THE Water Research FOUNDATION

Webcast

PROJECT NO.
4742

Probability Management for Water Finance and Resource Managers

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Housekeeping Items

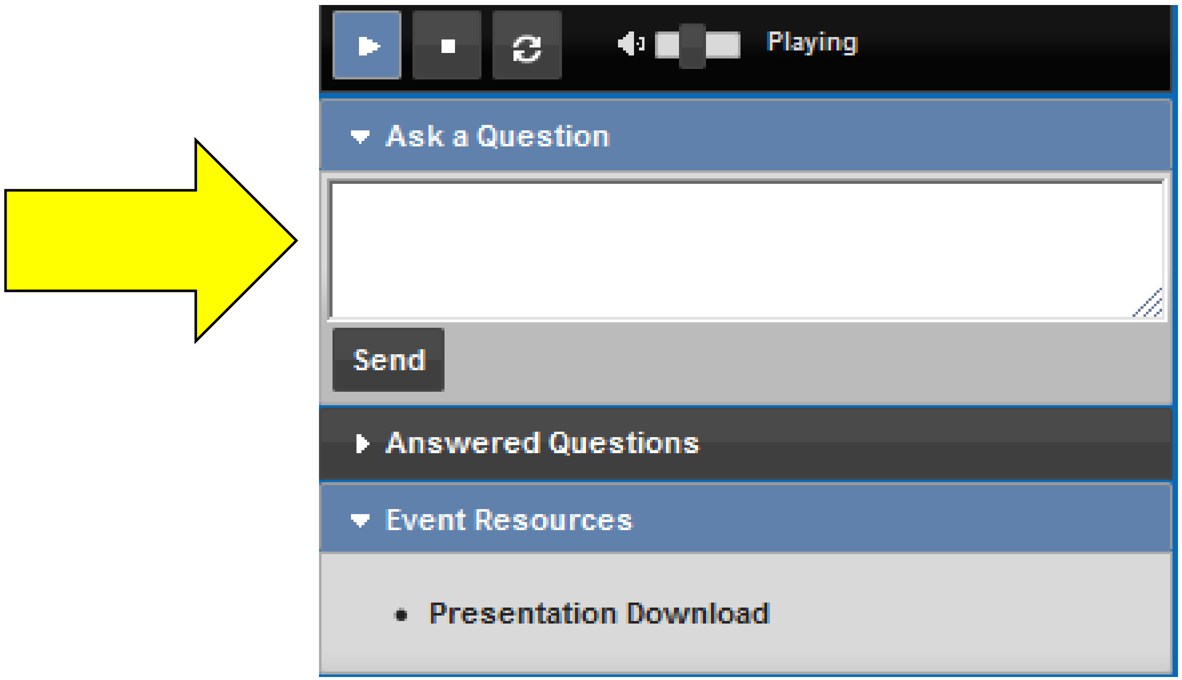
- Submit questions through the question box at any time. We will do a Q&A at the end of the webcast.

- Slides and a recording of the webcast will be available at www.waterrf.org/webcasts and on the project page.

- A certificate of completion will be available at the end of the webcast.

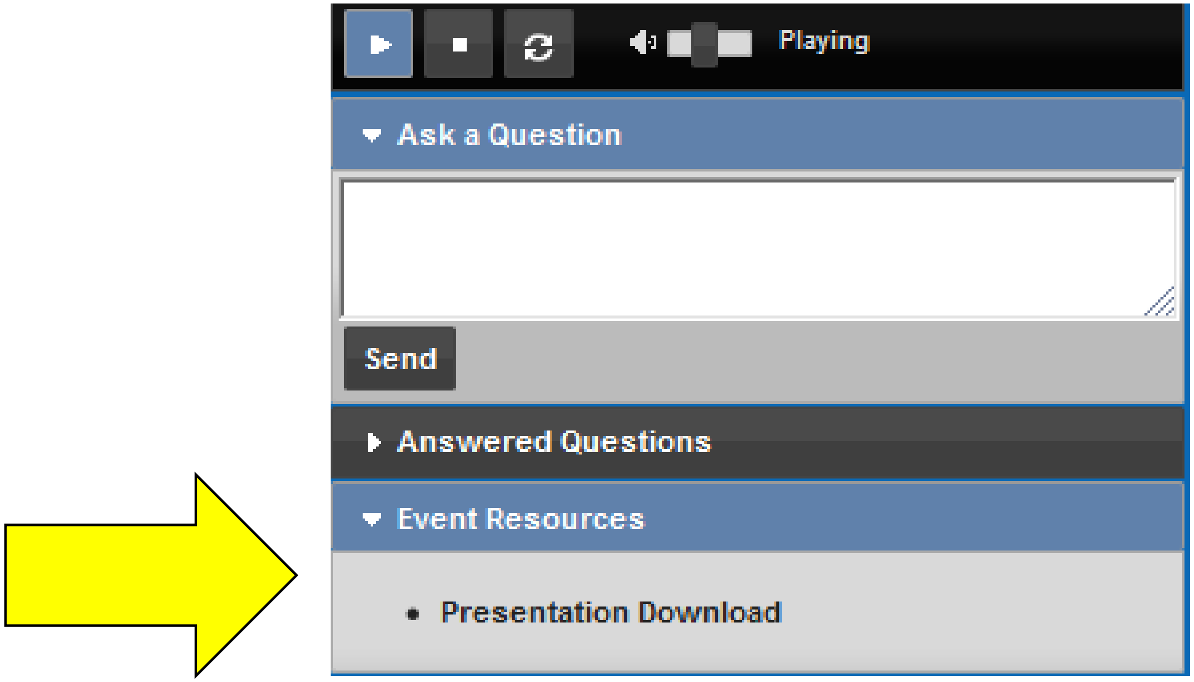
- Survey at the end of the webcast.

Input your webcast questions here



Q&A at end of webcast

Webcast Slides



You can download a PDF of the presentation at any time during the webcast. The recording will be available within 24 hours.

WRF Water Demand Research 2009-2017

Driver - drinking water utilities saw changing water use trends in last 20 years

18 projects funded, 16 published.

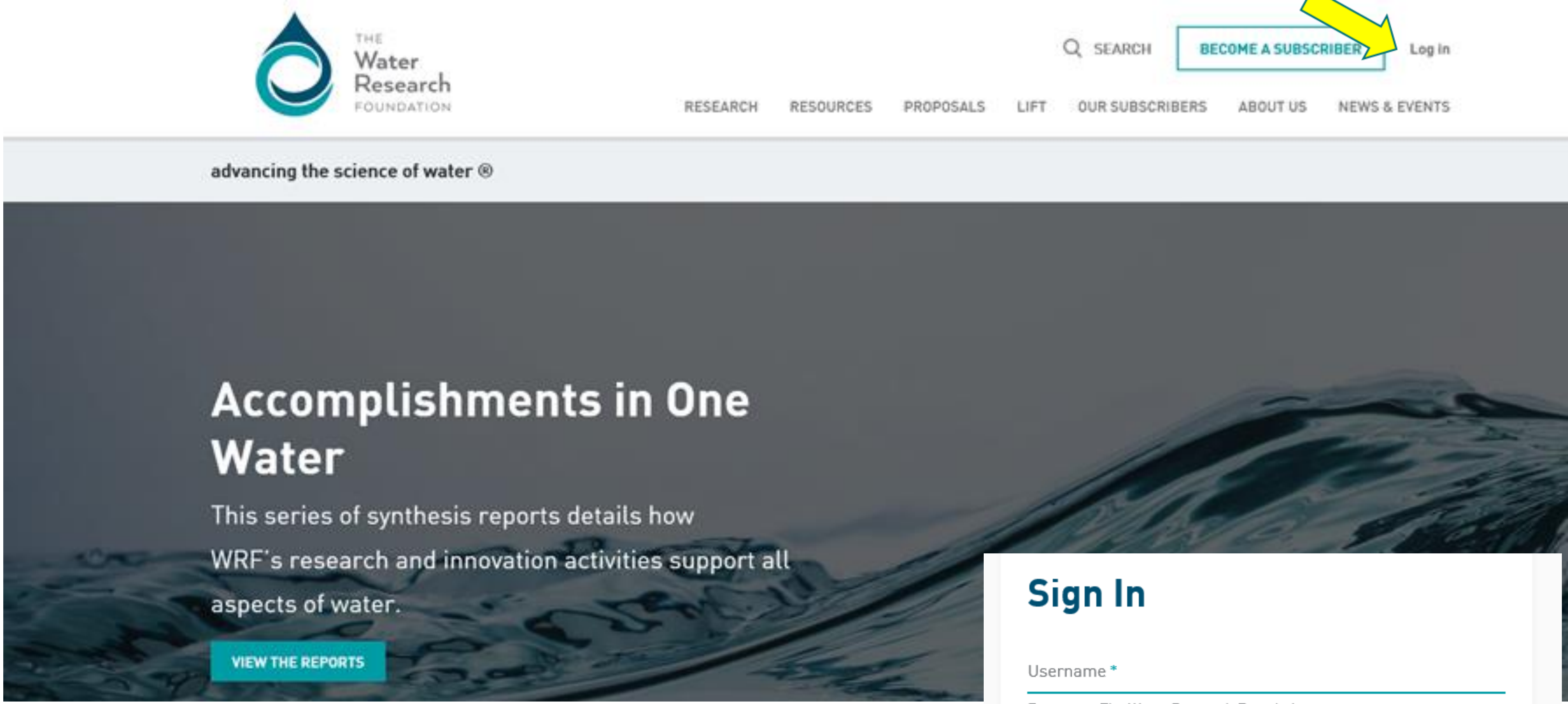
~$3.5M WRF + $3.1M co-funding, cost share, or in-kind

Studies of water use by customer category, demand forecasting, & planning under uncertainty.

Results are useful for planning utility operations, revenue, and capital improvements.

https://www.waterrf.org/news/water-demand-improving-effectiveness-forecasts-and-management

https://www.waterrf.org/research/topics/water-use-efficiency



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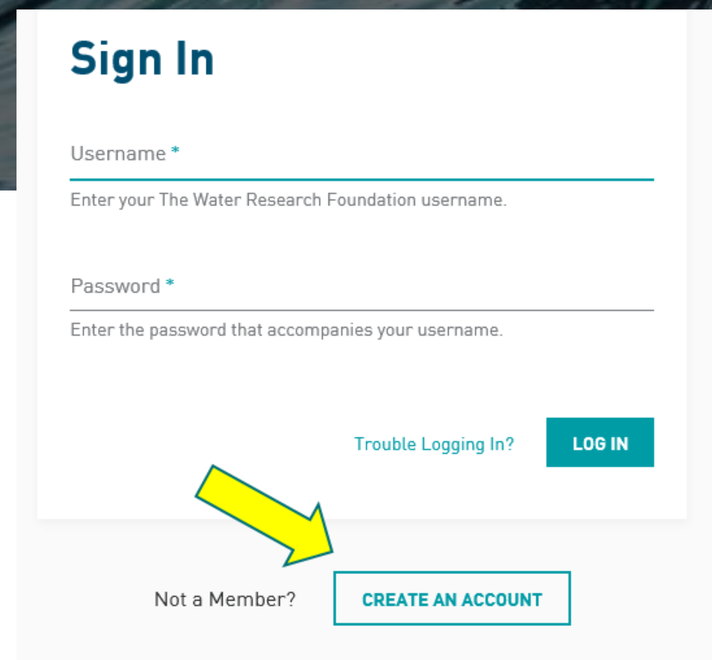
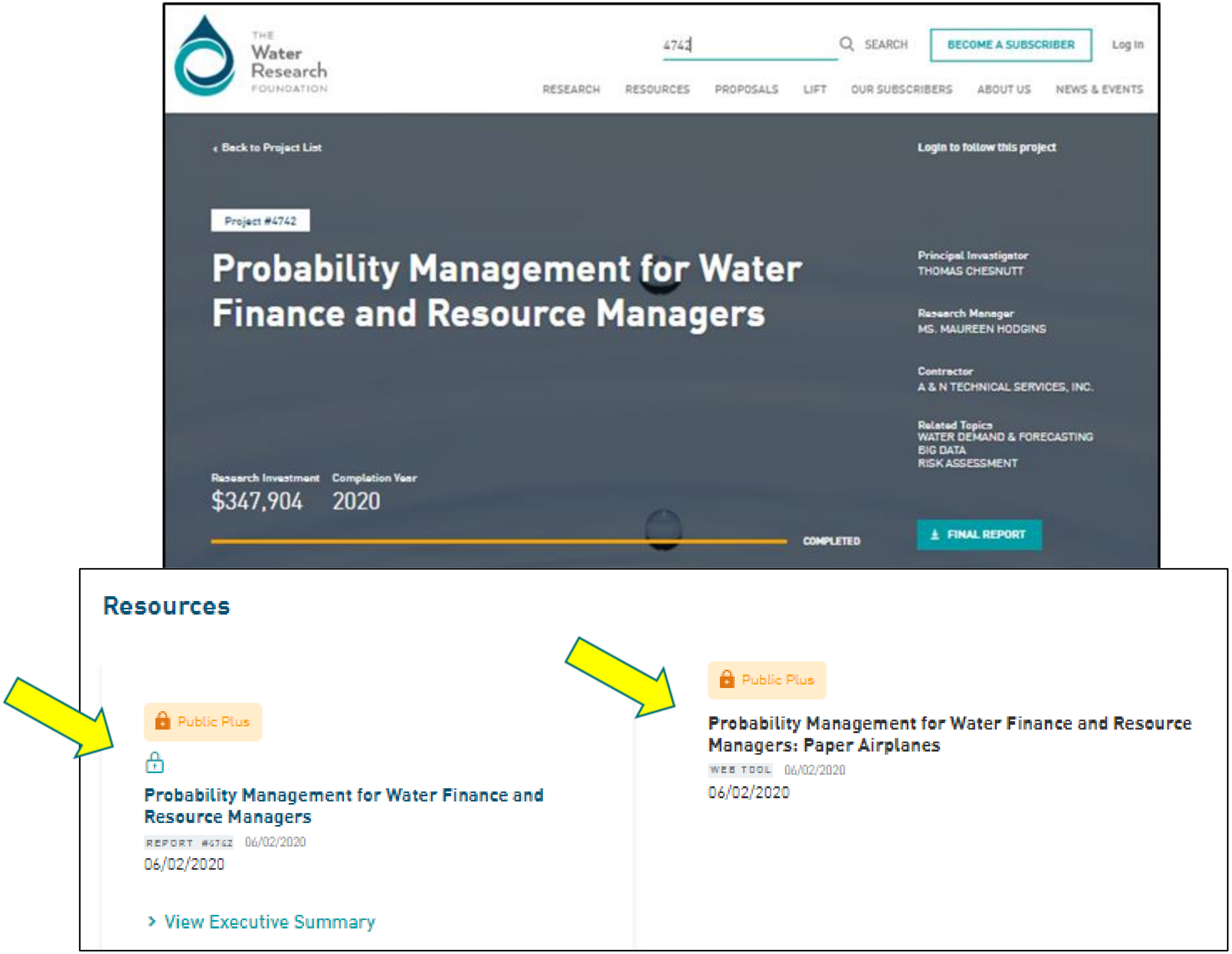


Content from 3 legacy orgs

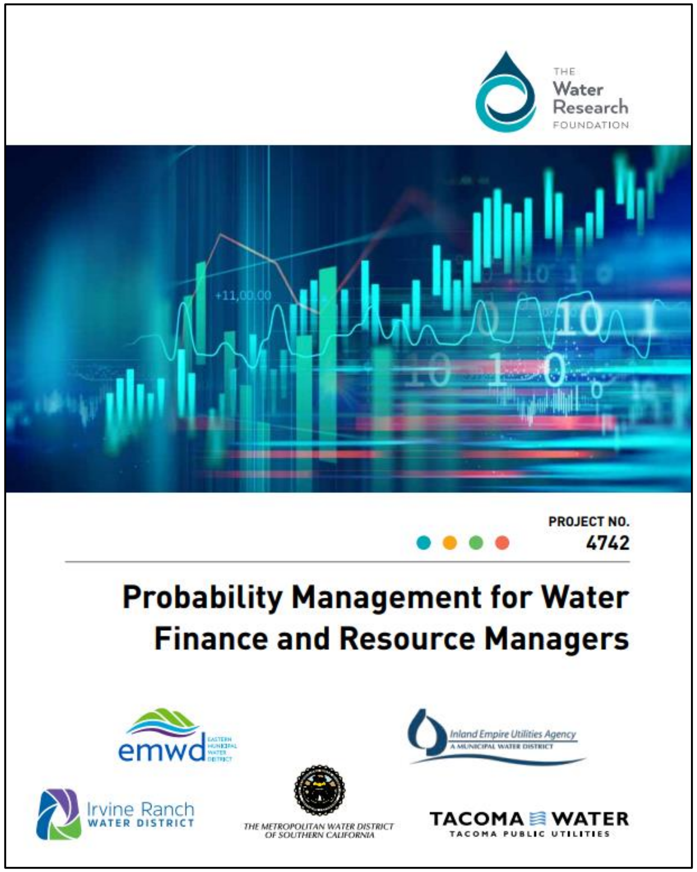
Create a website account: Log In, Create Account

- Public Plus account: access our "free to public" content
- Subscriber account: access all content

www.waterrf.org, search 4742



4742 Products

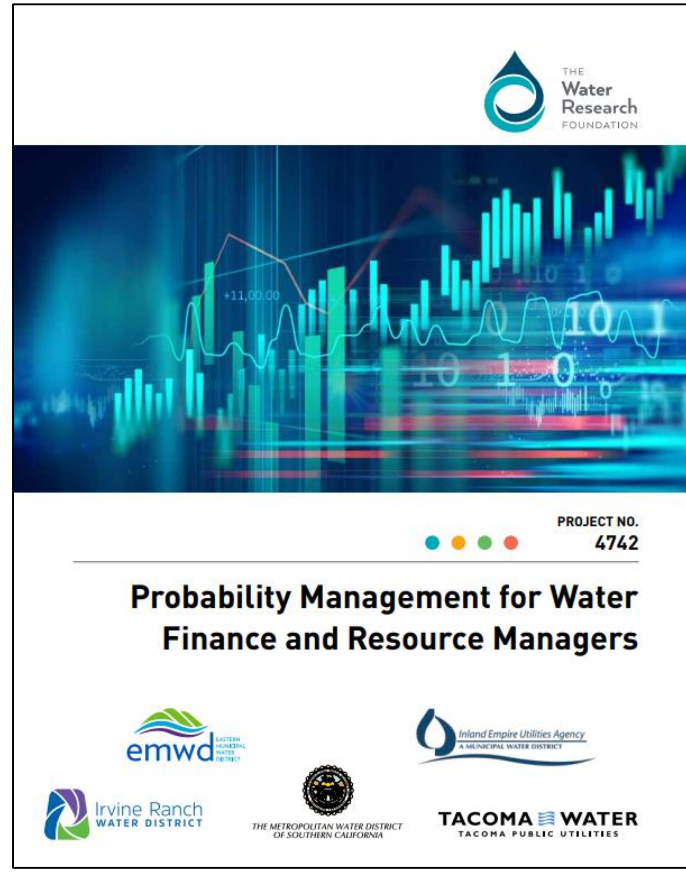


Name

- Asset Level Model.xlsx
- Consolidated Risk.xlsx
- Exponential Smoothing with updating.xlsx
- PM_LanduseDemandModel_Paper_Airplane_v5.xlsx
- PM_LongTermDemandModel_Paper_Airplane_v1.xlsx
- PM_PredictingNewConnectionsModel_Paper_Airplane_v0.xlsx
- Reliability MTBF with cost.xlsx

Webcast Overview

Topic	Speaker	Time
Introduction	• Maureen Hodgins, WRF	5 min
A Primer for Probability Management	• Tom Chesnutt, A&N Technical Services, Inc.	25
Case Study Applications	•Michael Hollis, MWD of So. California • Eric Akiyoshi, Irvine Ranch Water Dist. •Gordon Ng, Eastern Municipal Water Dist. •Shayne Kavanagh, Government Finance Officers Association	15
Q&A	All	15 min

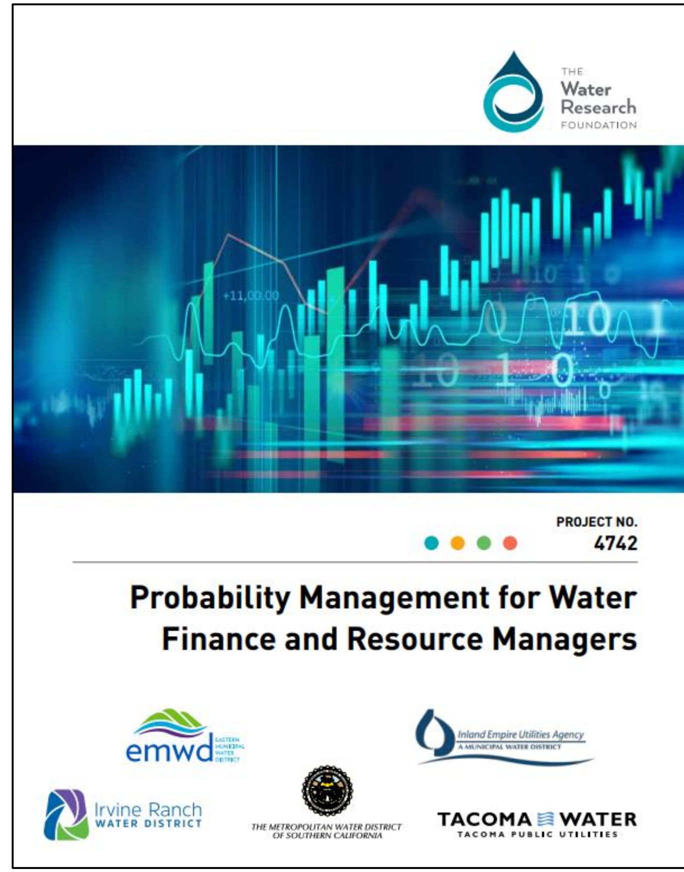


Webcast Topics

Tom Chesnutt, Ph.D., PStat®, CAP®
President, A & N Technical Services, Inc.

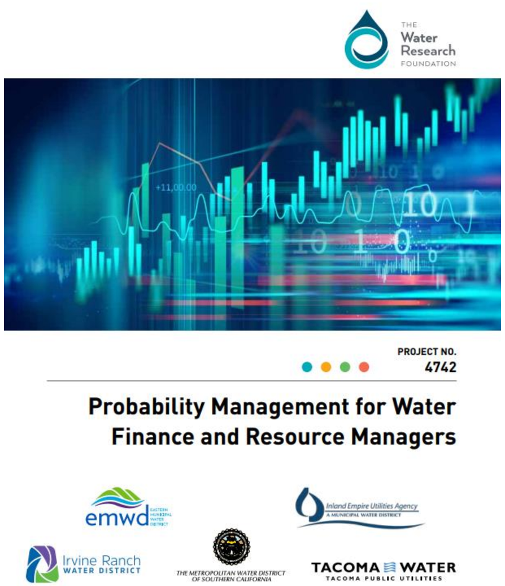
Webcast Topics

- Introduction
- A Primer for Probability Management
  - Definitions
  - Thinking about Uncertainty—Decision/Problem Framing
  - Identifying Uncertainties—The Influence
  - Quantifying and Combining Uncertainties
  - Value Functions
  - Visualization for Communicating Uncertainties
- Case Studies and Applications
  - Probability Management for Water Resources
  - Probability Management for Finance
  - Additional Application Areas for Probability Management



Research Objective

1. Clearly explain the principles of probability management (PM) for application to water demand/sales forecasting.
2. Explain how PM can be conducted using SIPmath™—including how stochastic information packets (SIPs) and stochastic library units with relationships preserved (SLURPS) can be mathematically combined—explain their relevance for the water industry.
3. Illustrate the use of PM tools in depicting uncertainty and informing the understanding of risk using four water industry case studies.



Participating Utilities:

- Metropolitan Water District of Southern California
- Irvine Ranch Water District
- Tacoma Water
- Inland Empire Utility Agency
- Eastern Municipal Water District

Research Approach

- A primer on Probability Management (PM) building on prior WRF literature reviews.
- Case Studies applying PM to water demand/sales forecasting.
- Hooks to recently completed and ongoing WRF research on
  - Anticipated changes in water demands due to long term drivers.
  - Analysis of the relationship between demand drivers.
  - Current mandatory and voluntary codes, standards, and regulatory programs that impact future water demand in a less than certain world.
  - Identification of information sources on demand drivers for demand forecasting.
- Beta-testing and evaluation of research products by water industry practitioners and managers.

Research Team

- ***Dr. Thomas W. Chesnutt, PStat®, CAP®*** (Principal Investigator) of A&N Technical Services, Inc.
- ***Dr. Michael Hollis, PStat®*** of the Metropolitan Water District of Southern California
- ***Shayne Kavanagh*** of the Government Finance Officers Association
- ***David L. Mitchell*** of M. Cubed
- ***Dr. David M. Pekelney*** of A&N Technical Services, Inc.
- ***Dana Holt*** of A&N Technical Services, Inc.
- ***Dr. Jean-Daniel Rinaudo*** (Outside Expert), of the French Geological Survey (BRGM)
- ***Marc Thibault*** the lead author of SIPmath™ v2 standards for probabilitymanagment.org.

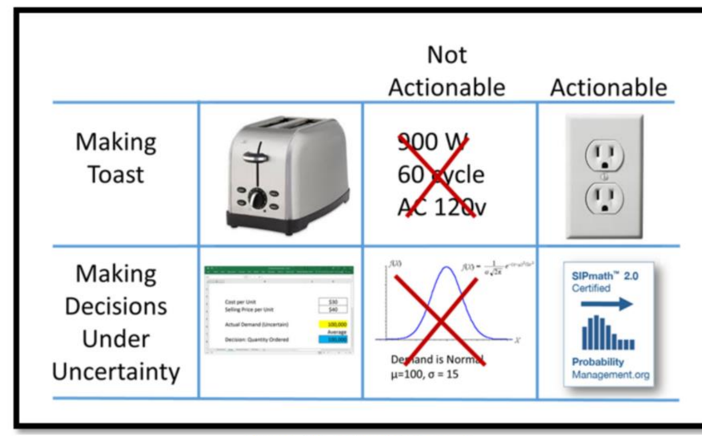


Figure 2-4. Actionable Example.
Source: Probability Management, n.d.

Introduction – What?

- **What Is the Downside of Ignoring Uncertainty?**
- Many common practices in the water industry use deterministic methods to address water resource and finance problems; this introduces serious errors when one assumes average values.

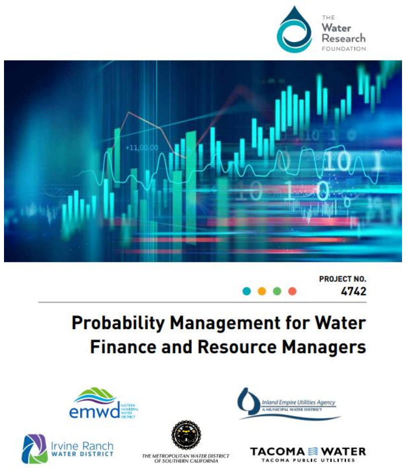
Fact 1 - Planning for the future is rife with uncertainties.

Fact 2 - Most people are not happy with Fact 1 and prefer to think of the future in terms of expected (average) outcomes.

Fact 3 - Plans based on average outcomes are, on average, wrong.

A Primer for Probability Management for Water - Overview

- Definitions
- Thinking about Uncertainty—Decision/Problem Framing
- Identifying Uncertainties—The Influence
- Quantifying and Combining Uncertainties
- Value Functions
- Visualization for Communicating Uncertainties



Introduction - Why?

- PM makes it easy to avoid errors produced by the "flaw of averages."
- PM preserves the signal in available noisy data.
- PM enables correct analysis of multiple sets of uncertain values.
- PM provides methods to extend the validity of existing deterministic models by incorporating uncertain values.
- PM open source tools can create models and graphs in Excel, so the interface is familiar, and
  spreadsheets are transferable to anyone with Excel.
- PM is promoted by ProbabilityManagement.org, a non-profit organization, and it makes it easy to transfer data to and from commercial products such as Crystal Ball, @Risk, and RiskSolver.
- PM makes it easy to produce auditable, repeatable results.
- PM helps to communicate a shared understanding of uncertainty. This leads to easier consensus around better decisions.
- All of the above can help avoid surprises and contribute toward job security.

Principles of Probability Management

(See probabilitymanagement.org)

- **Communicating Distributions as Data** –When estimating uncertain quantities, a "typical" or "average" value is used. Collapsing uncertainty to a scalar destroys information on variability.
- **Information** (measurement) can reduce total uncertainty and add credibility.
- **Interactive simulation** is a useful tactic for gaining simulated experience with how decisions affect risky outcomes. Visualization is an effective medium for communicating risk to decision-makers.
- **Coherence**—Distributions of causal forces are often related/dependent. The SIPmath Standard provides the **glue** logic for related uncertainties.

Definitions

Uncertainty – The existence of more than one possibility; a lack of complete certainty about an outcome or state.

Measurement – A quantitative reduction of uncertainty based on one or more observations (For further exposition, see Hubbard 2014).

Measurement of uncertainty – A set of probabilities assigned to a set of possibilities. For example, "There is a 5% chance of a flood in the next year."

Probability – The metric of uncertainty associated with the occurrence of an event. A number between 0 and 1. Higher values indicate a higher likelihood of occurrence.

Risk Components – The probability and magnitude of an undesirable outcome (a loss or an avoided gain). Note that having a probability and loss does not directly translate into risk without being valued. If I have no stake in the game, I have no risk.

Measurement of Risk – A set of possibilities with quantified probabilities & losses.

Risk Preferences – In risky decision situations, a person's preference for avoiding losses versus pursuing gains. Also referred to as risk attitude.

Risk Mitigation – is the practice of directly reducing identified risks. It is one of four types of risk treatment with the others being risk avoidance, transfer, and acceptance.

Thinking about Uncertainty

- Problem framing has a tradition in decision sciences, and an application for defining decision quality.
- Problem framing occurs on the front side of an analytics project.
- Steps involved in problem framing typically include the following:
    1. Appropriate Frame
    2. Creative Doable Alternatives
    3. Meaningful Reliable Information
    4. Clear Values and Tradeoffs
    5. Logically Correct Reasoning
    6. Commitment to Action

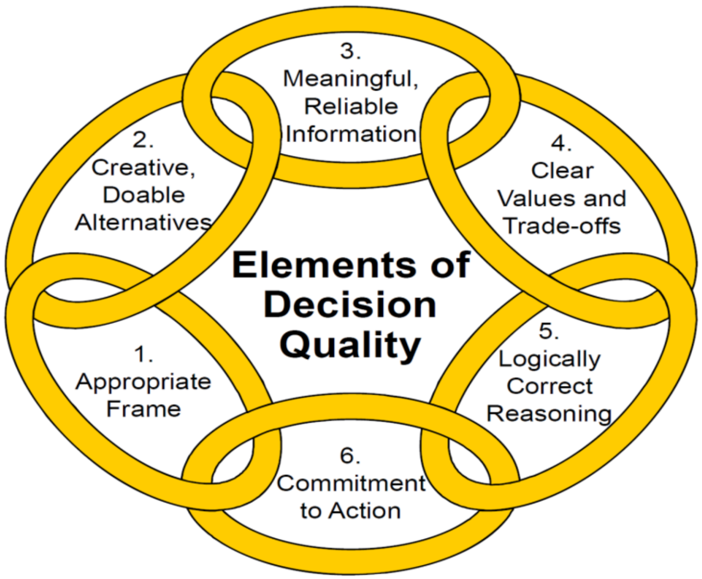
Decision Framing and Quality

Decision Maker's Bill of Rights

As a decision maker, you have the right to:

- A **decision frame** that structures the decision in the context most relevant to your needs,
- **Creative alternatives** that allow you to make a selection among viable and distinct choices,
- **Relevant and reliable information** upon which to base your decision, including the uncertainty of the information
- An understanding of the **potential consequences** of each alternative based on your choice criteria
- A **logical analysis** that allows you to draw meaningful conclusions from the information to reach **clarity of action**
- **Effective facilitation** to gain alignment and commitment to action

The insight into this approach comes from Jay Andersen and Jim Felli, Eli Lilly Co.
Visit the SDP web site: http://decisionquality.org/decision-makers-rights/

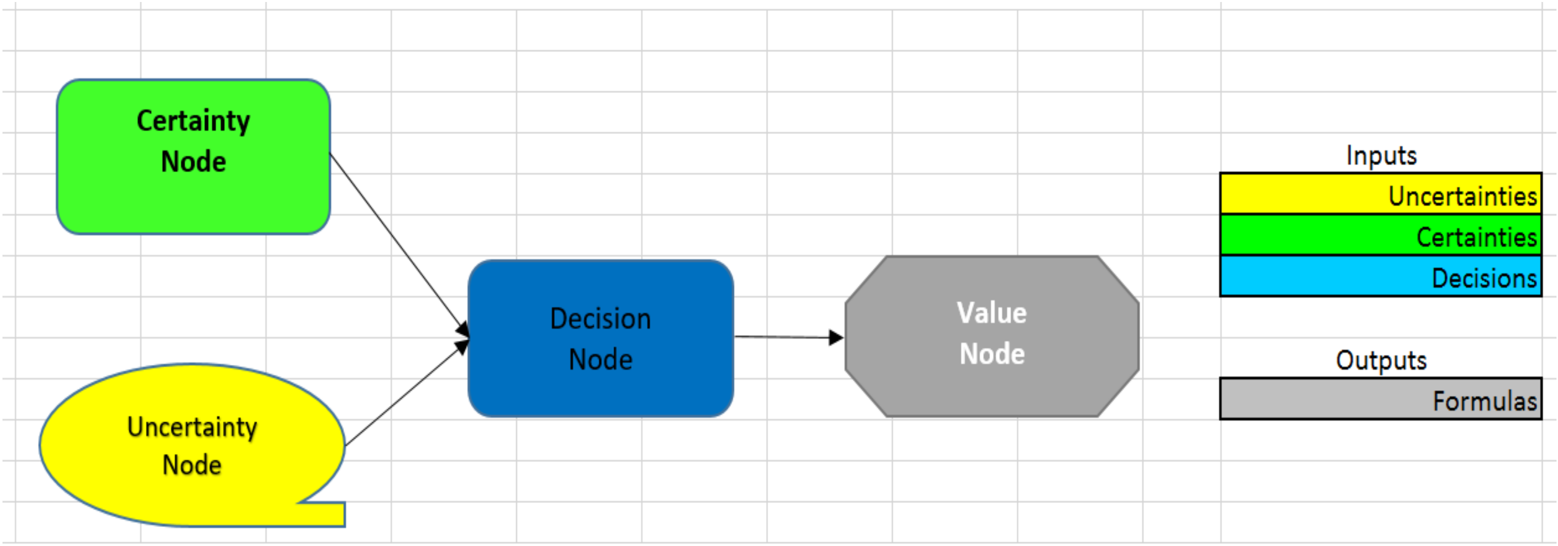


Decision Quality Chain; SDP, R Howard and A. E. Abbas

Identifying Uncertainties

- The principles for constructing influence diagrams, which compact graphs that represent the decision problem being analyzed, are:
  - Drivers (certain and uncertain)
  - Decisions (aka levers)
  - Outcomes (that are valued)
- Reasons to use influence diagrams as part of the PM modeling process:
  - To help get your arms around a problem, to figure out what you know, and what you don't know about the problem.
  - To see where information is lacking that could be filled in. To sketch a representation or model of a problem state.
  - To avoid ambiguity in model specification as an additional source of uncertainty.
  - To get agreement on exactly what is the problem to be solved.

Influence Diagram



Influence diagrams communicate the sources of uncertainty, the decision nodes, outcomes, and how those outcomes are valued.

Quantifying and Combining Uncertainties

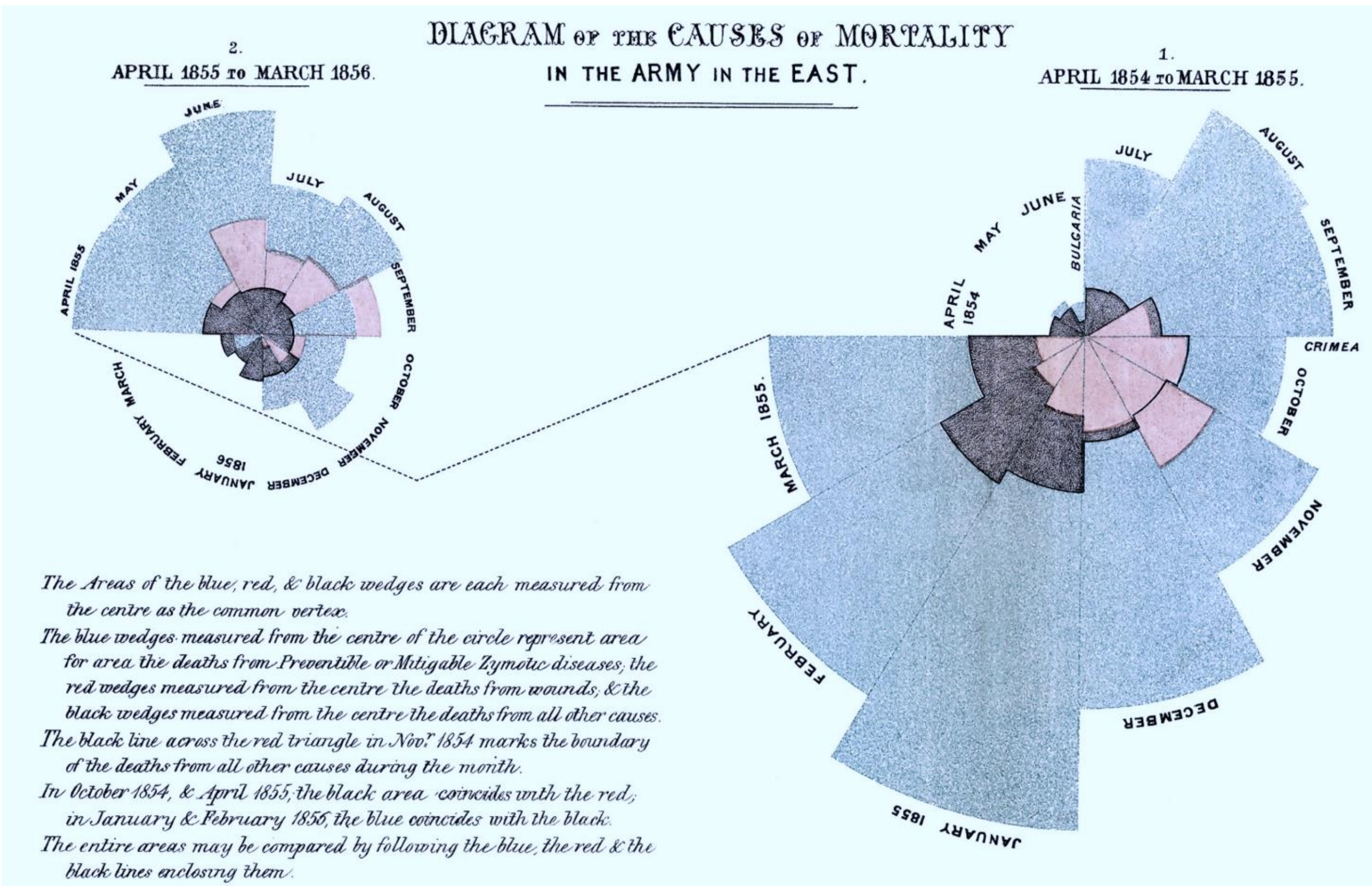
- This is where the math happens and ambiguity is removed.
- Explains how uncertain values can be used to quantify uncertainties and then how these uncertainties can be combined.
- Here, we need to build an understanding of probability management terms:
  - SIPs
  - SLURPs
  - SIPmath™
  - SIP Standard

SIPs, SLURPs, SIPmath™ and SIP Standard

- SIP – Stochastic Information Packet
  - *In the SIP Standard, uncertainties are communicated as data arrays, called SIPs (Stochastic Information Packets). Random samples from a probability distribution are stored in a single cell as a vector of realizations.*
- SLURP – Stochastic Library Unit Relations Preserved
  - *A coherent set of SIPs that preserve statistical relationships between uncertainties is known as a Stochastic Library with Unit Relationships Preserved (SLURP).*
- SIPmath™ and the SIP Standard
  - *The open SIPmath Standard enables legacy and future simulation models to communicate with each other, creating a new paradigm for enterprise risk management. SIPmath™ consists of tools and techniques showing how SIPs and SLURPs can be coherently combined to advance the modeling of uncertainty*

Visualization for Communicating Uncertainties

Who invented the infographic?
Hint: known as the mother of statistics



Case Studies of Probability Management

- Probability Management for **Water Resources**
  - Case Study #1—Land Use Demand Forecasting
  - Case Study #2—Long-Term Demand
- Probability Management for **Finance**
  - Case Study #3—Revenue from Connection Fees
  - Case Study #4—Sales Forecasting and Rate Model
- Additional Application Areas for Probability Management: **And More**

Irvine Ranch Water District
Case Study 1 - Land-Use Demand Forecasting

Eric Akiyoshi, PE

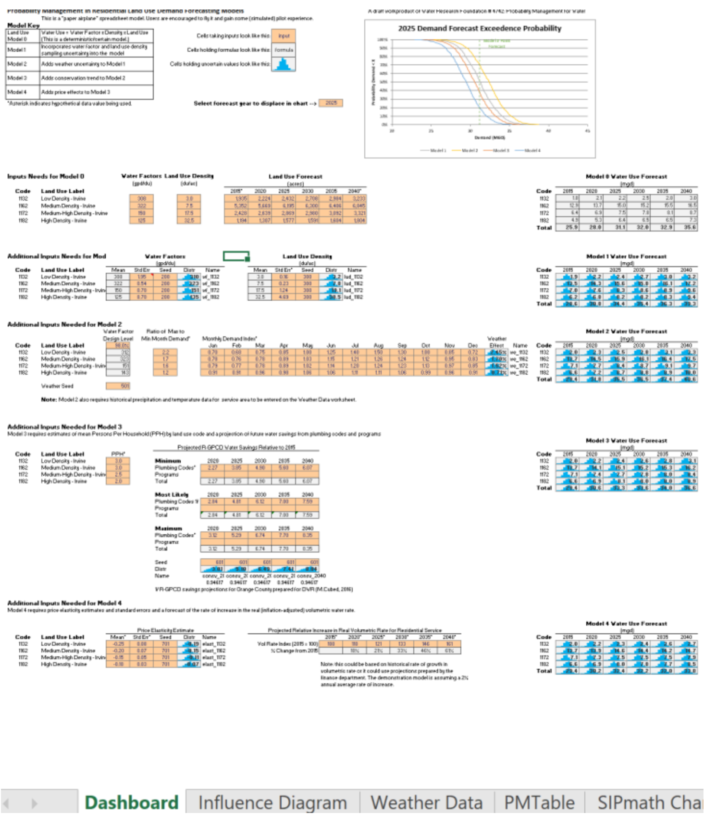
Engineering Manager - Planning and GIS
Irvine Ranch Water District

Irvine Ranch Water District
Case Study 1 - Land-Use Demand Forecasting

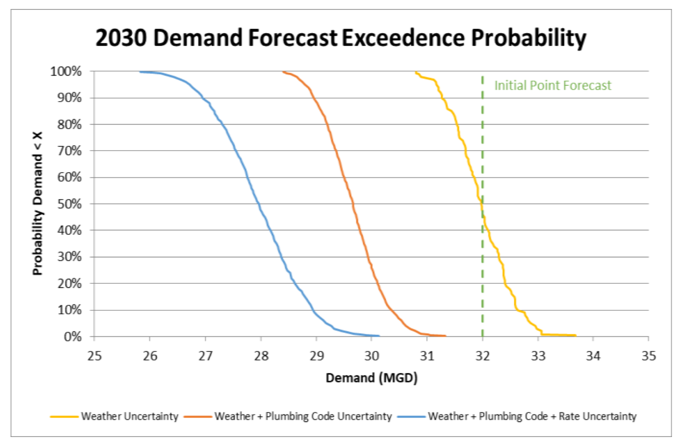
- Use Case
  - Land-Use Demand Forecast used for Distribution System Planning
- Limitation
  - Deterministic-Demand Factor (Gl/DU)*Density(DU/Acre)
- Approach
  - Include uncertainty in DF, trends in plumbing code, conservation, price response
- Lessons Learned
  - Forecasts that ignore the future effects of plumbing codes and rates produce forecasts with a significant upward bias.
  - Large economic consequences to timing of water infrastructure

Case Study 1 - Land-Use Demand Forecasting and Distribution System Roll-out

This case study examines ways this type of forecasting approach could be augmented to account for expected water savings from passive and active conservation as well as from changes in water rates.



PM Dashboard



PM The Shape of Demand Uncertainty

Metropolitan Water District of So. California Case Study 2 – Long Term Demand Forecasting

Michael Hollis, PhD, PStat®

Senior Resource Specialist

Metropolitan Water District of Southern California

Some Problems with a Mean-Centric ‡ Decision-making Framework

- Good decisions need to account for:
  - the entire shape of uncertainty (distributions) ; and
  - the consequences of risky outcomes (loss function).
- Averages obscure both, leading to mis-informed decisions.

‡ *Term coined by Dr. Michael Hollis, PSTAT®,*

Metropolitan Water District of So. California Case Study 2 – Long Term Demand Forecasting

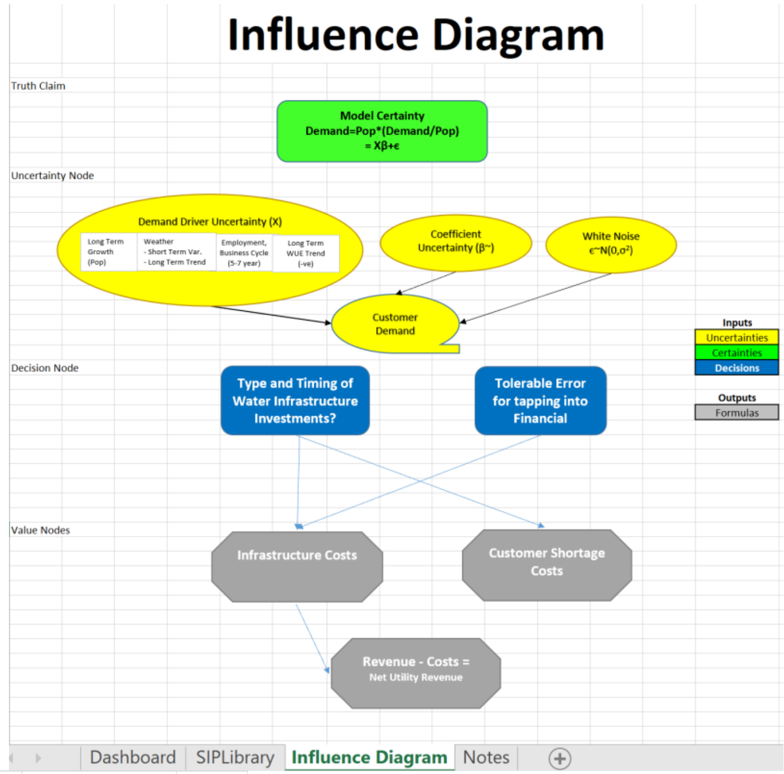
- Use Case
  - Demand Forecast used for Long Term Planning
- Limitations
  - Demand drivers are usually imperfectly measured
  - Some are not currently known
- Approach
  - Try to represent all sources of uncertainty in demand forecasts
- Lessons Learned
  - Customer shortage costs are not linear; ignoring shape of shortage costs leads to damaging deferral of needed infrastructure investments

White Noise Error	Normal mean: 0.00 sigma: 0.04	
WUE Trend	Uniform mean: -0.81 sigma: 0.02	
Weather/Climate	Triangular Min: 0.00 Med: 1.00 Max: 2.00	
Population Growth	Uniform mean: 0.84% sigma: 0.54%	
GPCD	?	?

Figure 3-10. Key Sources of Demand Model Uncertainty: Parameters and the Shape of Uncertainty.

Case 2: Long Term Demand

This case study examines the methodological approach used by many water utilities that develop projections of long-term future demand using projections of population and per capita use.

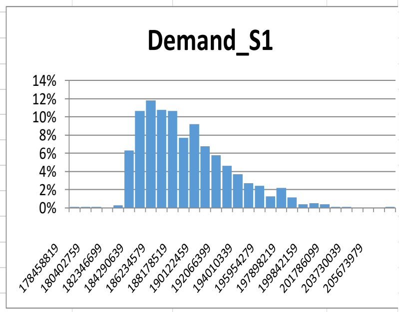


Model 0: Deterministic Water Demand with No Climate Change

PM_Index	Forecast Year	rep	Expected GPCD	Expected Pop	Flaw of Averages Demand_S0	
1	2020	1	135.39	1,359,256	184,032,026	
					188,822,381	mean
					2,675,275	sd

Model 1: Simulation of Per Capita Demand

PM_Index	Forecast_Year	rep	GPCD	Pop	Demand_S1	
1	2020	1	135.39	1,359,256	184,032,026	
					188,920,076	mean
					3,947,124	sd



Model 2: Simulation connecting Demand,Supply to a Value Function

PM_Index	Forecast_Year	rep	Supply	Shortage	PercentShortage	ShortageStage	ShortageCost	
1	2020	1	190,000,000	-	0.0%	0	$ -	
							$ 4,269	average
							$ 64,881	max

Eastern Municipal Water District
Case Study 3 – Revenue from New Connections

Gordon Ng, PE

Principal Water Resources Specialist

Eastern Municipal Water District

Eastern Municipal Water District
Case Study 3 – Revenue from New Connections

- Use Case
  - Fixed Revenue Forecast from new connection fees
- Limitation
  - New Connections highly uncertain
- Approach
  - Evaluated 4 different models from most simple to most complex
- Lessons Learned
  - Complex models yielded little predictive gain in high uncertainty
  - Most important forecast factor was the risk valuation
    - Finance wants a forecast of new connection revenue sure to obtain
    - Engineering wants to be ready for new connections (opposite risk preference)
  - Risk-aware forecasts implemented!

Different Risk Preferences

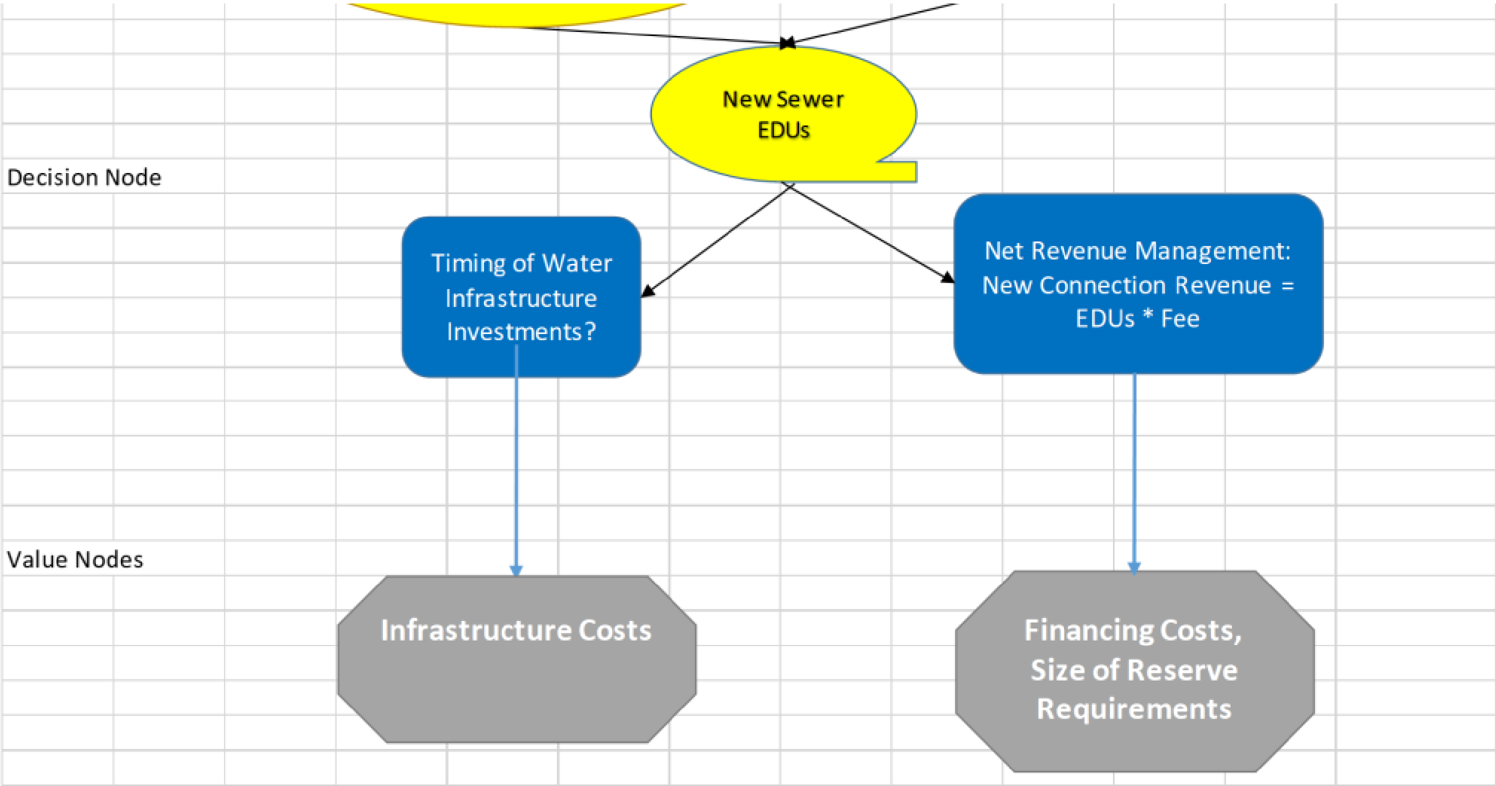
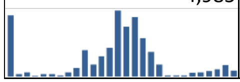
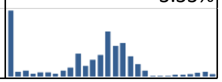
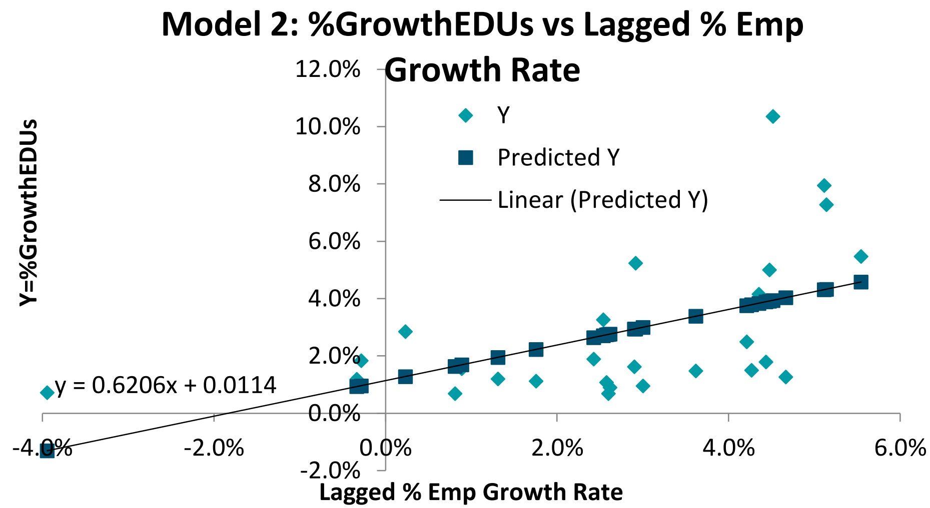


Figure 3-13. Influence Diagram.

Case 3: Growth of New Connections

This case study focuses on the annual change in EDUs, also known as "new connections" and the fixed charge revenue generated for each new connection

NewSewerEDUs		%GrowthSewerEDUs
3,116	median	1.71%
5,586	mean	3.14%
4,985	std dev	3.33%
		



		Actual			
		1998	Delta_EDU_Actual		
Model Key		Prediction		ModelError=Actual-Predicted (Y-Y_hat)	
Model 0	Pick the most likely (median ~= 3,000 Delta_EDU)	3260	median	-1262	d_Model0Error
Model 1	Pick year before Delta_EDU	2971	Delta_EDU_PriorYr	-973	d_Model1Error
Model 2	PctGro_RCEmployment	2102	PctGro_RCEmployment	-104	d_Model2Error
Model 3	year before Delta_EDU + Year before change in Emp grov	3421	dEDU_Emp_hat	-1423	d_Model3Error

Tacoma Water
Case Study 4 – Sales Forecasting & Reserves

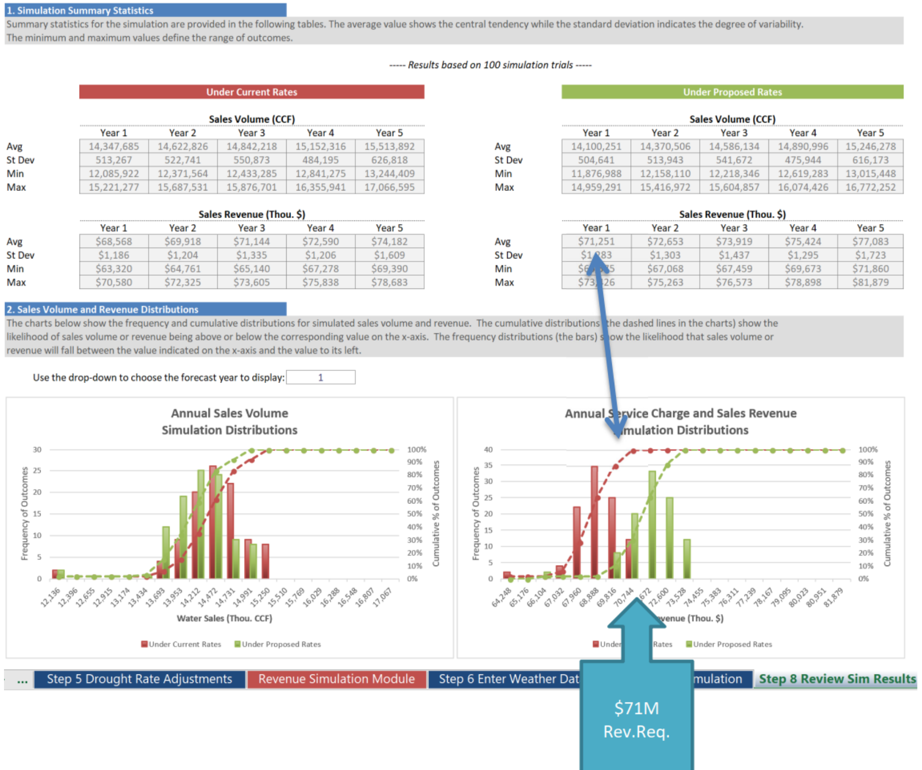
Tom Chesnutt, PhD, PStat®, CAP®
President, A & N Technical Services, Inc.

Tacoma Water
Case Study 4 – Sales Forecasting & Reserves

- Use Case
  - Sales Forecasting and Rate Model
- Limitation
  - Traditional Rate Models are Deterministic
- Approach
  - Include uncertainty in weather, customer growth, customer price response, and drought shortages
- Lessons Learned
  - Sales Forecasts embed uncertainty yield more accurate and reliable rate design.
  - Net Revenue Neutral Drought Rate Design is possible!
  - Sales variability and Revenue Vulnerability can be used to define needed Reserve Levels (GFOA)

Case 4: Sales Forecasting and Rate Model

- Tacoma Water has a history of demand modeling that measured and depicted historical and future forecasting uncertainties.
- Extending this causal analysis to shorter-term financial sales forecasting motivated this case study.
- Free off-the-shelf open-source model that complies with SIPmath™ standards—the Alliance for Water Efficiency (AWE) Sales Forecasting and Rate Model—is used to explore an approach that embedded principles of PM.



Under Current Rates

Sales Volume (CCF)	Year 1	Year 2	Year 3	Year 4	Year 5
Avg	14,347,685	14,622,826	14,842,218	15,152,316	15,513,892
St Dev	513,267	522,741	550,873	484,195	626,818
Min	12,085,922	12,371,564	12,433,285	12,841,275	13,244,409
Max	15,221,277	15,687,531	15,876,701	16,355,941	17,066,595

Sales Revenue (Thou. $)	Year 1	Year 2	Year 3	Year 4	Year 5
Avg	$68,568	$69,918	$71,144	$72,590	$74,182
St Dev	$1,186	$1,204	$1,335	$1,206	$1,609
Min	$63,320	$64,761	$65,140	$67,278	$69,390
Max	$70,580	$72,325	$73,605	$75,838	$78,683

Under Proposed Rates

Sales Volume (CCF)	Year 1	Year 2	Year 3	Year 4	Year 5
Avg	14,100,251	14,370,506	14,586,134	14,890,996	15,246,278
St Dev	504,641	513,943	541,672	475,944	616,173
Min	11,876,988	12,158,110	12,218,346	12,619,283	13,015,448
Max	14,959,291	15,416,972	15,604,857	16,074,426	16,772,252

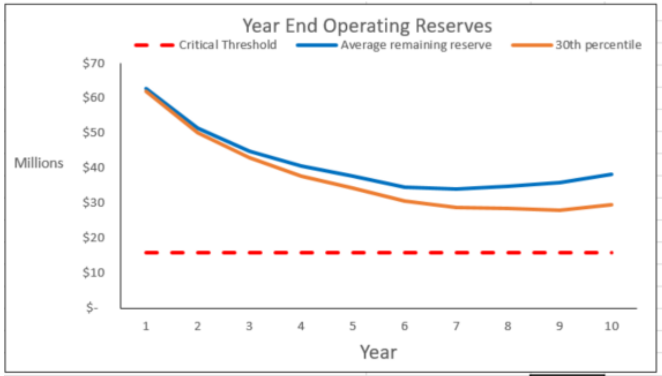
Sales Revenue (Thou. $)	Year 1	Year 2	Year 3	Year 4	Year 5
Avg	$71,251	$72,653	$73,919	$75,424	$77,083
St Dev	[illegible]	$1,303	$1,437	$1,295	$1,723
Min	[illegible]	$67,068	$67,459	$69,673	$71,860
Max	[illegible]	$75,263	$76,573	$78,898	$81,879

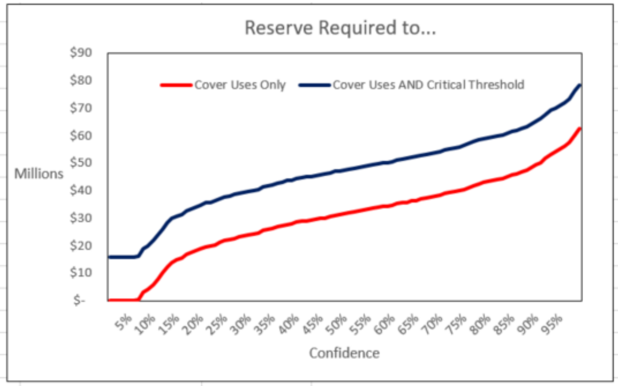
Figure 3-32. Simulation Results.

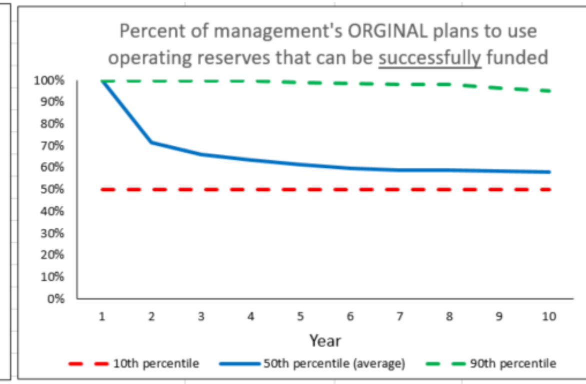
Tacoma Water
Probability Management & Reserves

Shayne Kavanagh
Senior Manager of Research
Government Finance Officers Association

Probability Management & Reserves

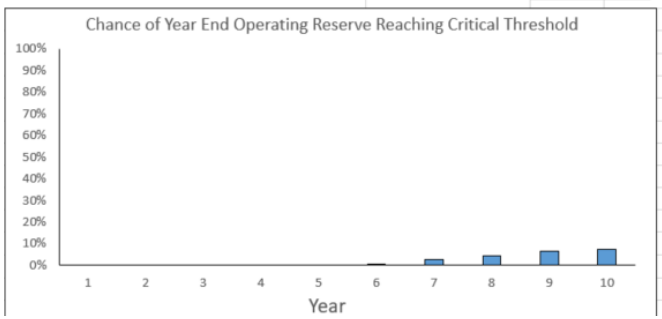






Percentile to show (reserves are below the line on graph this % of the time) 30%

Change the Trial Number Shown Above ->

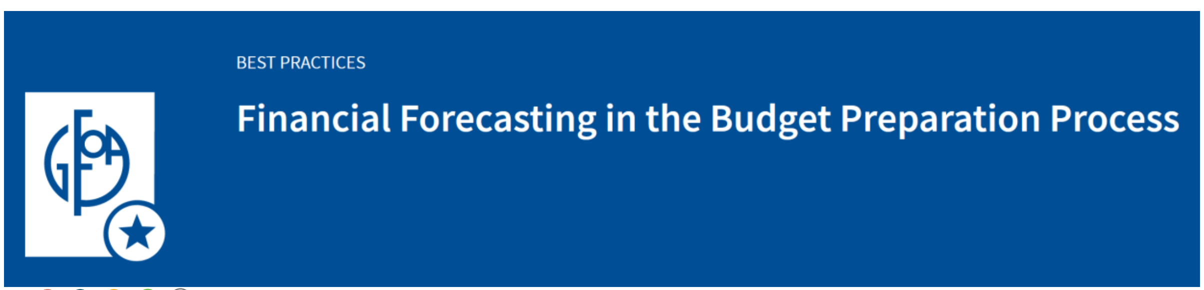


Amount of Reserves Required to Cover Uses of Reserves Over 10 Year AND Critical Threshold

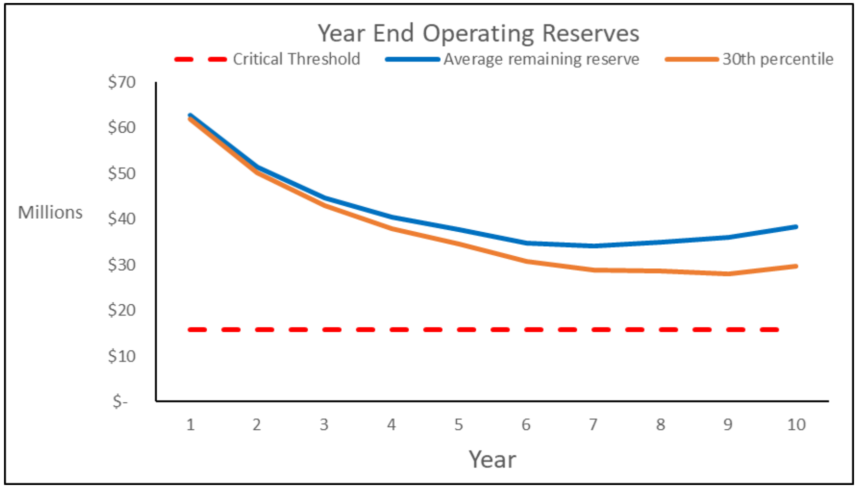
	Amount	**Confidence**	
$	65,300,000	90%	<-Values read off of graph above
$	59,200,000	80%	
$	54,200,000	70%	
$	50,600,000	60%	
$	47,500,000	50%	
$	44,400,000	40%	
$	39,800,000	30%	
$	34,800,000	20%	
$	21,800,000	10%	
$	67,700,000	92%	<-Enter your own confidence level here

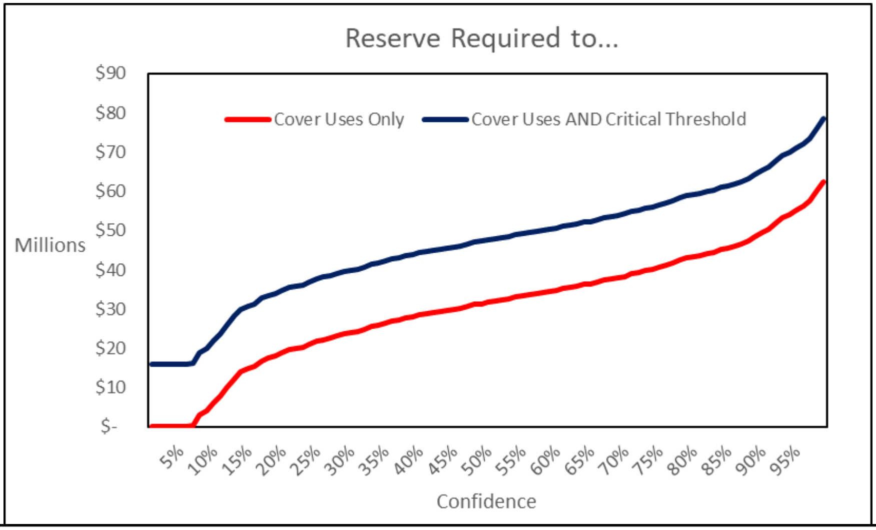
Chance TW experiences a liquidity problem at least once during the ten-year period in its operating fund

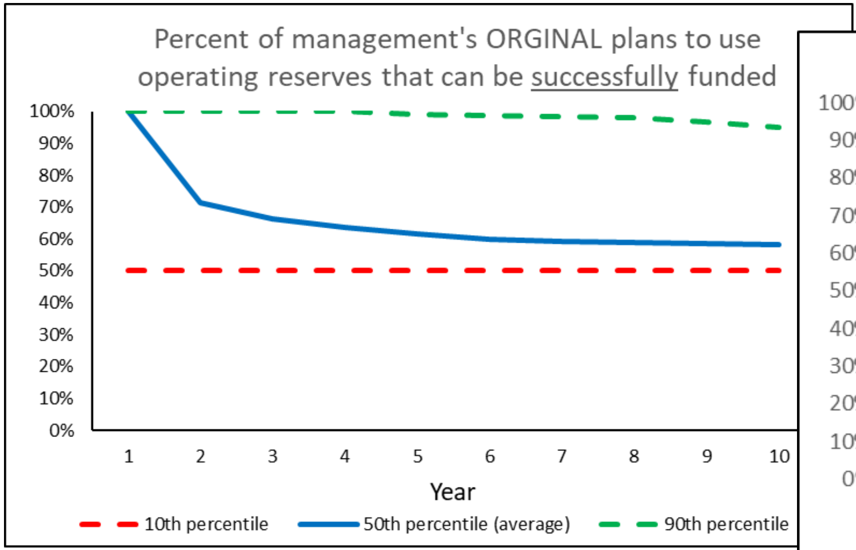
2%

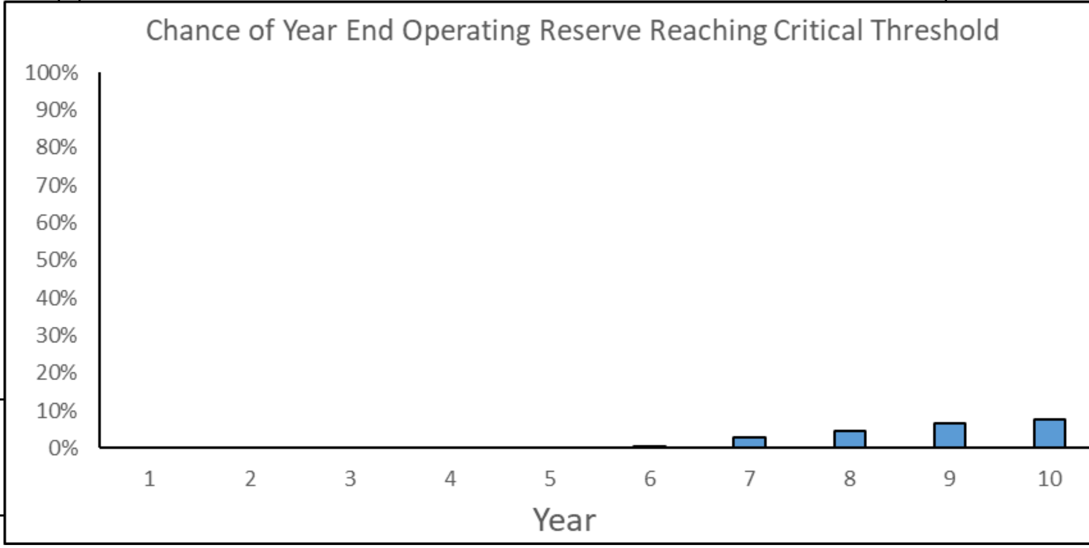


Probability Management & Reserves









https://www.gfoa.org/materials/topic/risk-assessment

Additional Application Areas for Probability Management

Tom Chesnutt, PhD, PStat®, CAP®
President, A & N Technical Services, Inc.

Additional Application Areas for Probability Management

- Additional applications for PM models were created by industry-leading practitioners. These additional PM application areas include:
  - Probability Management for Distribution Reliability, developed in a natural gas distribution network.
  - Paper Airplanes for:
    - Pump Failure (MTBF), estimating the mean time between failure of pumps is a necessary ingredient in risk analysis for water systems.
    - Exponential Smoothing, a simple method for budget or sales forecasting that can be quickly updated in real time.
  - Risk-Aware Budgeting, developed by GFOA Research, it uses PM and SIPmath to improve budget decision making when forecasts are not certain.

Probability Management for Distribution Reliability

Contributed by Sam Savage. Dr. Savage is the executive director of ProbabilityManagement.org, author of "The Flaw of Averages – Why We Underestimate Risk in the Face of Uncertainty," and an adjunct professor at Stanford University.

The SIPmath™ paper airplane "Asset Level Model.xlsx" demonstrates how different types of risks—financial, safety, and reliability—can be combined to show cost tradeoffs (Figure 3-36).

	B	C	D	E	F	G
1	Pipelines	External Corrosion		130.5	113.6	7.0
2		90%	th percentile:	139.785718	99.97050334	10
3	Trial 1 - 10,000		Threshold	130.00	90.00	9.00
4	1		Chance	64%	18%	23%
5			Tail Average	135.60	104.75	10.15

	PIPE	SEGMENT	ASSET	FINANCIAL	SAFETY	RELIABILITY	Sector
7	10	1	Valve	5.369954133	9.6	1	North
8	10	2	Valve	8.510687819	6.1	0	North
9	10	3	Valve	2.154034162	15.1	0	East
10	10	4	Valve	8.688891661	10.6	0	East
11	10	5	Pipe	0.968513954	0.0	1	South
12	10	6	Pipe	5.289537388	0.0	2	South
13	10	7	Fitting	3.670828758	10.6	0	West
14	10	8	Fitting	2.312012251	0.0	0	West
15	10	9	Fitting	11.09850682	0.0	0	West
16	15	1	Valve	0.936170026	13	0	North
17	15	2	Valve	5.423314586	0	0	East
18	15	3	Pipe	9.550374893	0	0	East
19	15	4	Pipe	2.207668842	11	0	East

Risk Rollup | SIP Library | Sheet2 | Sheet3 | PMTable | SIPmath Chart Data

Paper Airplanes

SIPmath™ models are easily assembled and easily modified making the creation of "paper airplane" and "balsa" models possibly. These reflects prototypes or proof of concept models that can then be
expanded to "commercial grade" models.

Pump Failure (MTBF) &

Exponential Smoothing

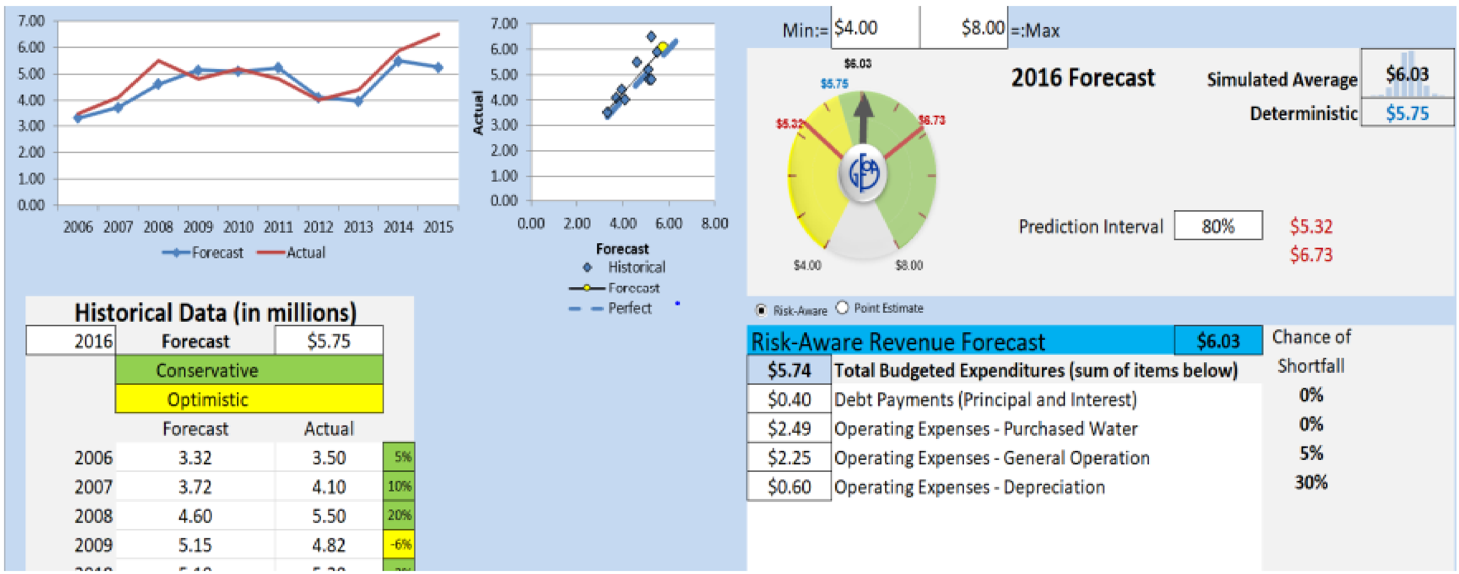
Contributed by Brian Putt, retired Chevron, Chair of Energy Practice at ProbabilityManagment.org

SIPmath™ Paper Airplane: YouTube:	"Reliability MTBF with cost.xlsx" https://www.youtube.com/watch?v=ZVAVtzPN4Aw https://www.youtube.com/watch?v=QTRB4FgYE88 https://www.youtube.com/watch?v=KCX-OZzWT5k

SIPmath™ Paper Airplane: YouTube: Reference :	"Exponential Smoothing with updating.xlsx" https://youtu.be/Pdh0pj84GQo https://en.wikipedia.org/wiki/Exponential_smoothin g

Risk-Aware Budgeting

Contributed by Shayne Kavanagh. Mr. Kavanagh is the Senior Manager for the Research, Government Finance Officers Association.



Demonstrates how budget forecasts can incorporate risk-aware principals using SIPmath™ to depict budget tradeoffs to decision makers

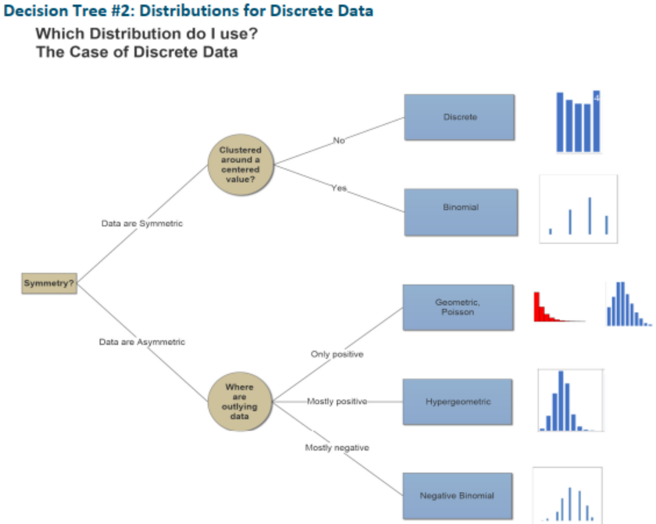
Conclusion

- Probability Management and SIPmath™ apply to a wide variety of uncertainty and risk analyses in water finance and resource management.
- SIPmath™ makes it easy to create spreadsheet models that represent influence diagrams, including their drivers, decisions, and outcomes.
- Probability management facilitates the development of dashboards, infographics, and other uncertainty communication tools.

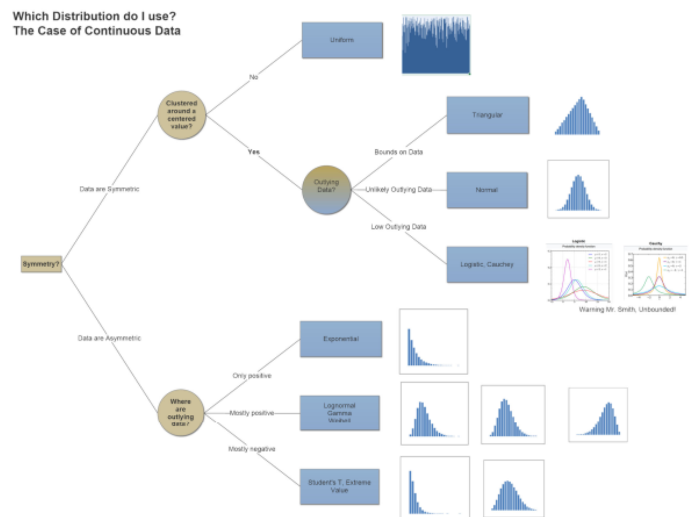
Appendices

- Appendix A: Which Distribution Should I Use?
- Appendix B: How Do I Combine Uncertainties?

A.2 Decision Tree #2: Distributions for Discrete Data



A.3 Decision Tree #3: Distributions for Continuous Data



Related WRF Research	
Project Title	**Research Focus**
Developing Robust Strategies for Climate Change and Other Risks: A Water Utility Framework (project 4262)	This project identified the most likely vulnerabilities associated with climate change, provided utilities with a tool to assess their own utility-specific vulnerabilities, and produced risk management tools to assist utilities in identifying appropriate strategies and actions to respond to the vulnerabilities that are identified.
Insights into the Use of Uncertain Information in the Water Utility Sector (project 4696)	This survey project provides important insights into where and how water professionals are using uncertain information, with a focus on climate projection and assessment information. Insights are also provided regarding the education, training, and support materials they self-identify as needed to successfully gather, use, and share the implications of using uncertain information with both internal and external audiences.
Multi-Objective Evolutionary Algorithm Application Guidance for Utility Planning (project 4941)	The complexity of municipal water supply planning is increasing due to climate change, infrastructure vulnerability, demand uncertainty, and changing social values. This complexity and uncertainty requires a robust framework for planning and decision making, in which a multitude of future situations and potential solutions can be evaluated simultaneously based on different objectives while accounting for the associated uncertainty. Generally, this can be referred to as Robust Decision Making (RDM). There is growing interest in using Multi-Objective Evolutionary Algorithms (MOEA) as a tool in an RDM process to help assess complex system tradeoffs for water utility planning. Using existing models and data from four utilities, this study will investigate how different problem formulations might impact planning decisions in real world planning settings for utilities. The ultimate goal is to develop a compendium of case studies describing the different water systems, planning challenges, and how the MOEA tools were used to help analyze those tradeoffs.
Short-Term Water Demand Forecasting: Survey, Manual and Research Report (project 4501)	The chief objectives of this project were to enhance understanding of the advantages and disadvantages of the various approaches to short-term water demand forecasting and to provide practical guidance to water utilities in choosing, implementing, and evaluating forecasting methodologies. The project focused on prediction over a time horizon of fewer than ten years, intended to inform decisions regarding budgeting, revenue planning, rate design, program implementation, and efficient management of system operations.
Uncertainty in Long-Term Water Demand Forecasting (project 4558)	This project conducted a literature review, survey, and workshop to prepare a comprehensive summary of the uncertainties related to forecasting long-term water demand for resource and infrastructure planning. The final report identifies and describes the range of uncertainties utilities face in long-term water demand forecasting, and presents leading strategies to manage these uncertainties.
Water Demand Forecasting in Uncertain Times: Isolating the Effects of the Great Recession (project 4458)	This project assessed how water demand was affected by the recent recession. It also evaluated how economic shocks can be differentiated from the many other factors known to have an impact on demand, and analyzed how water utilities may be better able to anticipate, adapt to, and minimize impacts of future economic cycles on water demand planning.

Questions?

Thank You

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