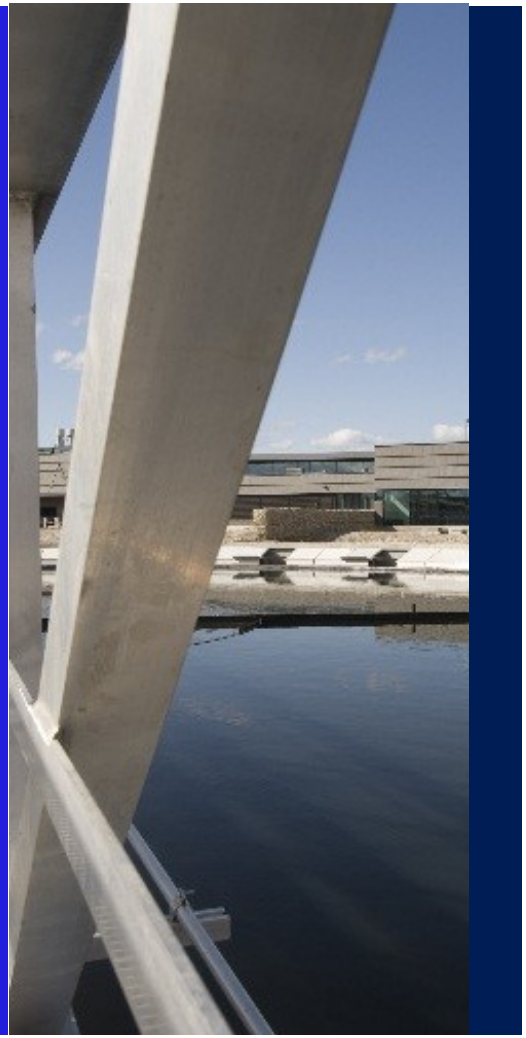
Jacobs Challenging today. Reinventing tomorrow.

Digital Twins: Enabling Data-Driven Water Reclamation/Reuse Solutions

In the **kNOW** Webinar Series

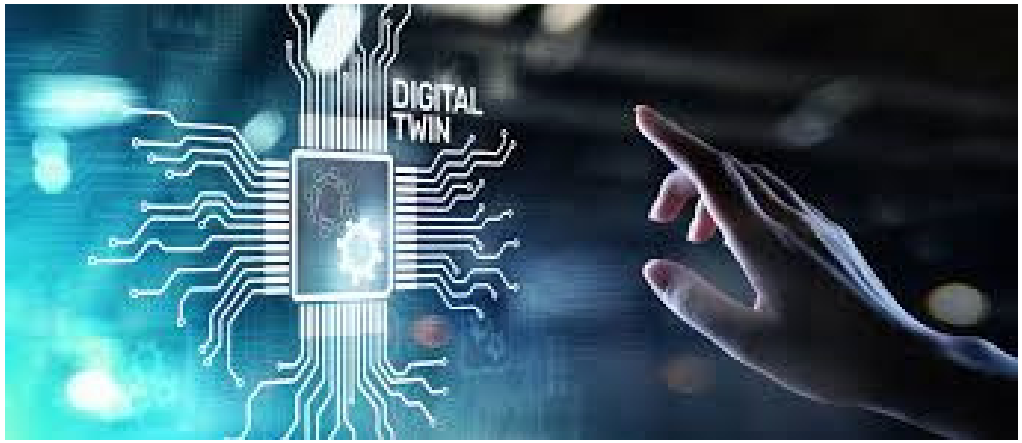
August 26, 2020



Safety Moment – Handling home deliveries

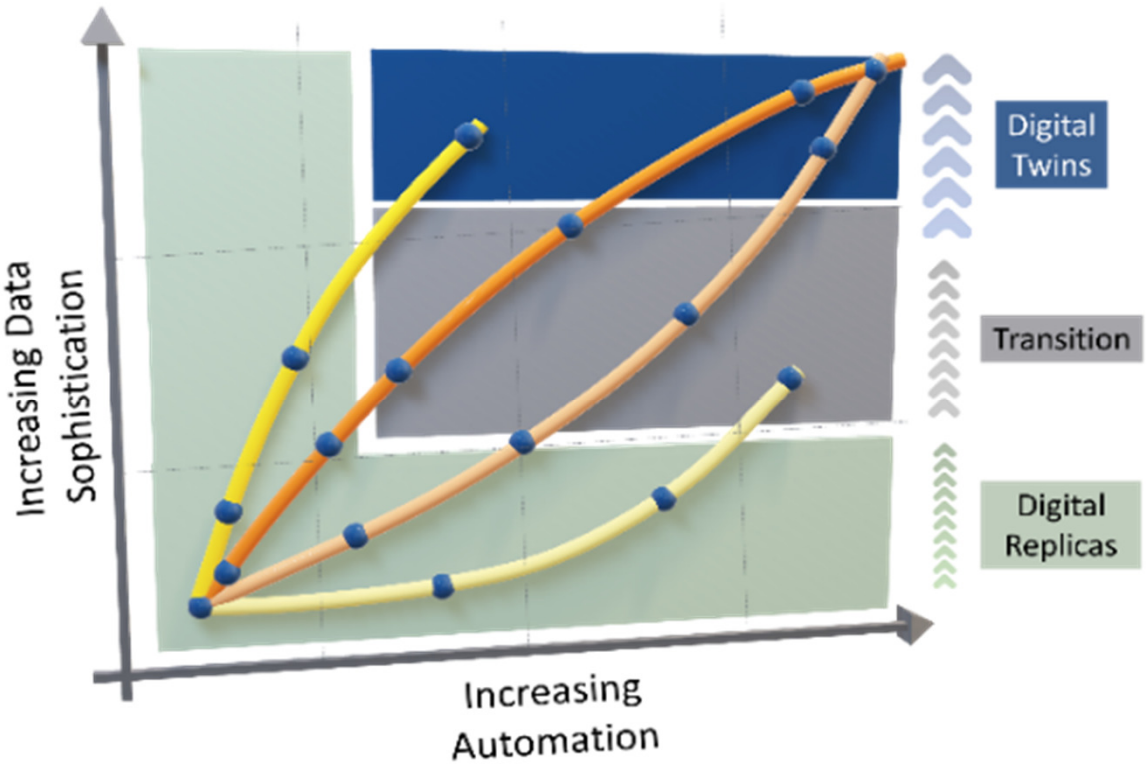
What is a Digital Twin?

A **digital representation** of a physical system **coupled with real-time data,** that can be used for synthetic data generation, scenario analysis, performance prediction and operational optimization



Relevant Terminology

- Digital Replica
  - A model without autonomous data exchange with physical system
- Digital Twin
  - A **Digital Replica** with autonomous information exchange to/from physical system



Agenda

- Simulating the Big Picture: An Integrated System Modeling Approach for Operational Resiliency – *Garrett Owens, Jacobs*
- Improving Process Efficiency Through Better Data Acquisition and Visualization – *Jim McQuarrie, MWRD*
- Utility Drivers and Experience with Data Driven Models – *Adrienne Menniti, CWS*
- Developing a “True” Digital Twin: The Changi WRP Story – *Bruce Johnson, Jacobs*
- Q&A

Jacobs Challenging today. Reinventing tomorrow.

Simulating The Big Picture

An integrated system modeling approach for operational strategy

Garrett Owens

Digital Twins Global Technology Leader, Jacobs

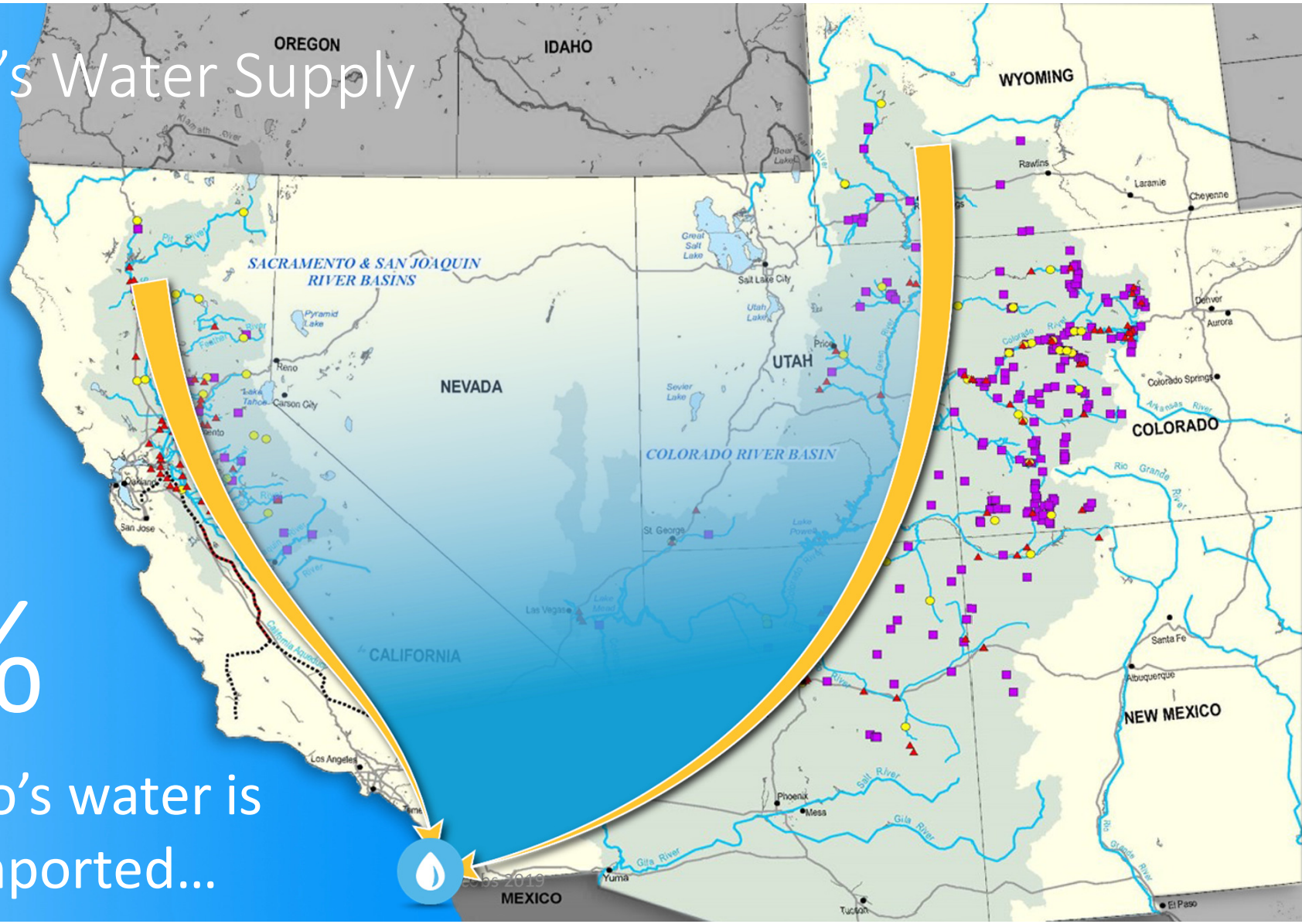
Acknowledgments

Monika Smoczynski
- NCWRP Expansion Project Manager (City of San Diego)

Mark Elliott
- Client Manager (Jacobs)

Troy Matsuura
- Project Manager (Jacobs)

San Diego's Water Supply



85%

of San Diego's water is currently imported…

We Face Numerous Water Challenges

- Limited local & imported supplies
- Population growth
- Bay Delta constraints
- Natural disaster risk
- Rising imported water costs
- Recurring drought

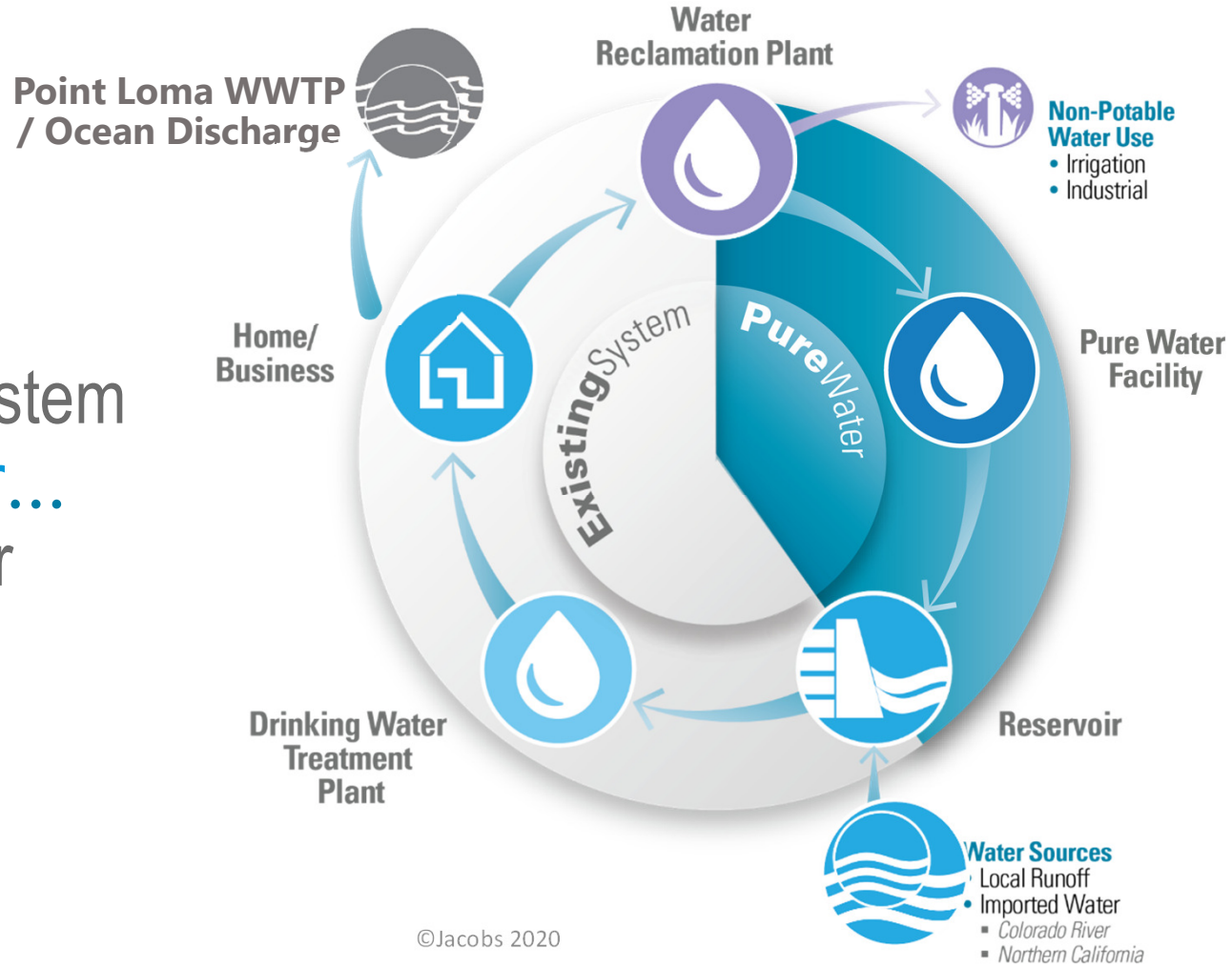
San Diego's Water Supply System

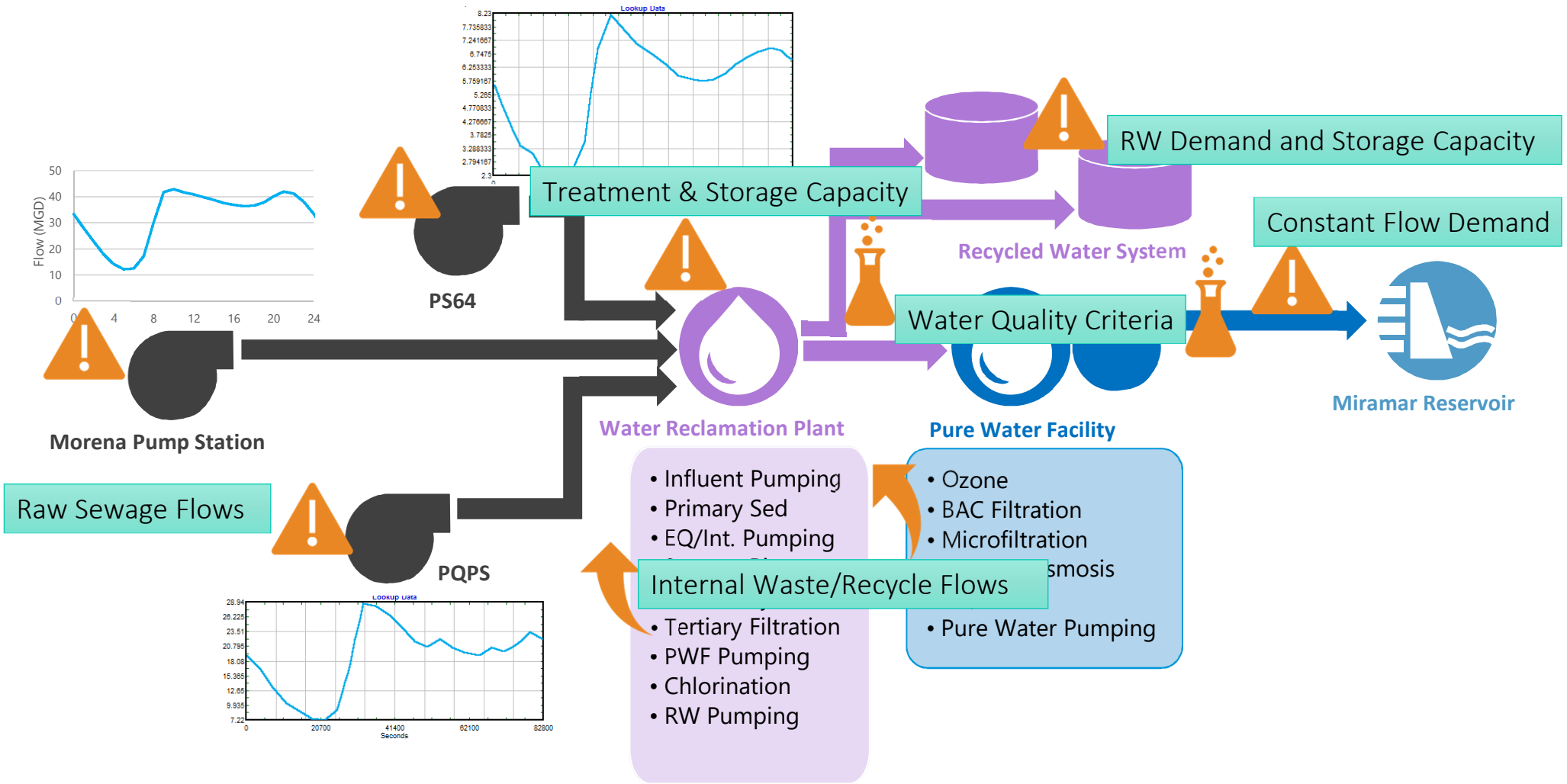
Existing System…

Primarily a Single-Use System

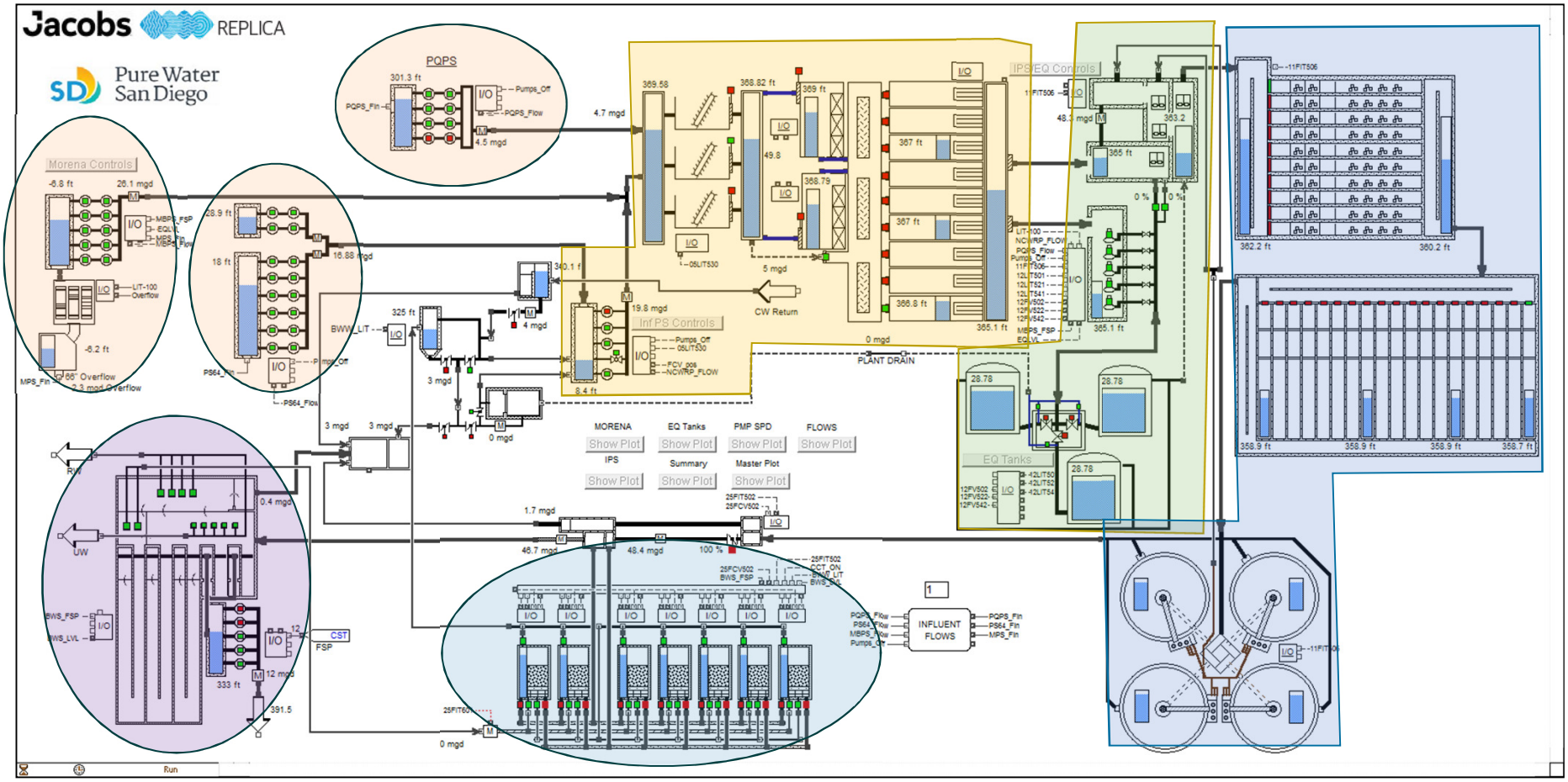
Pure Water…

Completes Our Water Cycle

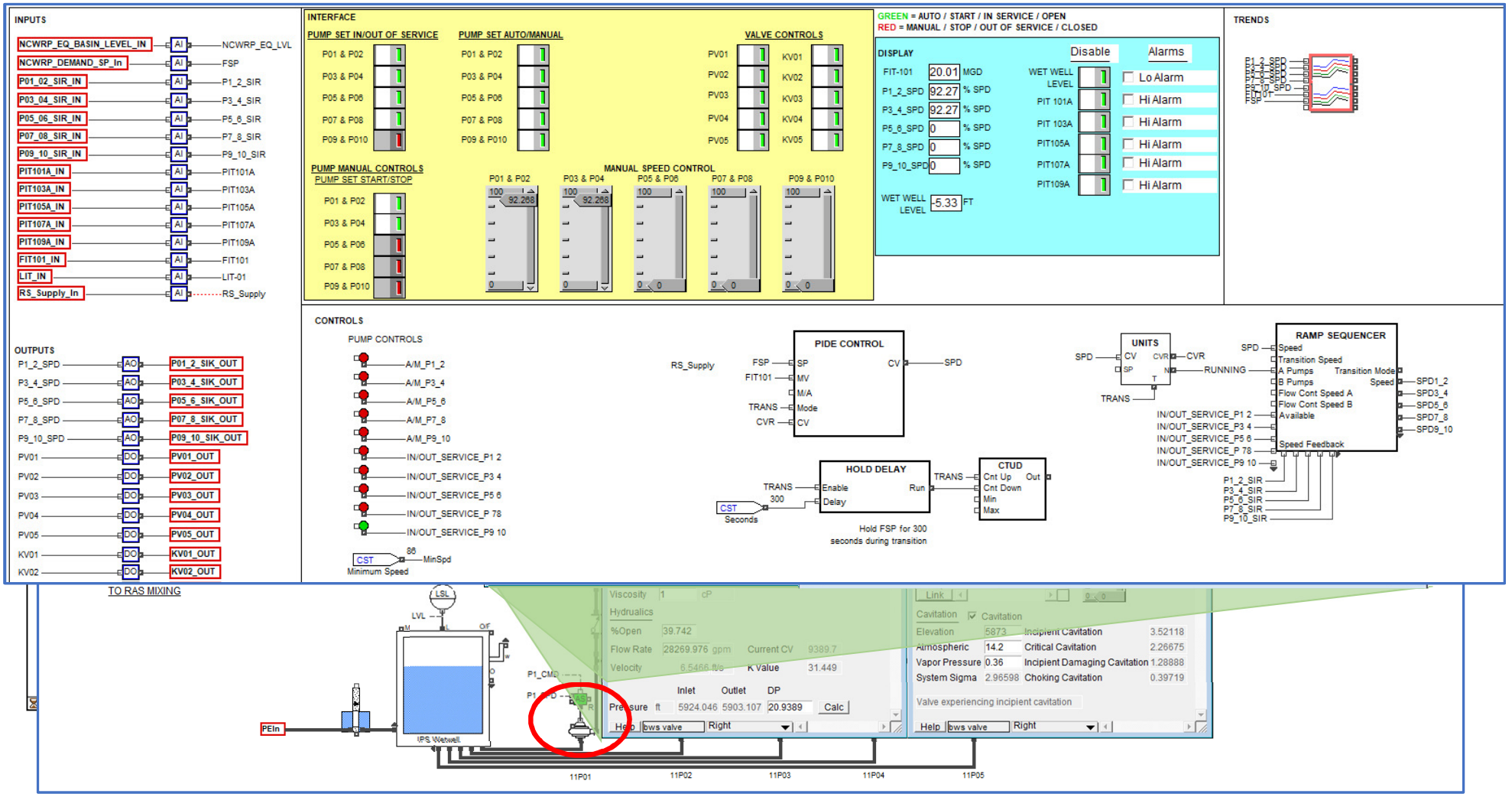



Lookup Data
Flow (MGD)
50
40
30
20
10
0
0
4
8
12
16
20
24
PS64
Treatment & Storage Capacity
RW Demand and Storage Capacity
Recycled Water System
Constant Flow Demand
Water Quality Criteria
Miramar Reservoir
Morena Pump Station
Water Reclamation Plant
Pure Water Facility
Raw Sewage Flows
PQPS
• Influent Pumping
• Primary Sed
• EQ/Int. Pumping
• Ozone
• BAC Filtration
• Microfiltration
Internal Waste/Recycle Flows
• Tertiary Filtration
• PWF Pumping
• Chlorination
• RW Pumping
• Pure Water Pumping
Lookup Data
0
20700
41400
62100
82800
Seconds

Water Reclamation Plant Digital “Replica”

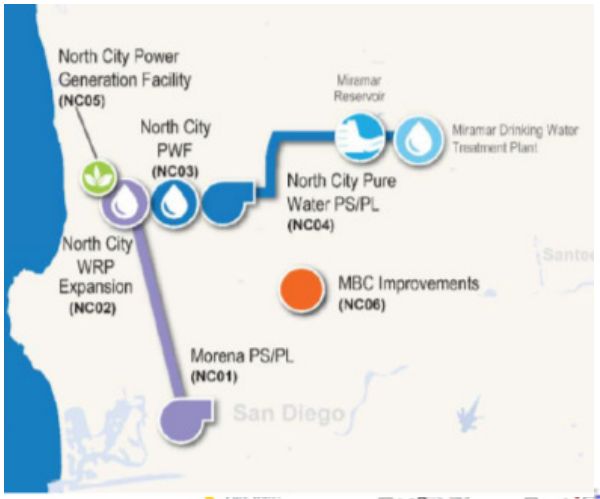


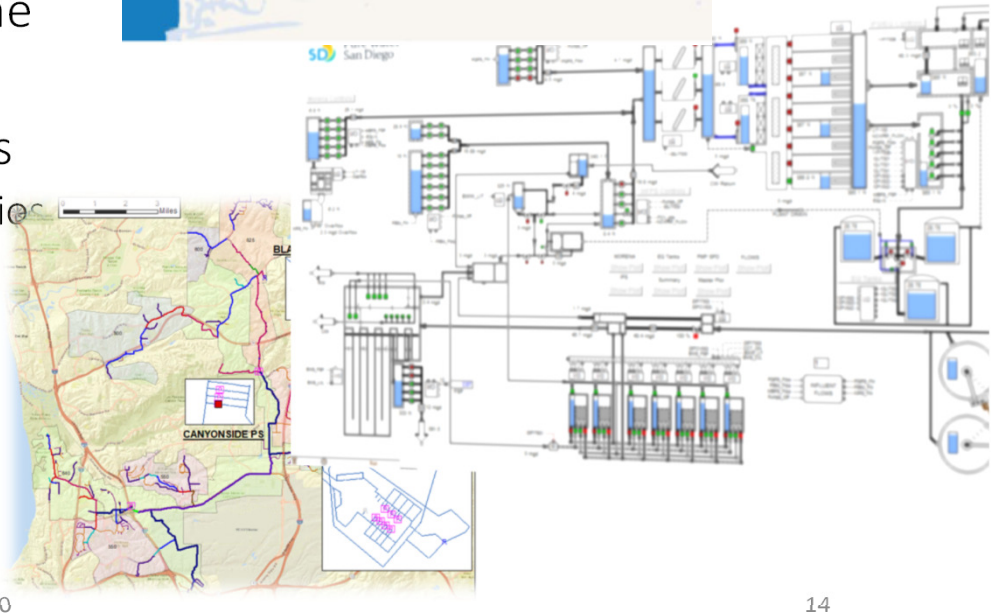
Water Reclamation Plant Digital “Replica”

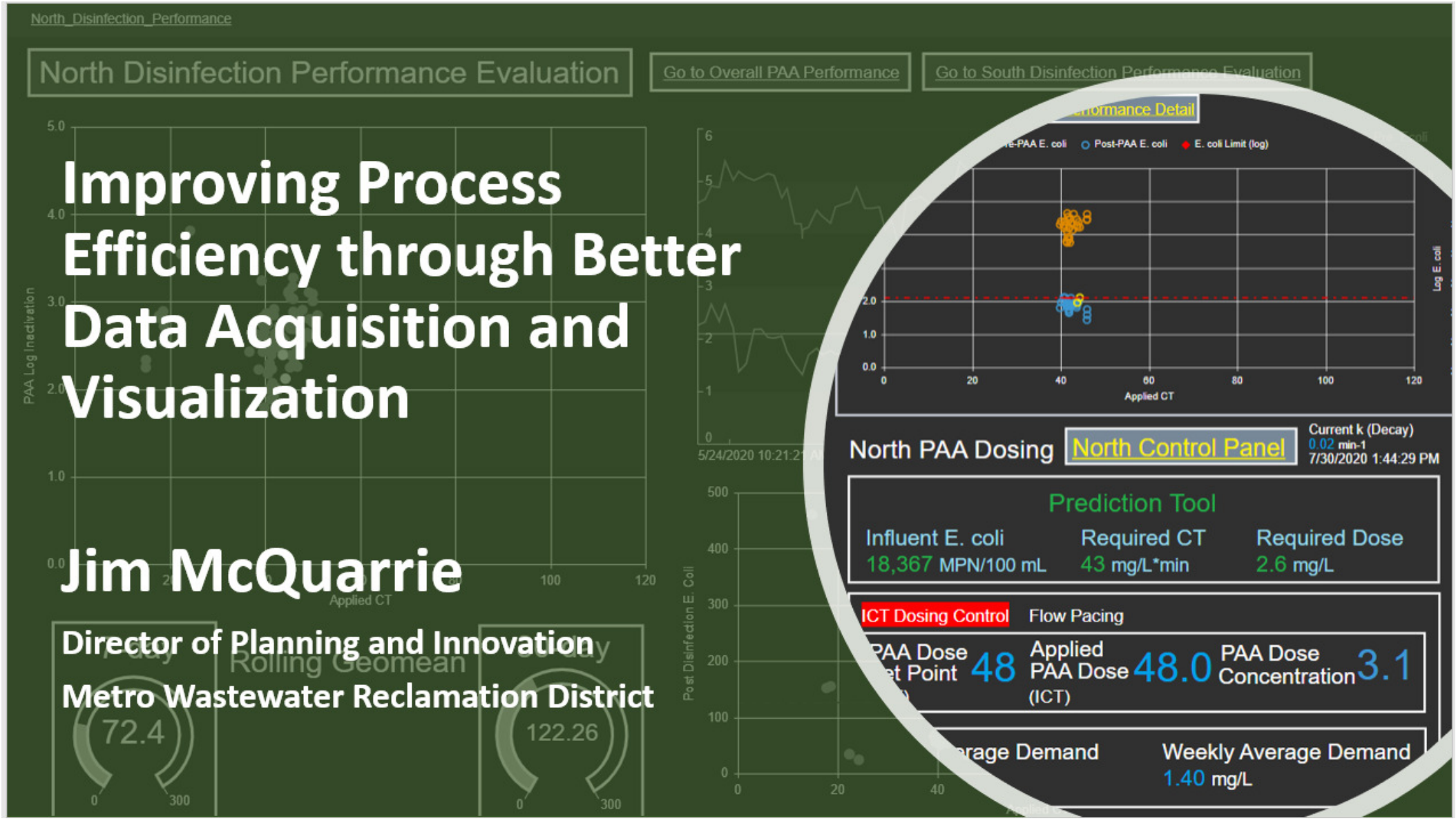


Summary

- Pure Water System is highly complex interaction between multiple facilities
- Data manually imported for calibration of existing components and from EPANET to represent inflows
- Digital Replica improves our understanding of the system and how to operate it
- Used as a “flight simulator” for what-if scenarios
  - Evaluate control strategies and efficiently test scenarios for more robust solutions
  - Optimize process control to reduce operating cost
- Can evolve to a Digital Twin once system comes online






North_Disinfection_Performance
North Disinfection Performance Evaluation
Go to Overall PAA Performance
Go to South Disinfection Performance Evaluation
Improving Process Efficiency through Better Data Acquisition and Visualization
Jim McQuarrie
Director of Planning and Innovation
Metro Wastewater Reclamation District
PAA Log Inactivation
Applied CT
Rolling Geomean
72.4
122.26
Post Disinfection E. Coli
5/24/2020 10:21:2
Pre-PAA E. coli
Post-PAA E. coli
E. coli Limit (log)
Log E. coli
North PAA Dosing
North Control Panel
Current k (Decay)
0.02 min-1
7/30/2020 1:44:29 PM
Prediction Tool
Influent E. coli
18,367 MPN/100 mL
Required CT
43 mg/L*min
Required Dose
2.6 mg/L
ICT Dosing Control
Flow Pacing
PAA Dose
48
Applied
PAA Dose
48.0
(ICT)
PAA Dose
Concentration
3.1
Weekly Average Demand
1.40 mg/L

The COVID-19 crisis presents an opportunity that few feel equipped to pursue.

Although most executives agree that innovating the business will be critical …

90%

believe that the COVID-19 crisis will fundamentally change the way they do business over the next 5 years

85%

are concerned that the COVID-19 crisis will have a lasting impact on their customers' needs and wants over the next 5 years

… few feel equipped to face the challenge.

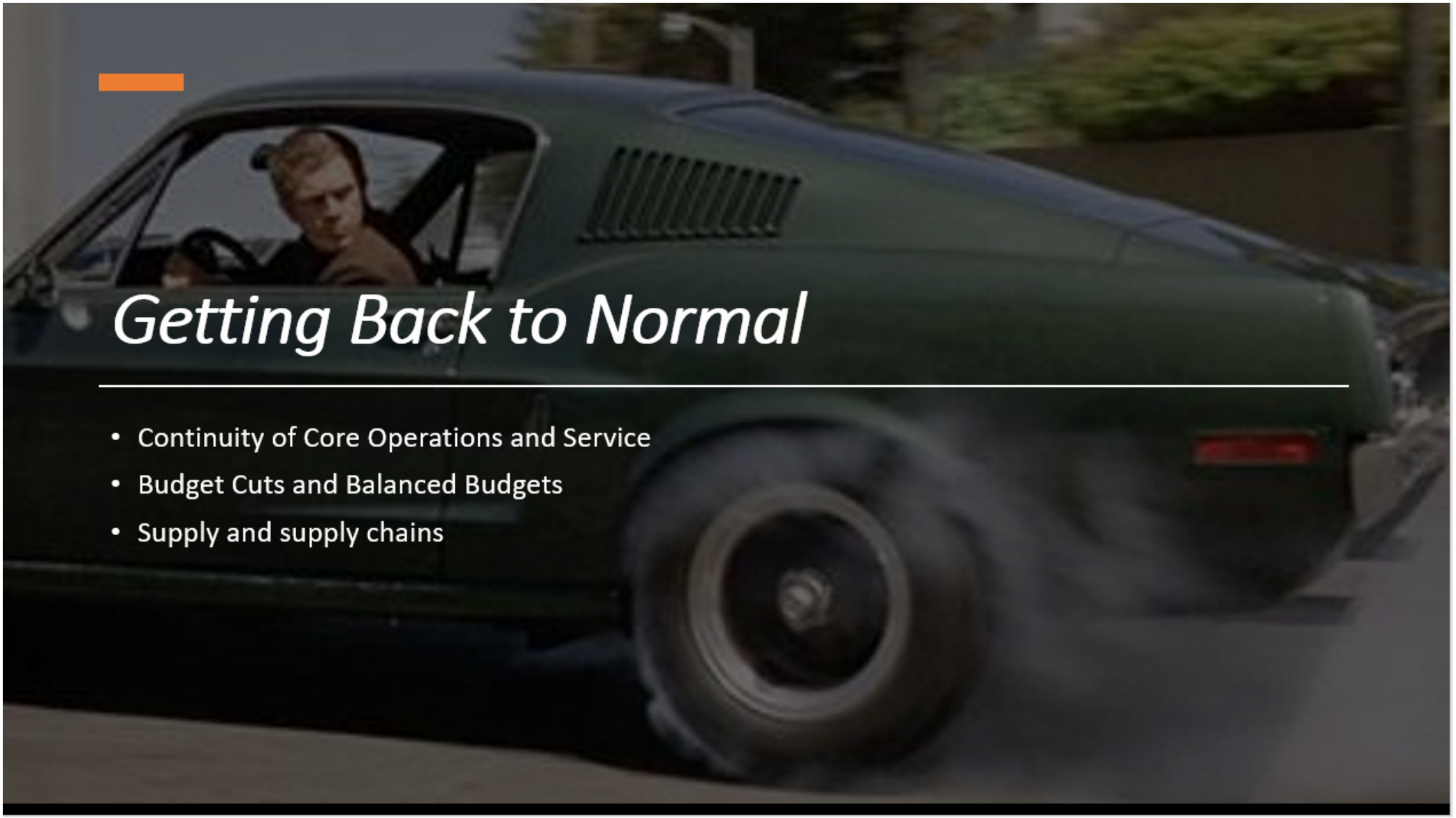
21%

have the expertise, resources, and commitment to pursue new growth successfully

2/3

believe that this will be the most challenging moment ir their executive career

McKinsey & Company

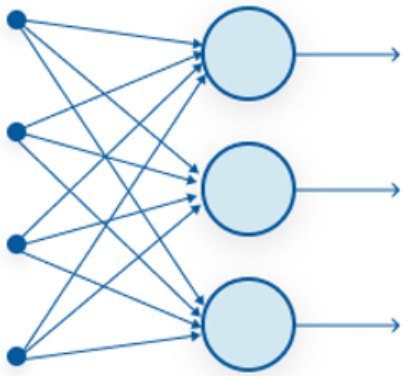

Getting Back to Normal
• Continuity of Core Operations and Service
• Budget Cuts and Balanced Budgets
• Supply and supply chains

Metro Wastewater Reclamation District

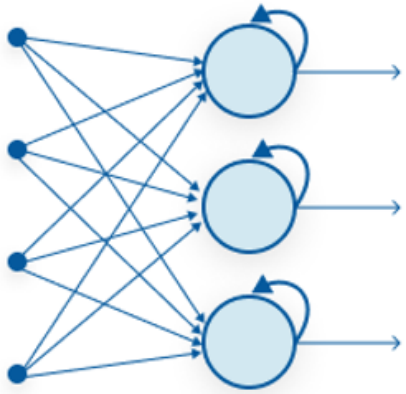
- 2+ Million PE
- Tiny Receiving Stream
- Converted from Chloramine Disinfection to Peracetic Acid
- Water Quality Benefits
- Operational Simplicity
- High Unit Price for PAA

Methods of modeling PAA performance

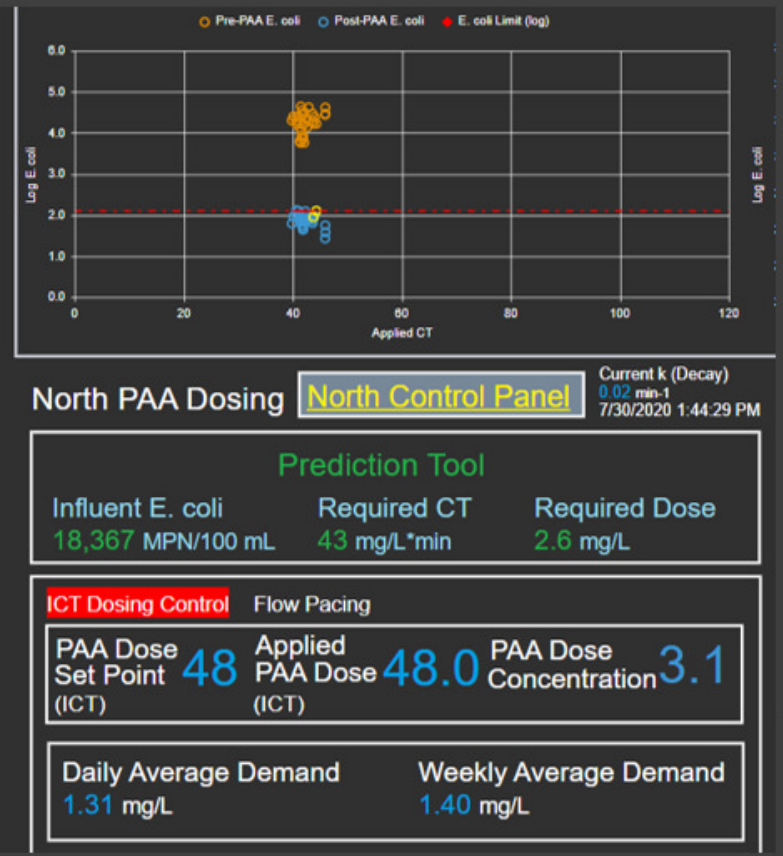
- Data
  - *Online*: Flow, temperature, SRT, nutrients, visual spectrum (2018)
    - **Instant, short-term** (5-60 min), **24-h avg**
  - *Lab*: 24-hour flow composite nutrients, TSS
  - *PAA & E. coli*: 168 total sampling events in 2018 and 66 in 2019
- Artificial neural networks (**ANN**) and recurrent neural networks (**RNN**)
  - 3,000 epochs
  - Softsign activation function
  - Min-max normalization
  - 2 hidden layers
    - number of features
    - number of features x 2
  - Long short-term memory unit (LSTM)
  - 10x train and test each observation

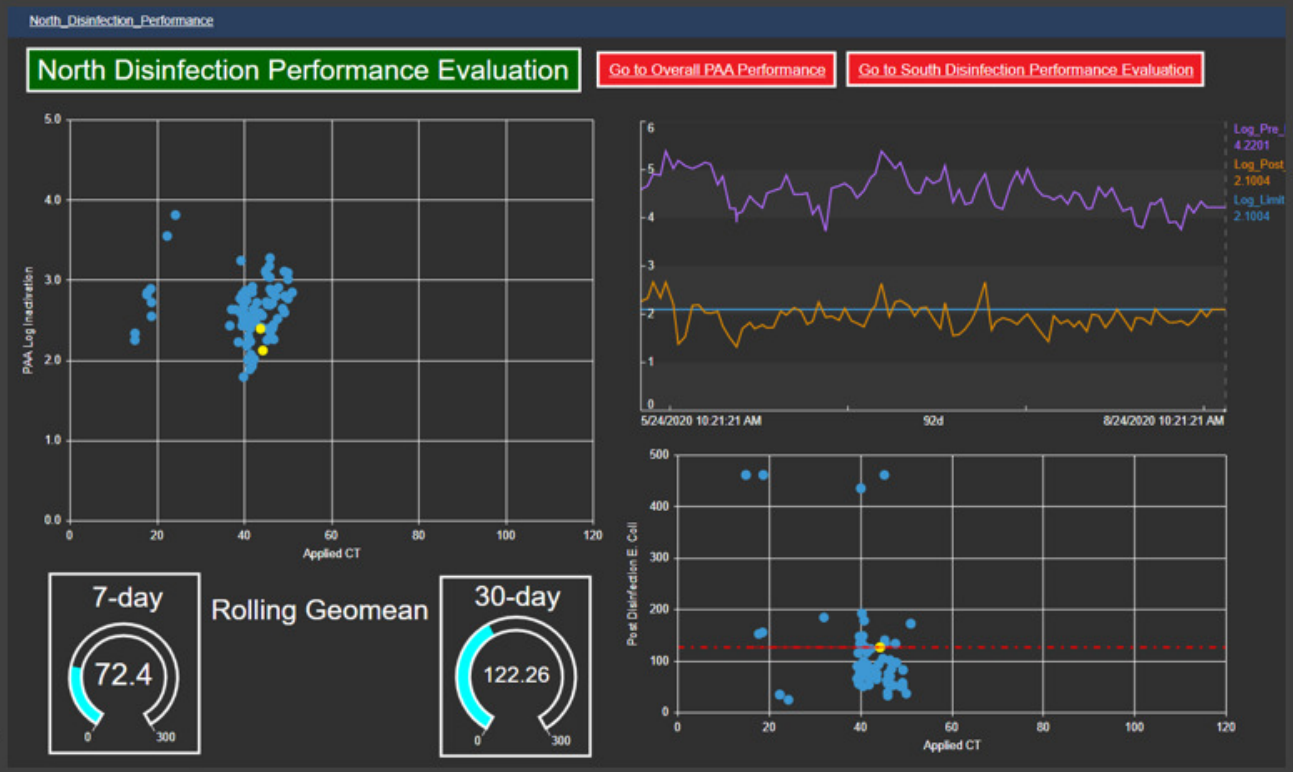


Feed-Forward Neural Network



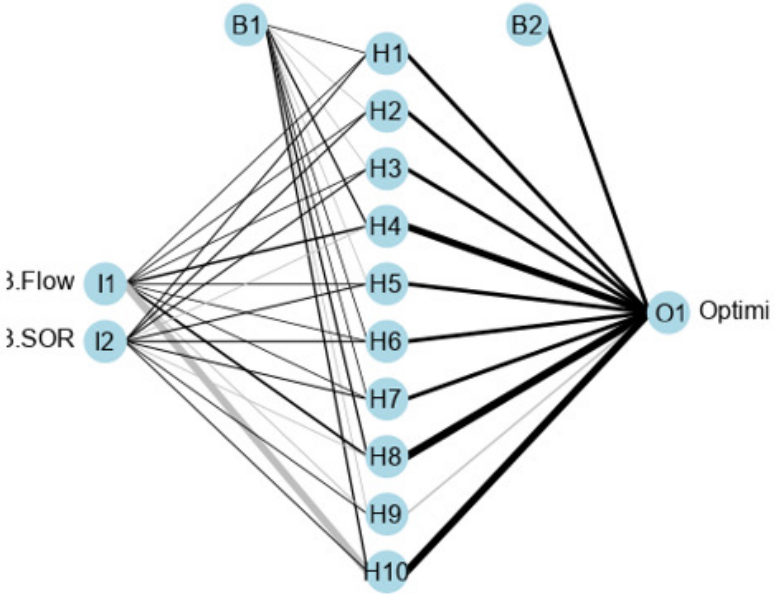
Recurrent Neural Network

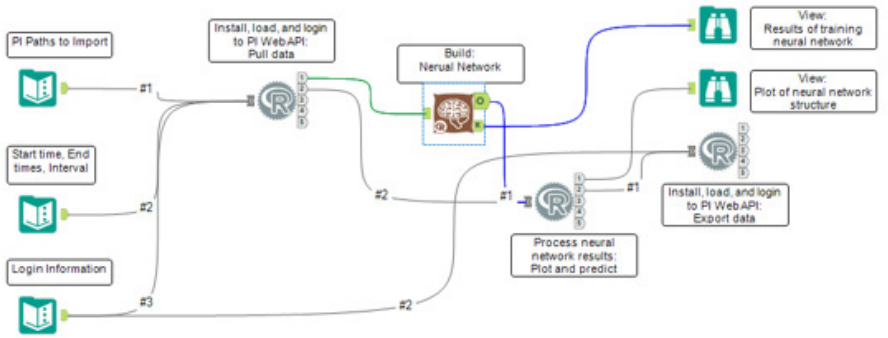




DISINFECTION PERFORMANCE DASHBOARDS

Primary Treatment





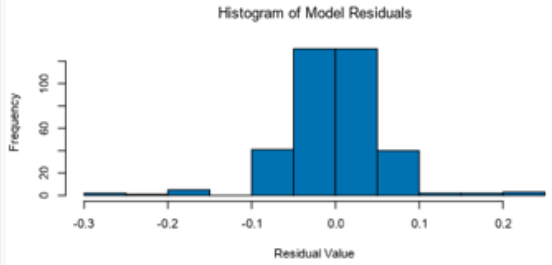
Primary Treatment NNM

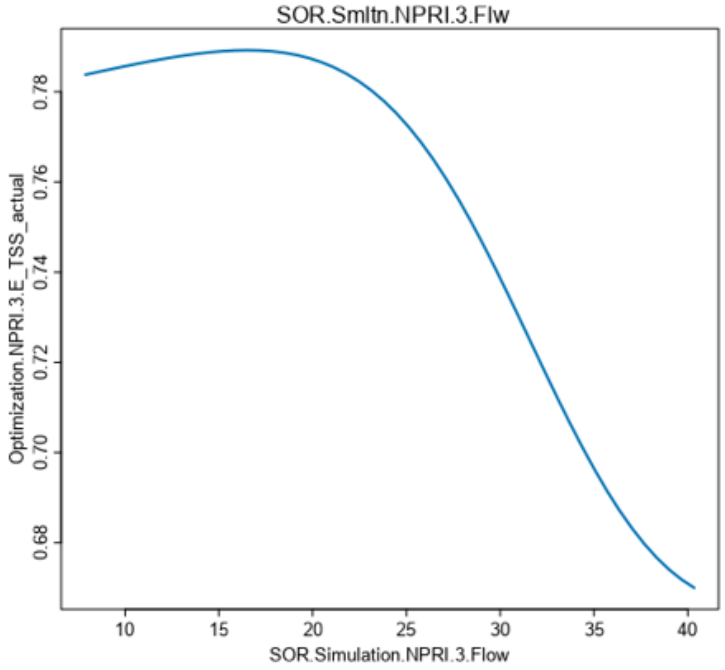
Record	Report
1	**Report for Neural Network Model Predict TSS Removal**

Basic Summary:

Call: nnet.formula(formula = Optimization.NPRI.3.E_TSS_actual ~ SOR.Simulation.NPRI.3.Flow + Optimization.NPRI.3.SOR, data = the.data, size = 10, linout = TRUE, rang = c(0.7), decay = 0.1, MaxNWts = 1000, maxit = 100)
Structure: A 2-10-1 network with 41 weights
Inputs: SOR.Simulation.NPRI.3.Flow, Optimization.NPRI.3.SOR
Output(s): Optimization.NPRI.3.E_TSS_actual
Options: Least-squares fitting , decay = 0.1
Final objective funcation value: Final objective function value: 1.214

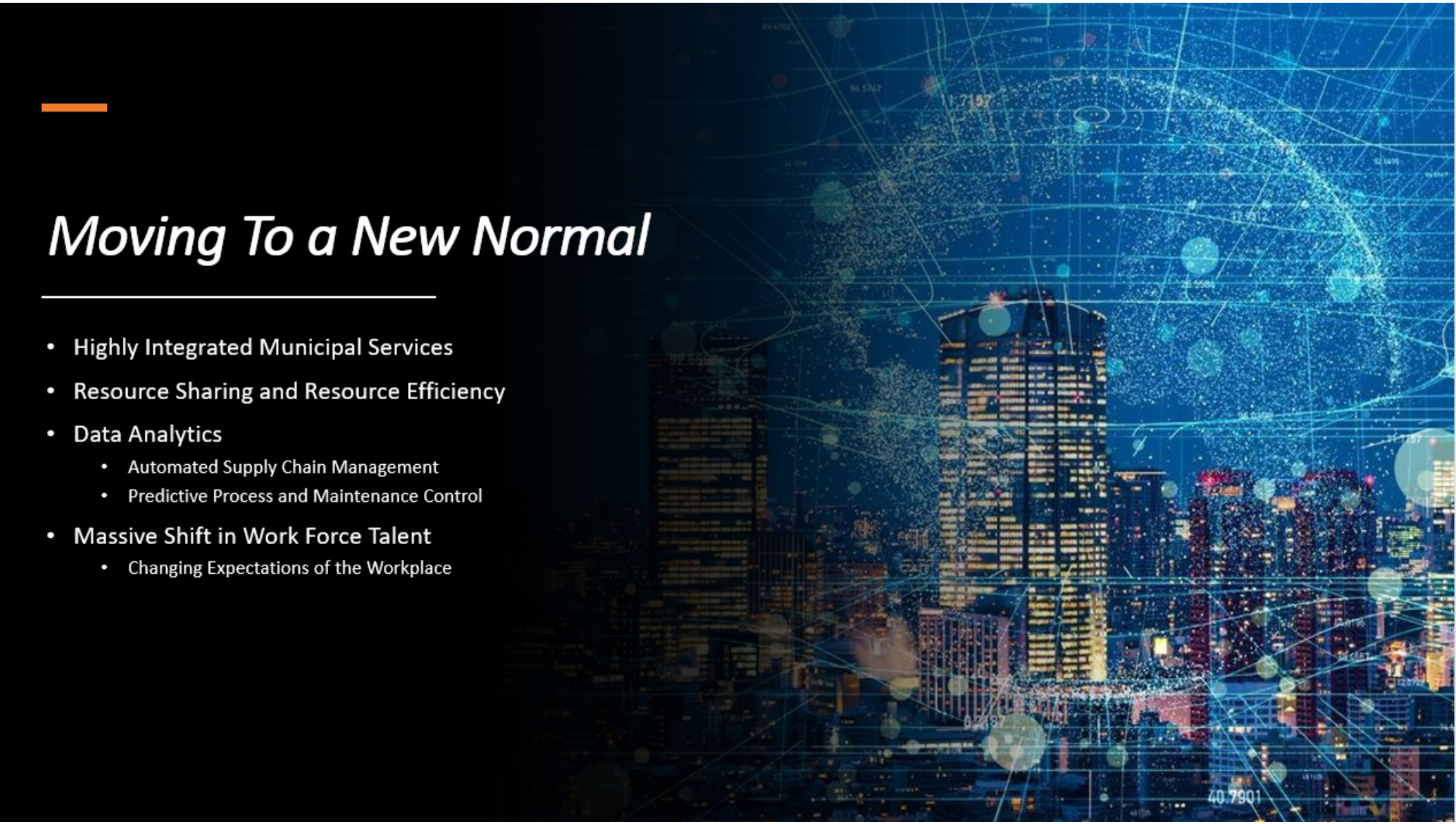
2





Moving To a New Normal

- Highly Integrated Municipal Services
- Resource Sharing and Resource Efficiency
- Data Analytics
  - Automated Supply Chain Management
  - Predictive Process and Maintenance Control
- Massive Shift in Work Force Talent
  - Changing Expectations of the Workplace



Jacobs Challenging today. Reinventing tomorrow.

Utility Drivers and Experience with Data Driven Models

Adrienne Menniti, PhD, PE

Principal Process Engineer, Clean Water Services

Clean Water Services

Who is Clean Water Services?

- Mid-sized utility in suburban Portland, Oregon
  - 2 bigger facilities treating 25-35 mgd on average
  - 1 small facility treating 5 mgd on average
  - 1 small seasonal facility
- Stringent seasonal phosphorus limit has been an innovation driver since the mid-1990s
- Culture of innovation pushes us to explore new opportunities as they make sense
  - Resource recovery
  - Cost effective new treatment technologies
  - Optimized operation for cost or performance
  - Data and decision support

Note: This presentation shows my perspective from the treatment department of our utility. We are all exploring these tools but not in a very comprehensive, district wide way.

Where does CWS see opportunities for data driven models or digital twins?

- Reduce human time spent sorting through data to support decisions
- Make better decisions if the tool provides a more comprehensive view or provides decision support information in a more streamlined way

But. . .

- We always see these tools as support for the process knowledge of our engineers and operations analysts

What is hindering our adoption of the technology?

- Uncertainty with longevity of technology platforms
- Relatively high cost to implement widely
- Lack of experience with the technology - unknown benefits/unknown risks

How to move forward?

- We are looking for smaller ways to gain experience with advanced analytics to understand how to responsibly and cost effectively apply them.
- We need to find places where a small investment can have a big impact to gain momentum.

Pilot Project Example

Data driven models to predict BPR stability

Driver

Stop using tertiary coagulant (alum) to meet our stringent phosphorus limit

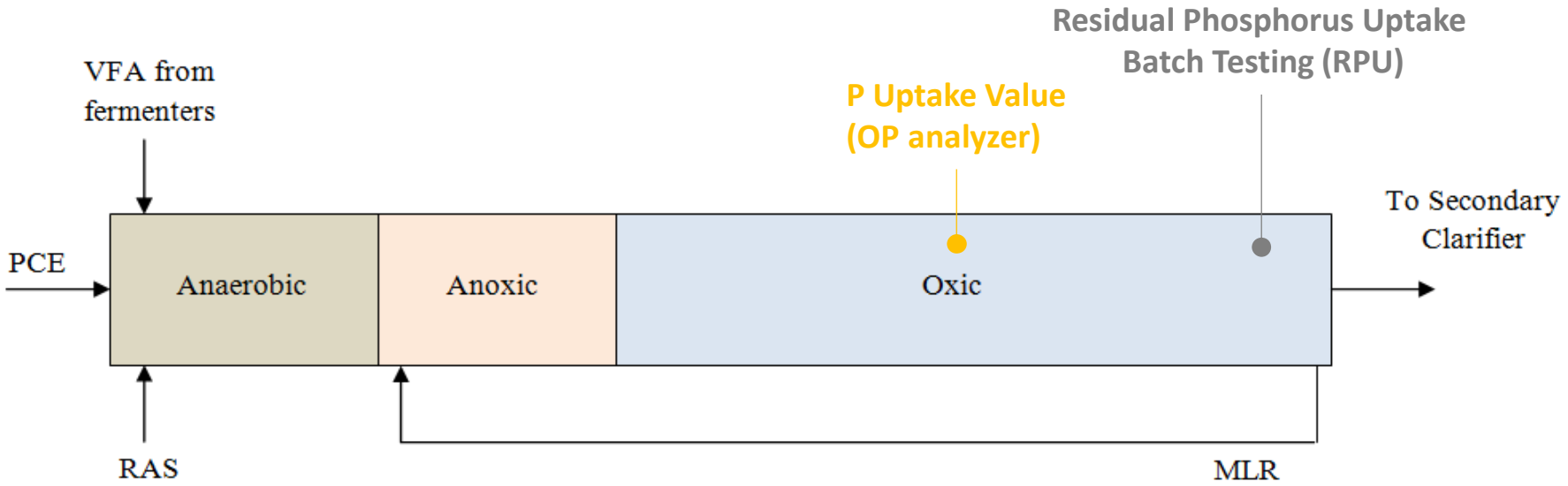
- Expecting new stringent limit on effluent aluminum (and iron)
- Working with our regulatory agency to shift the format of our phosphorus permit to allow little or no tertiary coagulant use
- Pilot this summer operating with no tertiary alum addition

No tertiary coagulant = no BPR back up

Effluent phosphorus limit = 0.1 mg/L monthly median TP, May-October

CWS search for early warning of BPR upset

- If you are only monitoring secondary effluent, BPR will be “stable” for long periods of time only to get upset unexpectedly.
- We have found ways to predict BPR upsets days or week in advance.

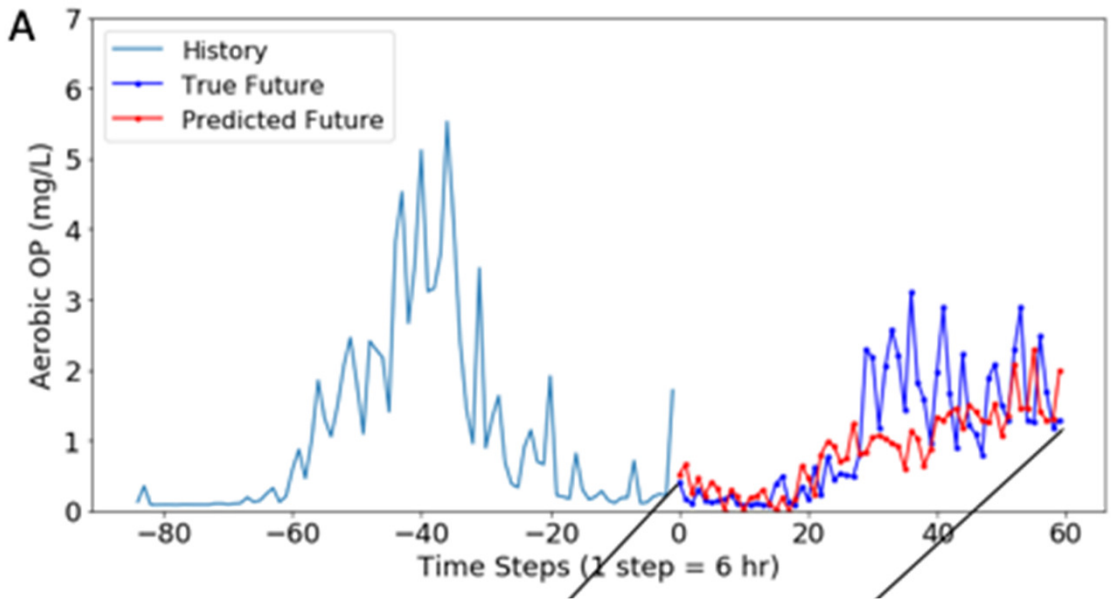


CWS search for early warning of BPR upset

We found a partner developing machine learning applications with an NSF grant

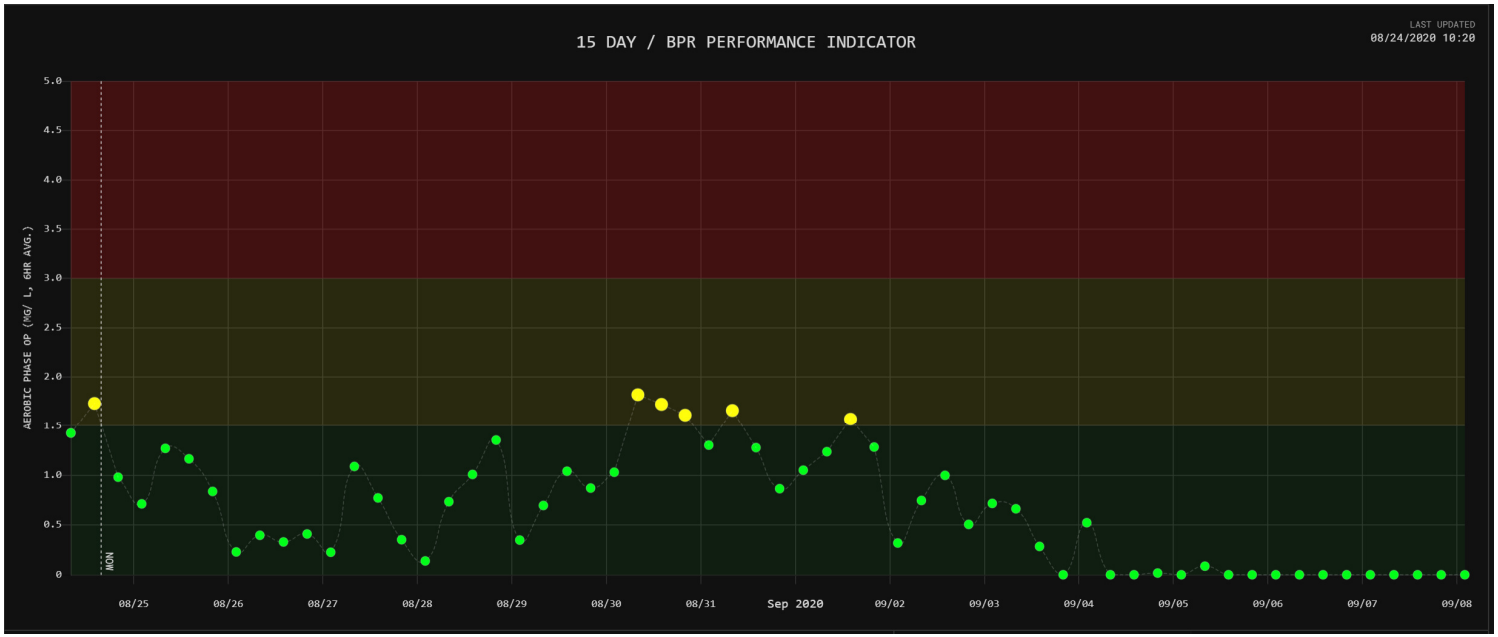
- The combination of our innovation drive as an agency and the BPR application we could offer was serendipity
- The grant offered a few hundred thousand dollars to explore the feasibility of using a data driven model to predict BPR stability

Results with historical data looked promising



CWS search for early warning of BPR upset

Preliminary results enough to convince NSF to provide an additional $1M grant to put the software online this summer through next summer.



What we've learned so far

As a utility, we have a lot of "high quality" data already, which is what made the data driven model successful.

- Our investment in data quality and infrastructure to support it (humans, instruments, lab) was very important.
- The model needed a data stream that had a lot of variability to make predictions on. It would not have worked if we only had secondary effluent OP to train it.

It took a lot of time (and cost) to develop and execute this project but we still don't know yet how useful it will be.

- This data driven model implementation is still clearly research. The cost would probably have been a deterrent from investing in this research.

Any tool that sits away from normal daily work flows better be very useful to get used routinely.

- Current summer pilot of meeting a stringent phosphorus limit without alum drove the operations analyst to use the machine learning tool.
- Early summer inaccuracy tested her willingness to seek out its information until she saw other warning signs and wanted extra data to make decisions.

Jacobs Challenging today. Reinventing tomorrow.

Developing a “true” Digital Twin: The Changi WRP Story

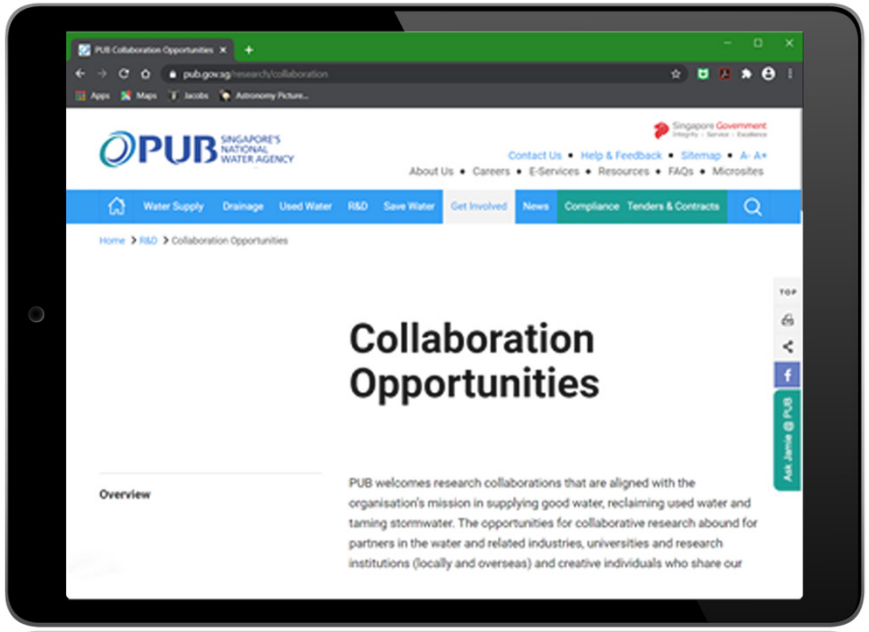
Bruce Johnson, PE, BCEE

Wastewater Technology Fellow, Jacobs

Changi Water Reclamation Plant (CWRP) Singapore

- Operated by Singapore Public Utilities Board (PUB)
- Currently treating an average of approximately 920,000 m^3/d (243 MGD) of used water
- Fed by a deep-tunnel sewer system
- Currently four bioreactor trains. Each train includes primary treatment and a parallel MBR and 5-pass step-feed bioreactor
- Most effluent is used for indirect potable reuse
- Solids include thickening, mesophilic anaerobic digestion, dewatering and drying

Changi WRP Digital Twin Research Project

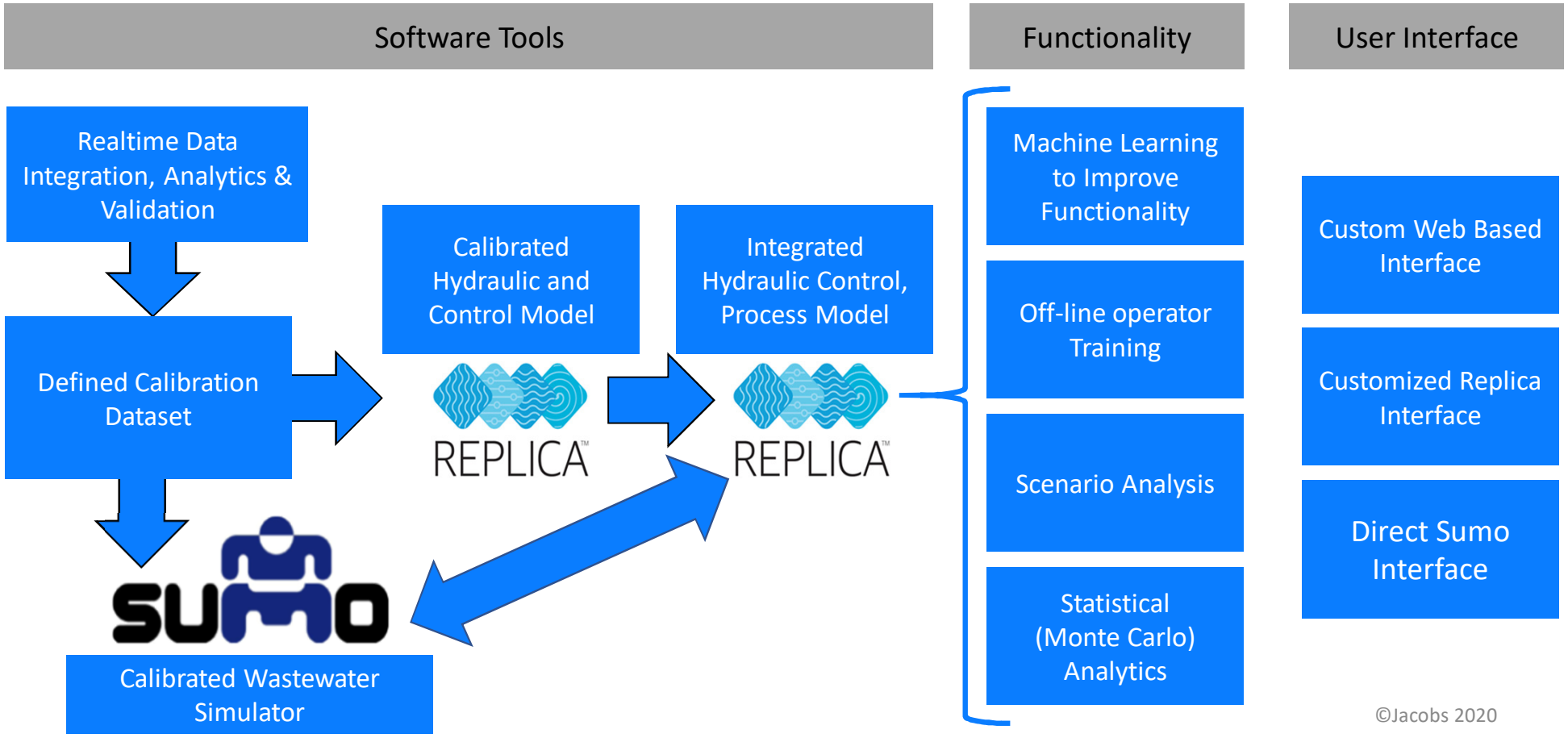


- A research collaboration between PUB and Jacobs in the development and application of a Digital Twin of CWRP
- The Digital Twin includes models of:
  - Full plant Hydraulics (liquids and solids)
  - All major process controls
  - Biochemical Process
- All implemented on a dedicated server with real-time data feed

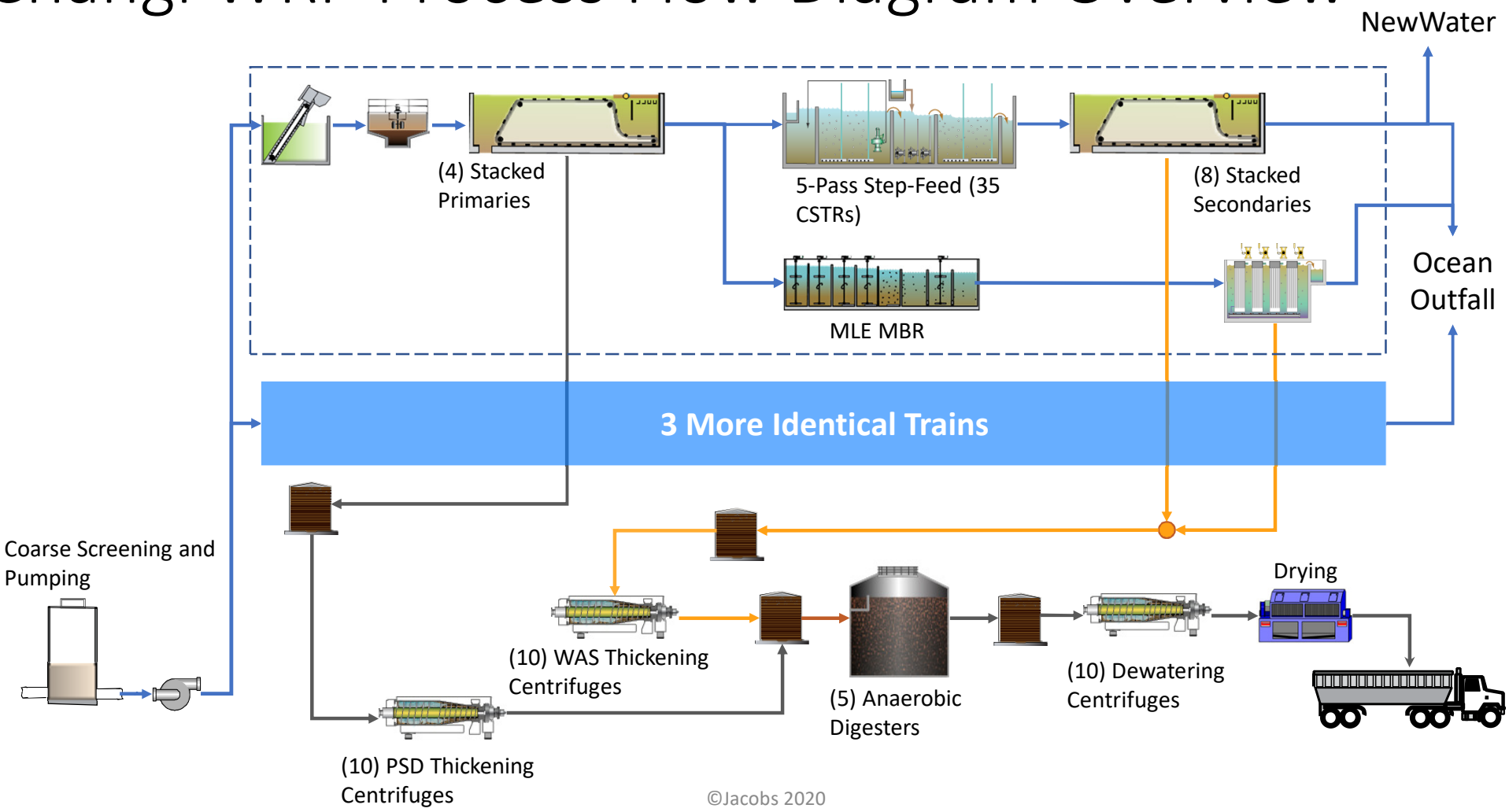
CWRP Digital Twin
Proposed Scope

What does it take to develop a “True” Digital Twin:
The Changi WRP Story

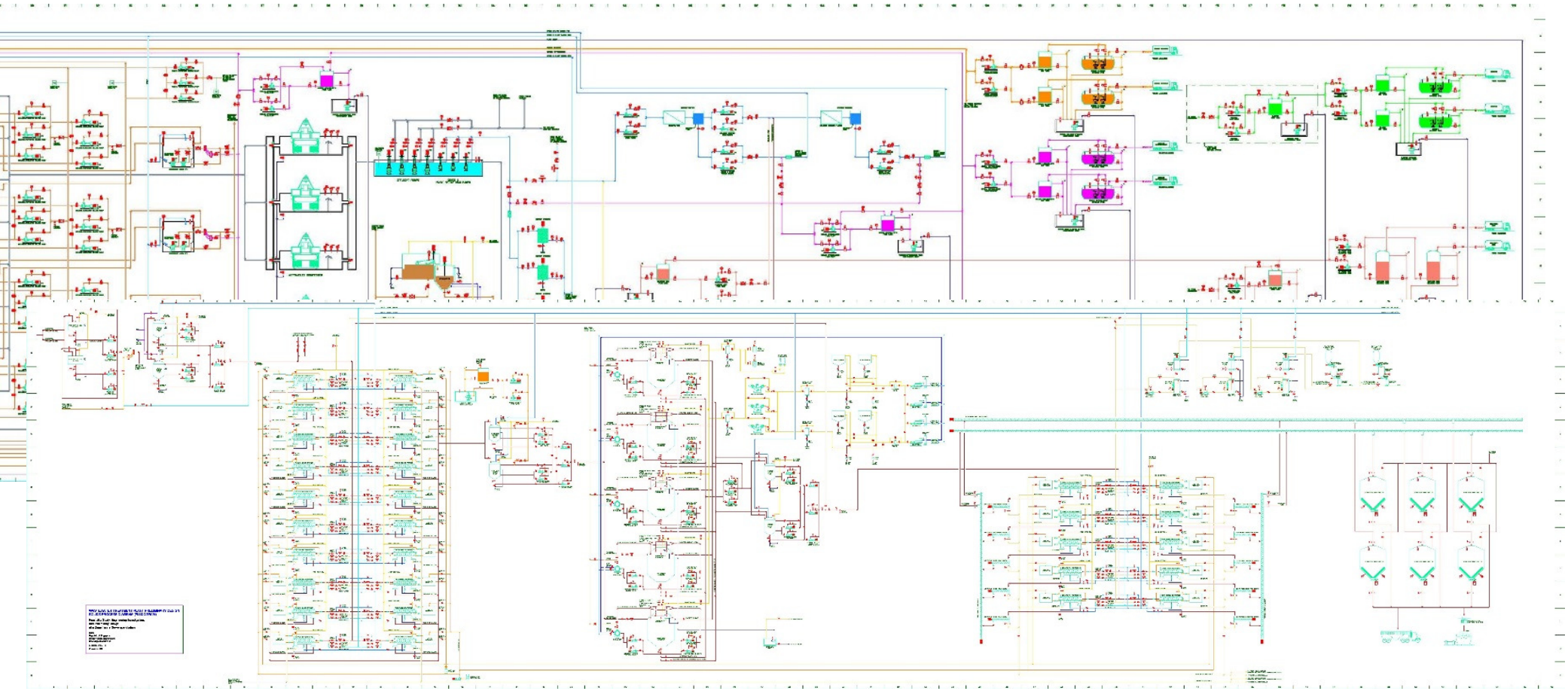
Overall Digital Twin Structure



Changi WRP Process Flow Diagram Overview



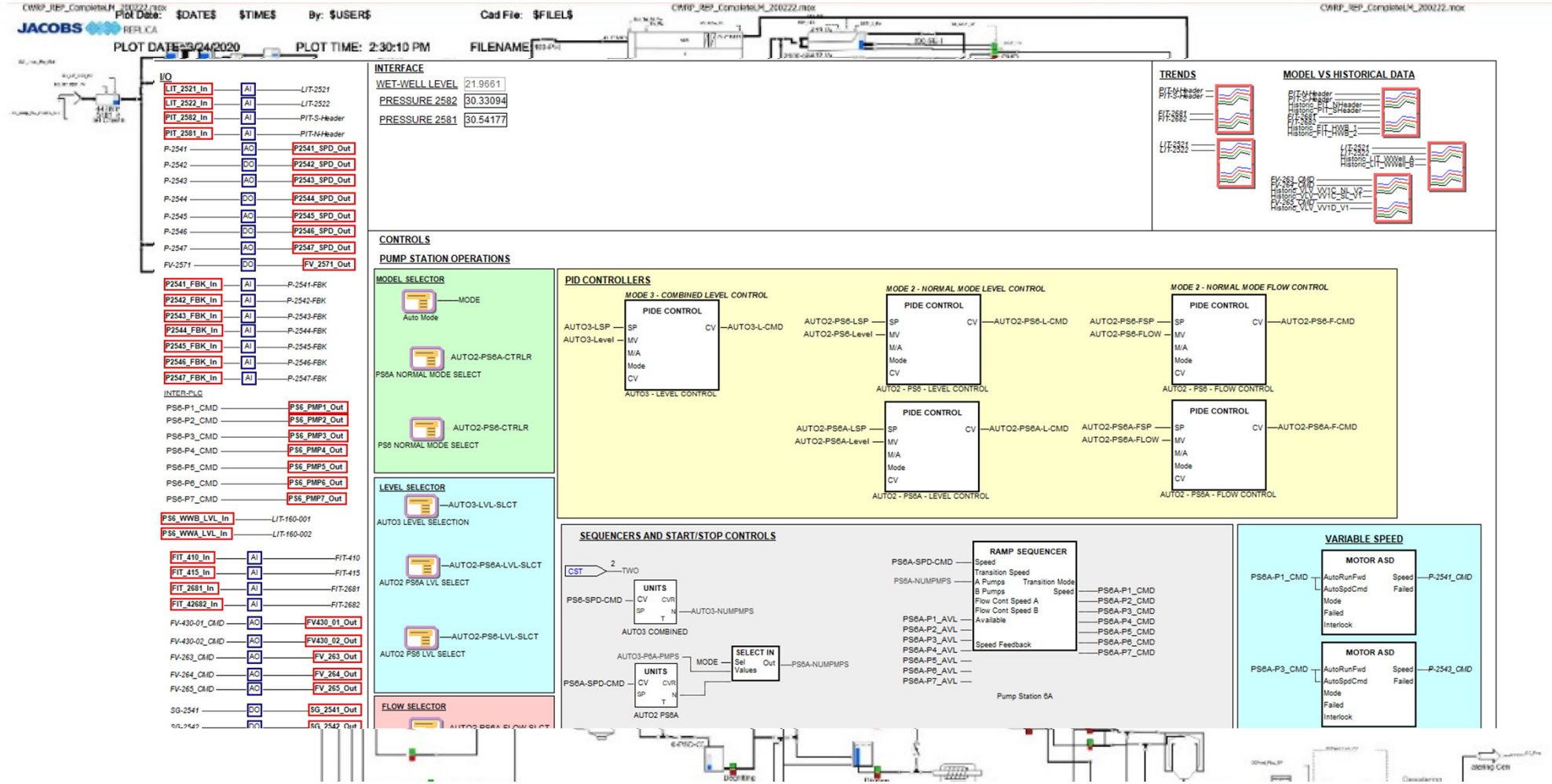
Partial PFDs (<u>one</u> of 4 liquids modules + Solids)



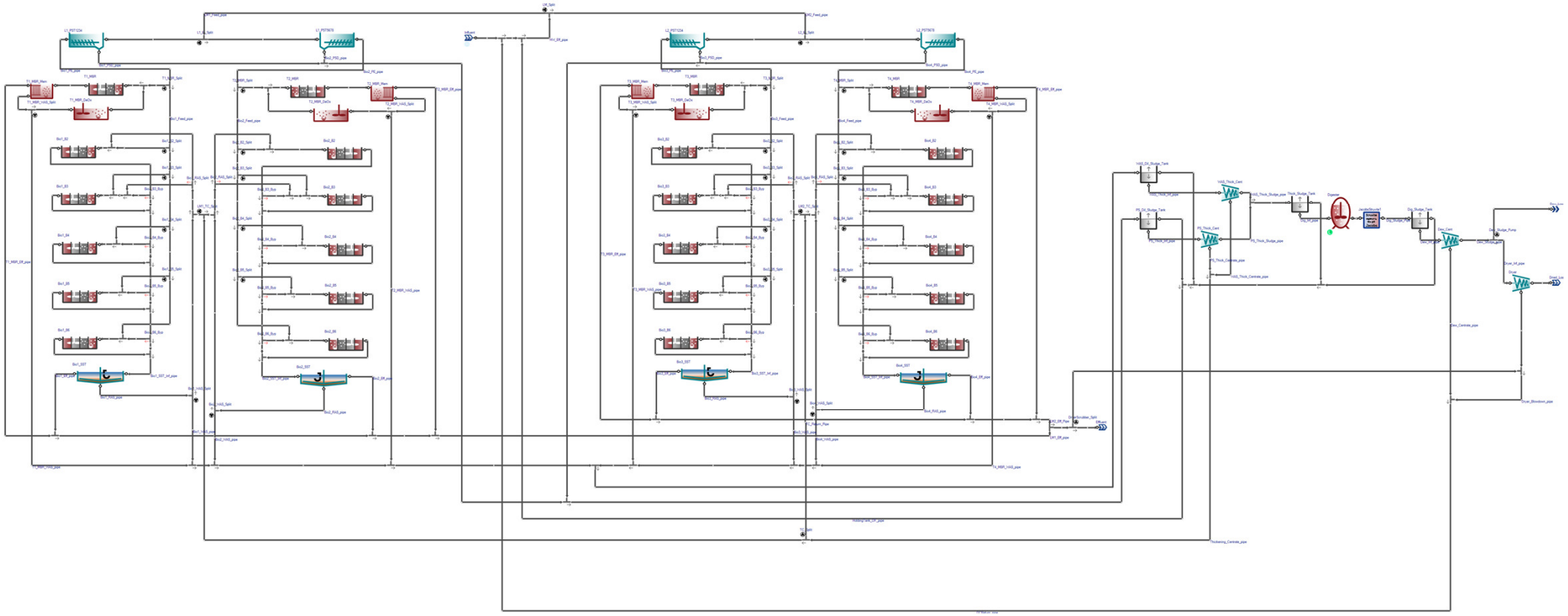
CWRP Digital Twin Models

What does it take to develop a “True” Digital Twin: The Changi WRP Story

CWRP Replica™ Hydraulics and Control Model

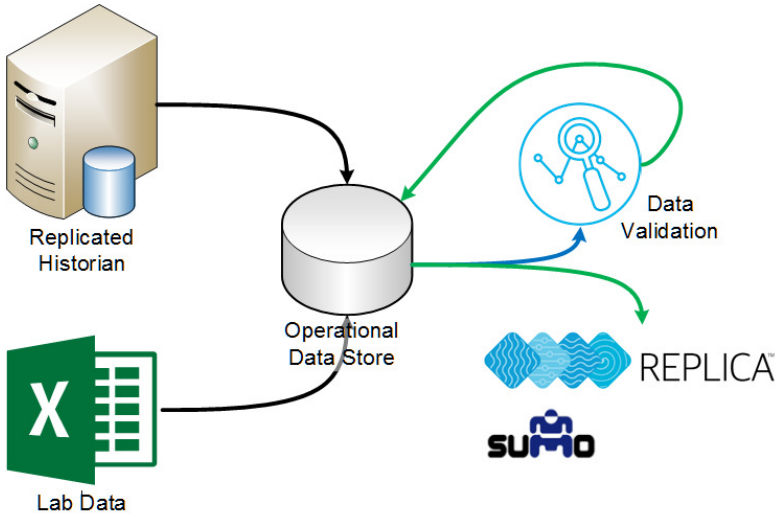


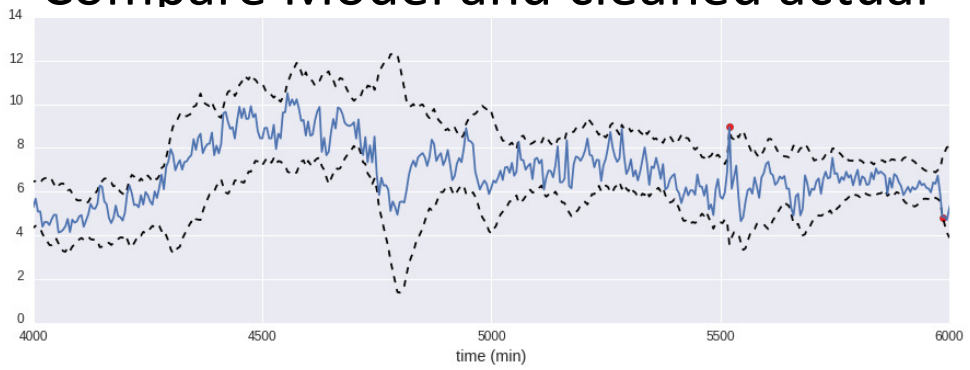
CWRP Sumo Process Model (169 biological reactors)

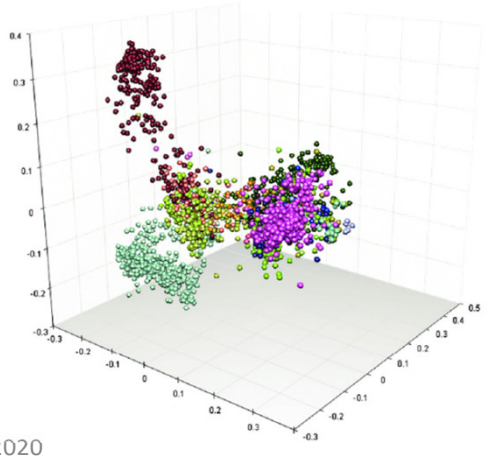


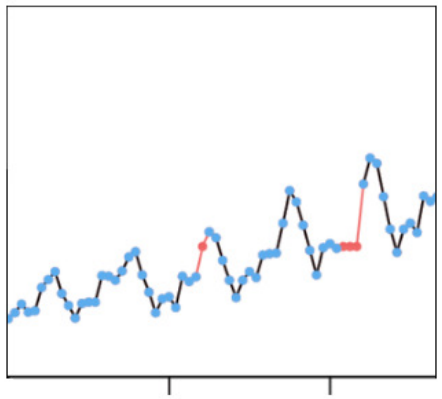
Live Data Make it a Digital Twin

- Outlier detection – identify anomalous data through various analytical methods
- Infilling: Both on-line and laboratory bad/missing data
- Process Deviations
- Compare Model and cleaned actual







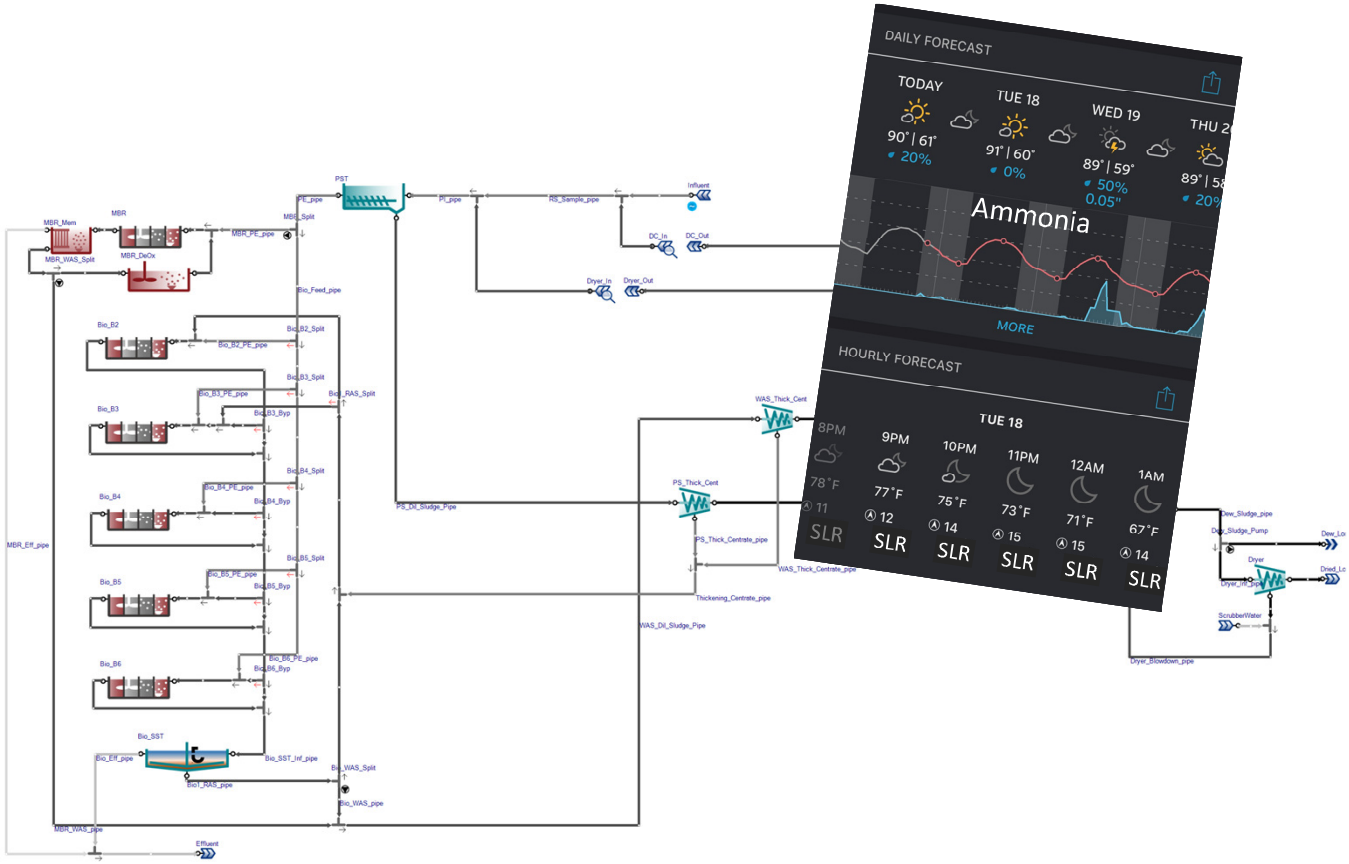


Machine Learning Reduces Utility Effort

- One of the most time consuming tasks: **keeping the model relevant**
- Machine learning auto-calibrates model, thus keeping it current
  - Requires direct connection to plant data

Predictive Analytics: Wastewater “Weather” Forecasting

- Use Monte Carlo tools to predict likelihood of events
  - 1, 3, and 5 days into the future
  - likelihood of clarifier overloading
  - high nitrates, etc.
- Uses simplified model for speed
  - “Only” 40 bioreactors
- Provide results in “Weather App” type format
  - familiar method of viewing probabilistic information!

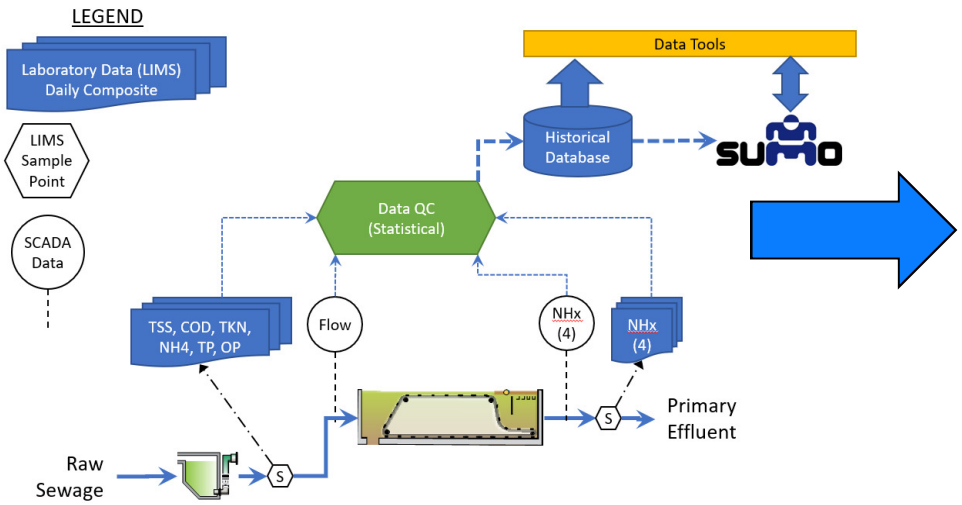


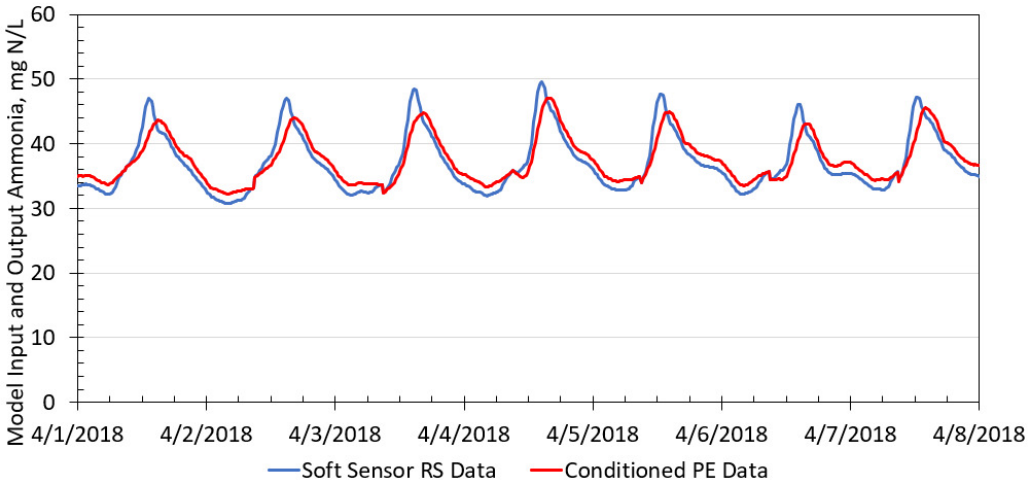
CWRP Digital Twin Example Results

What does it take to develop a “True” Digital Twin: The Changi WRP Story

Soft Sensors for Influent Quality

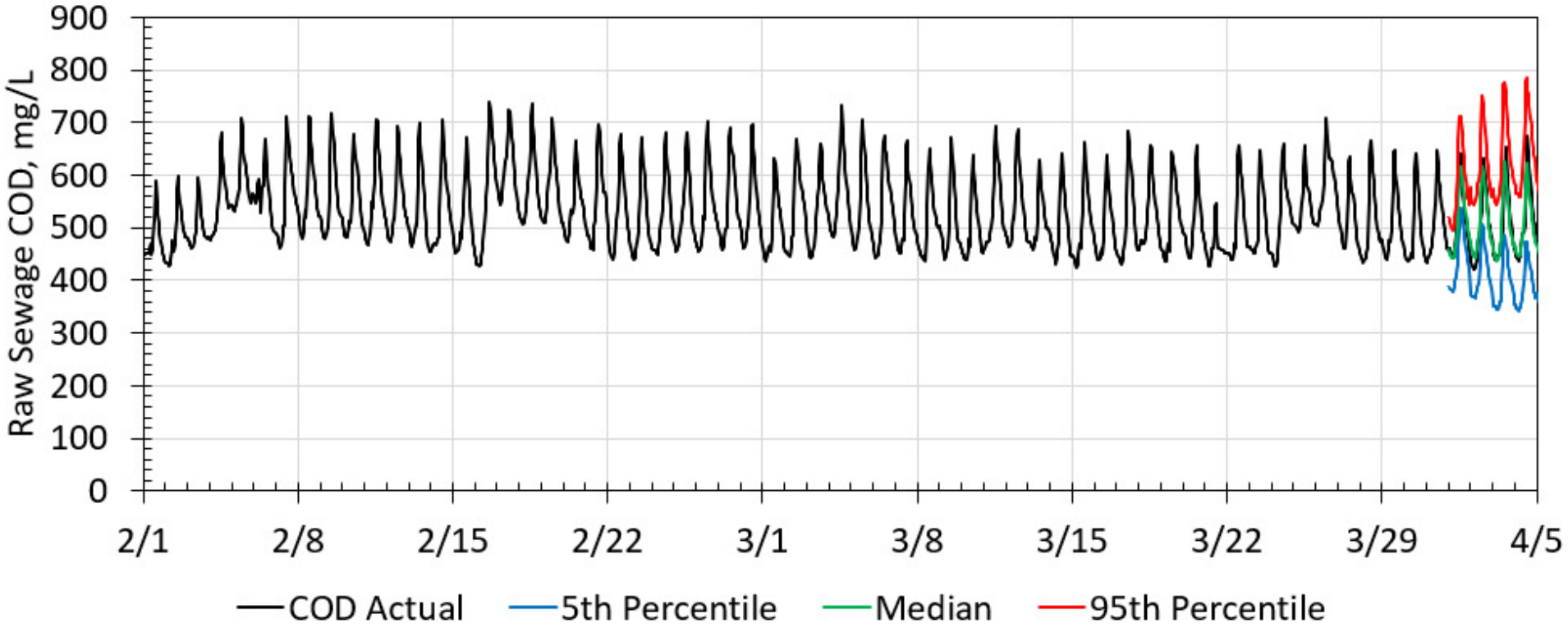
- A “soft-sensor” uses the model to estimate what a sensor might have read, without needing the sensor
  - Reduces capital and maintenance costs
- CWRP Raw Sewage Characteristics (ammonia example)
  - Uses primary effluent ammonia measurements (on-line and laboratory)





Looking Forward: Moving from Reactive to Proactive Operations

- Laboratory results are combined with predicted influent ammonia concentrations to develop 5-day dynamic predictions of COD concentrations



Digital Twin Summary

Changi WRP Digital Twin replicates all significant aspects of a facility on a digital platform, Hydraulics, I&C, Process

Benefits:

- **Increasing Productivity** with:
  Real-time operation insights and process trouble-shooting.
- **Enhancing Resilience of Operations** by:
  Moving from Reactive to Proactive
- **Optimize critical operation scenarios**

Process

Track components (Wastewater Quality)
- Treatment processes
- Separation
- Reactions

Powered by Sumo©

Hydraulics

Move fluids through system
- Pipes
- Pumps
- Valves
- Storage
- Channels

Powered by REPLICA™

Instrumentation & Controls

Drives system operation
- Measuring devices
- Transmitters
- Control Algorithms
- Controls Tuning

Powered by REPLICA™

JACOBS

Acknowledgments

- This research is supported by the National Research Foundation, Singapore, and PUB, Singapore's National Water Agency under Urban Solutions & Sustainability (CRP(Water) RFP 1803 <PUB-1803-0014>)
- This work could not have been accomplished without the extensive support, feedback, and contributions from PUB staff and a large team of Jacobs employees in both Singapore and the US

Digital Twins: Enabling Data-driven Water Reclamation/Reuse Solutions

- A **digital representation** of a physical system **coupled with real-time data**
- Offers multiple benefits to the water industry
- Development can be scaled to needs/capabilities
- Degree of sophistication ultimately depends on level of digital maturity

Jacobs Challenging today. Reinventing tomorrow.

Digital Twins: Enabling Data-driven Water Reclamation/Reuse Solutions

In the **kNOW** Webinar Series

August 26, 2020

Q&A