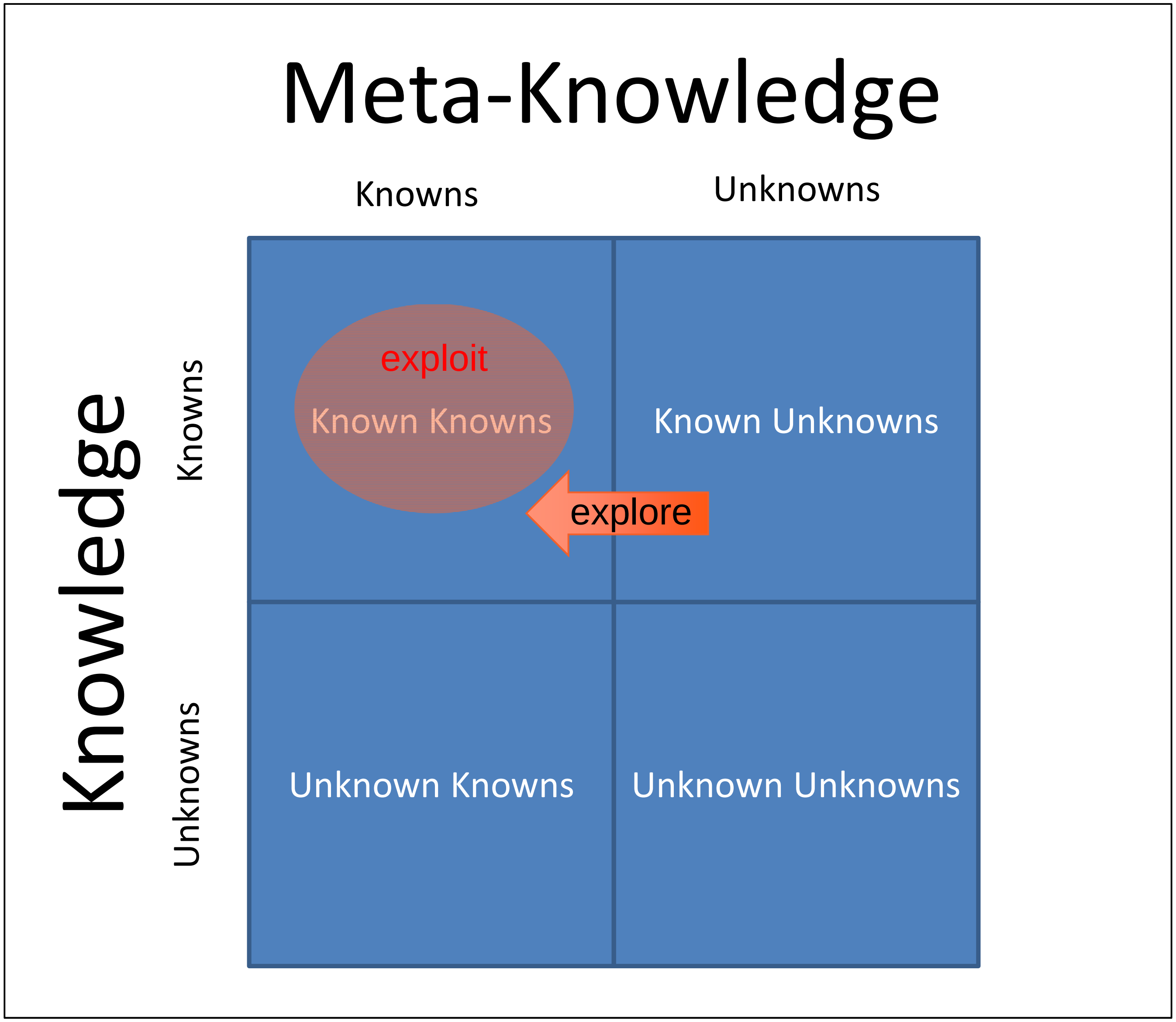

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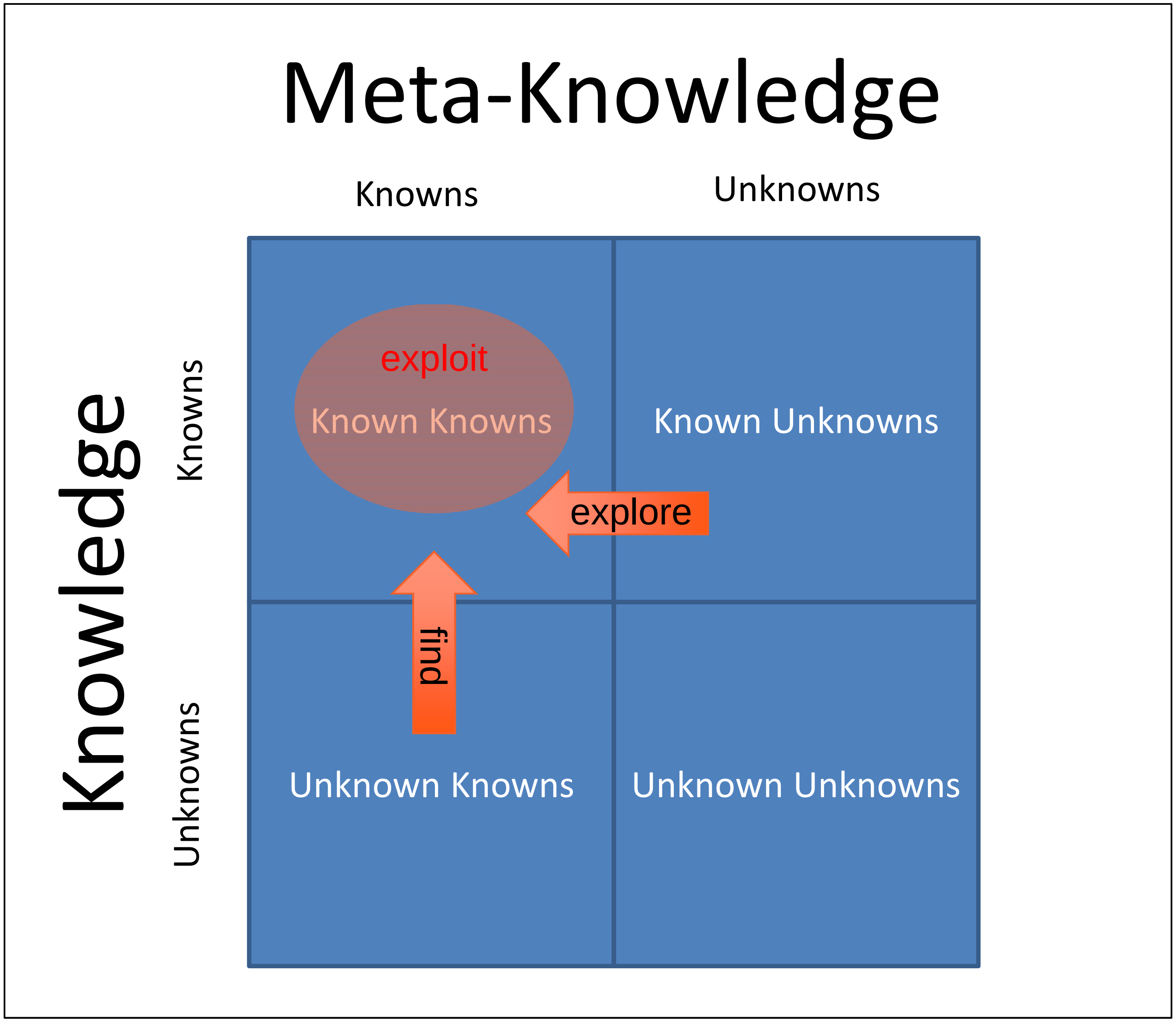

Relationships of Uncertainty to Knowledge