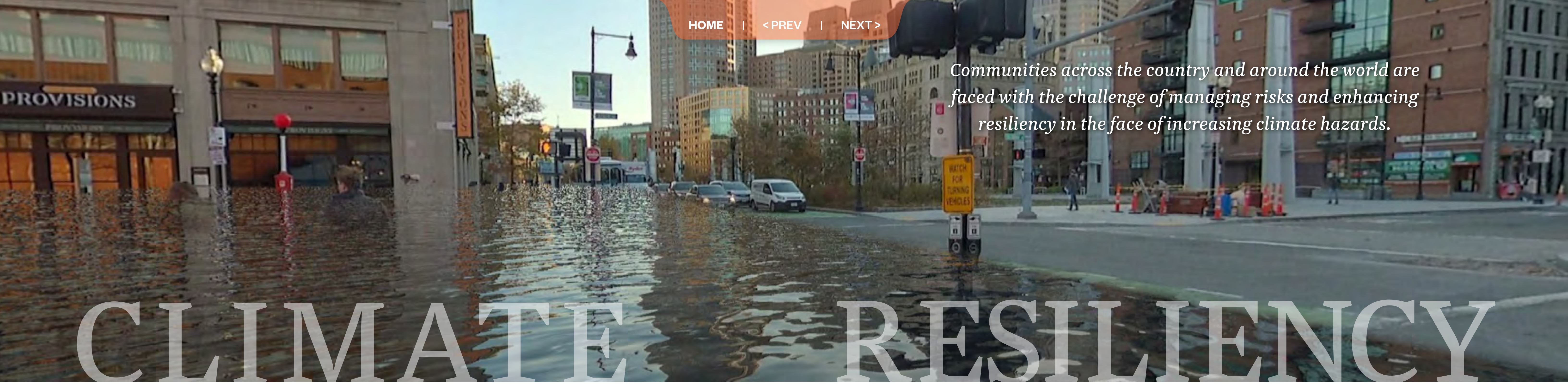
Hazen

HORIZONS

water environment solutions

SPRING 2021



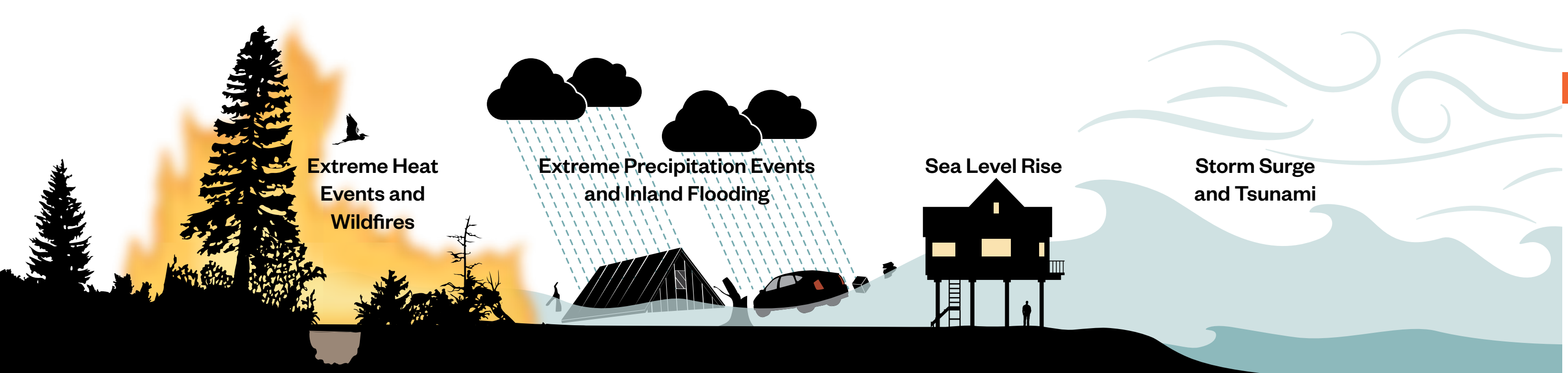
Communities across the country and around the world are faced with the challenge of managing risks and enhancing resiliency in the face of increasing climate hazards.

CLIMATE RESILIENCY

The good news is that most communities don't have to start from ground zero to take effective steps in resiliency planning. Models and other already available data within a city/town, or in the broader scientific/public domain, can be used as the foundation to build upon. Hazen has pioneered several innovative tools and approaches to build from those existing tools and take the next steps: identifying and assessing risks and vulnerabilities; evaluating cost-effective resiliency strategies; and implementing a plan for adaptation.

Climate change presents critical challenges to the management and operations of water and wastewater infrastructure. Rising sea levels, increasing storm intensities, longer drought periods, and more frequent heat waves all affect a community's ability to manage and protect source waters, supply clean drinking water, collect and treat wastewater, and mitigate flood hazards. In many cases communities are faced with planning for not just one, but multiple overlapping future climate change threats.

Hazen has developed and implemented ***effective resiliency frameworks and innovative tools*** *to support robust climate change planning and risk mitigation.*

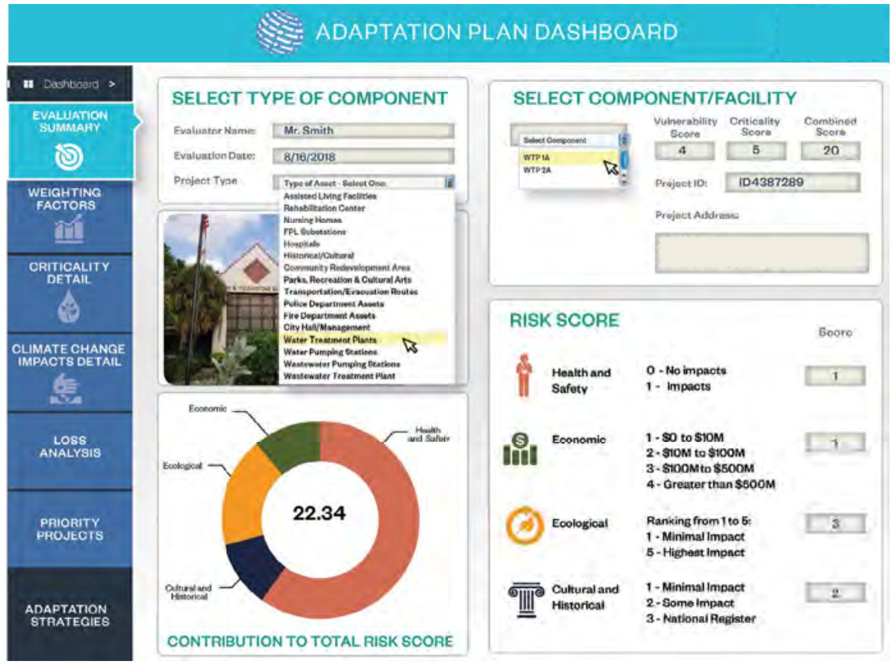


Vulnerability Assessment and Risk Management Tools

Above: The Inundation Model viewer, developed by Hazen for the Boston Water and Sewer Commission, displays 360-degree photographic renderings of landmark locations in the city to illustrate potential flooding alongside recognizable landmarks for intuitive public understanding.

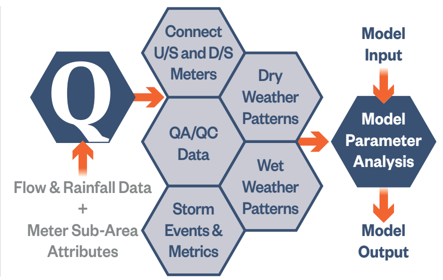
Decision Support Tool

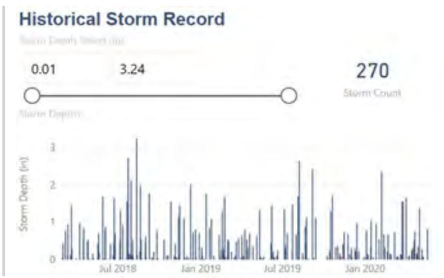
A user-friendly multi-criteria decision support tool. This tool facilitates effective stakeholder engagement in the prioritization of project goals across social, environmental, economic, and technical considerations.



HazenQ

Provides quick and easy management of flow monitoring data and calibrates hydraulic models, essential steps in identifying flood risks in collection systems.





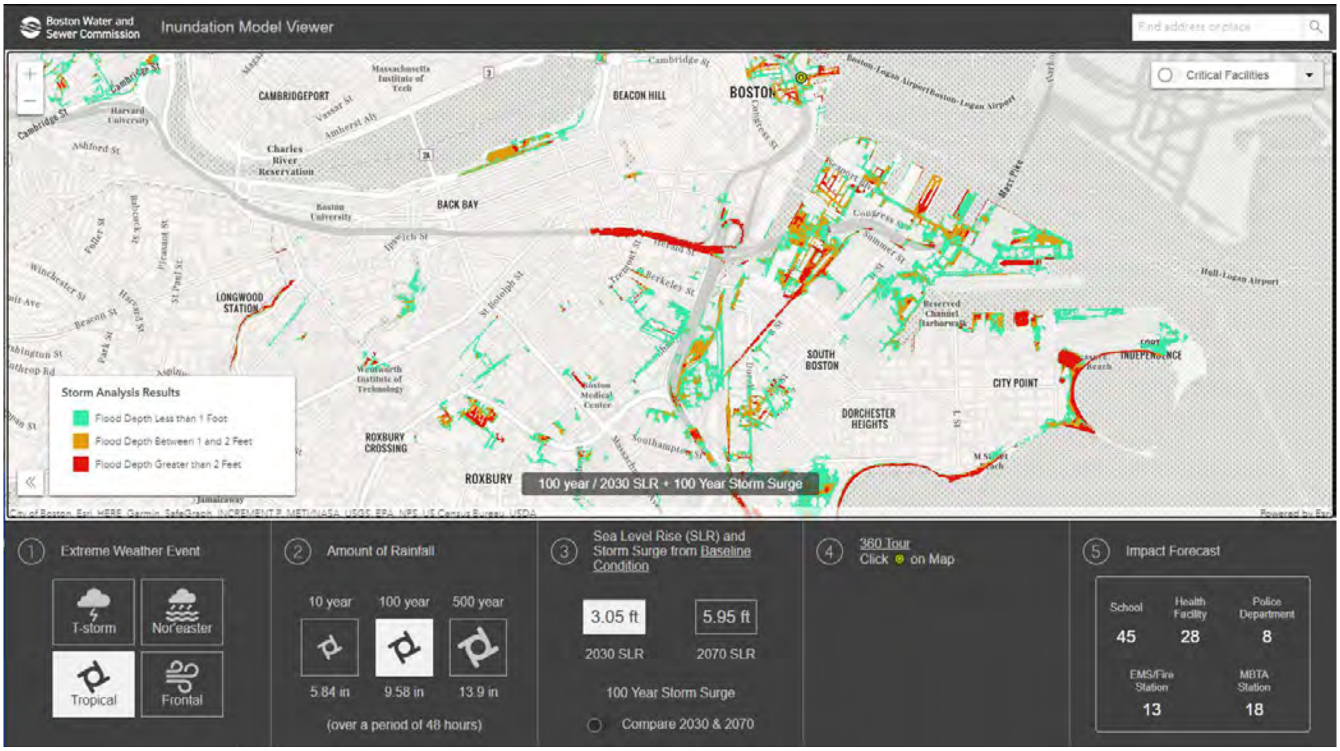
StormSight

Cost-effectively sifts through decades of historical rainfall data and derives storm intensity, depth, and duration statistics for a variety of return frequencies.

More on Boston Storm Inundation

Climate risks differ throughout the country, requiring that resiliency strategies be tailored based on each utility's specific circumstances. The following case studies include projects from a diverse mix of geographies, using a range of resiliency strategies.

CASE STUDY



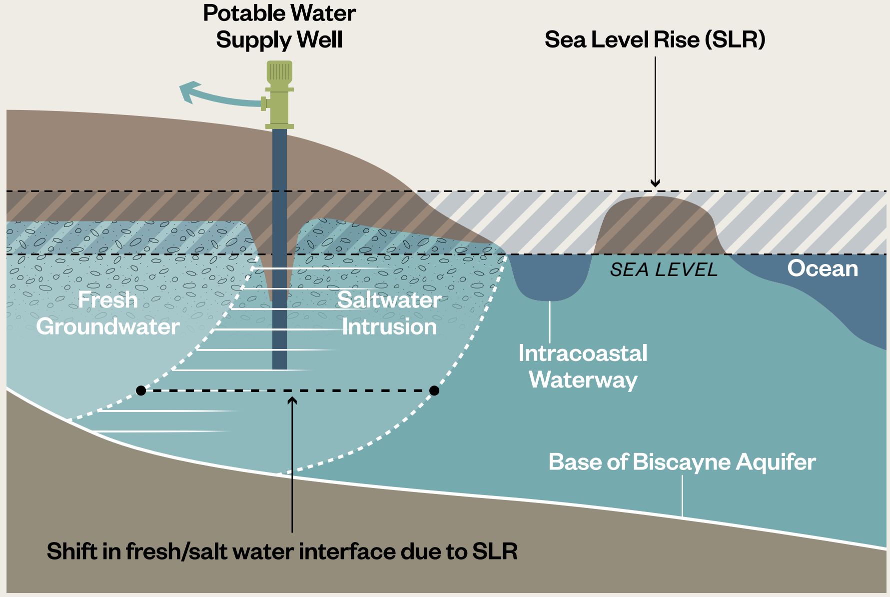
For the Boston Water and Sewer Commission (bwsc.org), Hazen used existing 1D hydraulic models as a starting point to develop a 2D model that predicts flooding from varied coastal and rain events throughout the city. GIS tools assessed impacts and vulnerabilities to critical infrastructure resulting from different inundation scenarios. Hazen analyzed dynamic rainfall events (thunderstorm, frontal, tropical, nor'easter) for 2-year and up to 500-year frequencies, and developed a web-based ESRI story map with a custom flooding results viewer. Several 360-degree photographic renderings were created of landmark locations throughout the city to clearly illustrate potential flooding within streets, against buildings, and more. This unique delivery of what has historically been very complex modeling data allows for a very distilled communication of flooding impacts to a wide variety of audiences, both technical and non-technical.

CASE STUDY

Like many other coastal communities in South Florida, the City of Fort Lauderdale is grappling with the challenges associated with creating a resilient future in the face of climate change, and particularly rising sea levels. With much of the city having ground elevations just a few feet above current mean sea level and more than 160 miles of waterways traversing the city, the task at hand is critical and complex.

In 2016, the city selected Hazen to assist with its Stormwater Masterplan Modeling and Design Implementation efforts, a major component of which is resiliency in the face of climate change. One of the primary tools used in this long-range, carefully phased battle is a comprehensive hydrologic and hydraulic (H&H) model. Historical modeling efforts in the city and throughout the region were not sufficient, as they did not simulate the interaction between surface and groundwater in robust enough fashion.

Hazen built upon the city's existing information by selecting a modeling platform, collecting data, and building a model that appropriately connects surface and groundwater. This tool has already been used to begin designing stormwater/resiliency infrastructure investments in seven initial areas of the city, and will be a dynamic tool in further assessing, planning, and designing improvements and enacting policies to help ensure the resiliency and prosperity of Fort Lauderdale for decades to come.



Much of South Florida is built atop the Biscayne Aquifer, a highly permeable geologic formation and great source of high-quality fresh water. Rising sea levels will advance saltwater intrusion, affecting water supplies, increasing seepage across tidal barriers, and complicating flood control efforts.

CASE STUDY

Orange County (CA) Sanitation District was one of the first wastewater agencies to conduct a comprehensive climate change resiliency study, with the objective of identifying and mitigating risks to the operation of two treatment facilities, 15 pump stations, and a significant capital improvement program.

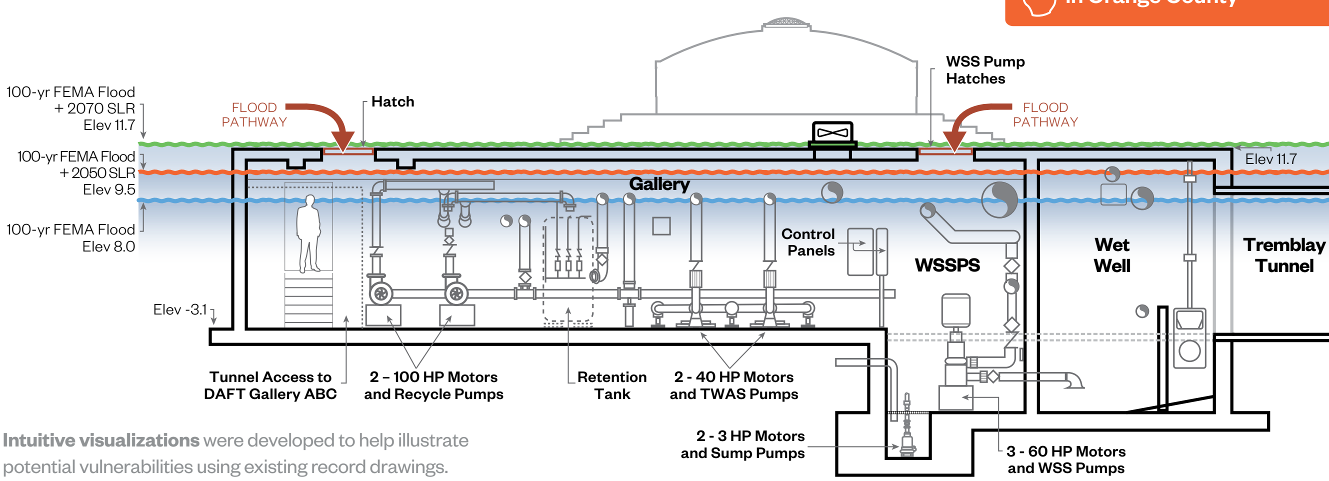
Using the City's existing record drawings and other accessible information as a starting point, Hazen assessed flooding and sea level rise using FEMA 100-year and 500-year flood levels. California's 4th Climate Change Assessment was used to develop projections for sea level rise for 2050 and 2070. Wildfire and extreme heat risks were also evaluated using data from California's 4th Climate Change Assessment and the state's Cal-Adapt website.

Four categories of adaptation strategies were evaluated for OCSD facilities: boundary, building, asset, and operation. Selected strategies included revised emergency response plans and design guidelines specific to the locations and risks to each piece of critical infrastructure.

For example, the Sanitation Districts of Los Angeles County and the City of Simi Valley have reclamation facilities in communities surrounded by forest and brush that have more vulnerability to wildfire, in desert communities more likely to experience high heat, and adjacent to rivers subject to flooding from changing precipitation patterns.

As a result of this work, Southern California's essential wastewater facilities can be better prepared and resilient to the effects of climate.

More on Climate Resiliency in Orange County



Intuitive visualizations were developed to help illustrate potential vulnerabilities using existing record drawings.

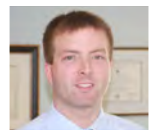
CASE STUDY

The Clarksville (TN) Wastewater Treatment Plant is the only facility that provides wastewater treatment for more than 100,000 residents of Clarksville. When the Cumberland Basin received more than 20 inches of rain in less than 48 hours, it caused massive flooding and the levees and floodwalls surrounding the plant were overtopped and the plant was inundated and heavily damaged.

Clarksville Gas & Water quickly contracted with Hazen to provide disaster recovery services and bring the facility back into operation as quickly as possible. As soon as floodwaters receded, the facility was dewatered to minimize impact to the levees and floodwalls and initial cleanup was completed. Primary treatment returned to operation just 10 days after the flooding. Even with the extensive damage to secondary treatment equipment and the biology of the plant completely lost, secondary treatment was also back in operation in less than three months.

A new perimeter berm was raised above the 500-yr flood elevation and the existing stormwater pump station was improved to handle run-on generated from a 100-yr storm. Throughout the project, Hazen provided daily status updates to the Tennessee Department of Environment and Conservation on damage incurred and the recovery process. Once the event was declared a federal disaster, Hazen worked closely with FEMA representatives to develop proper justification and project worksheets for reimbursement of a portion of the recovery cost.

For more information contact:



Charles Wilson, PE

Clarksville Wastewater Treatment Plant – May 2010: Levees and floodwalls surrounding the Clarksville WTP were overtopped and the plant was inundated and heavily damaged after the Cumberland Basin received more than 20 inches of rain in less than two days.

More on the Clarksville Flood Event

Saving Time Through Data Visualization and Application

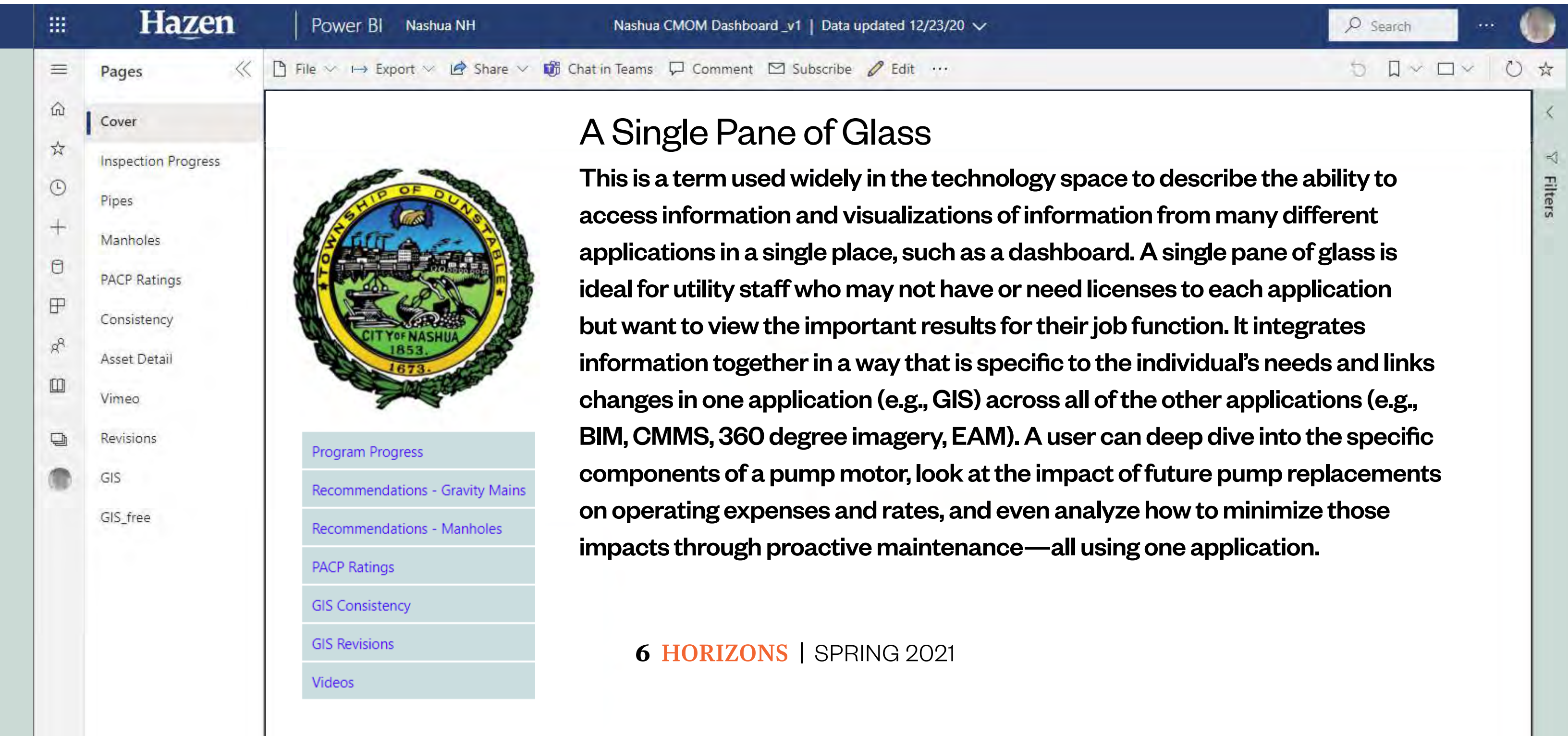
Building a new facility or renovating aging assets is typically a significant investment of capital, staff time, and other resources. The time investment starts at the early stages of planning and continues to rise through design, construction, and commissioning. It does not stop there—an often-overlooked aspect of new facilities is moving as-built information into asset management systems, which can take weeks to months of manual labor. Every minor change must be tracked, recorded, and validated in the system. Similar impacts on resources and available staff hours include mapping the assets in GIS, determining and implementing maintenance schedules, and providing insight into the facility across functioning units.

Most utilities have the tools available at their fingertips to streamline this process and save time and money but have yet to harness the power of connecting the right applications. For example, most utilities already use GIS products and many are using CAD or BIM files to store data about their facilities, though few people within the organization can access the data in one location. Likewise, computerized maintenance management systems (CMMS) and enterprise asset management (EAM) systems are often siloed without direct linkages to available tools across the organization. This results in a fractured view into the operation of the utility with inefficiencies in collecting, visualizing, and acting on information.

To lessen the impact on staff and manpower, utilities can integrate software from multiple vendors, streamlining the collection and digitization of asset data. Visualizations of assets, maps, facilities, and more can be combined with BIM data from design and construction teams into a single application or website to support workers and work flow.

The integration of applications and software licenses already owned by a utility can save hundreds of staff hours from routine tasks.

The following key terms and case studies demonstrate some of the most frequently used tools and outcomes from digital strategy development:

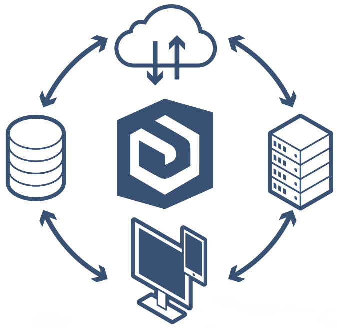


A Single Pane of Glass

This is a term used widely in the technology space to describe the ability to access information and visualizations of information from many different applications in a single place, such as a dashboard. A single pane of glass is ideal for utility staff who may not have or need licenses to each application but want to view the important results for their job function. It integrates information together in a way that is specific to the individual's needs and links changes in one application (e.g., GIS) across all of the other applications (e.g., BIM, CMMS, 360 degree imagery, EAM). A user can deep dive into the specific components of a pump motor, look at the impact of future pump replacements on operating expenses and rates, and even analyze how to minimize those impacts through proactive maintenance—all using one application.

CASE STUDY

Creating Visibility and Insights Across the Organization



Hazen and the Passaic Valley Sewerage Commission (PVSC) in New Jersey recently embarked upon a data management strategy to integrate BIM, GIS, and business intelligence systems into a single pane of glass. This digital strategy was deployed to enable secure and scalable data sharing between business groups and different enterprise IT systems, minimizing repetitive information and maximizing the usefulness of the data PVSC receives and creates.

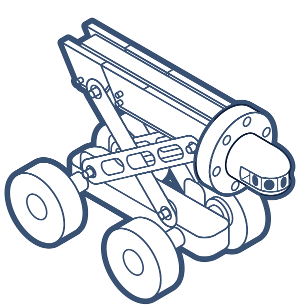
The team worked with the PVSC IT Department, Microsoft, ESRI, and the PVSC GIS team to outline and implement a new ESRI Enterprise ArcGIS Portal in their Microsoft Azure Cloud, creating a single pane of glass for integrated viewing of building information data, geodata, operation data, and more. This initial phase also created the necessary cloud infrastructure to develop, test, and host Digital Twin technologies that represent near real-time information in 3D model view, 2D plans and maps, and BI visuals. This seamless integration has allowed PVSC staff to analyze and visualize GIS data alongside other data sources.

Dashboarding

Dashboards are typically created through packages such as PowerBI or Tableau, providing a means to quickly and easily view high-level data before drilling down into points of interest. By integrating the display capability of various software applications, dashboards can provide cross-enterprise insight through GIS maps, CMMS recommendations, and architectural and structural drawings. Integrated dashboards enhance each user's access to information and minimize the downtime often required by requesting data, screenshots, maps, etc., from other work units within the utility.

CASE STUDY

Collecting and Analyzing Data in Accessible Ways



The City of Nashua has been working with Hazen to manage the development of a "Collection System O&M Plan" as part of its wastewater NPDES Permit that covers the pipes, manholes, and pump stations in the sewer and stormwater systems. The data-rich program required collecting and analyzing data in a way that was accessible and easily viewed across the organization. It includes video, app-based GIS maps, condition assessment and risk management ratings, and work order tracking, all of which needed to be integrated through a web-based dashboard application.

After inspection with CCTV cameras, the status of each asset is added to ArcGIS Collector in real-time for both Hazen and the city to see. The map can also be edited, allowing for new assets or different configurations of previous map data to be added as needed. Hazen's GIS updates and CMOM recommendations are available to the city in real-time through a web application hosted on the Hazen GIS Portal, with results and data trends displayed in Power BI. The Power BI report utilizes CCTV and CMOM GIS data to create a powerful and connected tool, with data refreshing on a scheduled interval to stay up to date. The report allows the city to track the inspection, data implementation, review, and revision progress for each water type using easy to understand visualizations such as tables, charts, and maps.

Integrating Technology

Many vendors create snippets of code that help different software applications talk to one another, and the software that utilities already pay for very likely has this capability built in. Hazen leverages these communication tools to create new ways of connecting data and visualizing that information to create actionable insights. Leveraging existing licensing to create something new saves time and provides better clarity into the system.

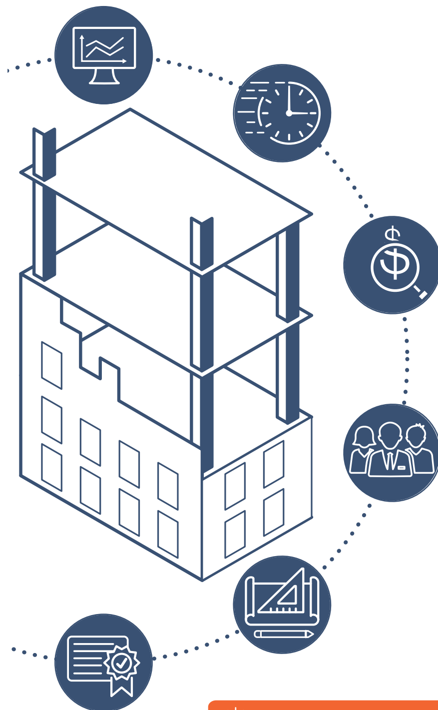
CASE STUDY

Standardizing Design Practices with BIM

The standard water industry model of distinct design, build, operation, and maintenance phases for facilities does not lend itself to the seamless transfer of data from one phase to the next. While developing Hampton Roads Sanitation District's (HRSD) digital strategy for the District's asset portfolio lifecycle, Hazen also created a framework for integrating asset management and O&M information with GIS and CMMS for the SWIFT Research Center.

Development of an intelligent BIM model with standard project templates and use of bridging software to sync and connect BIM data to CMMS and GIS allows consistency in format and presentation developed by varied stakeholders. Powerful visualization tools in the O&M stage provided a holistic understanding of a facility's asset attributes, maintenance, and renewal and replacement status by use of automated color-coding and the ability to quickly access work order history.

BIM guidelines and standard practices for HRSD streamlines the collection of asset information during design, which improves future capital planning and O&M practices. Future facilities will be developed using this approach to connect data from design through long-term operations.



More on BIM and CMMS for AWT

Better Decisions Quicker

Hazen's work on behalf of utilities in this space has been recognized by ESRI, AutoDesk, Microsoft, HoloBuilder, and more as an example of the benefits of integrating data across applications. Our clients have seen the benefits in the improved quality and efficiency of design and construction projects, compelling maps and visualizations of storm surge inundation to support the case for facility hardening, developing financial models that foster smart investment, and comprehensive asset management dashboards that improve efficiency and staff morale. No matter the application, the goal is to create a time-saving view into the function of a utility that drives efficiency, fosters the development of actionable insights, and enables staff to focus on the most important aspects of their work.

For more information contact:

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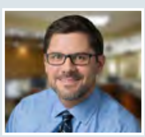
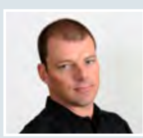
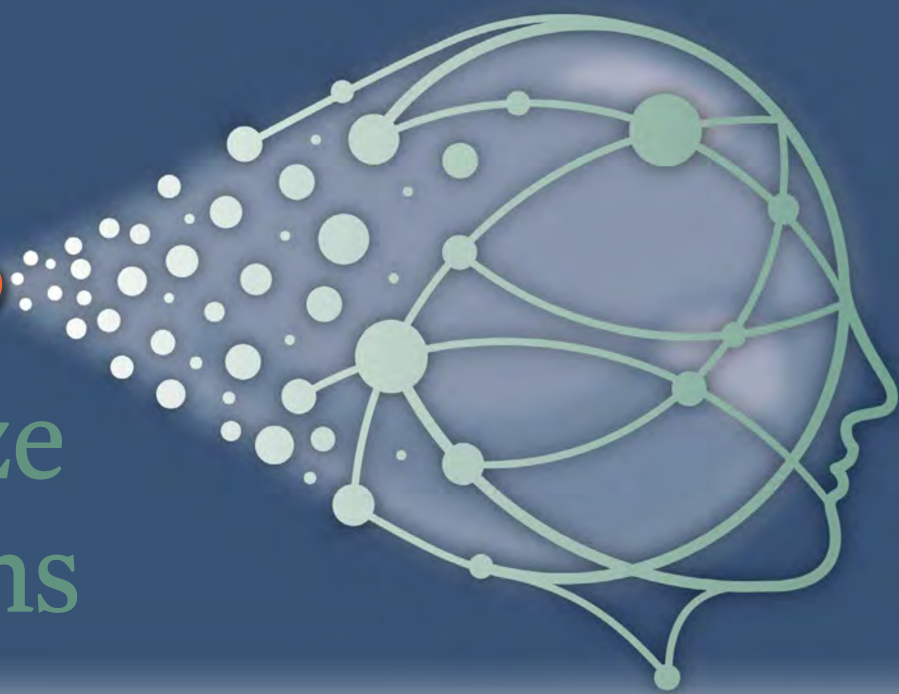


Ryan Nagel, PE, ENV SP



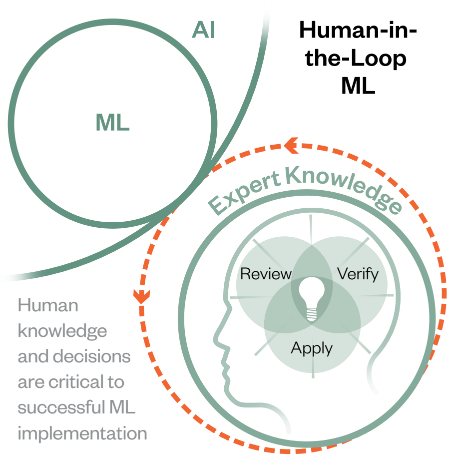
Jamie MacDonald

Using Machine Learning *to* Optimize Operations



With tremendous leaps in smart sensors and processing power for data analytics, ***the water utility industry is beginning to recognize and apply machine learning (ML) as a tool*** *to optimize system operations in a way that was not possible even a few years ago.*

As a branch of the broader field of artificial intelligence (AI), ML has vast possibilities for the water industry. At its simplest, machine learning is learning from data. Every day, various types of data are recorded on a massive scale throughout the water sector and ML can be used to analyze these complex datasets, helping operators by leveraging the objective and powerful capabilities of computers to identify and utilize patterns from the data that a human may not recognize. Machine learning models are developed through model training; the model is given a certain percentage of a data set (usually 75-80% of the data) and is then tested by



predicting the rest of the data set, or "unseen data." Well-trained (or calibrated) ML models can explore and process massive and diverse datasets in real time while also providing rapid predictions and/or recommendations for operators—a difficult and sometimes impossible task for a human, especially in a short time frame.

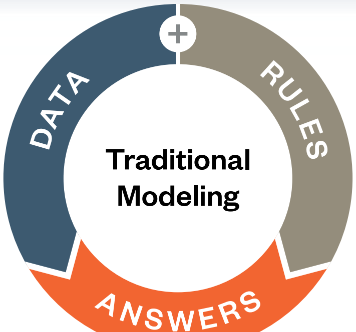
One common misconception is that ML tools will replace human operational decision making. Operational experience and expertise is fundamental to successful ML development and implementation. Water experts are critical to integrating the science of water into model development. And once in production, it will always be important for a human to review the recommendations of the model, periodically verify the model is continuously learning, and apply their own judgment and experience to the question at hand.

Machine Learning vs. Traditional Modeling

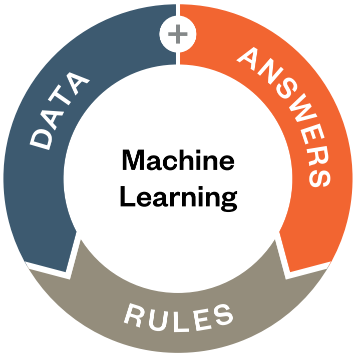
Models in the water industry have traditionally focused on known relationships derived from years of research. These mechanistic models simulate known relationships like Monod kinetics for the growth of organisms or the Manning equation for open channel flow. Those equations (rules) along with their inputs (data) can be coded directly into a computer model.

The potential shortcomings of using mechanistic models in real-time decision making may include that the model could be out-of-date and/or not representative, the time it takes to obtain a result is too long to have practical use for an operator, or the model and the real-time data are not connected.

ML offers an alternative approach that uses data and answers to learn rules, and uses error minimization algorithms to find the best way to represent a relationship between the data and the answers. ML can be used to gain insight into processes that are not well understood, or too complex to use a conventional equation, or when mechanistic models don't represent the system well. Some examples include predicting sludge settling characteristics or the percent total solids from a dewatering unit.



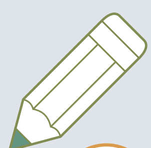
Traditional mechanistic modeling requires data and rules be coded into a model to provide an answer.



Machine learning provides data and answers to an algorithm that then learns the rules and can make predictions.

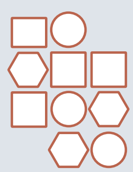
Types and Levels of Machine Learning

Machine learning is highly scalable, flexible, and can provide different levels of insights to inform operations. This can include a descriptive model (see figure on right) that provides an operator with informed decisions to more complex prescriptive models that recommend a particular action (i.e. set pump speed to 50%) or allow a computer to make the decision and implement the action. More importantly, a machine learning model is only as good as the data used for its "training." For example, if a model predicts collection system flow and an upstream storage tank is built to attenuate flow, the ML model will have to be retrained to learn how the storage tank affects flow. This is also another example of the critical nature of the human element—while we call these models "smart," they need human intelligence to be applied correctly.



DESCRIPTIVE
Collect and report existing data.
We have different types of pipe materials in Street X ranging in age from 10-to-50 years.

DIAGNOSTIC
Examine causes of reduced performance or failure.
A ductile iron pipe in Street X is broken, primarily due to the age of the pipe.



PREDICTIVE
Detect patterns that signal impending events.
A ductile iron pipe in Street X will break in Jan. 2021, due to age and corrosion.

PRESCRIPTIVE
Identify measures to improve outcomes to correct problems.
A ductile iron pipe in Street X will break in Jan. 2021. Order 20 ft. of replacement pipe from Company Y and schedule repair in Dec. 2020.

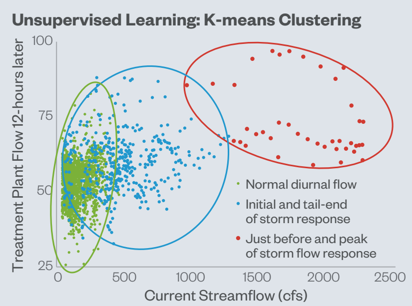
The Three Types of Machine Learning

Machine learning covers a wide variety of approaches to generating insights from data. ML encompasses three prominent methods.

Unsupervised Learning

GOAL Gain insights from data, without specific target variable.

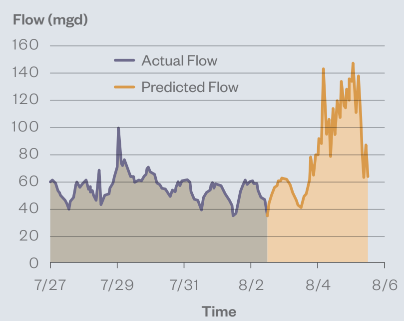
can provide insights into variables that can be related. In this case there is not a specific target variable one is trying to predict. With unsupervised learning, algorithms can find commonalities and uncover complex relationships across many dimensions.



Supervised Learning

GOAL Achieve something specific, such as predicting or classifying a target variable.

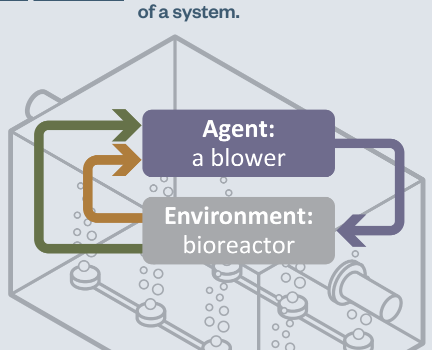
involves forecasting the value of a target variable such as influent wastewater flow given a combination of current known and/or forecasted conditions; or classifying a variable into different groups, such as low dosing or high dosing range for a chlorination system. The goal is to provide specific output for an operator or a PLC to make a decision.



Reinforcement Learning

GOAL Optimize performance of a system.

is currently the least explored, but has tremendous value for process optimization and automation. This example model optimizes blower speed to maintain a specific DO setpoint and target effluent ammonia value by assigning rewards and penalties for being too high or too low; reinforcement learning could also include adding energy costs as penalities.



State: *DO and ammonia concentration*

Action: *increase/decrease blower speed*

Rewards/Penalties: *numerical values for rewards and penalties*

Machine Learning Life Cycle in a Case Study:

NEUSE RIVER RESOURCE RECOVERY FACILITY (NRRRF) | RALEIGH, NC

1 Problem Definition

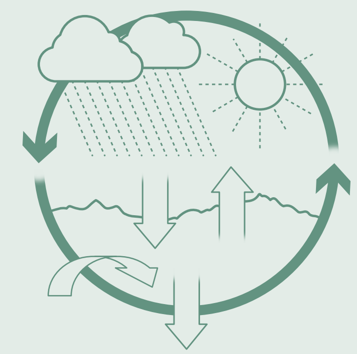
What problem do you want to solve?

Predict influent flow at the 75-mgd NRRRF. ML tools were used to determine the optimal flow at which to utilize equalization so the retention time in the biological nutrient removal process is maximized. ML also integrated with the secondary clarifier guidance tool to determine how many clarifiers are required for a given flow, RAS flow, SVI, and MLSS concentration.

THE NRRRF CASE STUDY IS DESCRIBED ON PAGES 14-15

2 ML Development and Training

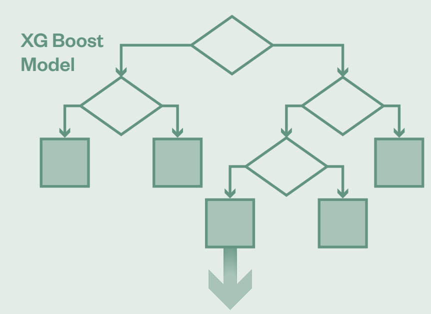
Gather Historical Data



Gathered 6+ years of hourly flow data and hourly weather data that our subject matter experts thought would be relevant. This included rainfall and streamflow data with streamflow serving as a proxy for inflow and infiltration.

Exploratory Data Analysis
Explored *which variables had strong links with future plant flow,* for example, streamflow was closely correlated with future plant flow by linear regression.

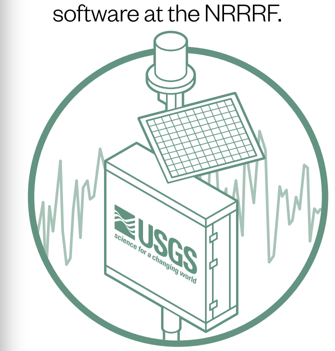
ML Model Development
LSTM and XGBoost algorithms in Python were used *to train a model to 6 years of data.* The model had to predict 72 target variables; the flow predicted 1-to-72 hours from the current time.



Model Evaluation
The trained model was tested on 25% of the historical data to verify it made good predictions. *A subset of the data was used to quantify the model's performance specifically for wet weather events.*

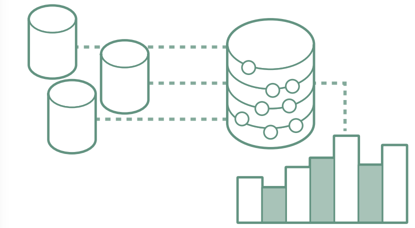
3 ML Deployment

Real-time Data Connectivity
A pipeline was developed to gather real-time data in a SQL database for use by the model. *This process also included data screening and validation.* Past flow data from the plant was connected to SQL through Ignition software at the NRRRF.

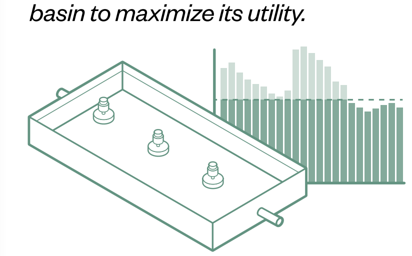


Rainfall and USGS streamflow data were connected from third party APIs.

Model Deployment
Azure Data Factory and ML Studio were used for deployment of the ML model. *A pipeline was setup to pass the real time data* from SQL to the ML model and return the predictions to SQL.



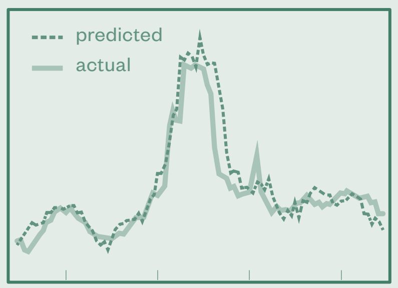
Data Visualization
Microsoft Power BI was used for presenting the predicted results of the ML model. *The dashboard includes a tool to estimate the optimal point to fill the equalization basin to maximize its utility.*



Hourly flow predictions from the Azure pipeline are stored in the same SQL server, which Power BI queries hourly and displays the prediction.

4 ML Evaluation and Retraining

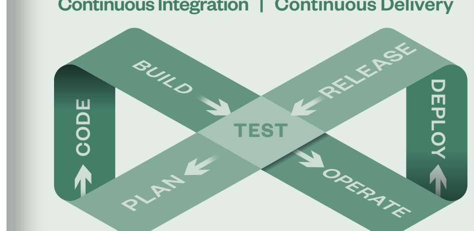
Performance Evaluation
Comparing the prediction with the actual values quantifies accuracy and any need for retraining. *Below we see how well the Raleigh model predicts a recent storm 3 hours in advance.*



Continuous Integration (Automated Retraining)
Retraining involves *returning to the model training step and adding all the data gathered since the model was last deployed* to the training data. The performance of a retrained model and the deployed model are then compared.

Continuous Deployment
The more accurate model becomes the productionized version. *This allows the model to stay current as system changes occur without having to rebuild the pipeline, thus maximizing the investment.*

Continuous Integration | Continuous Delivery



Note: Continuous training was not included in the Raleigh project but may be implemented in the future.

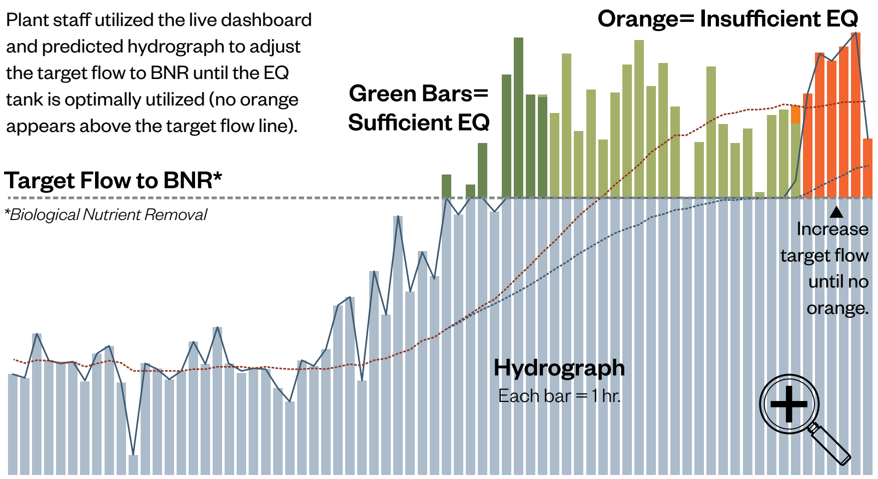
Holistic Wet Weather Management Combining Machine Learning, Treatment Plant Optimization, and Predicting Collection System Influent Flow Hydrographs

CASE STUDY

The 75-mgd Neuse River Resource Recovery Facility (NRRRF) operated by Raleigh Water in North Carolina has a daily flow of 48 mgd and peak hydraulic capacity of 225 mgd.

The facility has stringent total nitrogen (TN) limits of less than 3 mg/L at permitted flow, and a quarterly average effluent total phosphorus limit of 2 mg/L. High flows can impact the facility's ability to meet these strict nutrient limits; influent flows increase dramatically during heavy and/or sustained rainfall, which can shorten treatment time.

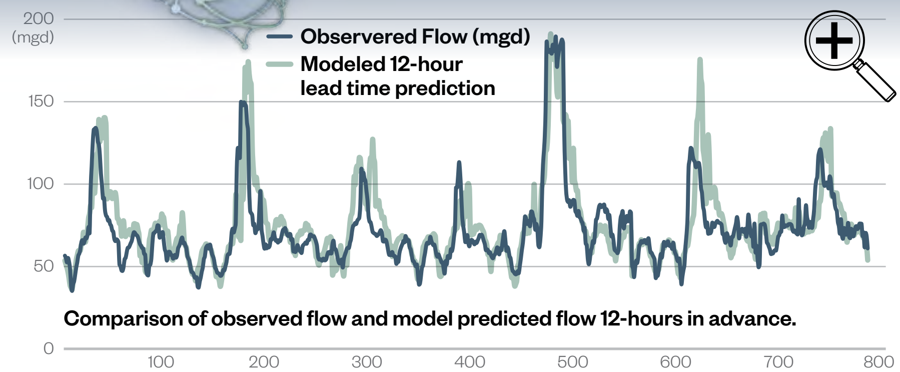
The NRRRF has a 32-million-gallon equalization basin (EQ) to withhold a significant portion of the flow and load entering the facility during high flow events. Historically, NRRRF staff utilized collection system pump station data, weather forecasts, and experience to determine when to move flow into the EQ basin.



Pump station data provided about 30-60 minutes of advance warning but could not predict if flows would continue to increase, leaving operators to use their own judgement and experience to optimize the utility of the EQ basin. Raleigh Water realized requiring a human to process the available data and recall how past storm events unfolded was neither practical nor efficient, and that it could benefit greatly from a quantitative model with the ability to predict the flow hydrograph in advance of and during a rainfall event.

Raleigh Water has a traditional collection system model and collection system flow monitors. The collection system model is an excellent tool for planning but is not equipped to provide flow forecasts in real-time, and the flow monitors are not predictive. Hazen determined that this would be an excellent opportunity to develop and implement a machine learning tool to provide real-time flow hydrograph forecasting.

The model development process was conducted entirely on a desktop computer. Hazen used supervised and unsupervised machine learning to gain insight into the input parameters that best predict future flow. The resulting model has 77 inputs, including streamflow, rainfall (past and predicted), and past plant flow. The ML algorithm was calibrated to 6 years of historical data, covering 38 storms, and the model accuracy was +/- 2.8 mgd for any point during the storm. Once the desktop model was developed, the project entered the deployment step.



Comparison of observed flow and model predicted flow 12-hours in advance.

Azure and SQL were used for the automated data pipeline, with predictions displayed in a web-based Microsoft Power BI dashboard tool. The entire pipeline including data visualization dashboard was securely deployed to work alongside a closed SCADA network. The model errs on the side of being conservative, occasionally predicting a flow that is higher than the actual wastewater flow. Local streamflow surfaced as the most significant variable in predicting the peak flow, so models that predict future streamflow based on predicted rainfall quantities were also developed and incorporated into the ML model.

The project was deployed in a test mode in December 2019 and completed in July 2020. Since then, at least eight major storm events—including Hurricane Isaias—have occurred and been predicted well beforehand. With this tool the plant implemented its wet weather standard operating protocol: putting 2 additional primary clarifiers online, then one additional BNR basin, and finally diverting flow to the EQ basin. Raleigh Water has employed wet weather equalization four times since the model was finalized and the equalization basin volume was never exceeded. The largest rainfall event involved 6.7 inches of rain over a 9-hour period with a peak rainfall intensity of 4.5 inches per hour. Seventeen of the available 32 mg in the EQ basin were utilized and effluent quality the day after the storm was the same as the day prior, indicating the program helped the utility maintain superb nutrient removal and properly utilize its equalization volume.

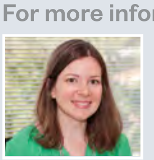
The resultant model is an extremely valuable tool that provides operators with highly informed decisions, resulting in greater efficiency and reliability to meet stringent effluent limits. The model is responsive to real-time measurements of streamflow, rainfall, and plant influent flow, and its accuracy generally improves the closer it gets to the wet weather event actually occurring.

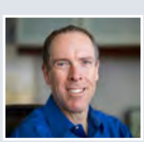
The Future of Machine Learning and Water

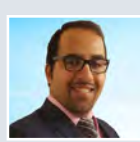
Using machine learning tools alongside expert knowledge will empower the water industry to make more informed and timely data-driven decisions. Machine learning is scalable and can be used to provide timely output for manual operational decisions, or to provide real time operational recommendations and even operational control.

The practical application and planning of ML in operations is expected to increase rapidly as sensor accuracy, prices, and communication speed continue to rapidly improve. The key is to understand the problem at hand, apply the right tool, understand its limitations, and include human expertise in all phases of development and deployment.

For more information contact:


Katya Bilyk, PE


Sean FitzGerald, PE


Javad Roostaei, PhD

OVERVIEW

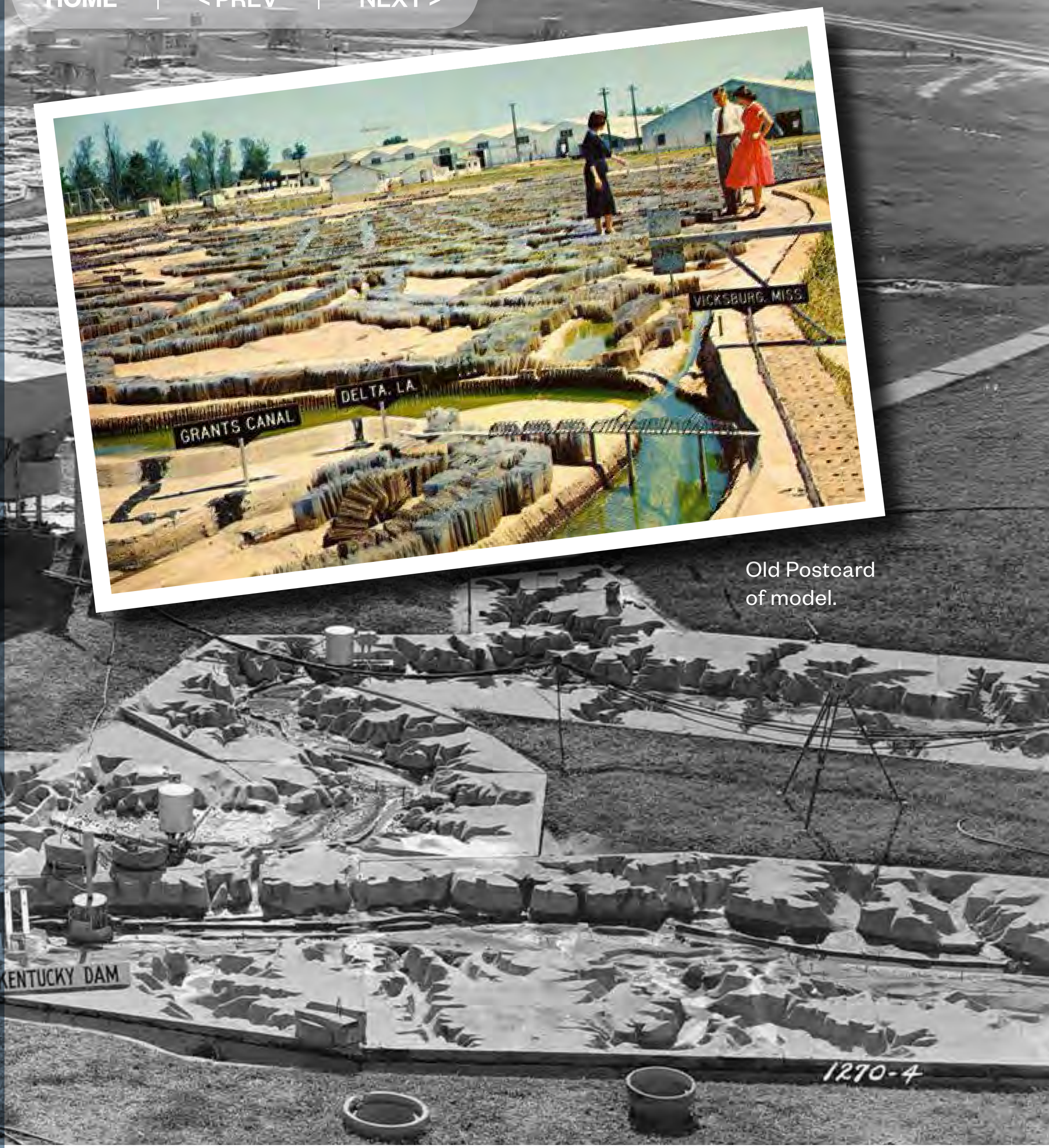
River Basin Water Supply Modeling

The predecessors to today's sophisticated river basin models originated in the 1940s with scaled down physical models of river systems like the Mississippi.

Water could be added in large volumes "upstream" to gauge where flooding might occur and infrastructure could be added to simulate the impact of a new dam or reservoir on those same flood conditions.

These models were developed with an understanding that local management of river processes was imperfect – that a bigger picture, holistic view was needed for effective management.

Over time, these physical systems were represented with electrical analogs, then with resistors and capacitors, equations, and ultimately with computer software. As computer power increased over time, the level of detail and sophistication of models advanced.



Old Postcard of model.

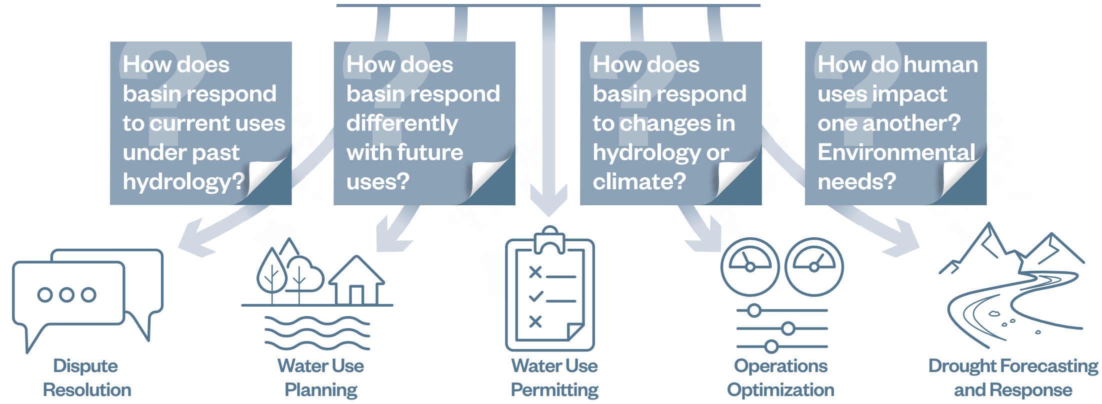
Basin water supply models are designed to simulate how storage and flow in networks of reservoirs and streams vary over time—from days to decades—using observed or proposed withdrawals by water users, return flows by dischargers, reservoir operations and evaporation losses, inter-basin transfers, and any other human or natural process that impacts the basin water balance.

These models are used to evaluate the system-wide impacts of local water decisions and use on availability, water quality, and other criteria basin-wide. They are often used to support basin-wide regulatory planning and permitting, resolve disputes among water users, inform environmental impact assessments, detect supply risk due to drought, and evaluate future operational and structural options for improving supply reliability. Models may also include integration with real-time data systems for operational decision-support, inflows under climate change scenarios or paleoclimate conditions, and/or water quality models. Basin water supply models are typically developed through several common tasks, illustrated on the following page.

Hazen's Basin Water Supply Modeling

KEY BENEFITS

The model is a flexible, living tool that can help answer vital questions supporting adaptive management.



MODEL TEMPLATE

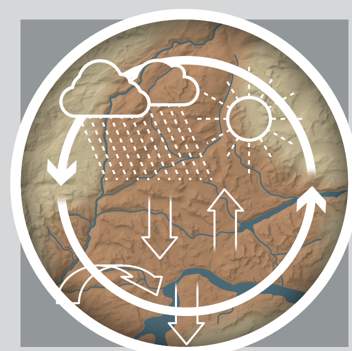
Basin water supply models are typically built through a series of sequential tasks.

Frame Scale & Scope of Model

Identify the problem to be solved and performance metrics for decision making.

Draw River Basin Network

Use the network to show how water flows between reservoirs, withdrawers, dischargers, streams, pipes, aqueducts, and other locations of interest.

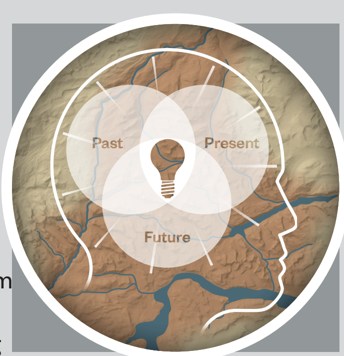


Perform Water System Balance

Run historical inputs of runoff, baseflow, withdrawals, discharges, and reservoirs to validate the model, comparing them to gage flows and/or historical reservoir elevations.

Develop Model Logic

Use model logic to describe current, past, or proposed future water actions by emulating the effects of human-controlled actions at predetermined time intervals. Logic controls how much water is transferred from one node to another at each time step, while also enforcing priorities and limits on uses.



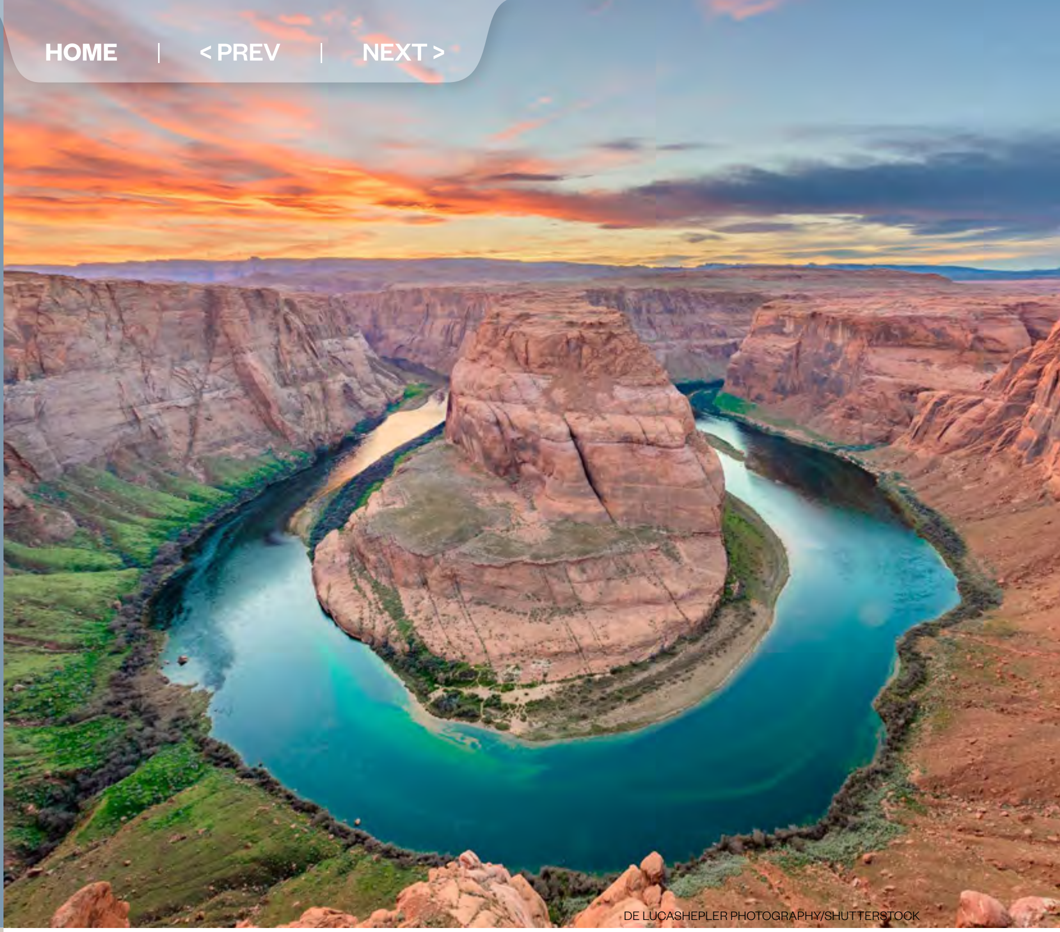
Apply Model

Apply the model to **simulate the impact of changes** to the system in order to develop solutions to the problems posed in Step 1. The flexibility of the model allows for an array of possible applications, including some that may not have been anticipated beforehand.

CASE STUDY

Colorado River Basin Modeling Supports Local Planning Efforts

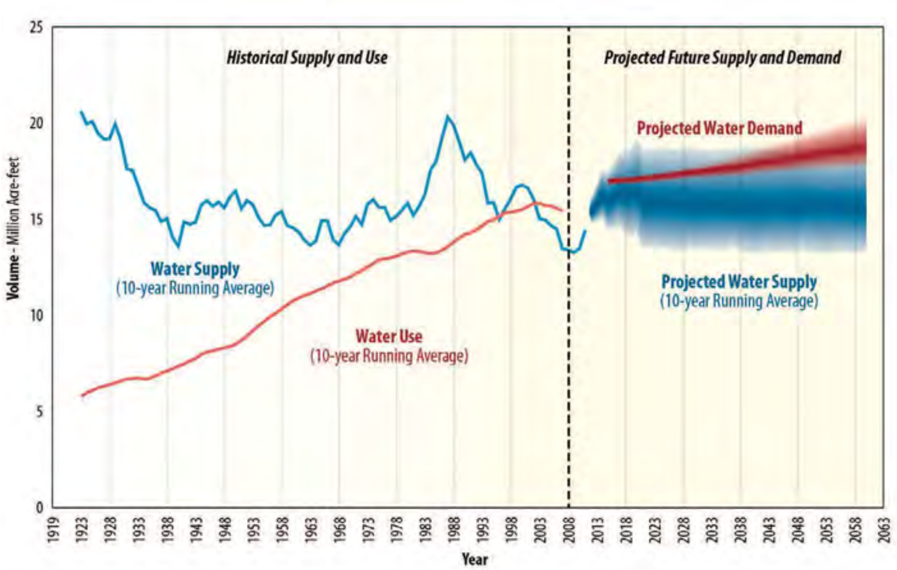
The Colorado River Basin spans seven states and encompasses 252,000 square miles. It serves more than 40 million people as well as over 5 million acres of farmland and is an important economic and water resource locally and nationally. Inflow varies greatly, and as demands have increased and drought persists, the need to prepare for the range of potential future conditions is paramount.



DE LUCASHEPLER PHOTOGRAPHY/SHUTTERSTOCK

The Colorado River Simulation System (CRSS) basin model was developed in the 1970s by the Bureau of Reclamation and translated to the RiverWare software platform in the 1990s. The model uses inflow and demand data along with usage rules to route water through the system and is intended to be used for long-term planning, short-term operational planning, and regional or local planning. Long-term projections were used most recently in the Colorado River Basin Study (2012) that examined potential alternatives to mitigate projected future gaps in supply and demand through 2060.

Historical Supply and Use | Projected Future Colorado River Basin Water Supply and Demand

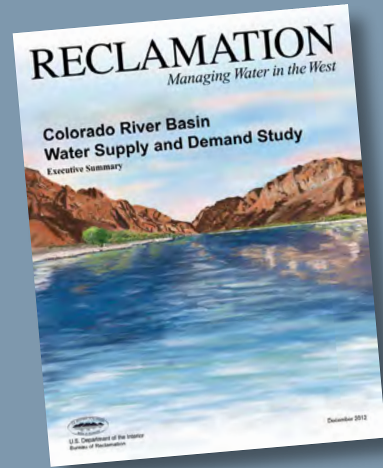


NOTE: Water use and demand include Mexico's allotment and losses such as those due to reservoir evaporation, native vegetation, and operational inefficiencies.

COLORADO RIVER BASIN WATER SUPPLY AND DEMAND STUDY, U.S. DEPARTMENT OF THE INTERIOR BUREAU OF RECLAMATION, 2012

The output of CRSS provides insight into potential future conditions and the model is under continuous development with new features added to better represent the system and provide improved tools for decision making. It was most recently used by Hazen to inform efforts to develop the City of Santa Fe's Water Resources Planning Model.

The CRSS has been the primary tool for evaluating water supply, operations, and environmental impacts. It was instrumental in developing guidelines and evaluating treaty minutes. Likewise, the model will continue to be important in evaluation of options as the interim guidelines for operations expire.



CASE STUDY

Tennessee Duck River Basin Modeling Facilitates Consensus on Minimum Flows

River Basin models can play a key role in building relationships and solving problems with diverse and, at times, opposing stakeholder groups. When a model is developed collaboratively and/or transparently— fostering confidence in its outputs—negotiations, planning, and emergency responses can be grounded in the realistic conditions captured in the model.

Using Hazen's OASIS modeling software, a planning effort was conducted on Duck River and Normandy Reservoir with a 100-year daily historical inflow record. Analysis showed that the system would be able to meet projected system demand and downstream flow targets for the next 50 years with very high reliability. The Duck River Agency established a planning process to periodically review demand projections and other system requirements and in 2003, the Agency adopted its first basin water supply plan.

In 2017, Hazen led an operations exercise using the OASIS model (see photo above) to test water management scenarios in a virtual drought before the next real drought hits.

When a drought-of-record hit in 2007, both the model and relationships were already in place to negotiate acceptable flow and water use reductions. Trust in the model and between the various stakeholders helped to facilitate consensus on a drought response plan by the end of September and an environmental assessment by mid-October of that year. Operational changes were then adopted and continued through February 2008.

Hazen is currently using the basin model to evaluate allocation schemes that include a new withdrawal several river miles downstream from the existing utility intakes. Application of the OASIS model has provided a platform upon which regulators, utilities, and environmental stakeholders can reach consensus on key decisions in the Duck River basin.

CASE STUDY

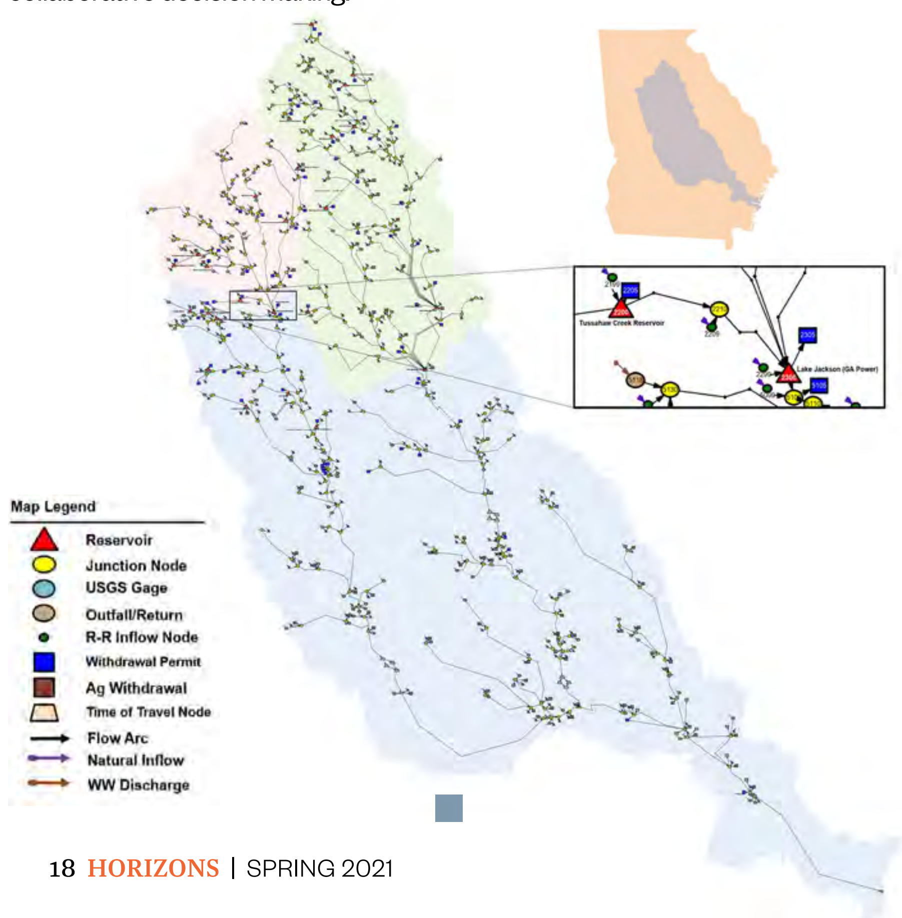
Georgia Basin Modeling Facilitates Integrated Planning and Permitting Decisions

State regulatory agencies often rely on river basin models for planning and permitting activities. Georgia Environmental Protection Division (GAEPD) has recently joined Kansas, North Carolina, and Tennessee in acquiring a state-wide license for Hazen's OASIS software to support the state's water withdrawal permitting activities and Statewide Water Plan development.

Assessing potential local and basin-wide impacts of new permits anywhere in the state necessitates an unusual combination of fine spatial resolution and large geographic scope.

Through a pilot study for GAEPD, Hazen completed one such model for the Oconee, Ocmulgee, and Altamaha (OOA) River system which spans from eastern Atlanta and Athens to the coast near Brunswick. The OOA model includes each individual permitted withdrawal, outfall, and water supply reservoir on each reach and tributary, resulting in approximately 850 individual nodes (compared to 11 planning nodes in the prior model for Statewide Water Plans in the same basin). To build a model of this complexity, Hazen devised several enhancements to automate modeling procedures that are normally performed manually, including schematic development, upstream-downstream location searching, and unimpaired inflow calculation incorporating microscale basin-wide rainfall/runoff models.

The more granular model also benefits Statewide Water Plan updates, which have to contend with a range of stakeholders and could not previously take into account mitigation actions and corresponding impacts by individual users. With a runtime of only 5 minutes, the model can be applied in real-time during planning meetings. Through this and upcoming follow-up efforts, Hazen will develop similar models for all 15 major basins spanning the entire state. These models will be used to facilitate effective statewide planning to ensure that utilities, local governments, and regulatory agencies fully understand the implications of current and future surface water withdrawals, impoundments, and discharges on supply reliability. This effort indicates that value can be achieved efficiently in a package that can also be applied for future, collaborative decision making.



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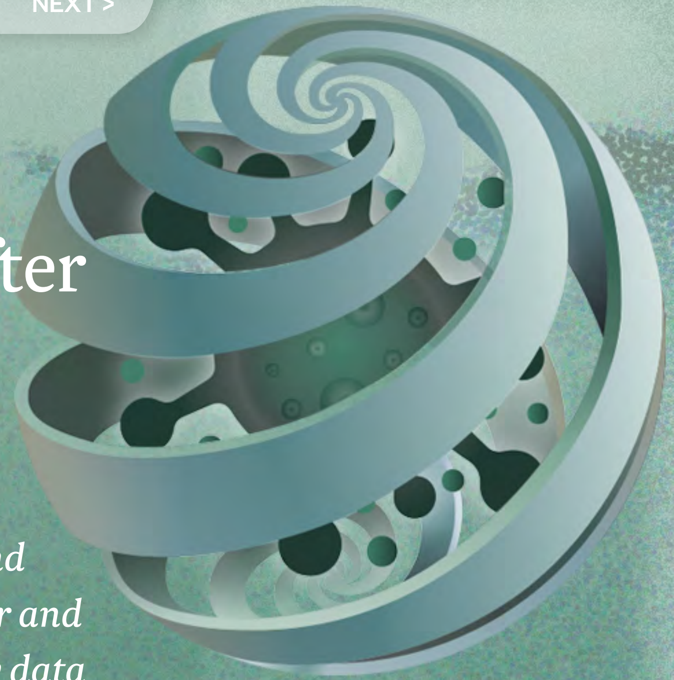
UTILITY TIPS

Maintaining Financial Resiliency During and After the COVID-19 Pandemic



Business shutdowns and stay-at-home orders resulting from the COVID-19 pandemic have significantly contracted America's economy and quickly reshaped the demand for potable water and wastewater treatment at many utilities. Utility data indicates a dramatic decrease in water consumption by commercial, government/institutional, and industrial customers. Concurrently, residential demand has surged in many communities. Domestic wastewater generation patterns have followed a similar pattern.

The magnitude of financial impacts to individual utilities will be driven by customer demographics, local economic conditions, pre-COVID-19 financial strength, and the duration and extent of the regional lockdown. Changes in the demand for water and wastewater services could have far reaching impacts on a utility's creditworthiness, its rate affordability, and its capacity to execute capital investment plans to meet level of service objectives, including robust asset management.

The pandemic has heightened the need for utilities to identify potential vulnerabilities to their long-term financial health and develop strategies to manage those risks. By taking a phased approach in addressing financial risks, utilities can improve resiliency, weather the COVID-19 pandemic, and cope with other unforeseen disruptive events that may occur in the future.

> *America's water utilities entered the pandemic as one of the most financially healthy sectors in the U.S. economy. As such, most will be able to maintain their financial health in the face of continuing economic turbulence and uncertainty. However, moving forward all utilities should continuously review their financial management practices so that they emerge from this pandemic stronger than ever and prepared for whatever the future brings.*

The short-term magnitude of financial impacts to drinking water and wastewater utilities is projected to be quite large.

In April, the American Water Works Association (AWWA) issued a report that estimates revenue losses of up to $15 billion or 20% on an annual basis at drinking water utilities.

The National Association of Clean Water Agencies (NACWA) estimated wastewater revenues decreasing by $12.5 billion.

A survey conducted by AWWA during the first week of June reported that 32 percent of the respondents were experiencing a decline in revenues compared to the previous year.

CASE STUDY

PHOTO BY BOBAK HA'ERI

The Town of Nantucket in Massachusetts is a relatively affluent community and well-known tourist destination. It also has a very substantial 10-Year CIP estimated to cost $231.8 million. Gauging the magnitude of impacts of the CIP on the Town's finances, including the impacts on sewer rates and property taxes (the latter of which is used to fund much of the capital expenditures) was difficult because the Town did not have a robust planning tool. ***Nantucket tasked Hazen to perform a series of financial evaluations including a financial capability assessment, development of a dynamic rate model, and a financial investment timing model to prioritize and optimize the proposed investments.*** The series of financial evaluations identified— among other issues—that under the current rates the Town would generate insufficient revenue in the Capital Improvement Reserve to cover debt service by 2024. Accordingly, the Town has conducted a detailed reassessment of its rates, its rate structure, and other financial management practices to ensure that sewer program costs are fully funded, debt service payments are covered, all costs are borne in an equitable manner, and that a robust planning process is put in place to ensure the financial health and resiliency of the Town's Utility Department.

These initiatives will not only ensure that the Town will meet all its financial obligations but will have built a planning process to ensure its financial health even under unpredictable, adverse economic conditions.

Potential Financial Risks... ...From Unpredicted Events

	ISSUES	PHASED APPROACH TO ADDRESSING FINANCIAL RISKS	
PHASE I	• Distribution of cash flow • Large changes in revenue source allocation • Maintaining staffing levels • Disruption of CIP projects • Loss of utility rate revenue	• Conduct scenario planning to identify all potential impacts • Review payment policies and procedures to maximize collected revenue • Review rate structure to ensure revenue adequacy and equitable rate class allocation	• Review all critical financial metrics • Evaluate State and Federal emergency assistance options
PHASE II	• Sustained reduction in projected revenue • Misaligned rate structure • Increased affordability issues • Shortfalls in planned financing of CIPs	• Repriortize O&M and capital improvement expenditures • Determine need and identify Federal, State, and Municipal funding assistance to further reduce capital costs (SRF, WIFIA loans)	• Identify potential opportunities for cross-training of management and operations staff • Reassess rate levels and structure to cover changes in cost of service
PHASE III	• Meeting regulatory requirements • Bond rating downgrades • CIP planning and execution disruptions of mission critical projects	• Optimize overall debt structure • Leverage existing low interest rates to lock-in long-term savings • Obtain competitive labor and construction materials costs given macroeconomic conditions	• Invest in Smart System Technologies including Advanced Meter Infrastructure

More on Economic and Financial Studies Support

Moving Forward

Across the country, utilities implemented emergency and business continuity plans at the onset of the COVID-19 pandemic to ensure seamless operation of their facilities and protection of their workers and the communities they serve by purchasing PPEs, rotating operations workers, and performing business functions remotely where feasible.

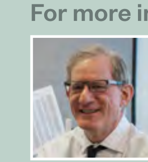
While some initiatives were implemented immediately, others can have progressively longer time horizons. Because the timing of businesses reopening is uncertain and will vary by location, progress will not be uniform or linear, especially if there are continued cycles of "reopening" and "closing" the economy. As the recovery ultimately begins to take hold, utilities should gain a greater insight into what the "new normal" will look like.

Although the financial impacts to water utilities have been highly variable and less severe than first expected, many uncertainties remain. Revenues may continue to be lower than normal; rate structures might become misaligned, unemployment rates might remain elevated, and low-income households, who have been disproportionately impacted by the pandemic could face increasing affordability issues. As future spikes and further spread of COVID-19 are possible, and as the benefits of the Federal financial stimulus packages wane over time, additional water and sewer bill defaults are possible.

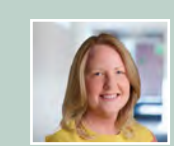
Frequent, rapid changes in the status of (and response to) the pandemic makes predictions of long-term financial impacts more difficult. Changes in business practices and consumer preferences and behavior may have lasting effects that could affect future expectations and long-term outlooks. Utilities should consider potential longer-term impacts of the pandemic on regulatory compliance, bond ratings, CIP planning, and the execution of mission critical projects with longer horizons. Utilities with AAA Bond ratings typically have more than a year of operational reserve while a less financially secure utility might fall short of even the minimum target of 90 days. Early indications are that utilities are carrying on with ongoing projects but are delaying new project startups to maintain cash reserves in a time of tremendous uncertainty.

Accordingly, it is important that utilities reassess all aspects of their financial management and identify strategies and policies that will enhance their financial resiliency to disruptive events such as the COVID-19 pandemic while considering the chance of future events with similar or even greater disruptive power. For example, it would be prudent to reassess whether consumption behavior has changed sufficiently to reassess the current rate structure and future water supply plans. Scenario planning can also be used as a "stress test" to help utilities identify where they are most vulnerable, so plans can be developed to manage and mitigate impacts should the pandemic continue or be confounded by other macroeconomic conditions.

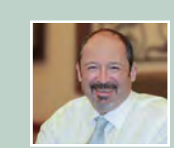
For more information contact:



Alan Karnovitz, MPP



Grace Johns



Jack Kiefer

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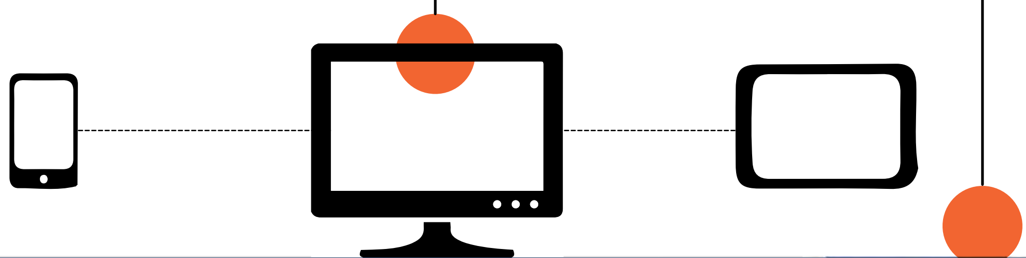

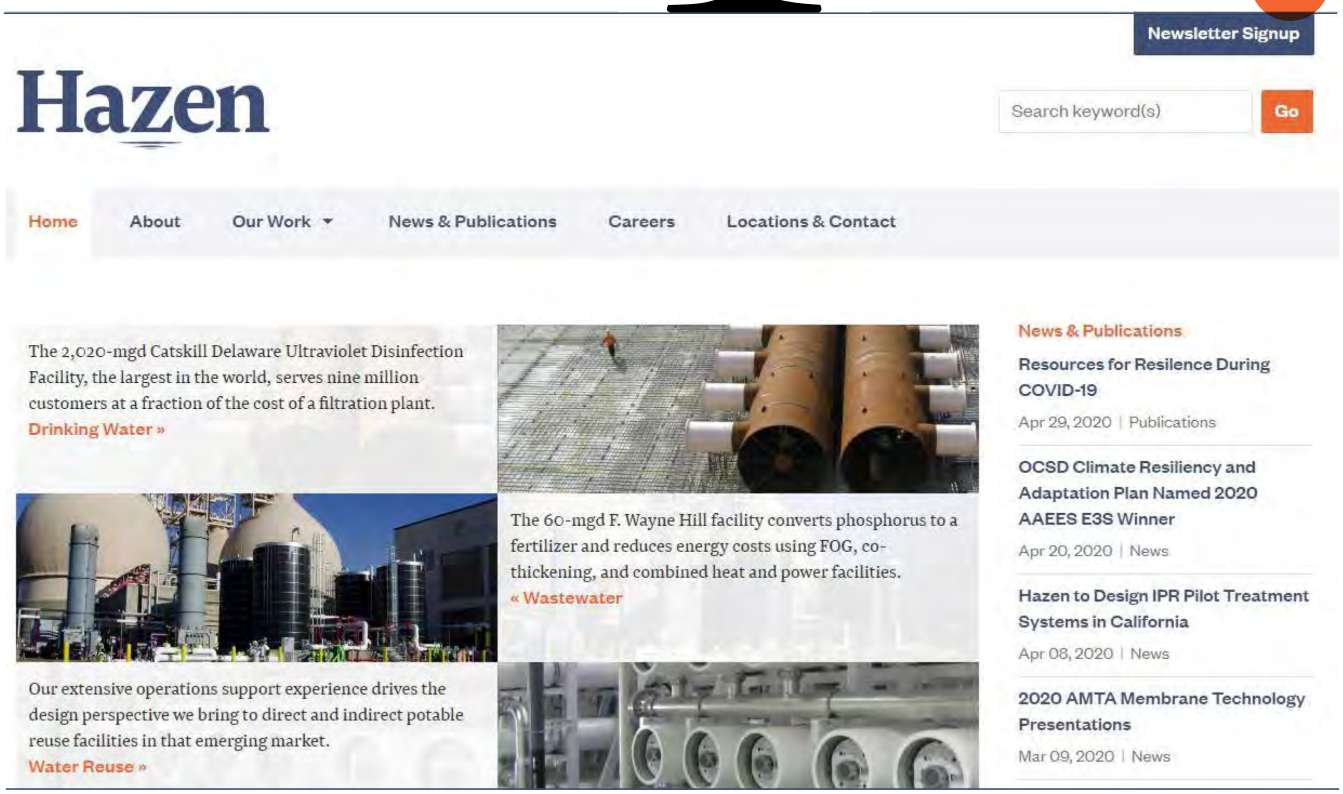

HORIZONS
water environment solutions

On the Cover:
Crocus Spring, Silver Spring, MD

Hazen

Published by Hazen and Sawyer