08 JUNE 2022

16:00 CEST

IWA Specialist Group on Modelling and Integrated Assessment Webinar Series

The incorporation of risk and uncertainty in mathematical models to aid the design and operations of WRRF

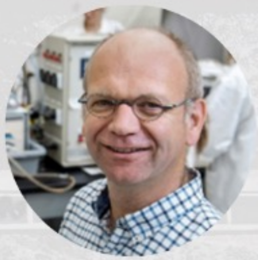
Speakers

Ulf Jeppsson
Lund University

Lina Belia
Primodal Inc.

Lorenzo Benedetti
Waterways

Bruce Johnson
Jacobs



Peter Vanrolleghem
modelEAU
Université Laval

Marc Neumann
Basque Centre for Climate Change

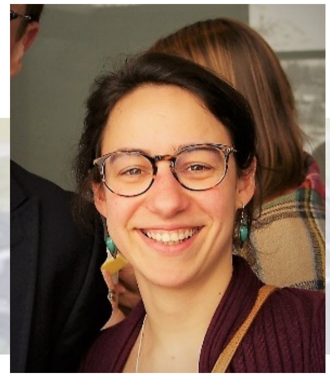
The webinar is going to be recorded and shared on the MIA SG Youtube channel afterward.

MIA Welcome Note

IWA Modelling and Integrated Assessment Specialist Group

Dr. Ulf Jeppsson (Chair of MIA SG)

Dr. Elena Torfs (Vice-chair of MIA SG)



LUND UNIVERSITY

GHENT UNIVERSITY

MODELLING AND INTEGRATED ASSESSMENT SPECIALIST GROUP (MIA SG)

"This group targets people from research, consulting companies, institutions and operators to think along ***the use of models and computing tools to support the understanding, management and optimization of water systems****."*

PRIORITIES

- Interact with other IWA SGs and other professional organizations
- Organize specialized conferences, sessions and workshops
- Engage and activate YWPs in the domain.

CURRENTLY 1900 MEMBERS

How to find us

Website: http://iwa-mia.org/

https://iwa-connect.org

MIA SG: ACTIVITIES

Task Groups (TGs)

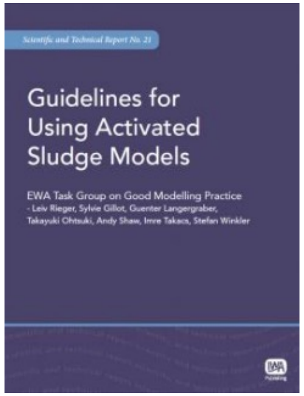
- Benchmarking of Control Strategies for WWTPs (BSM) AND Good Modelling Practice (GMP) AND Design and Operations Uncertainty (DOUT) AND Use of Modelling for Minimizing GHG Emissions from Wastewater Systems (GHG) (all four finished)
- Generalised Physicochemical Modelling (PCM) (in press)
- Membrane Bioreactor Modelling and Control (MBR)
- Good Modelling Practice in Water Resource Recovery Systems

Working Groups (WGs)

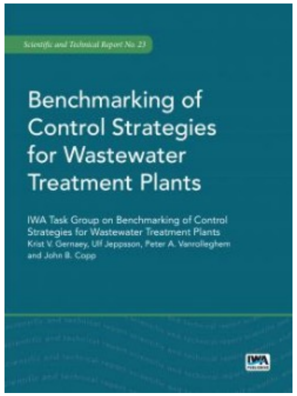
- Integrated Urban Water Systems (IUWS)
- Computational Fluid Dynamics (CFD)
- Good Modelling Practice (GMP)

Conferences / Events

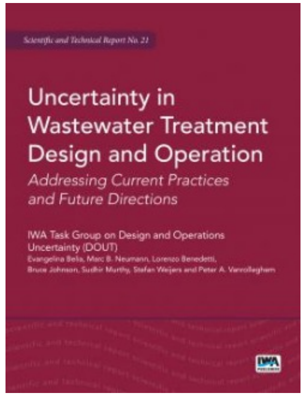
- WRRmod
- Watermatex



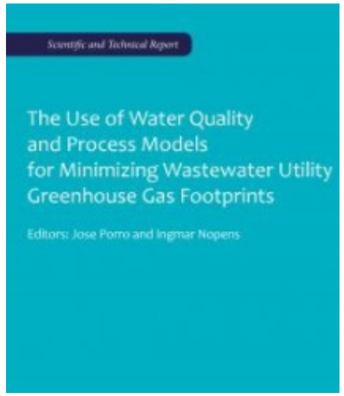
STR
(Sept. 2012)



STR
(Sept. 2014, open access)



STR
(2021)



STR
(2022, open access)

MIA SG: UPCOMING CONFERENCES

8th Water Resource Recovery Modelling seminar (WRRmod2022+)

- Location: Stellenbosch, South Africa, 15-18 January 2023
- Chair: Dr. David Ikumi (Univ. Cape Town)

11th Symposium on Modelling and Integrated Assessment (Watermatex2023)

- Location: Québec City, Canada, late summer 2023
- Chair/vice-chair: Prof. Peter Vanrolleghem (Univ. Laval)/Dr. Elena Torfs (Univ. Ghent)

9th Water Resource Recovery Modelling seminar (WRRmod2024), Stowe, Vermont, USA

FIND MIA SG ON SOCIAL MEDIA

Follow the Modelling and Integrated Assessment Specialist Group on:

- IWA Connect: https://iwa-connect.org/group/modelling-and-integrated-assessment-mia/timeline
- LinkedIn: https://www.linkedin.com/company/iwa-mia-specialist-group-on-modelling-and-integrated-assessment
- Twitter: https://twitter.com/iwa_mia_sg
- **MIA SG open web site** http://iwa-mia.org

to get informed about our latest events, publications and news! Plus MIA Newsletter and MIA YouTube channel.

MIA Open Group meeting at WWC&E2022, Copenhagen, Denmark

AGENDA AND HOUSEKEEPING

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Speaker 2
Lorenzo Benedetti (Waterways, Croatia)

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DOUT
Design and operations uncertainty task group

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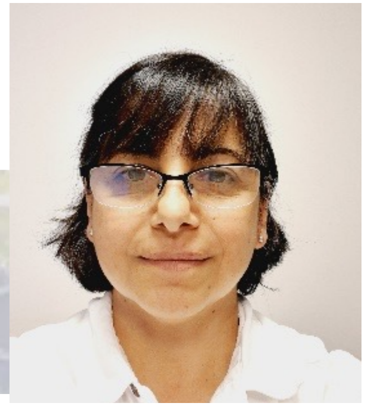
Webinar overview and introduction to the DOUT Group and the STR

Evangelia (Lina) Belia, PhD, P.Eng.



Primodal
Earth Essential Technologies
www.primodal.com

WEBINAR OVERVIEW

Topic	Speaker
The DOUT Group and the STR	Lina Belia
Introducing the principles of uncertainty evaluation	Lorenzo Benedetti
Steady-state case study	Bruce Johnson
Dynamic case study	Peter Vanrolleghem
DOUT perspectives	Marc Neumann
Q&A Discussion	All

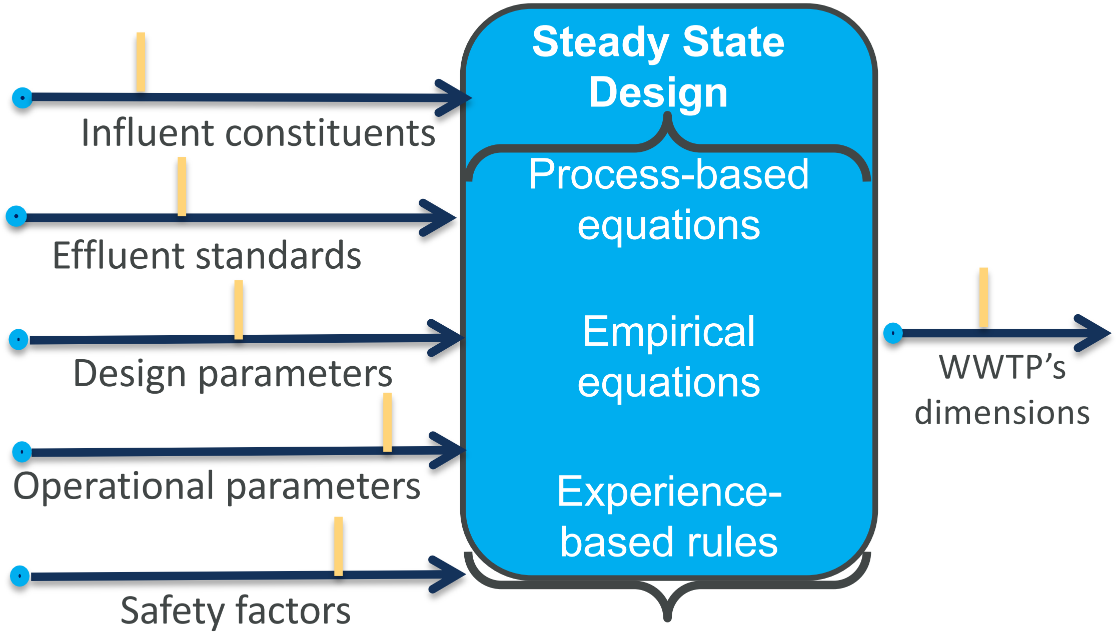
IWA/WEF DOUT GROUP

Working Group

Y. Amerlinck
D. Bixio
C. Bott
M. Burbano
B. Chachuat
J. Copp
X. Flores-Alsina
S. Gillot
T. Hug
J. Jimenez
B. Karmasin
D. Kinnear
J. McCormick
H. Melcer
JB Neethling
M. O'Shaughnessy
A. Pena-Tijerina
B. Plosz
L. Rieger
O. Schraa
A. Shaw
G. Sin
S. Snowling
G. Sprouse
K. Villez
J. Weiss
N. Weissenbacher.

MOTIVATION

- Conventional steady state design
- How is risk currently handled?



Critical states engineering

- Based on worst-case analysis
- Guaranteed availability of infrastructure
- Redundancy

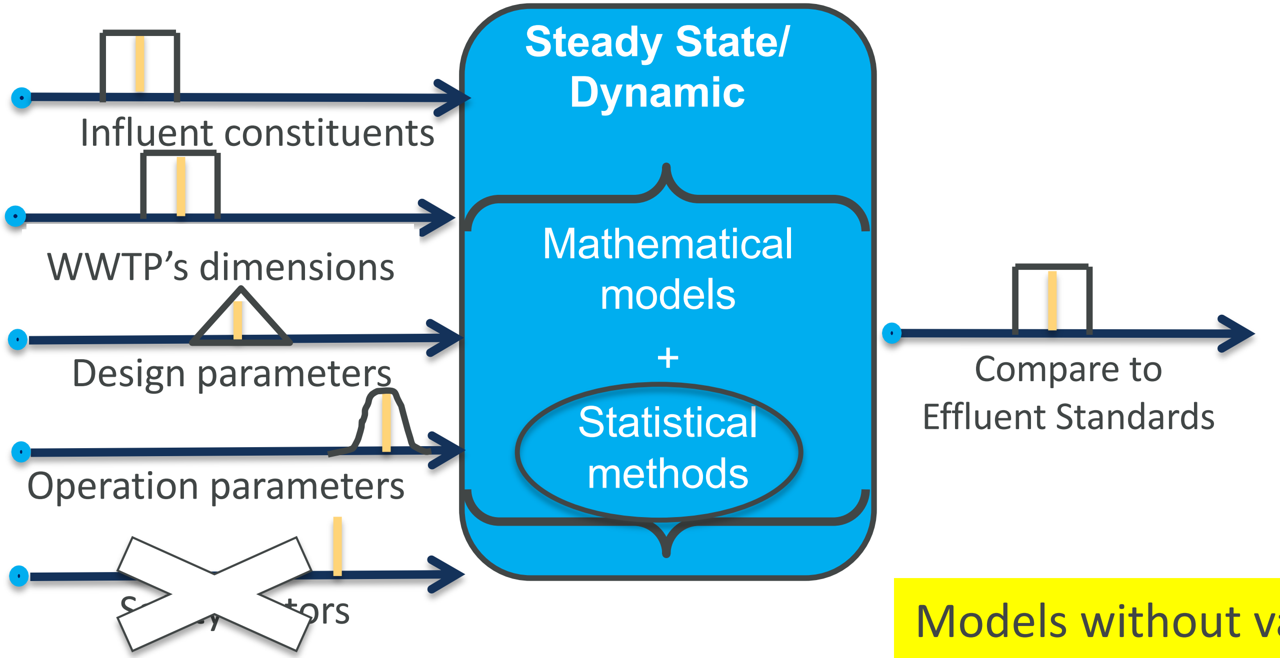
Best effort engineering

- Average case analysis
- No guaranteed performance

Mansour Talebizadeh (2015) Probabilistic design of wastewater treatment plants. PhD. Thesis. modelEAU-Université Laval, Québec, QC, Canada

MOTIVATION

Paradigm shift: make risk explicit



Models without variability and uncertainty considerations do not give the full answer

Mansour Talebizadeh (2015) Probabilistic design of wastewater treatment plants. PhD. Thesis. modelEAU-Université Laval, Québec, QC, Canada

STR CONTENT

SECTION I: SYSTEM UNDERSTANDING	SECTION II: TESTED AND TRANSFERABLE METHODS	SECTION III: DOUT FRAMEWORK	SECTION IV: BROADER VIEW AND WAY FORWARD
CHAPTER 1 Key concepts	**CHAPTER 4** Tested methods for WRRF application	**CHAPTER 5** Combining models, statistics and design guidelines	**CHAPTER 7** Broader view of factors influencing engineering decisions
CHAPTER 2 Current practices		**CHAPTER 6** Case studies	**CHAPTER 8** Future and perspectives
CHAPTER 3 Models - application and benefits			
Appendix A **Appendix E**	**Appendix C** **Appendix D**	**Appendix B**	

SOURCES OF VARIABILITY AND UNCERTAINTY

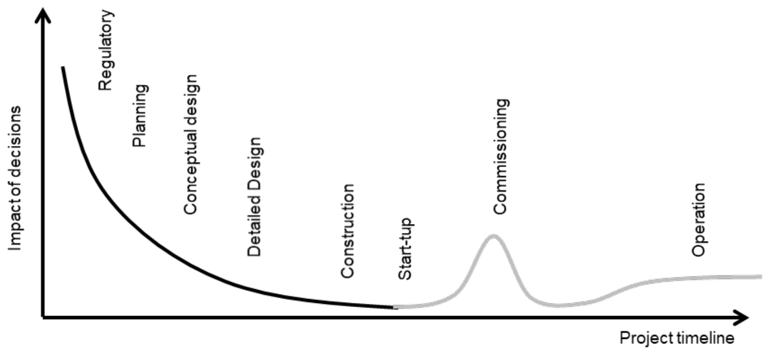
THE UNCERTAINTY MATRIX

Location	Details	Sources	Examples
Inputs	Measured data	Influent data Physical data Operational settings Performance data Additional info	Current and future predicted flow, COD, ammonia Tank volume and geometry DO set points Effluent data, reactor concentrations Input from connected systems e.g. sewers, catchment
	Model parameters	Hydraulic Biokinetic Settling	Number of tanks in series Maximum growth rates Settling coefficients
Model structure	Models		Influent model, hydraulic model, aeration system model, process models (biological, settling, ...)
	Interfaces between models		Waste activated sludge pumped to an anaerobic digester; digester effluent pumped to sludge treatment
Numerics	Software (model technical aspects)	Solver settings Numerical approximations Software limitations Bugs	
Model output	Propagation of uncertainty	All model uncertainties	Probability of meeting effluent criteria

INCLUDING UNCERTAINTY ANALYSIS IN MODEL-BASED PROJECTS

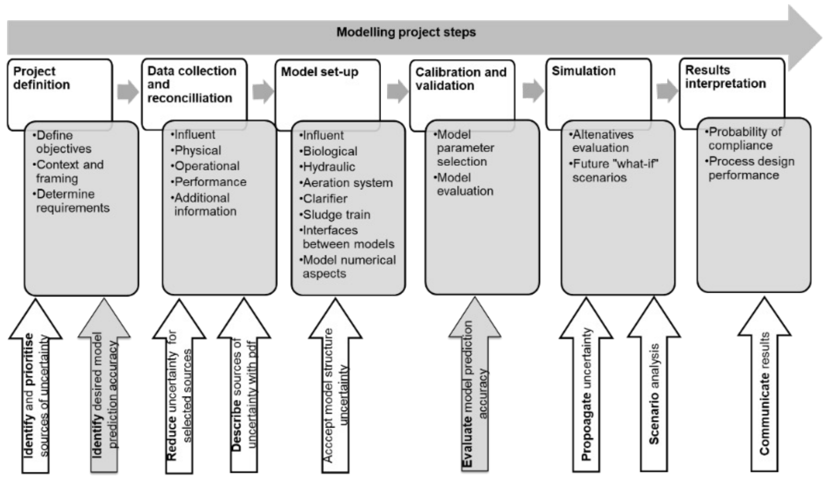
PROJECT PHASE

- Regulatory
- Planning
- Conceptual/Preliminary design
- Detailed design
- Construction
- Start-up
- Operations



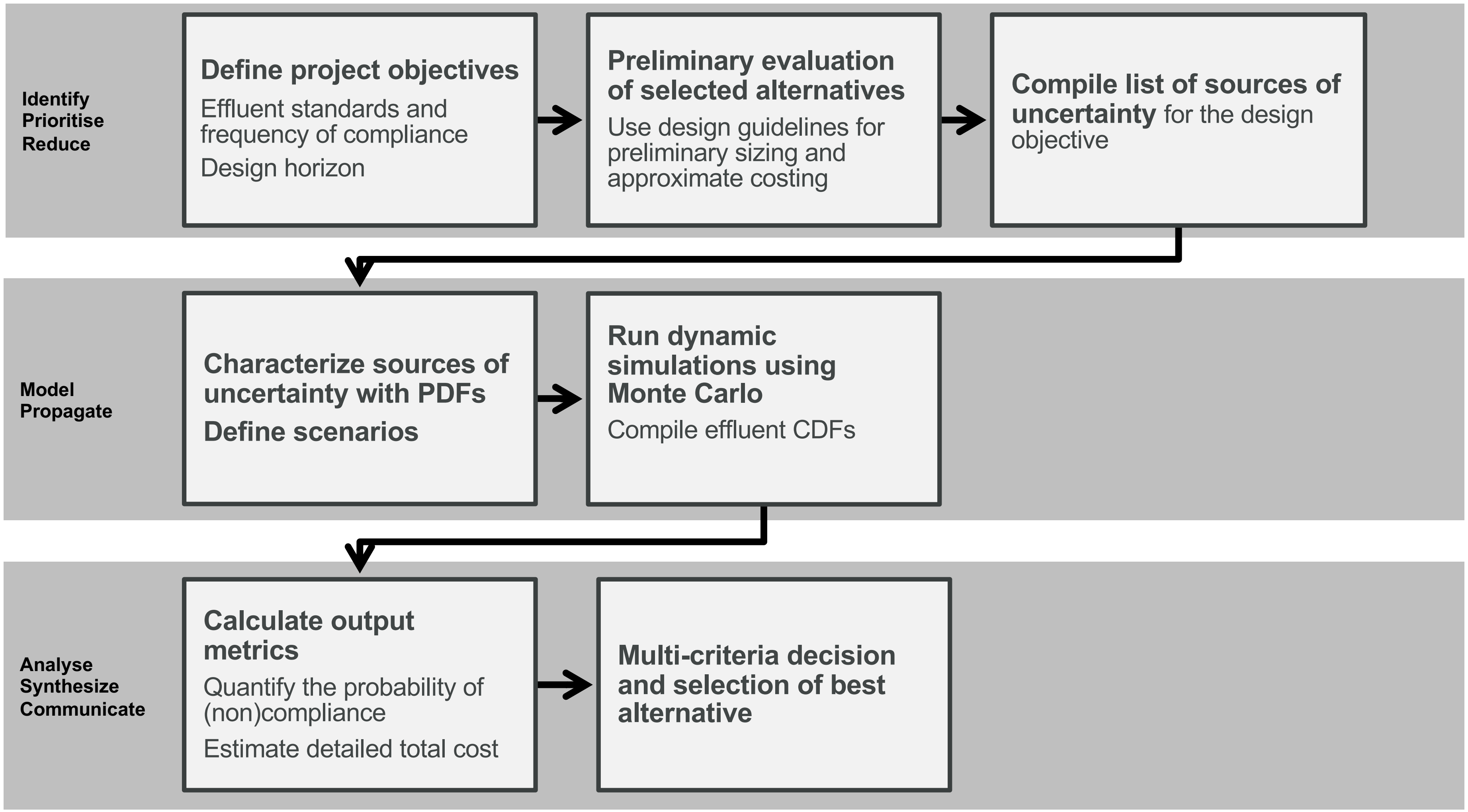
MODEL STEPS

- Project definition
- Data collection
- Model set-up
- Calibration
- Simulation



PROPOSED DESIGN PROCEDURE

COMBINING MODELS, STATISTICS AND DESIGN GUIDELINES



Adapted from: Talebizadeh, M. (2015). Probabilistic design of wastewater treatment plants. PhD. Thesis. Département de génie civil et de génie des eaux, Université Laval, Québec, QC, Canada. https://corpus.ulaval.ca/jspui/handle/20.500.11794/26196

THE BIGGER PICTURE

OTHER FACTORS INFLUENCING ENGINEERING DECISIONS

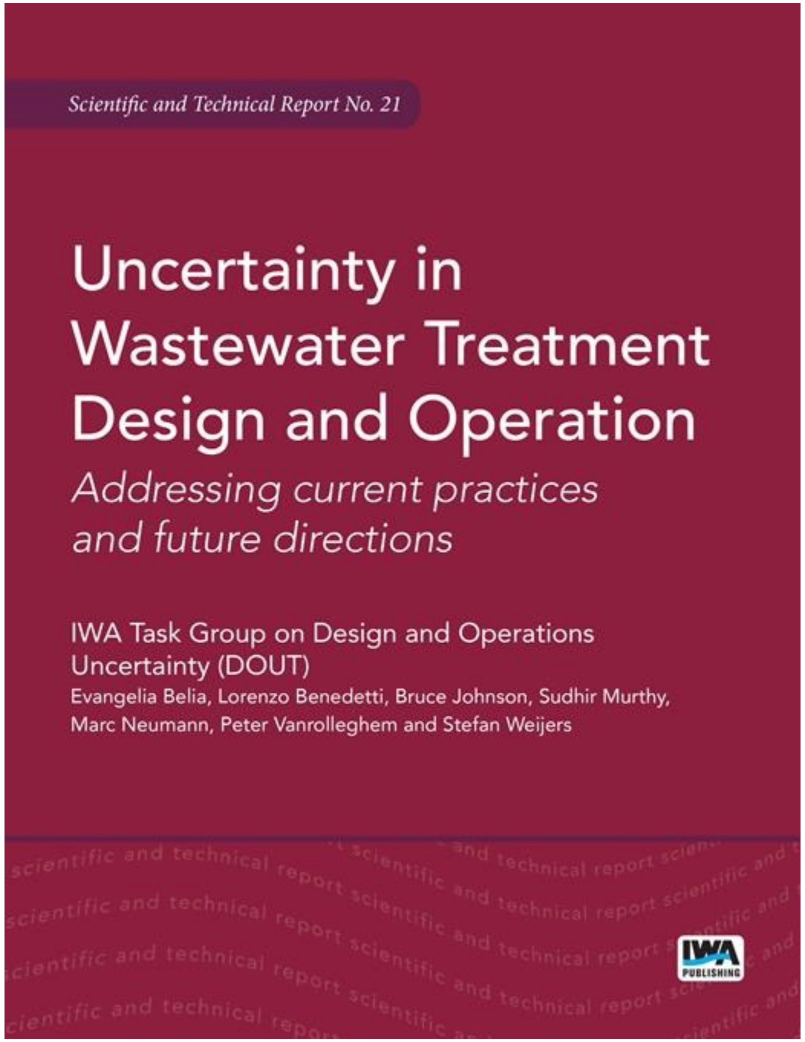
STAKEHOLDERS

- Citizens
- Regulator
- Government
- Utility
- Contractor

CONTRACT TYPE

- Design Bid Build
- Design Build
- Design Build Operate
- ….

SCIENTIFIC AND TECHNICAL REPORT (STR)



https://iwaponline.com/ebooks/book/838/Uncertainty-in-Wastewater-Treatment-Design-and?redirectedFrom=PDF

https://www.iwapublishing.com/books/9781780401027/uncertainty-wastewater-treatment-design-and-operation

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Introducing the principles of uncertainty evaluation

Lorenzo Benedetti, Ph.D.

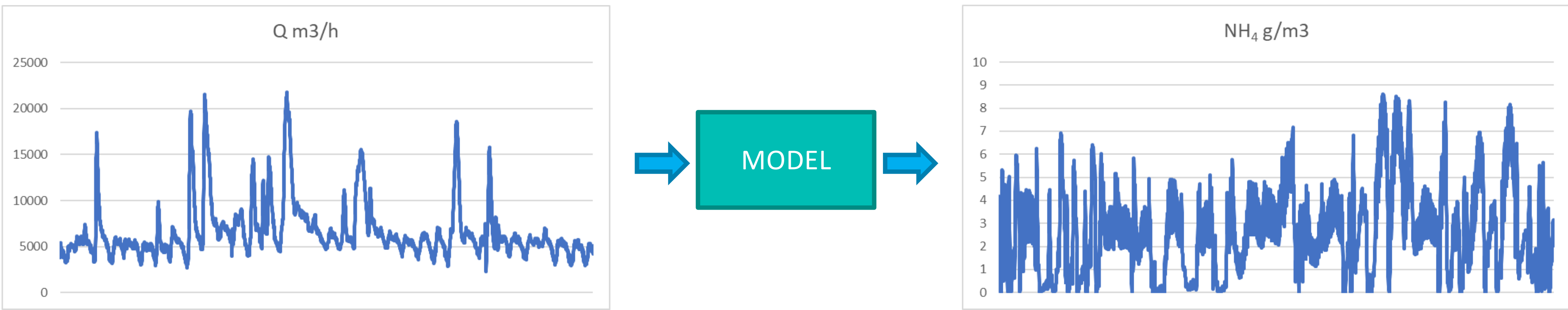
WATERWAYS

KEY DEFINITIONS

- Variability
- Risk
- Uncertainty
- Propagation in models

VARIABILITY

- "Lack of consistency or fixed pattern"
- A measurable quantity that varies in time – timeseries
- Variability is intrinsic, cannot be reduced



RISK AND UNCERTAINTY

- **Risk** = expectation of losses associated with a harmful <u>event</u>

  <u>Example</u>: = Risk of failure (exceeding effluent permit)

  Risk = [Probability of failure] * [Cost of failure]

- **Probability**: is it "likely" or "unlikely“ that the event will happen?

  <u>Example:</u> Probability of a design to meet effluent standards

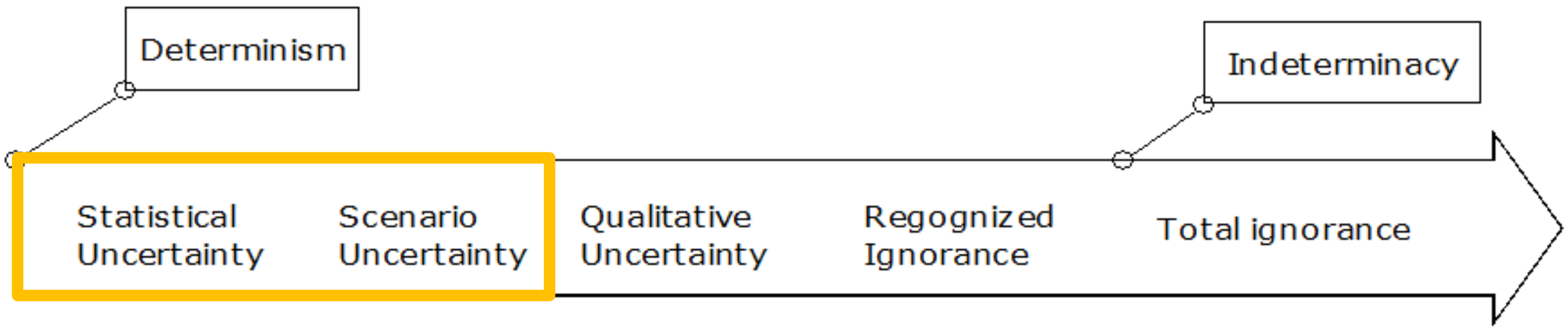
  Probability is the expected likelihood of occurrence of an event

- **Uncertainty** assessment and propagation are:

  Quantification of probabilities

  Quantify risk = assess <u>uncertainty</u> = quantify probability

LEVELS OF UNCERTAINTY

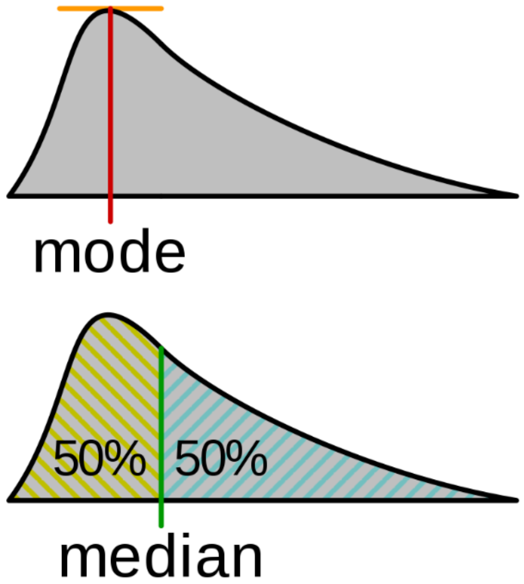


SCENARIO UNCERTAINTY

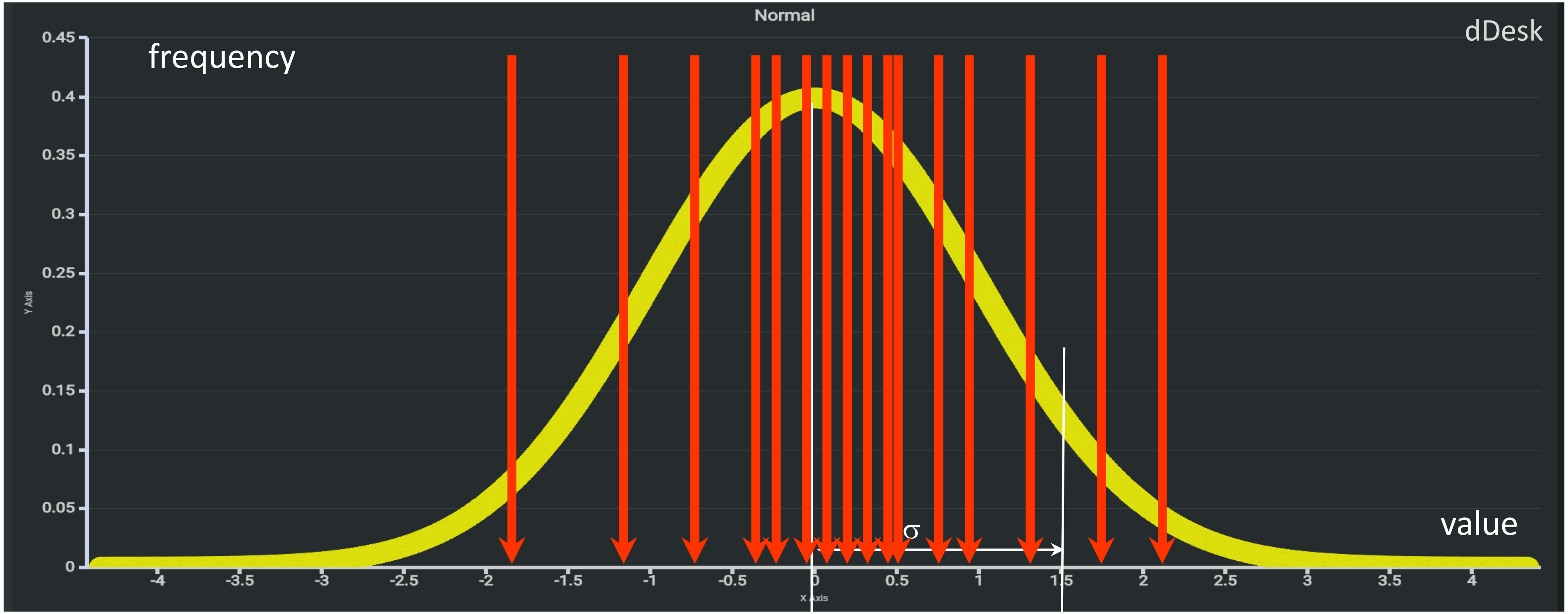
- What is going to happen at my plant in the next 30 years?
  - New industry
  - New treatment technologies
  - New legal requirements
  - …..

STATISTICAL UNCERTAINTY

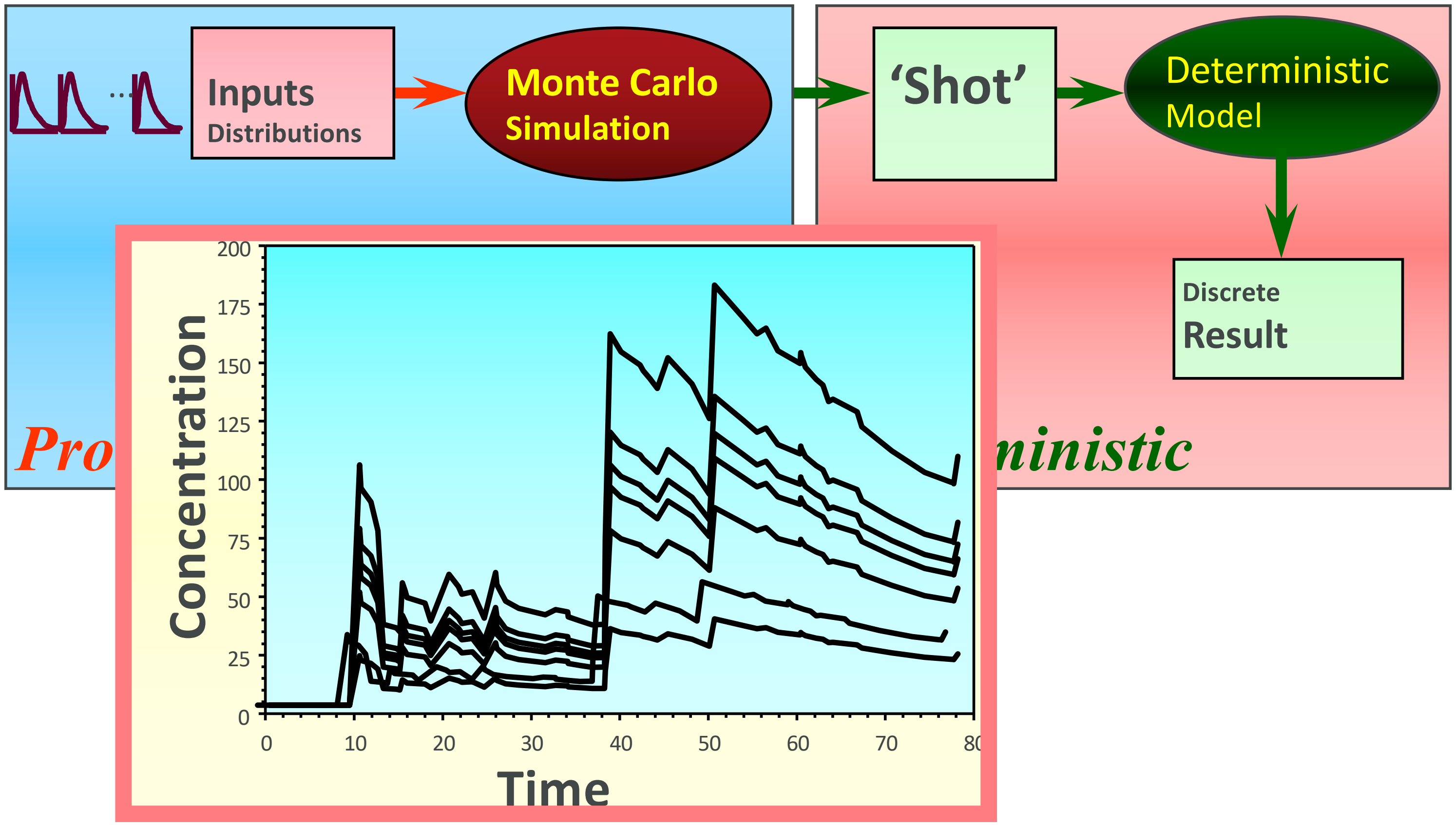
- “Refers to epistemic situations involving imperfect or unknown information”
- “A state of limited knowledge where it is impossible to exactly describe the existing state or a future outcome”
- Probability Density Function (PDF)
- Uncertainty can be reduced by more research



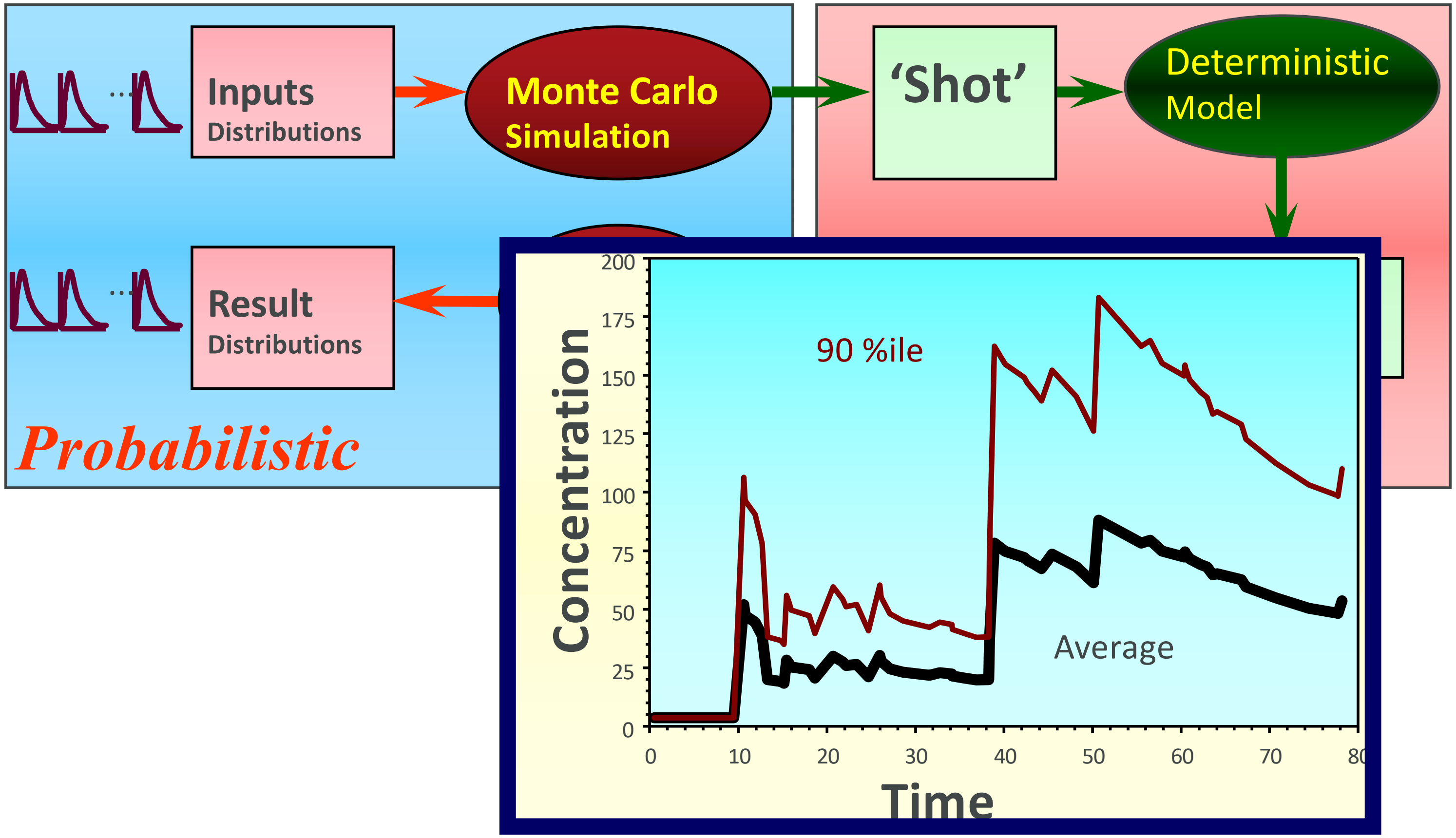
UNCERTAINTY PROPAGATION: MONTE CARLO SIMULATION



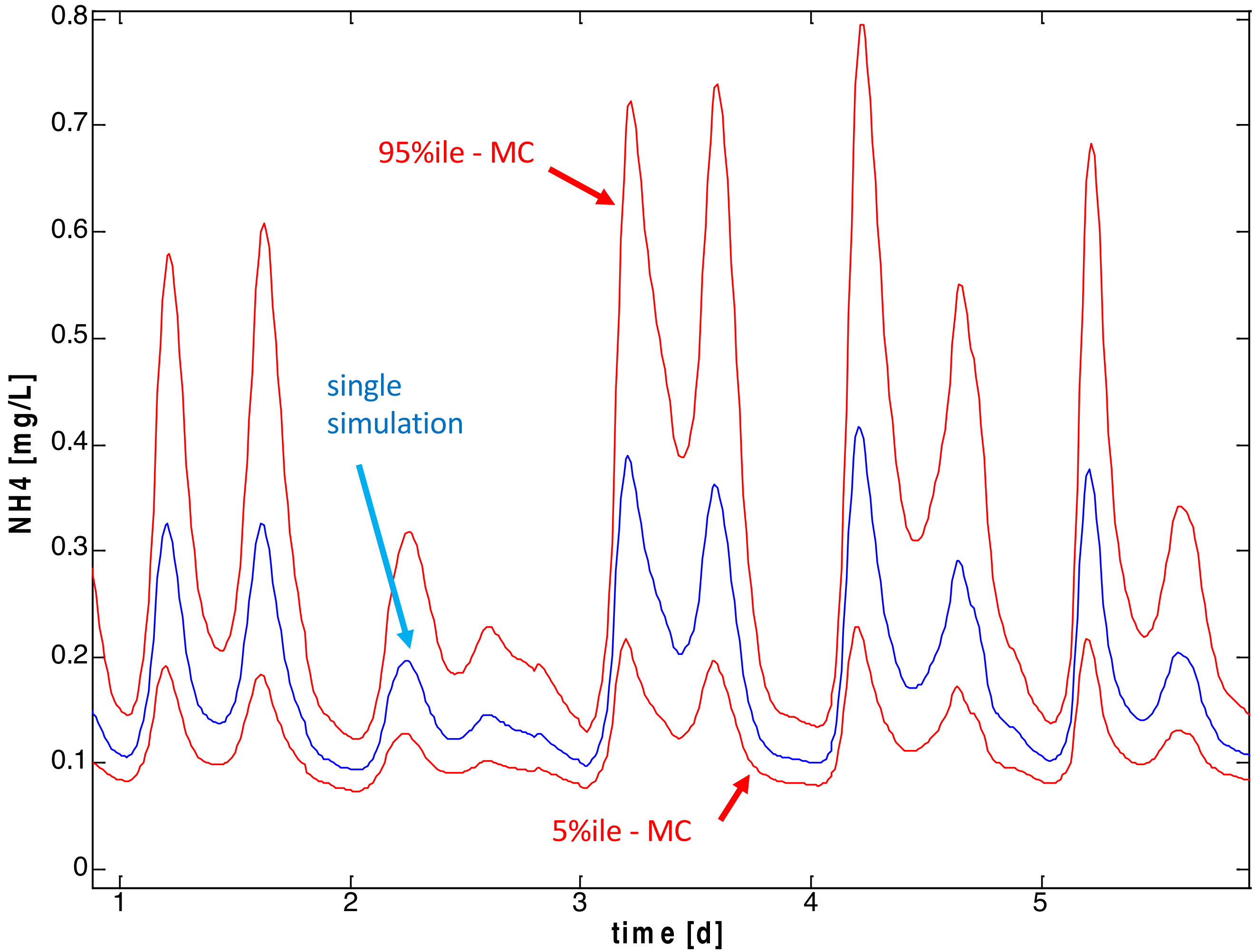
MONTE CARLO SIMULATION



MONTE CARLO SIMULATION



VARIABILITY AND UNCERTAINTY – MODEL OUTPUT



in blue:

temporal variability

due to influent

variability

in red:

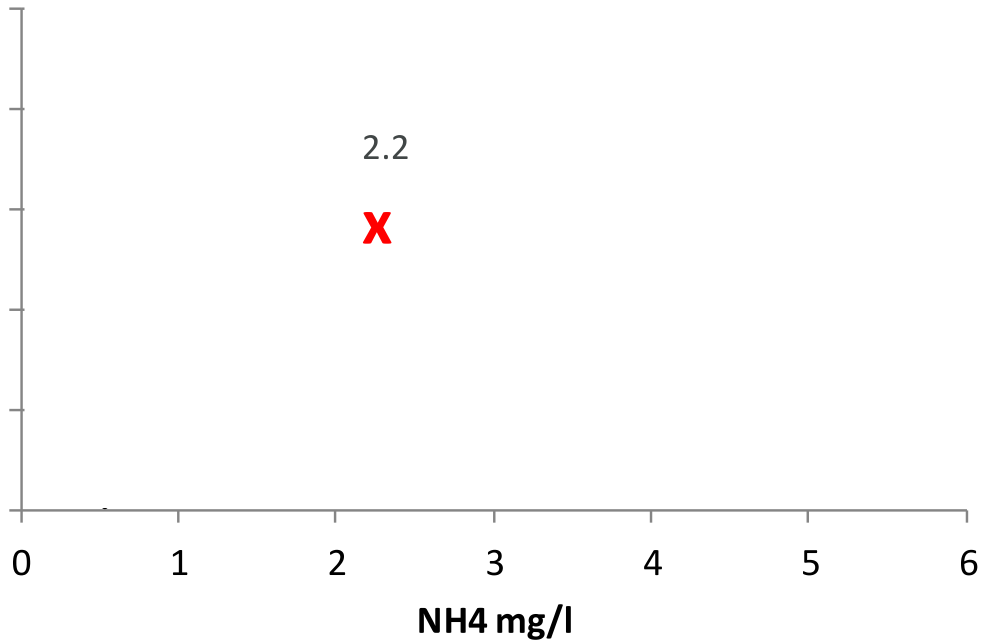
output uncertainty band

due to parameter

uncertainty

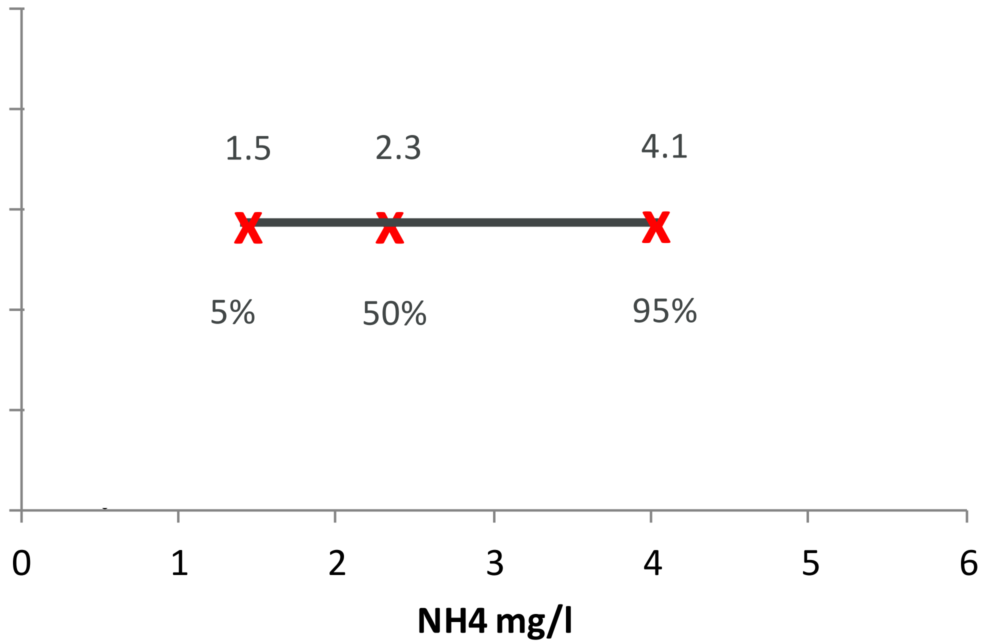
Four different ways to combine variability (steady state or dynamic simulation) and uncertainty (single or MC simulation)

STEADY STATE – NO MC (1 SIMULATION)
Point estimate

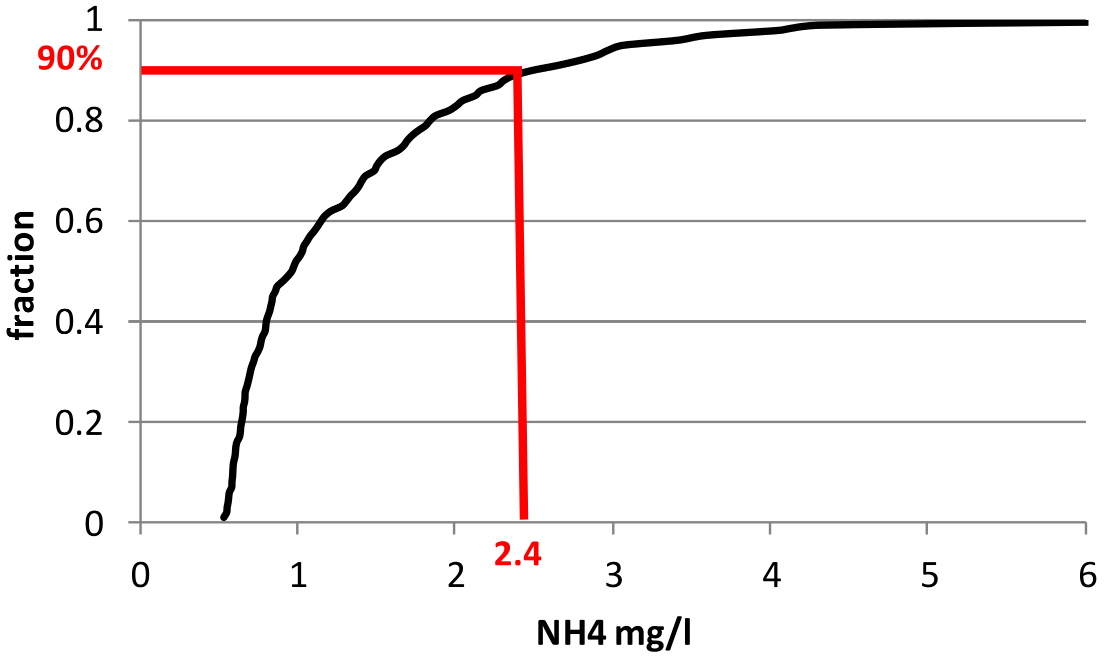


STEADY STATE – MC (1000 SIMULATION)

Confidence interval (uncertainty)

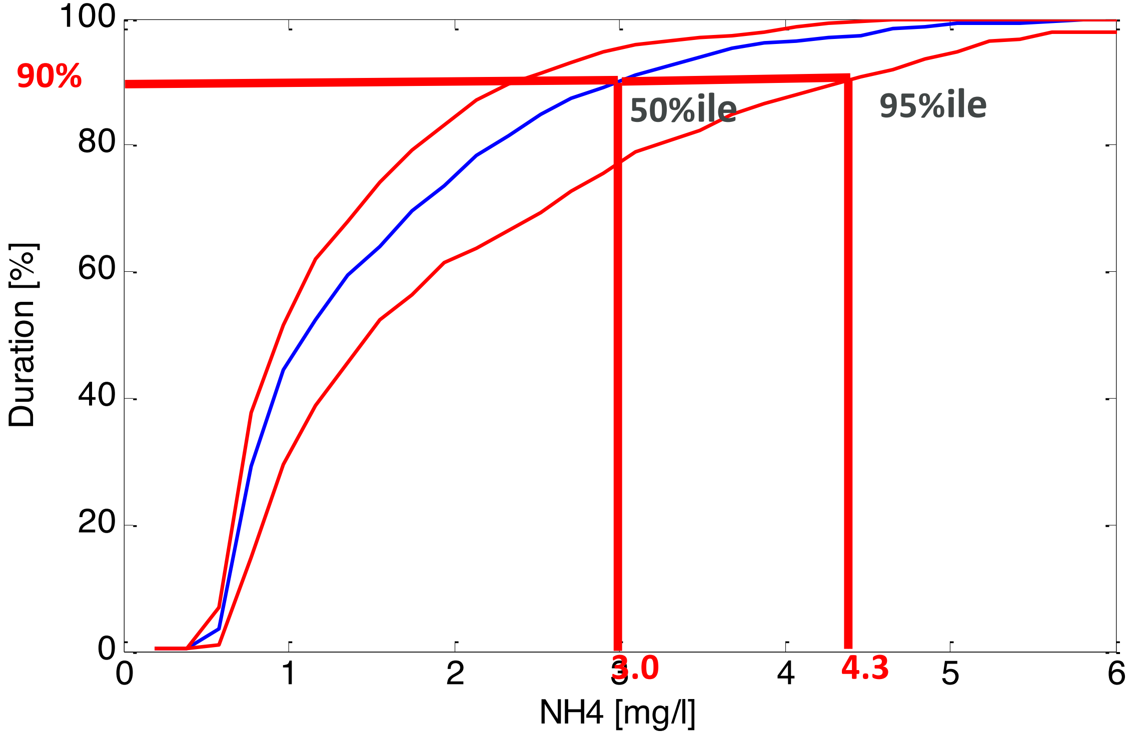


DYNAMIC – NO MC (1 SIMULATION)
Frequency estimate (variability)



DYNAMIC – MC (1000 SIMULATION)

Frequency + confidence (variability + uncertainty)



IN SUMMARY

- **Variability** is something "**sure**":

  we push it throught the model and we get the

  frequency of **compliance**

- **Uncertainty** is about **possible futures**:

  confidence means "in how many possible futures

  something is happening"

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Steady State Applications of Uncertainty Analysis

Bruce R. Johnson, P.E., BCEE, IWA Fellow

Denver, Colorado, USA

Sudhir Murthy/NEWhub, PhD, PE, BCEE, IWA Fellow, WEF Fellow

Glen T. Daigger/University of Michigan, , PhD., PE, BCEE, NAE, IWA Distinguished Fellow, ASCE Distinguished Member, WEF Fellow

Adrienne Menniti/Clean Water Services, PhD, PE

Heather Stewart/Jacobs, PhD

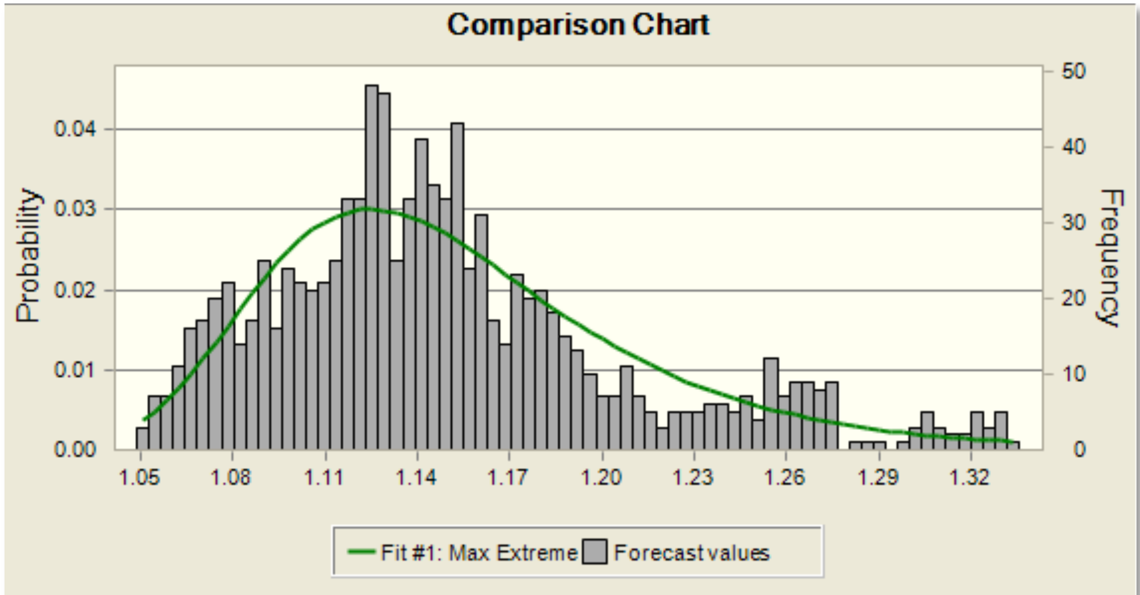
Jacobs Challenging today. Reinventing tomorrow.

NEW APPROACHES FOR BALANCING COST AND BENEFIT

- Balancing costs/benefits/performance has been going on for a long time
  - Typically there is very little quantitative information about how conservative/robust a design is for a facility that can be used to balance risk and benefits
- What is new is the widespread use of simulators to mathematically model the sizing and performance of a water resource recovery facility
  - There are just recently in the last few years industry standards on how to properly use wastewater facility simulators (Biowin, GPSx, West, Simba, Sumo, etc.)
- Models do not give THE ANSWER
  - Current Simulators have thousands of Parameters, not even considering time varying characteristics
- With all these variables is it even possible to get an exact answer?
  - NO, Never, No Way
  - The actual influent/input parameters are always different from those modeled

MODELS DO NOT GIVE THE ANSWER, BUT…

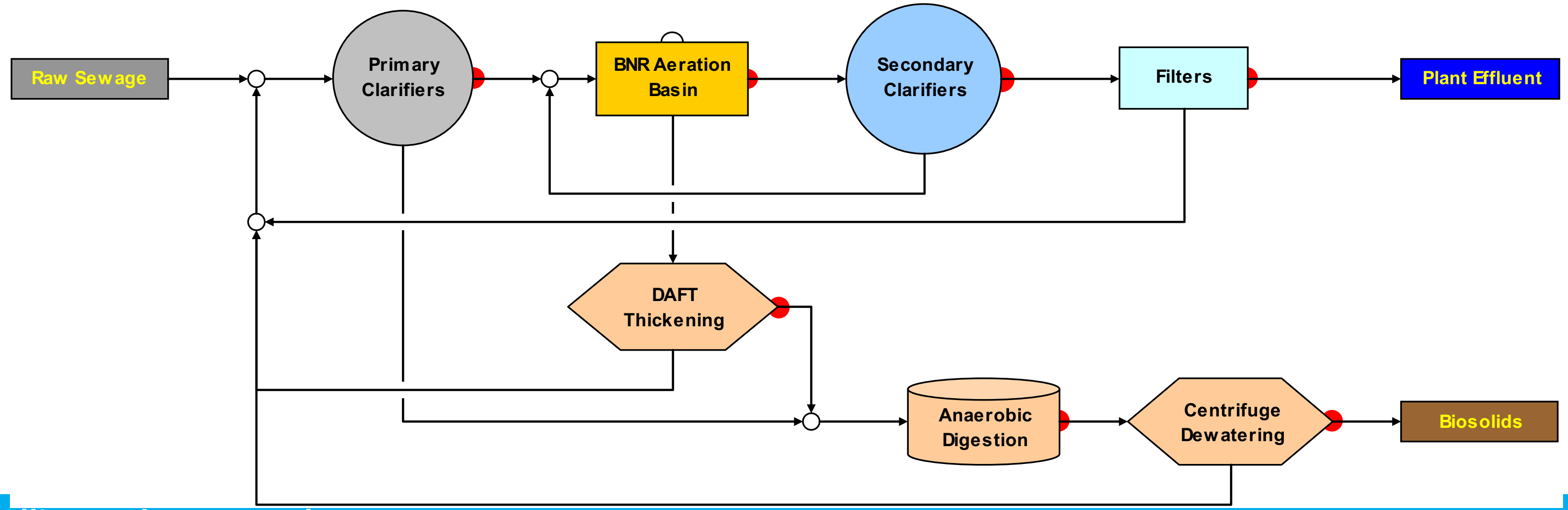
- It is now possible to *quantitatively* evaluate the statistical likelihood of achieving a particular effluent/performance criteria
  - This requires an accurate knowledge of the actual plant performance
  - *Requires* "Daylighting" the conservatisms buried (i.e. dealing with them directly) in the various design assumptions
- This approach allows risk to be managed rather than avoided
  - IT IS NOT POSSIBLE TO AVOID RISK
  - Managing risk can be daunting at first



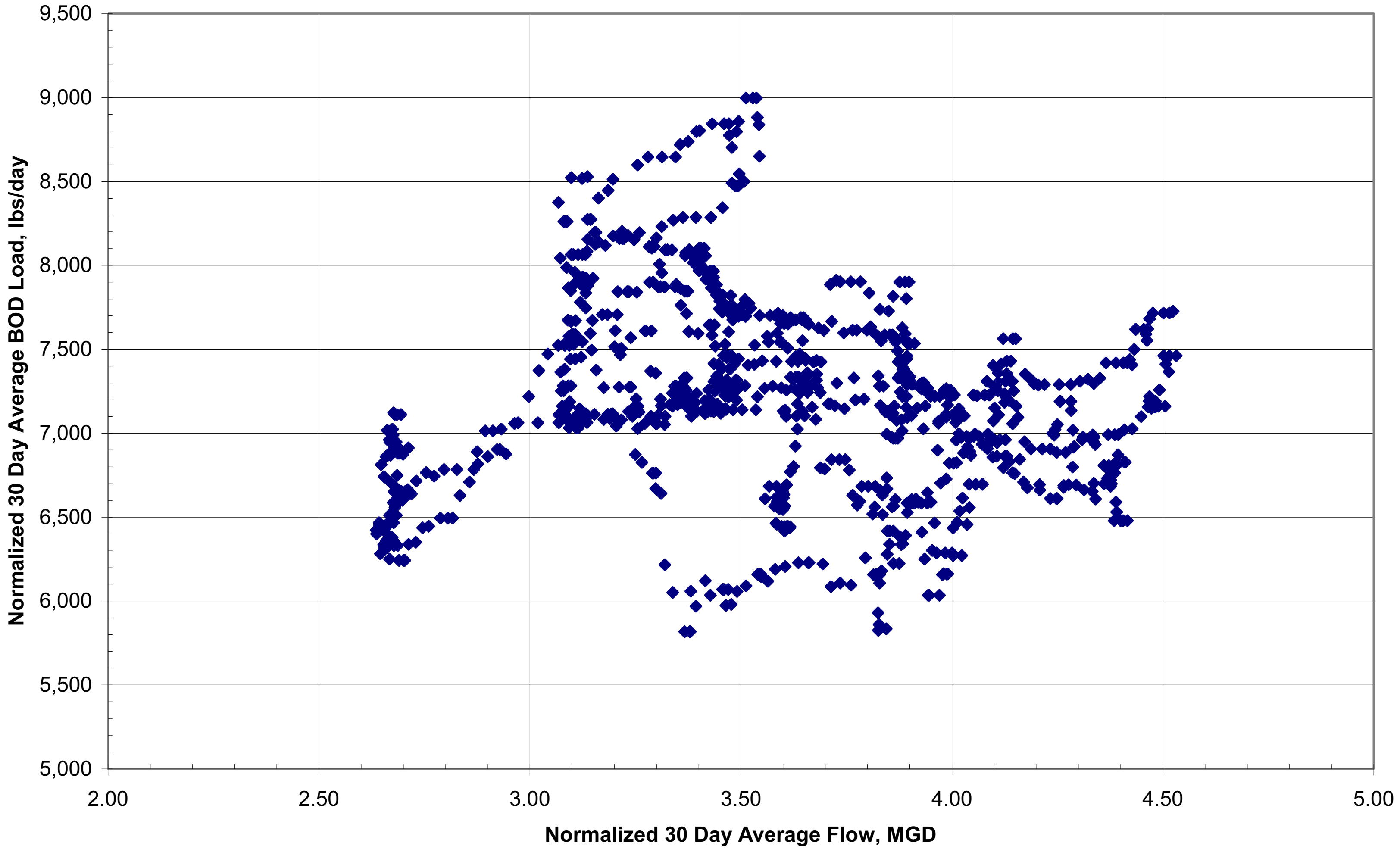
Statistical Re-Rating of Facility Capacity:
Meridian, Idaho USA

PROJECT DEFINITION

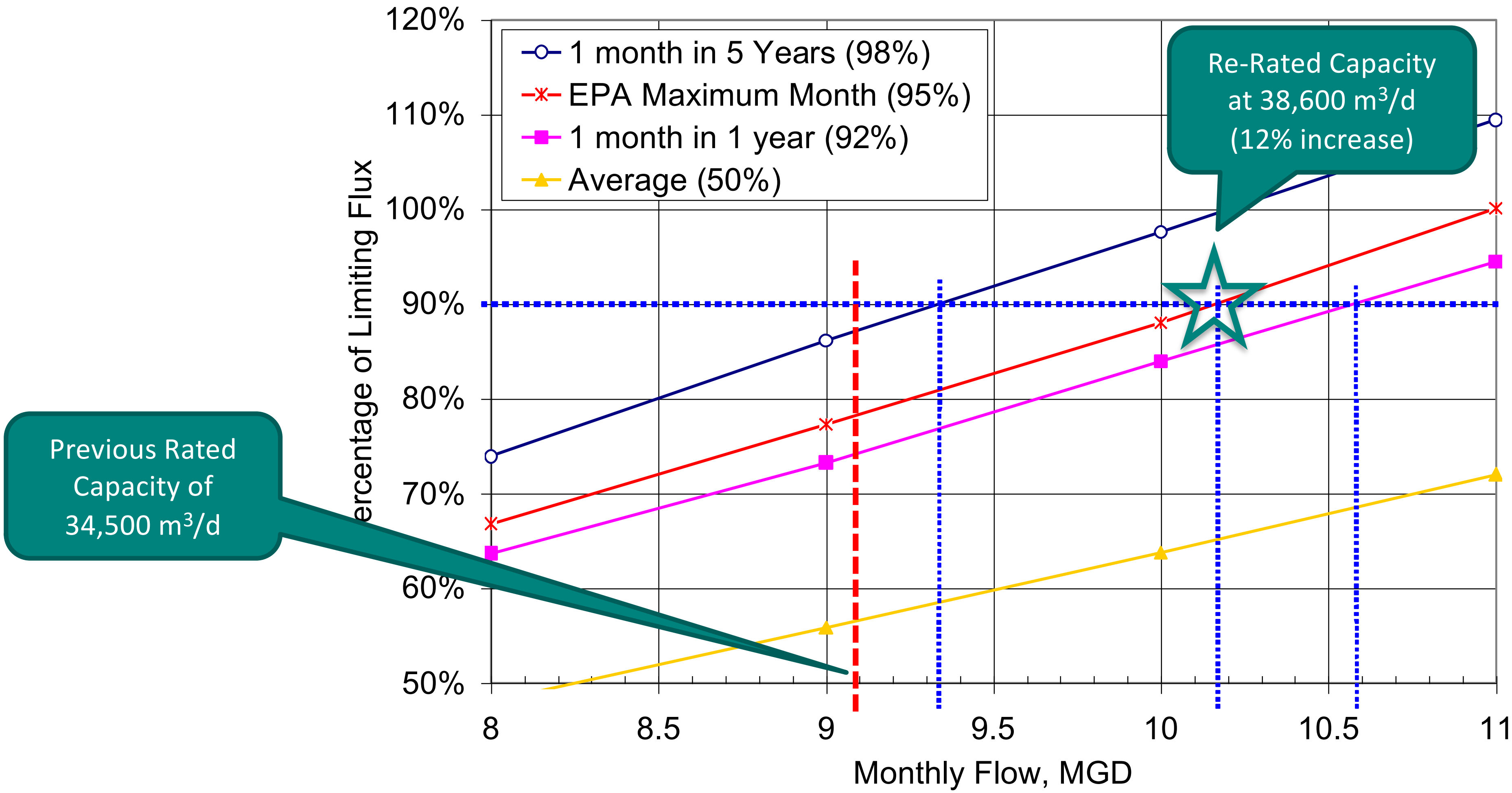
- Idaho WWTP Capacity
  - Conventional Capacity Rating = 34,500 m^3/d
  - Based upon maximum month flows and loads occurring at the same time
  - Resulting solids load on the clarifier defines the plant rated capacity
- Statistics and Uncertainty principles were used to better determine capacity
  - Overlapping worst case conditions are not likely and should not define capacity
    - Flow
    - Ratio of Average to Peak Day Flow
    - Load
    - Primary Clarifier Performance
    - Bioreactor Solids Yield
    - Sludge Volume Index (SVI)



INFLUENT FLOWS AND LOADS ARE NOT STRONGLY CORRELATED WITH EACH OTHER



CAPACITY RESULTS



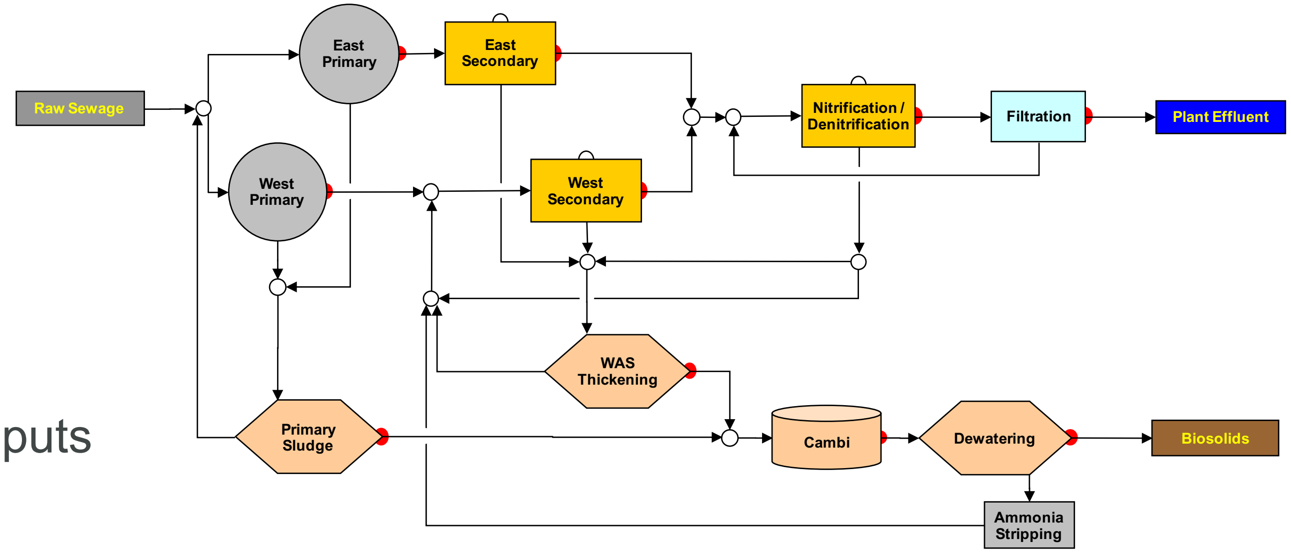
Reliability of a Selected Treatment Alternative: Blue Plains AWT, Washington DC, USA

PROJECT DESCRIPTION

- The District of Columbia Water and Sewer Authority (DCWater) Blue Plains AWTP, located in Washington D.C. USA
- Expansion to achieve total nitrogen goals of less than 4 mg/L:
  - Design flow is 1,400,000 m3/day
  - Denitrification volume was added to the second stage nitrification/denitrification system
- It was unclear if the available volume was adequate to meet the effluent criteria

UNCERTAINTY METHODOLOGY

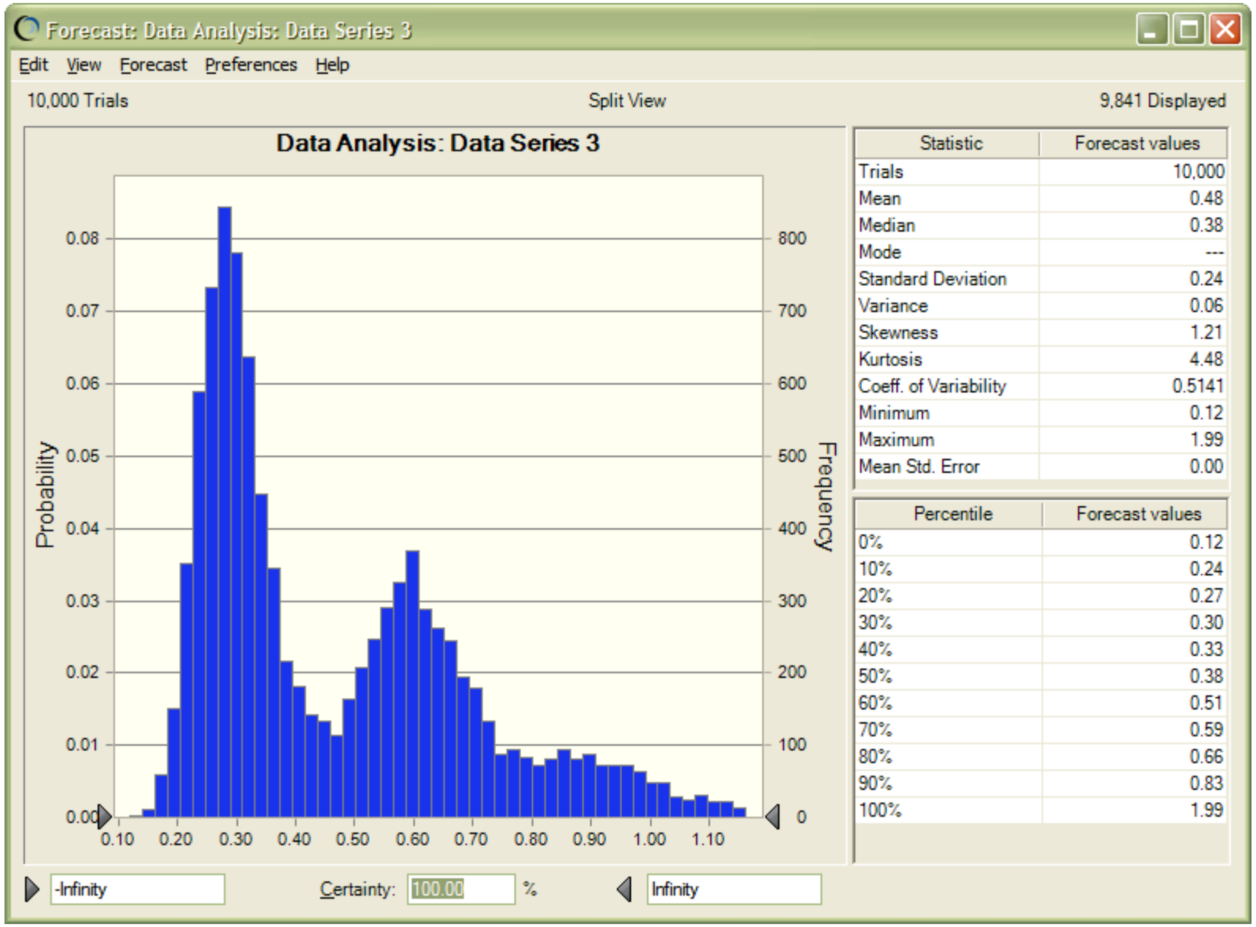
- Needed a large number of runs to cover the ranges of parameters
  - 3,000 whole plant simulations
- Used Average Monthly conditions with a steady state solution
  - Final goals were yearly average results
  - Average monthly results could be combined in various ways to make up “years”



- Monthly Average Model Inputs
  - Flows and loads
  - Influent temperature
  - Primary suspended solids removal
  - Secondary SRT (first stage)
  - Secondary effluent suspended solids
  - Nitrification safety factor
  - SVI
  - **Nitrification tank(s) OOS**
  - **Clarifier(s) OOS**
  - **Denitrification tank OOS**
  - Autotrophic oxygen half saturation (Ko,a)
  - **Methanol Availability**
  - Maximum Day/ Maximum Month Flow Ratio

TOTAL INORGANIC NITROGEN (TIN) ANNUAL RESULTS

- Values in excess of 1 mg/L TIN are almost all a result of automatic control
  - Real operations could address
- 96% of the results were less than 1 mg/L TIN
- Equivalent to 1 year in 27 years of operation

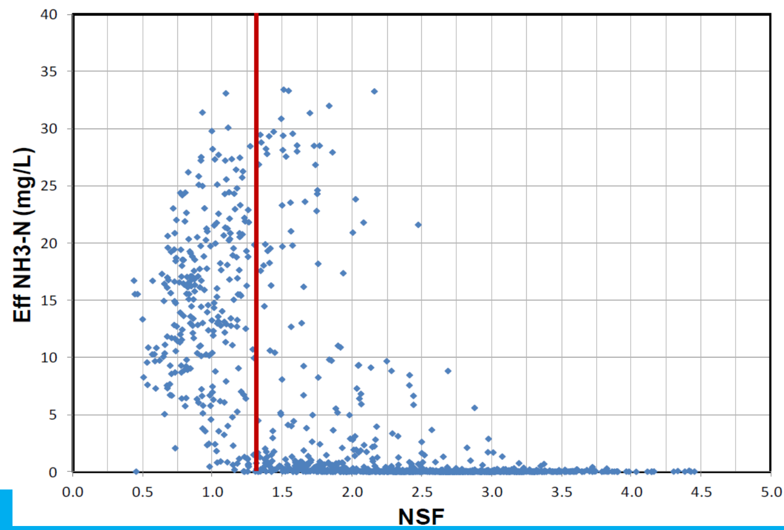


Operational Strategies for New Effluent Criteria: Durham AWTF, Tigard, Oregon, USA

Adrienne Menniti/Clean Water Services, PhD, PE

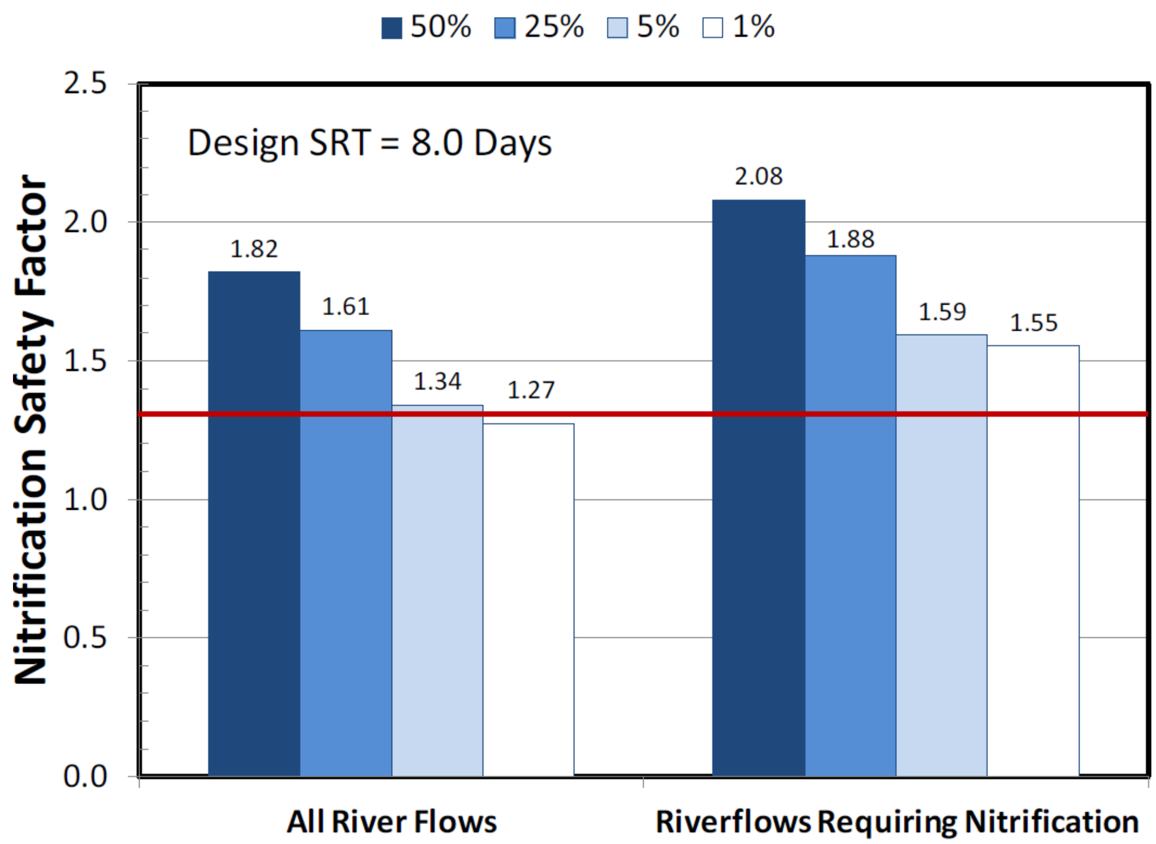
PROJECT DESCRIPTION

- Clean Water Services (Tigard, Oregon, USA) was exploring how best to operate their Durham facility if it became necessary to nitrify year around
  - The current permit only requires nitrification during the summer season
- The expected effluent permit ammonia levels would be based on the receiving river flow, with lower river flows requiring higher levels of nitrification
- Operations staff needed to know what operating sludge age they should target in the winter that would allow them to achieve the winter ammonia targets
- EPA's Nitrification Safety Factor (NSF) calculation was used to determine the likelihood of achieving nitrification when river flows were low
- Model Input Parameters
  - Target SRT, River Flow and Influent Temperature:
  - Historical patterns
  - Autotrophic maximum specific growth rate (μmax), decay rate (b), and half-saturation value for oxygen (KOA):
  - Expert input equal probability



WINTER NITRIFICATION RELIABILITY

- The 1.3 NSF resulted in a target operating sludge age of 8 days during the winter season
- The NSF of 1.3 was able to be met for all likely river flows requiring nitrification
- Did not quite meet a 99th percentile reliability for all river flows
- ***Reduced the need for plant expansion***



OTHER UNCERTAINTY QUANTIFICATION PROJECTS

- **UOSA, VA** – Master Plan. Uncertainty applied within steady state process modelling to plan for expansions and evaluate alternative processes. Process simulations occurred every 5-years throughout the 50-year plan.
- **TRA, TX** – Master Plan. Uncertainty applied within steady-state process modelling to understand process alternative nutrient removal performance. Uncertainty also implemented within economic evaluation.
- **NEW Water (Green Bay), WI** – Phosphorus Plan. Uncertainty applied to performance variability of existing and new processes to plan for future mass reductions. Uncertainty also implemented within economic evaluation.
- **Oshkosh, WI** – Phosphorus Plan. Uncertainty applied within dynamic process models (100-dynamic design years) to plan for future mass seasonal reductions. Uncertainty also implemented within economic evaluation.
- **Carol Stream, IL**– Phosphorus Plan. Uncertainty applied within steady-state process to plan for future possible permit limits. Uncertainty also implemented within economic evaluation
- **MWRD (Denver), CO**– Operational optimization. Uncertainty applied in steady-state process modelling to evaluate configurations that would provide the most stable operation.
- **Duffin Creek, ON** – Phosphorus Plan. Uncertainty applied within dynamic process models (100-dynamic design years) to evaluate operational strategies and to plan for future upgrades.
- **Casper, WY** – Capacity rerating study. Uncertainty applied to final clarifier analysis to determine the reliable solids loading rates. Results utilized to justify capacity rerating.

CONCLUSIONS

- The use of uncertainty analysis in wastewater treatment design and operations has been shown in these three case studies to provide both quantitative risk data and associated cost savings
  - Utilities can now participate in a very quantitative way in the decisions around how much they want to spend to meet their risk management goals (rather than just trusting the consultant or Vendor)
  - Allows for more informed decisions in the design, construction, and operation of any facility.

CONCLUSIONS

- These approaches can be as simple as applying Monte Carlo analysis to
  - Basic design equations, or
  - Whole plant simulator runs
- The use of uncertainty analysis in the design and operation of facilities is a logical next step to provide data to make informed decisions and reduce capital and operating costs.

AGENDA AND HOUSEKEEPING

Speaker 1
Evangelia (Lina) Belia (Primodal Inc., US & Canada)

Speaker 2
Lorenzo Benedetti (Waterways, Croatia)

Speaker 3
Bruce Johnson (Jacobs, USA)

Speaker 4
Peter Vanrolleghem (modelEAU, Université Laval, Canada)

Speaker 5 & Q&A Session Moderator:
Marc Neumann (Basque Centre for Climate Change (BC3), Spain)

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DYNAMIC CASE STUDY

Peter A. Vanrolleghem
(Peter.Vanrolleghem@gci.ulaval.ca)
modelEAU – Université Laval

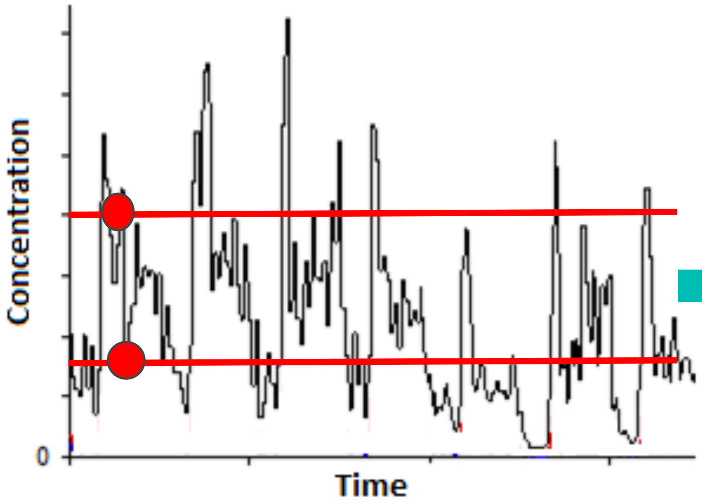
Talebizadeh Mansour (2015)
Probabilistic design of wastewater treatment plants.
PhD. Thesis. Université Laval, Québec, QC, Canada.

UNIVERSITÉ LAVAL

modelEAU

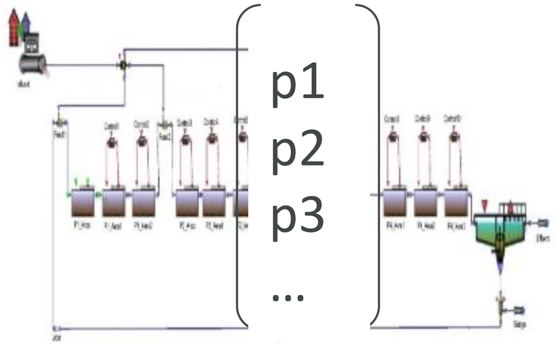
PROBLEM STATEMENT

- WRRF are dynamic systems
- Steady state design = constant values for design inputs



Design guidelines with safety factors

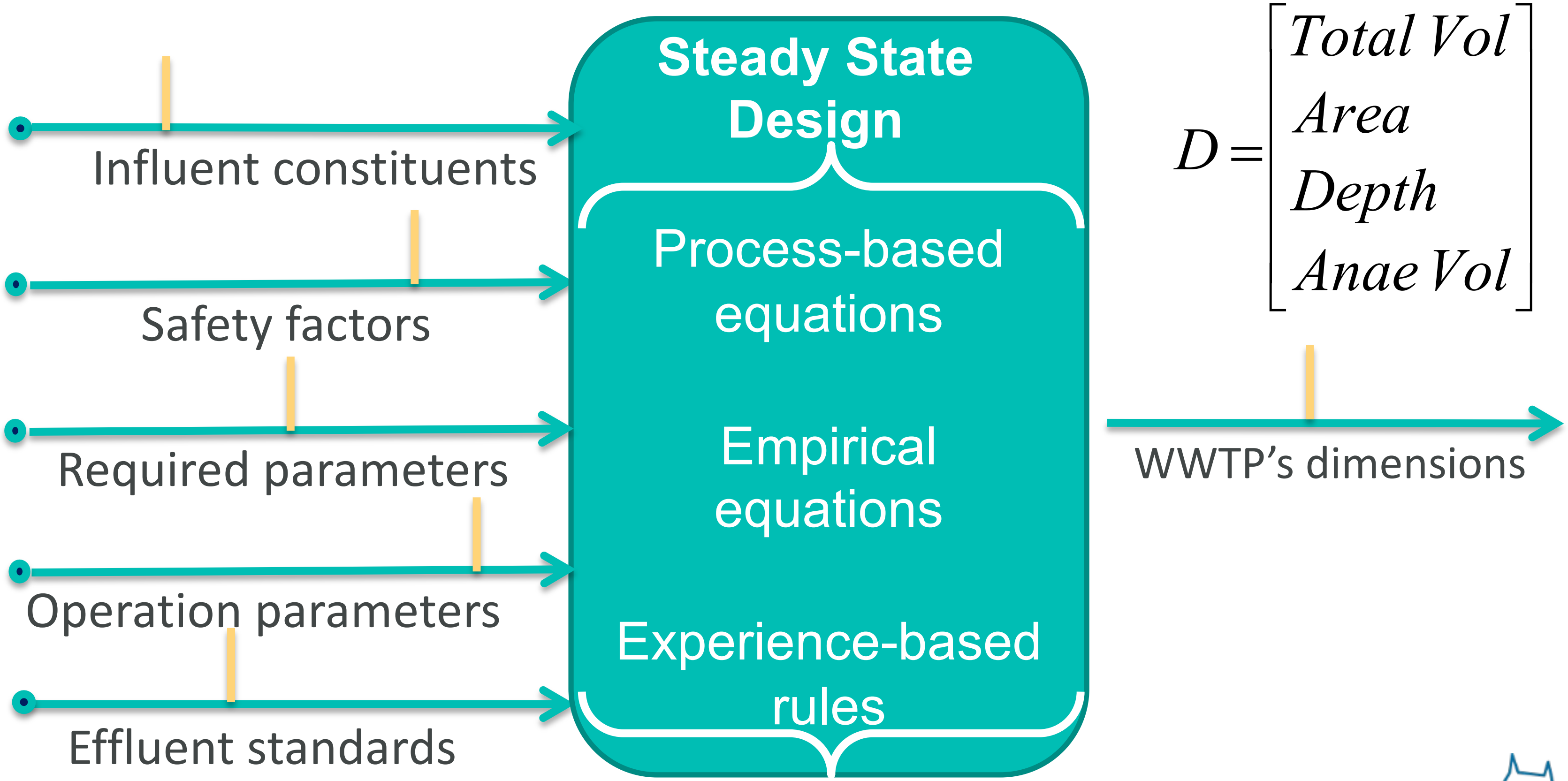
$$D = \begin{bmatrix} Total\,Vol \\ Area \\ Depth \\ Anae\,Vol \end{bmatrix}$$



p1
p2
p3
...

CONVENTIONAL STEADY STATE DESIGN

- Steady-state design:



$$D = \begin{bmatrix} Total\ Vol \\ Area \\ Depth \\ Anae\ Vol \end{bmatrix}$$

OBJECTIVES

- Consider influent variability
  and model parameter uncertainty explicitly
- Quantitative evaluation of the
  Probability of non-compliance (PONC)
- Complement conventional design
- Applicable to actual design projects

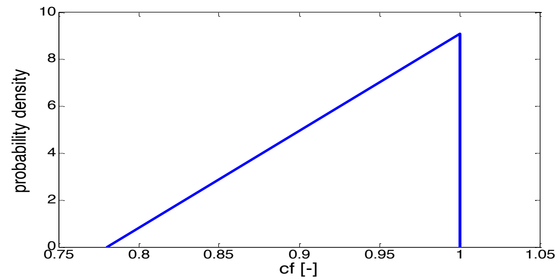
PROPOSED DESIGN METHODOLOGY

Steady state pre-design with different levels of safety

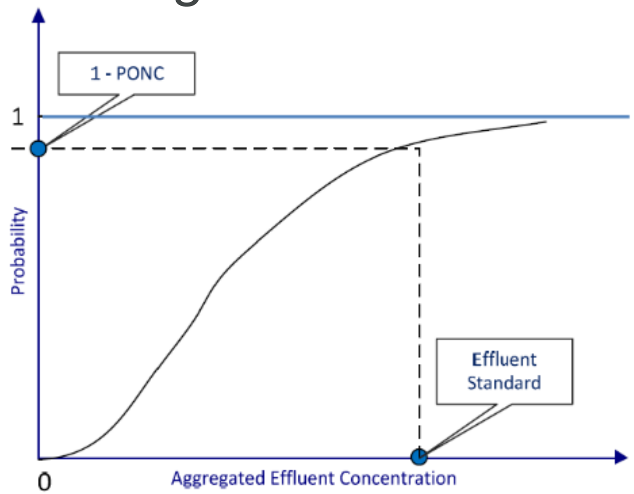
Screening of pre-designs and preliminary evaluation

Quantification of PONC using dynamic simulation

Inputs=range of values



Performance of design=curve or area



CASE STUDY

- **Eindhoven WWTP**

Plant capacity=750,000PE
Effluent requirements:

TN (g/m3)	**10 (annual)**
NH_4 (g/m3)	2 (daily)
BOD_5 (g/m3)	20 (daily)
COD (g/m3)	125 (daily)
TSS (g/m3)	30 (annual)

PROPOSED DESIGN METHODOLOGY

Steady state pre-design with different levels of safety

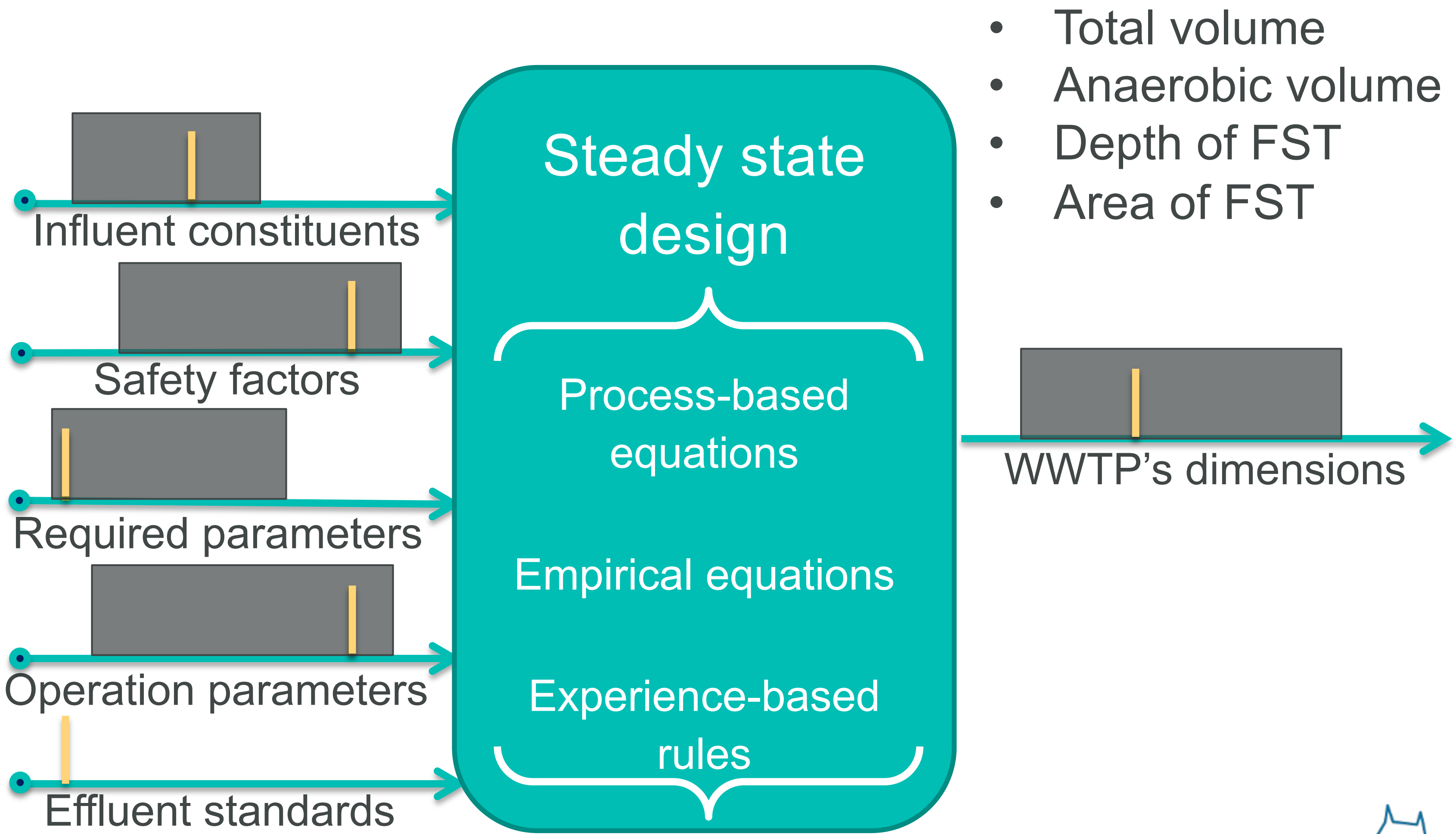
↓

Screening of pre-designs and preliminary evaluation

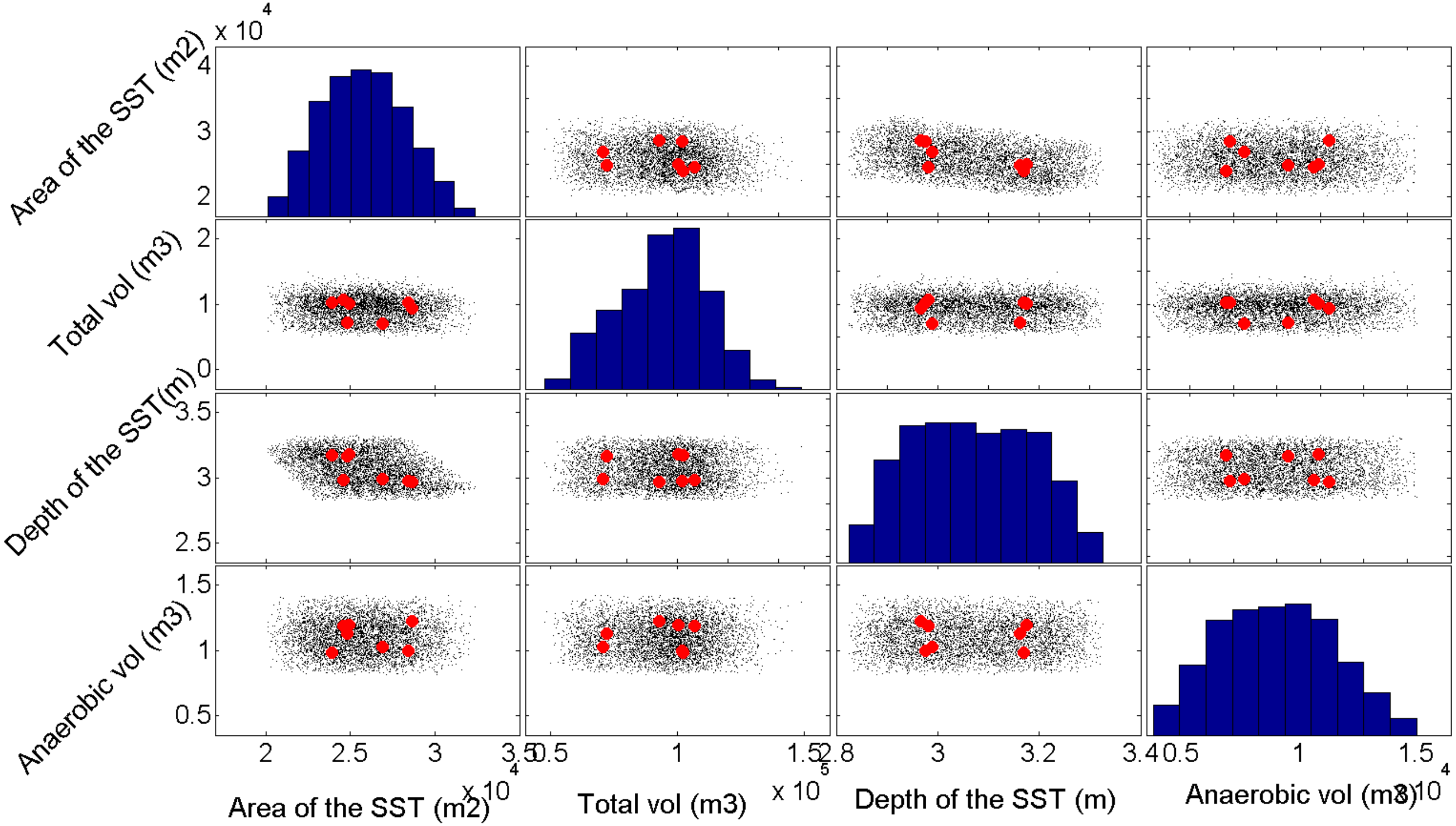
↓

Quantification of PONC using dynamic simulation

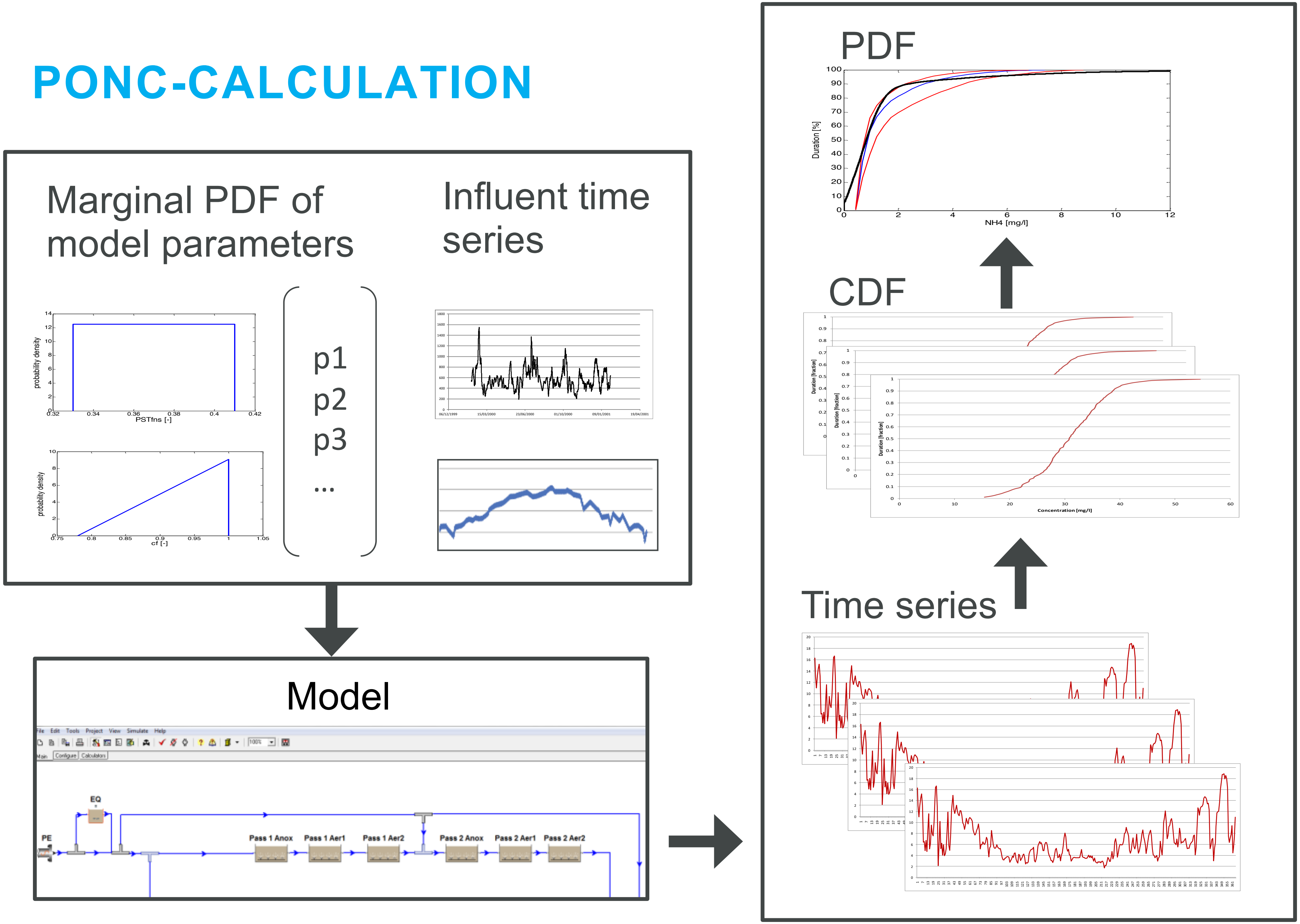
STEADY STATE PRE-DESIGNS



SCREENING OF PRE-DESIGNS – CLUSTER

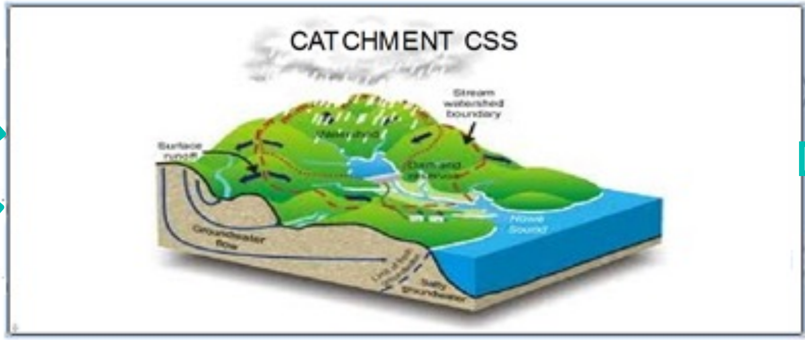


PONC-CALCULATION



INFLUENT GENERATION

Rainfall
(Markov chain gamma model)



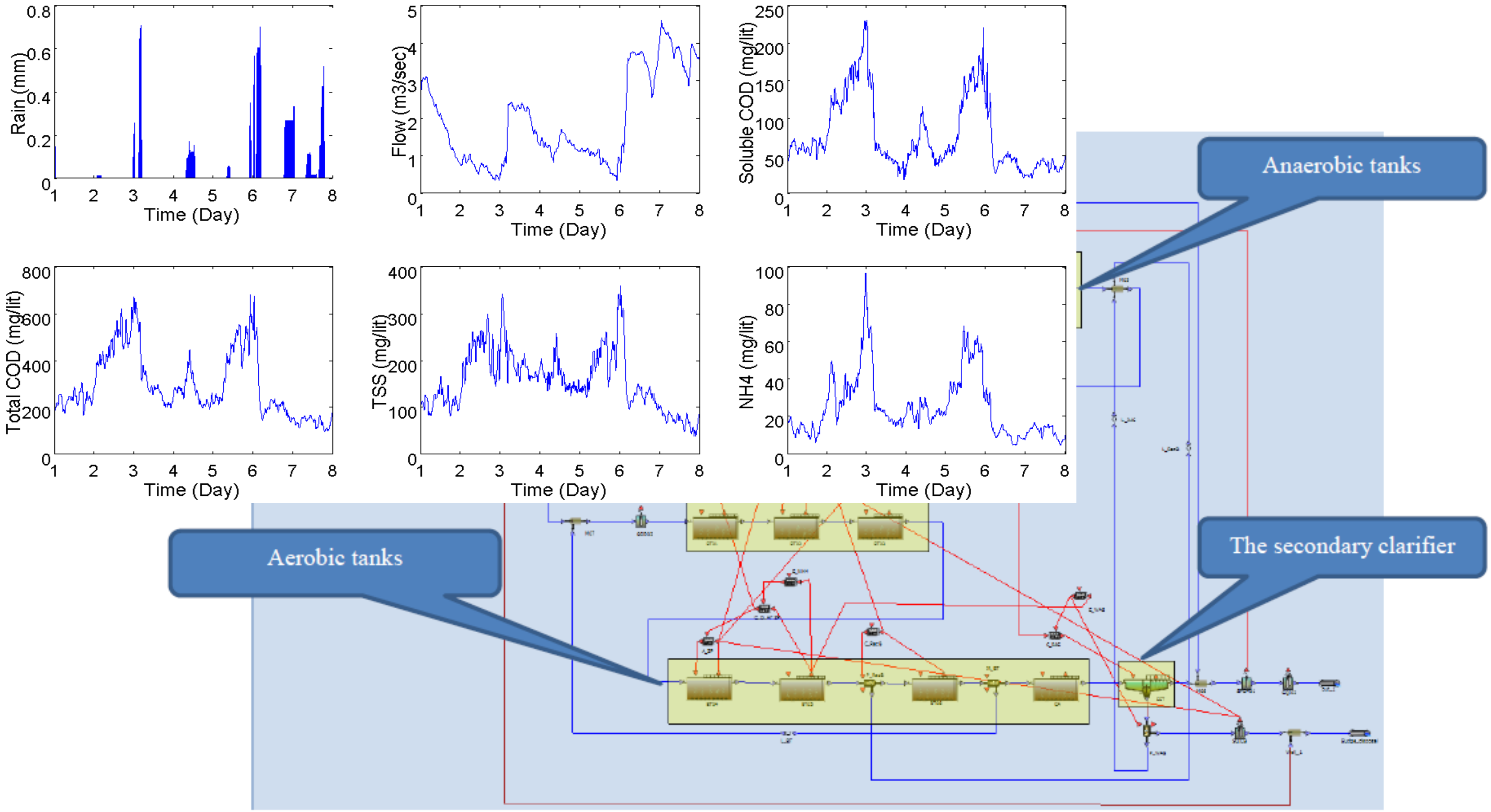
Influent time series

Influent in dry conditions
(Multivariate AR model)

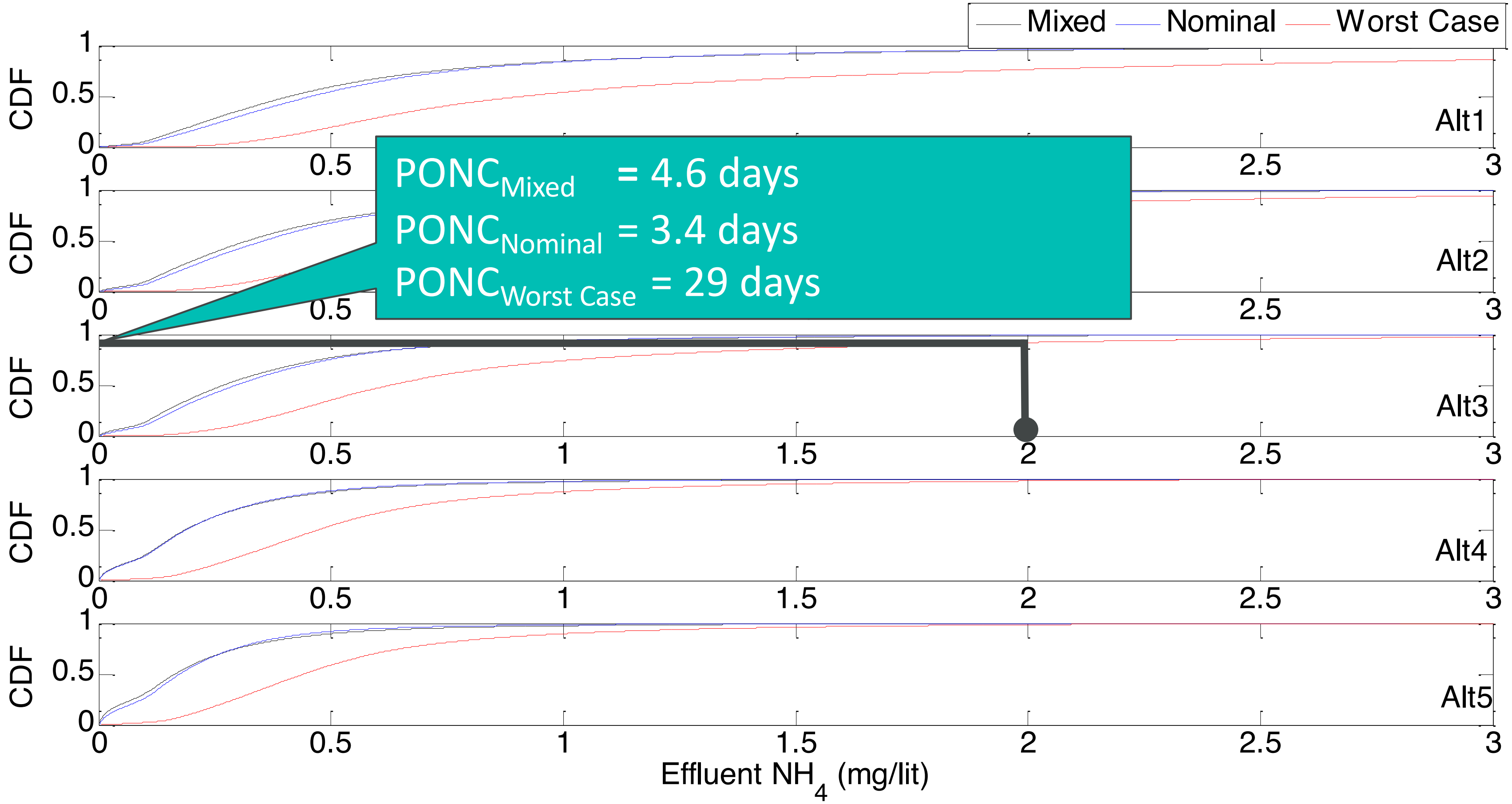
- CITYDRAIN Conceptual model
  - Flow: Effective rainfall based on the concept of virtual basins
  - Pollutant: Accumulation-wash off
  - Muskingum routing

Talebizadeh, M., Belia, E. and Vanrolleghem, P. A. (2016) Influent generator for probabilistic modeling of nutrient removal wastewater treatment plants. Environ. Modelling & Software, 77, 32-49.

DYNAMIC SIMULATION OF CASE STUDY



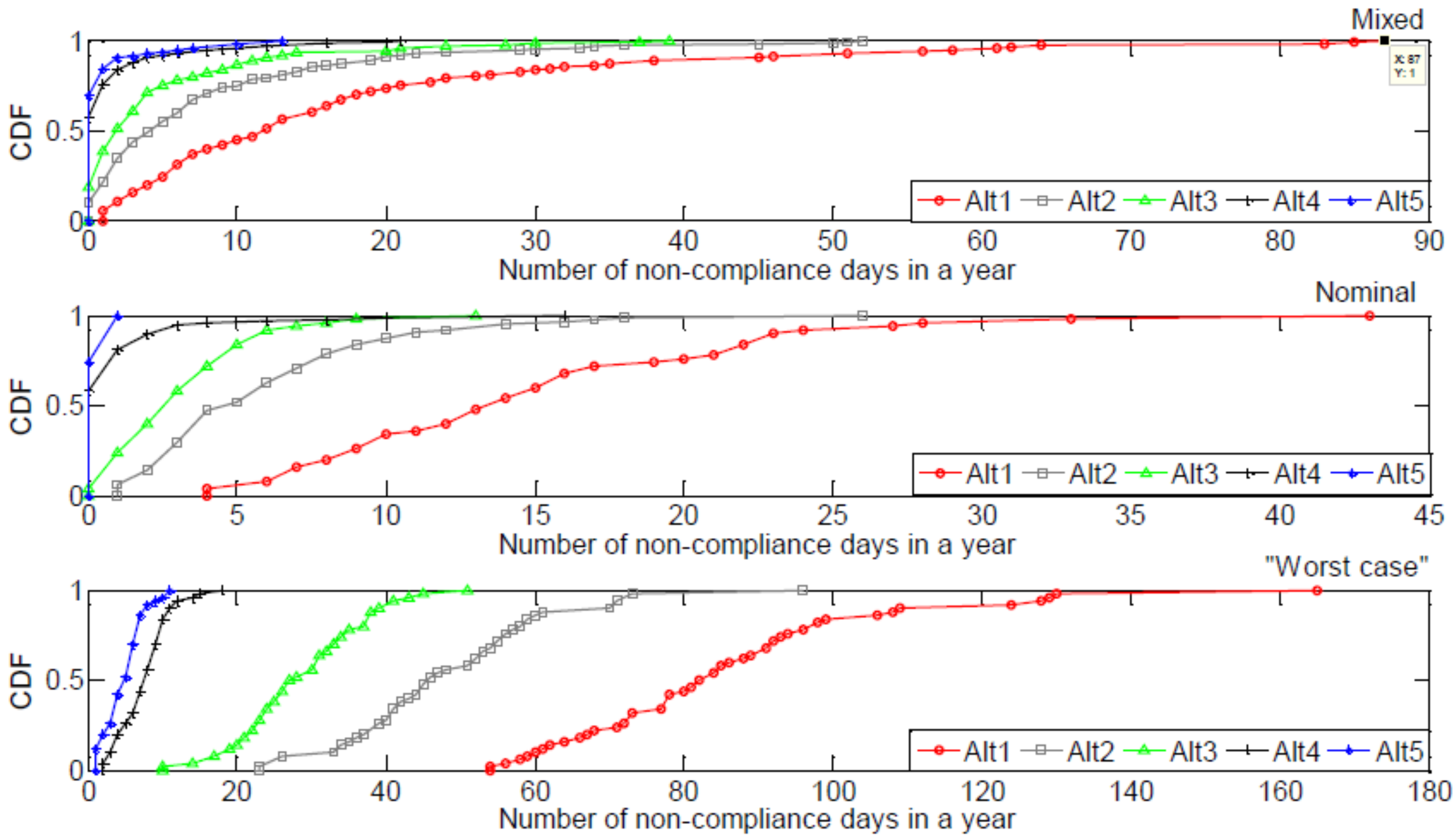
QUANTIFICATION OF PONC



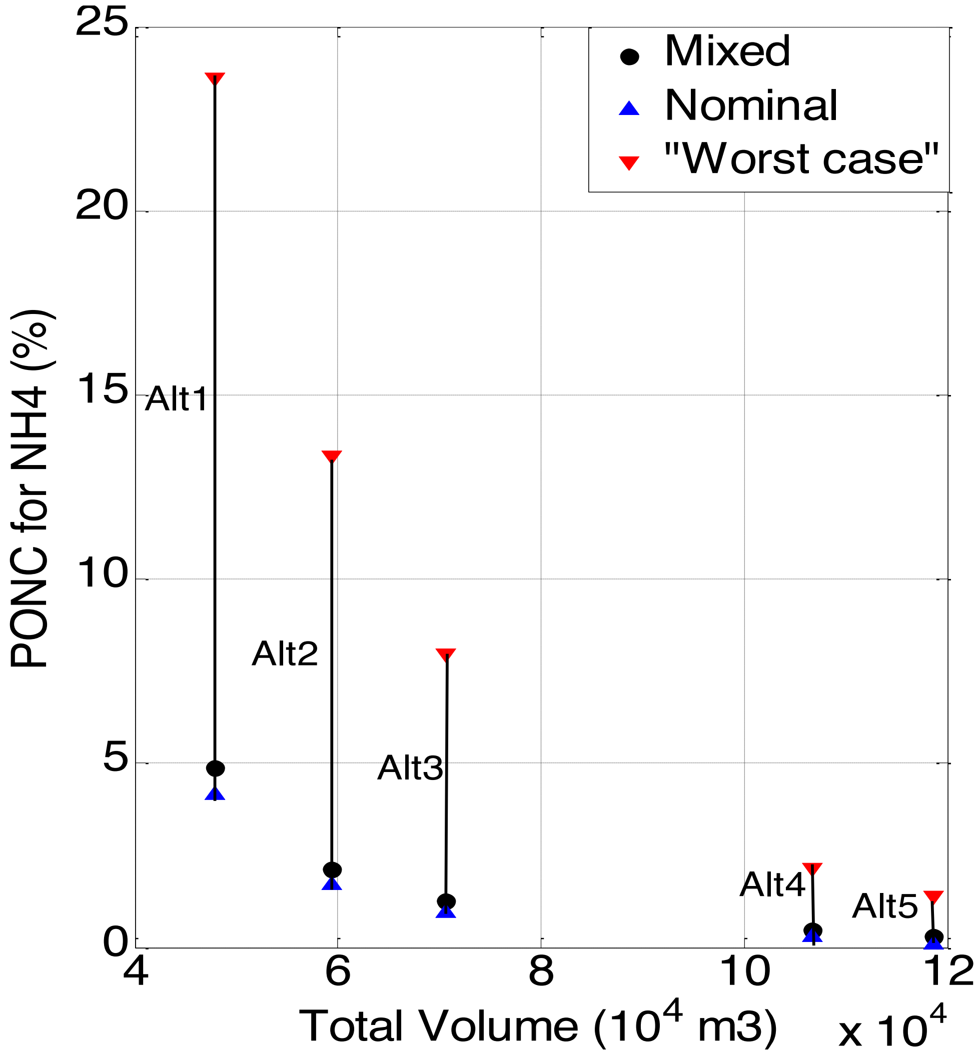
COMPARISON DESIGN ALTERNATIVES

Design alternatives	Total volume (m^3)	Anaerobic volume (m^2)	Depth of the secondary clarifier (m)	Area of the secondary clarifier (m^2)
Alt3	70 650	10 250	3.0	26 900
Alt4	106 650	11 850	3.0	24 600
Actual design	79 160	11 196	2.5	21 696

ALTERNATIVE PRESENTATIONS OF PONC



ALTERNATIVE PRESENTATIONS OF PONC



SUMMARY

- Development of a design method based on the explicit characterization of variability and parameter uncertainty
- Development of an influent generator capable of preserving the observed statistics
- Method for rigorous calculation of the probability of non-compliance
- Application of the proposed probabilistic method to an actual case study

ACKNOWLEDGEMENTS

Natural Sciences and Engineering Research Council of Canada

Primodal Inc. – Québec City Canada

DOUT Design and operations uncertainty task group

IWA/WEF Task Group on Design and Operations Uncertainty (DOUT)

Marc Neumann, PhD
Cristina Martin, PhD
Mansour Talebizadeh, PhD

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Perspectives on the work of the DOUT Group

Marc Neumann, Ph.D.

BASQUE CENTRE FOR CLIMATE CHANGE
Klima Aldaketa Ikergai
Sustainability, that's it!
EXCELENCIA MARÍA DE MAEZTU

PERSPECTIVES I: DOUT HAS…

- Focused on quantitative approaches for planning, design, optimisation and operations.
- Been co-produced by academia and practice (regulators, utilities, consultants, software developers)
- Unpacked issues of uncertainty across:
  - Project phases
  - Stakeholders
  - Project delivery methods
- Sparked further academic investigations as well as uptake/testing of methods in practice.
- Provoked new ideas and questions.

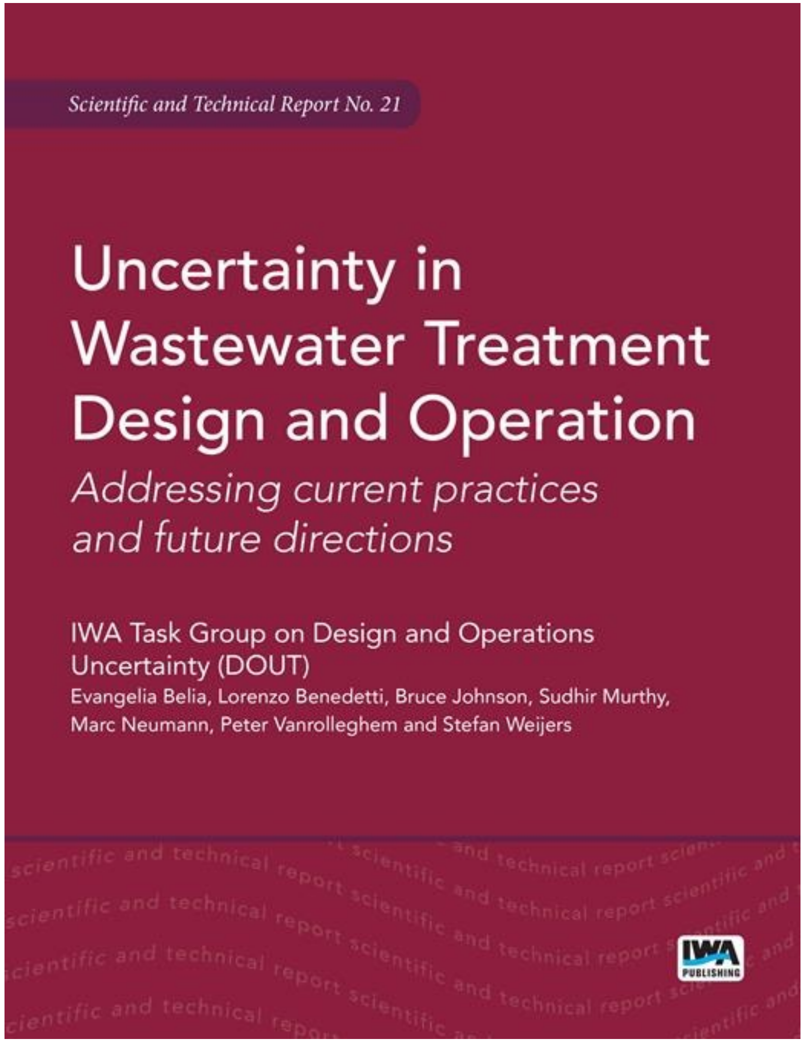
PERSPECTIVES II:

- Broader issues:
  - Transparency & Explicitness (clarify assumptions)
  - Learning (e.g. continuous monitoring, ex-post assessments of designs)
  - Governance (spreading of benefits, costs and risks across the different agents)
- Model and simulator evolution:
  - some uncertainties are eliminated through higher resolution: CFD.
  - Integrated models (catchment, drainage, WRRF) allow for catchment wide optimisation.
  - Model predictive control
  - Powerful statistical analysis as computational cost decreases: full Bayesian analysis
- Integration and complementation with socio-economics:
  - Fore-sighting techniques
  - Life cycle assessment
  - Multi attribute utility theory
  - Benefit-cost-risk analysis

PERSPECTIVES III: ALTERNATIVE APPROACHES

- Adaptive capacity:
  - Decentralisation
  - Modularity
  - Real Options
- Robustness:
  - satisfactory outcomes for many possible futures vs. optimal solution for expected future
  - Safe failure
  - Redundancy (with powerful ICA equipment)
- Resilience:
  - Qualitative approaches that explore more facets: complexity, unintended consequences of interventions, embeddedness within wider techno-socio-ecological system.

SCIENTIFIC AND TECHNICAL REPORT (STR)



https://iwaponline.com/ebooks/book/838/Uncertainty-in-Wastewater-Treatment-Design-and?redirectedFrom=PDF

https://www.iwapublishing.com/books/9781780401027/uncertainty-wastewater-treatment-design-and-operation

CLOSING REMARKS

Great thanks to all presenters for a wonderful show!

Look out for MIA's NEXT webinar in September 2022:

"Topic to be decided"

If you have ideas for your own future webinar then contact MIA MC and we will help you make it happen!

Find out more at

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https://iwa-connect.org