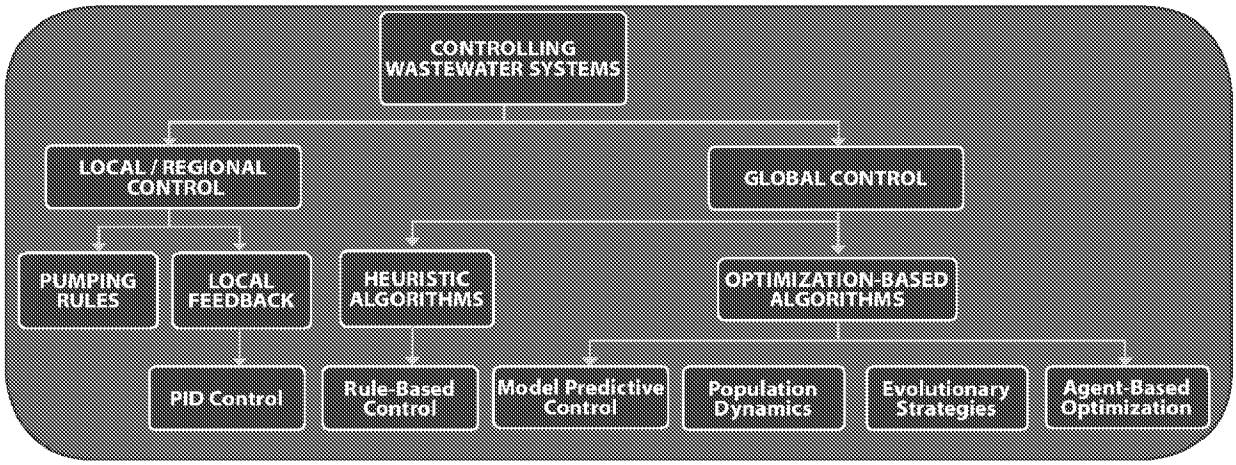


Figure 4. Control strategies for wastewater utilities

Optimization-based strategies involve an optimization problem that represents the desired behavior of the wastewater system. Various algorithms can be used to solve the optimization problem (e.g., model predictive control, agent-based optimization). More detailed descriptions of optimization strategies and mathematical models can be found in Papageorgiou (1988) and Garcia-Gutierrez et al. (2014).

In the last 20 years, model predictive control has been the most extensively used optimization-based strategy. This approach uses a mathematical model of the wastewater system to generate a sequence of future actions—within a finite prediction horizon—that minimizes a cost function (Gelormino and Ricker 1994). Interest in model predictive control is justified by its ability to explicitly express constraints in the system, anticipate future system behavior, and consider non-ideal elements such as delays and disturbances.

Optimizing the collection system requires continuous and strategic adjustment of control devices, as well as predictions of upcoming inflows and their spatial distribution (Cartensen et al. 1998). With proper conditions being monitored, acknowledged, and controlled, a **global RTC system** considers the distribution of flow in the entire system, both in current conditions and in the future. By using a global RTC, a utility has the ability to control flow by opening and closing gates or pumps allows for transfer flow and storage capacity between sites, thus providing the temporary storage and controlled release of significant volumes of wastewater.

Table 2 summarizes which components of the overall system must work properly to support different control modes/levels (U.S. EPA 2006). Notably, forecasting may be part of a rule-based system, but it is not mandatory. A global RTC system often involves a mixture of lower levels of RTC and static controls.



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Table 2. Components Required for Different Control Modes

| Control Mode | Instruments | PLCs | SCADA/Communications | Central SCADA server | Active Operator Input, Monitoring | Central RTC Server | Rainfall Forecasting | Online Model |
|---|---|---|---|---|---|---|---|---|
| Local manual control | X | | | | X | | | |
| Local automatic control | X | X | | | | | | |
| Regional automatic control | X | X | X | X | | | | |
| Supervisory remote control | X | X | X | | X | | | |
| Global automatic control—rule-based | X | X | X | X | | X | | |
| Global automatic control—optimization | X | X | X | X | | X | X | X |

## 5.4 Guidelines for Applying RTC

In most cases, RTC implementation can offer benefits and improve the performance of urban wastewater or stormwater systems. The costs and extent of these benefits may differ from one system to the next.

The first step in evaluating if RTC is a suitable and viable solution for a utility is to develop criteria for a macroscopic evaluation of RTC potential using a scoring system (Erbe et al. 2007, Schütze et al. 2004). Criteria may include environmental and financial objectives, the topology of the catchment area, collection system characteristics and conditions, operational system behaviors, etc.

The utility may, however, skip the first step if it has already invested in a hydrological and hydraulic model that adequately represents its system and operation and/or has substantial monitoring coverage (which provides good system understanding and condition assessment). The utility can use these existing tools and data in the second step, which involves a preliminary analysis of RTC potential and costs/benefits. The analysis should include a simulation study of a full range of RTC control levels to determine which is the most appropriate; staff interviews with operators, engineers, and other stakeholders; and equipment surveys.

If the various scenarios demonstrate the feasibility and benefits of RTC, the third step involves detailed planning of the RTC system and its implementation, including:

- Detailed planning of control infrastructures.
- Detailed design of control algorithms.
- Risk and failure analysis.
- Detailed design of data infrastructure (or gap analysis if data infrastructure exists).
- Staff training and other organizational planning (i.e., new roles and responsibilities).
- Preparations for obtaining consent by the regulatory authorities.

It is critical to involve operator input from the beginning of the design process. The operators are ultimately responsible for the system operation and performance. Early involvement will ensure that operators' O&M concerns are



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addressed in the system design and that operators buy in and accept the RTC system.

## 5.5 Key Considerations for RTC Systems

An RTC system should have robust operation, adequate communication, supervisory manual override, operational confidence, and adaptability (Gonwa et al. 1993, Colas et al. 2004). The system must be designed and configured to ensure a high level of performance under normal conditions and safe operation under downgraded conditions. Its performance should be better than or equal to the system that existed before RTC implementation.

Under all conditions, there are critical constraints, such as operating safely, avoiding equipment damage, and avoiding flooding. A well-designed RTC system must effectively manage different operational objectives and transition between different operational modes to operate reliably and efficiently; at a minimum, it must address externally caused equipment failures and emergency conditions.

The fail-safe procedures must be configured so that they are triggered when the requirements for the system's current operational mode cannot be met. These procedures should automatically place the system into the next (lower) mode/level of operation that can be fully supported. For example, if the system is operating in local automatic control mode and the PLCs malfunction or lose power, it would need to revert to local manual control.

RTC system risk management procedures must include the ability to deal with emergency conditions detected using field measurements.

Special rules can be defined to react to conditions such as rapidly rising levels within the system. The emergency response can be either to adjust the automatic control strategy or change operational mode by giving the operator a standard operating procedure.

**Using Smart Data Infrastructure to Promote Resiliency**

In response to the historic drought conditions recently experienced in California, the city of San Diego has decided to quantify the potential nexus between stormwater capture and its ongoing effort to reclaim wastewater as a drinking water resource (San Diego currently imports more than 80 percent of its water supply). The city equipped its stormwater control measures with RTCs and assessed them to optimize the management of stormwater storage and release to the reclaimed water system. The simulations suggested that stormwater harvesting could substantially augment local water supplies while complying with stormwater quality regulations.

The reliability of all RTC system components is key to successful implementation. In addition to fail-safe and risk management procedures, system effectiveness can be obtained through the following:

- Proper selection, location, and number of sensors to ensure accurate and adequate measurements.
- Installation of redundant equipment at key locations using different technologies.
- Real-time validation of monitoring data to minimize the amount of low quality data entering the decision-making process.
- Design of safety features, including emergency isolation gates, power supplies, generators, and equipment interlocks specifically designed for safe operation when a critical alarm is activated.
- Preventive and targeted maintenance to ensure equipment availability.
- Stock of replacement pieces for critical infrastructure.



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# 6. Data Management and Sharing

Good data management and sharing can allow operators and control systems to integrate data faster and more effectively. Organized and carefully designed data management systems readily obtain and act on data from various sources, reducing redundancy and the cost of collection system operation.

## 6.1 Big Data Management

More monitoring requires more data management and storage. To address the challenges of storing, processing, recovering, sharing, and updating large data sets, organizations are finding smarter data management approaches that enable them to effectively corral and optimize their data use.

Some of the best practices for big data management are to reduce the data amount (because the vast majority of big data is either duplicated or synthesized), to virtualize the reuse and storage of the data, and to centralize management of the data set to transform big data into small data (Ashutosh and Savitz 2012).

A smarter data management approach not only allows big data to be backed up far more effectively, but also makes it more easily recoverable and accessible at significantly lower cost. Other benefits include the following:

- Applications require less to process data.
- Data can be better secured because management is centralized, even though access is distributed.
- Data analysis results are more accurate because all copies of data are visible.

## 6.2 Data Sharing

In addition to the needs of public notification and regulatory reporting (e.g., post-construction performance monitoring, permit compliance), there is a rising need for data sharing among various departments within an organization to improve efficiency and interoperability. Organizations must also be able to securely exchange data with outside administrative domains for transparency and for integrated solutions on city-wide or region-wide scales.

As more data have moved to cloud-based storage, the protection and encryption of off-site data has become more important. While there are still cybersecurity risks, significant improvements have made it much more difficult for outside parties to access critical data and information.

**Cybersecurity**

The interconnectivity of hardware and data management has increased the need for utilities to plan and manage cybersecurity. Although networking multiple systems provides operational value, it can also expose systems to new data security risks. As utilities move to advanced data storage solutions, addressing cybersecurity will be an essential aspect of master planning activities. Cybersecurity provides insurance to protect utility assets against attacks, outages, and threats, and it reduces the costs of downtime.

Key considerations for data infrastructure and data sharing include the following:

- As organizations become more dependent on cloud-based systems and other internet-based solutions, the importance of a robust, maintainable, and secure network infrastructure becomes critical. Nothing works when the network goes down. Secure, redundant, and scalable internet connections are now required for day-to-day business as essential processing is moved off site.
- Network architecture is increasingly important, and robust, secure solutions must be designed into systems to manage



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devices potentially numbering in the thousands, each with multiple data points. Simply using a "firewall" to secure a network is no longer feasible.

- Formerly isolated SCADA/industrial control systems (ICS) are now required to communicate over the internet. To securely realize the vast benefits of cloud computing and the IoT, secure data interconnectivity is essential. Standards have been produced to ensure a high degree of interoperability and security for evolving SCADA/ICS solutions.

**Emerging Technologies for Big Data Management**

For big data management, all types of data analytics will be more widespread and incorporate more artificial intelligence. Already, machine learning has been applied in predictive analytics for I/I characterization, based on analysis of long-term data trends.

**Real-Time Public Notification with SmartCover™ Systems**

The city of Newburgh, New York, replaced its combined sewer telemetry system with a wireless SmartCover™ System. The prior telemetry system used pressure sensors that had to be located beneath the influent channel, in direct contact with the flow and in the combined sewer regulator environment where they would be regularly impacted and damaged or displaced by debris. The new SmartCover™ System's sensors hang from the manhole cover above and do not contact the water, avoiding damage. The new system's wireless satellite connectivity is more reliable than land phone lines at a lower cost. Any computer, tablet, or smartphone with internet access can communicate with the telemetry system, allowing for real-time staff and public notification of CSO events.

## 6.3 Real-Time Public Notification and Transparency

Implementation of a smart data infrastructure allows utilities to disseminate relevant and current information to ratepayers and stakeholders. Public notification is becoming the norm for informing interested parties of current utility conditions. While some data must be kept private due to security issues related to protecting treatment processes, some data can be shared to better inform the end user. A common example includes the public notification for current/recent overflow activity to local receiving waters. The real-time notification of overflow activity informs the public that recreational uses may be temporarily compromised, potentially reducing public health issues. Public notification can also include automated notification to the regulating agencies as part of permit requirements.

# 7. Data Analytics

Most utilities already generate a substantial amount of process and monitoring data for various purposes. As the amount of data generated each year increases at an exponential rate, it is increasingly critical to convert those data into useful information (Greiner 2011). Technical advancements in complex multidimensional data analysis and data mining can help utilities analyze incredible amounts of data to detect common patterns or learn new things. This can lead to significant operational improvements and dollar savings for wastewater systems.

Big data analytics, a well-established concept, involves analyzing the data collected to discover trends and correlations, uncover hidden patterns and other insights to understand why certain behavior or incidents happened, and



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then use that insight to predict what will happen. Today's technology and advancements in big data analytics bring speed and efficiency, which enable utilities to analyze large quantities of data and identify insights for immediate decisions (Figure 5).

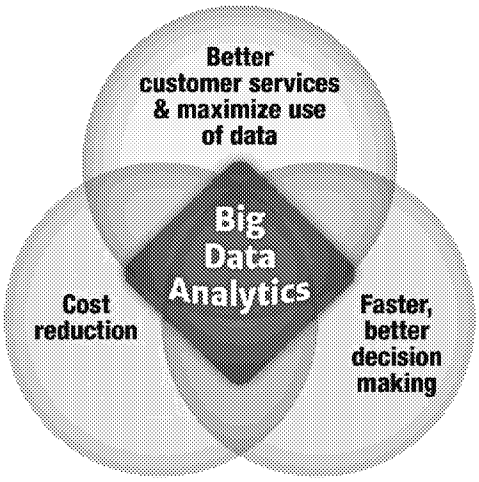


Figure 5. Big data analytics support enhanced decision-making and more effective and less costly operations

Utilities that have already invested heavily in continuous monitoring could use data analytics to get significant value from the data they collect.

There are many data analysis and data mining solutions, which also incorporate data warehousing, database management systems, and online analytical processing.

## 7.1 Data Validation and Filtering

Data validation is an important consideration for wastewater utilities, particularly for monitoring data within the harsh environment of a wastewater collection system. Raw monitoring data can contain erroneous readings, which could be due to one or a combination of the following:

- Noise (high frequency fluctuations)
- Missing values
- Values out of range
- Outliers (sudden peaks)
- Constant (or frozen) values
- Drifting values (changes in values over a longer period of time)

As the quality of the insights gained from data analytics or the control system's performance will be directly linked to the quality of the data used, raw data collected from the sensors needs to be validated and possibly filtered before being used for further analysis or control purposes. This is an important step to improving the data's reliability.

**Emerging Technologies for Data Analytics**

The IoT industry trend is to provide more accessibility through cloud computing platforms and open source technologies. The digital platform will streamline the integration of data from various legacy systems and eliminate data duplication and bad data for more effective and powerful data analytics and insight. Cloud-based computing has already been implemented for SCADA system applications and RTC applications.

Data validation can be carried on a single variable (single data validation methods) or by comparing two variables when two or more measures are correlated (cross-validation) (U.S. EPA 2006, Sun et al. 2011).

Single data validation methods include the following:

- **Range validation:** The values that are outside an expected range are flagged as invalid. The expected range is based on the working range of the sensor itself and on the process monitored. For example, a water level in a collection system cannot be lower than the bottom of the chamber where the sensor is located and can seldom exceed ground level.
- **Gap filling:** When data are missing (due to communication failure, sensor automatic



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calibration, etc.), it is possible to use an estimate instead. In a real-time context, the last valid value can be used. If correlation exists with other measurements, cross-validation techniques can also be used to produce better estimates (see below). In a post-event analysis, a simple linear interpolation between the values before and after the gap can often be used.

- **Rate of change validation:** If values change at a greater rate than a probable change in measured conditions and sensor noise, then the value is marked as invalid.
- **Running variance validation:** A value is flagged as invalid if the variation over a past value is too small. A frozen value is often due to a sensor failure.
- **Long-term drift:** Expected mean check and acceptable trend check are two methods to detect long-term drift. Once detected, the source of the bias or drift then needs to be identified as it could be caused by sensor drift, as well as a long-term trend of the measured value.

Cross-validation methods are used when it is possible to develop a model or relation between two or more values. The simplest case is where some sensors are redundant and measure the same value or if software can be used to produce another sensor's estimate. A range or rate of change validation can then be carried on the difference between the two values. In more complex cases, the redundancy can come from combining sensor data with a model to produce many estimates of a specific variable (soft sensors or virtual sensors). The data reconciliation technique can then be used to better estimate the variable.

Filtering can be used to reduce the measurement noise inherent to sensor data. The result is smoother and easier to analyze and usually produces better results with control processes.

All RTC system data should be validated in real time. Data validation can be implemented at the local PLC and at the central control station. Whenever possible, data validation processes should take advantage of the correlation between the measurements (i.e., cross-validation methods). At minimum, the data validation algorithms should use sensor alarms and be able to detect missing data, out-of-range values, outliers, and frozen measurements.

## 7.2 Key Performance Indicators

Developing key performance indicators (KPIs) based on computations of validated data can provide a quick and general understanding of the system's performance. Some of the meaningful KPIs applied for wastewater and stormwater systems include the following:

- **Precipitation frequency:** The average recurrence of rainfall can be assessed using rain gauge readings (NOAA n.d.). Maximum rainfall depth over various durations is calculated and compared to precipitation frequency estimates for the area and precipitation data used for hydraulic model development and calibration.
- **Treated flow:** Maximum flow conveyed to the wastewater treatment plant (WWTP) is compared to the WWTP's treatment capacity. If CSOs or significant retention occur while the treatment capacity is not met, it can signal a suboptimal system or control.
- **Untreated flow:** Estimated or measured overflows from the collection system prior to treatment is compared to total flow treated at the WWTP. This is typically measured as number of overflows and/or the volume of overflows. These values can be compared to those projected or allowed under an approved Long-term Control Plan or NPDES permit to assess system performance and compliance.
- **Partially treated flow:** Estimated or measured volume of wastewater receiving



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only partial treatments prior to discharge. These values can be used to assess system performance and compliance.

- **Retention volume:** Maximum stored volume can be presented relative to full capacity. If CSOs occur while the full retention capacity is not met, it can signal a suboptimal system or control.
- **Retention duration:** Exceedingly long durations can lead to odor problems in wastewater storage systems.
- **CSO/SSO volume and duration:** Overflow discharges can be reported to the public in a timely manner.

# 8. Data Visualization and Decision Support Systems

Data visualization is the presentation of large amounts of complex data using charts or graphs—a quick, easy way to universally convey concepts. It enables data users and decision-makers to visually explore analytics, so they can grasp difficult concepts or identify new patterns. Interactive visualization allows the user to take the concept a step further by using technology to drill down into charts and graphs for more detail, to interactively change the data displayed and how it is processed (SAS n.d.).

Data visualization is a key component of the user interface for any decision support system (DSS). A DSS (also known as decision-making software or DMS) is a computer-based information system that supports business or organizational decision-making activities. DSS has three main functions: information management, data quantification, and model manipulation.

- **Information management** refers to the storage, retrieval, and reporting of information in a structured format convenient to the user.
- **Data quantification** is the process by which large amounts of information are condensed and analytically manipulated into a few core indicators that extract the essence of data.
- **Model manipulation** refers to the construction and resolution of various scenarios to answer, "what if" questions. It includes the processes of model formulation, alternatives generation and solution of the proposed models, often through the use of several operations research/management science approaches (Inc. n.d.). Its main objective is to convert data into usable and actionable knowledge.

There are two main types of DSS tools, one for planning purposes and another for real-time decision support (Hydrology Project n.d.). For wastewater and stormwater applications, DSS is typically structured to allow users to access and analyze monitoring data, run model simulations, and assess the impact of potential decisions by using "what if" scenarios. While the data can be displayed and analyzed in real time to identify areas that need attention or improvement, the appropriate actions can be taken at a later time. For example, DSS can display real-time level data correlating to expected flow behavior. Abnormally high-level data would indicate a potential debris blockage, and the corresponding response decision would be to schedule a maintenance crew to perform a field investigation. However, this action could be optimized with other work orders to improve maintenance efficiency.



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An RTDSS allows decision-makers to respond to short-term variations in wastewater and stormwater systems where lead times for decisions vary from a few hours to a few days at most. Typical RTDSS examples include:

- Hydraulic flow diversions
- Storage basins to manage levels or volumes
- CSO or SSO discharge warnings
- Flood forecasting and warnings

See Section 5.2 for additional details on the RTDSS.

Before buying the various computer systems and software needed to create a DSS, utilities should consider (Inc. n.d., WERF 2005):

- Establishing business needs and value for DSS, such as providing guidance for complex operation.
- Evaluating the development of DSS applications using available software, such as spreadsheets, SCADA, or asset management software.
- Integrating information spanning more than just one functional domain into the DSS, as well as support decisions from multiple domains.
- Creating user-friendly DSS for easy viewing and access, as well as allowing users to create scenarios and to simulate and analyze the impacts of different scenarios.
- Ensuring the investment in terms of time and effort to incorporate DSS into daily operations.
- Providing necessary training and knowledge to use DSS effectively.
- Understanding how the DSS is used, such as the limitations or assumptions of the mathematical calculations or processing model used within the DSS.
- Examining other factors, such as future interest rates and new legislation, in the decision-making process.

# 9. The Future of Data Gathering Technology for Wet Weather Control and Decision-Making

Rapid advancements in data gathering technologies have already led to substantial improvements for real-time operational support and decision-making systems. Future advancements will continue to be made in the following areas:

- Monitoring the frequency, volume, and duration of overflows and discharges within combined and separate sanitary sewer systems.
- Water quality of flows within sewer systems, discharges, and receiving streams; specifically, real-time measurements of bacteria, nutrients, suspended solids, and possibly emerging pollutants.
- Operational data to inform asset management systems and long-term planning.

As these advancements continue, dischargers and regulators will need to adapt to new ways of thinking and embrace the increased role that smart data infrastructure will play in wet weather control and decision support. Dischargers will need to overcome barriers in educating personnel to operate and interact with new technology and systems, as well as adapt to a new culture of enhanced data operations.



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New technologies will only be able to maximize end-user benefits if they can be implemented within the framework of regulations.

The advancement and proliferation of new technologies for gathering and analyzing wet weather infrastructure data will lead to the generation of more accurate information and provide for lower-cost operations. With more accurate data, operators will be able to make more informed decisions, increasing efficiency and reducing risks.

Technology advancements will continue to improve our ability to quantify wet weather events and monitor water quality in ways we have never been able to before. In the future, better technology will exist for generating data related to the frequency, volume, and duration of wet weather events. Operators will have increasingly better information to determine the occurrence of wet weather discharges and to calculate the impact of wet weather events on collection system capacity. Better understanding these system characteristics will lead to improved infrastructure design and management, and ultimately the prevention of failures and overflows.

Pollutant sensor technology will also continue to improve, and operators will be able to monitor pollutant impacts on water quality more often and in real time. Operators will also be able to more closely monitor pollutants (such as bacteria) of particular concern to public and environmental health.

Continued improvements in data gathering will increase the effectiveness and reliability of data-informed operations, and ultimately change the pace at which operational decisions can be made, moving increasingly toward real time. Increasing the amount and frequency of reliable data will also enhance asset management programs and promote more informed capital planning. Wet weather system O&M was at one time conducted on a solely reactive basis. As technology and operational strategies have advanced, and more precise and accurate data are more readily available, operators have now shifted their approaches toward preventive and, in some cases, predictive O&M practices.



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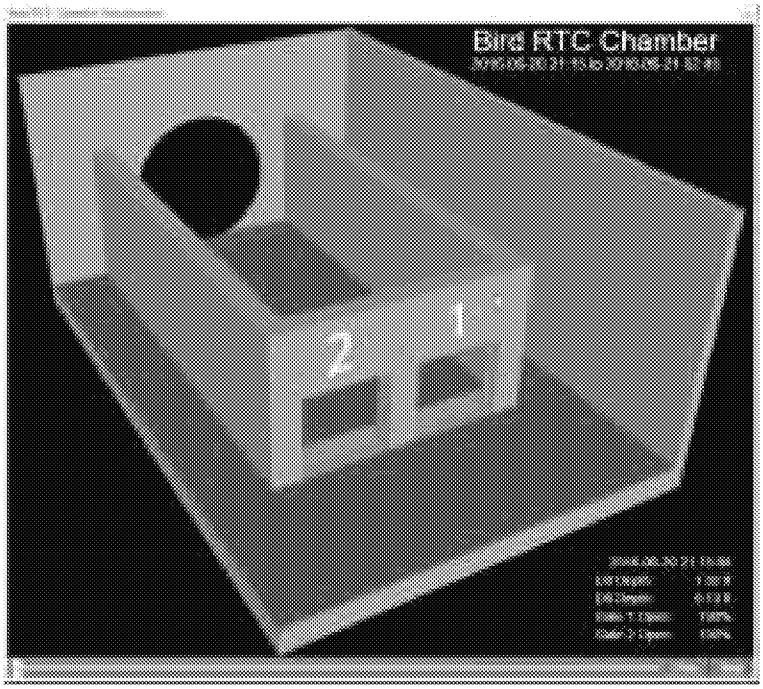
# Appendix A
# Case Studies

# Buffalo, New York: Real Time Control of Inline Storage




| OWNER |
| --- |
| Buffalo Sewer Authority |
| **LOCATION** |
| Buffalo, New York |
| **INCEPTION** |
| Commissioned winter 2016; study period March–May 2016 |
| **REFERENCES/LINKS** |
| BSA Awarded EPA Environmental Quality Award<br>www.emnet.net/clients/buffalo-new-york<br>www.ghd.com/usa<br>www.arcadis.com |

## KEY FEATURES

- Reduced combined sewer overflow (CSO) by 13.3 million gallons at two initial RTC sites between March 1 and May 31, 2016.
- Sixteen real-time control (RTC) sites to be established by 2020.
- Expected to reduce CSO by 15 to 20 percent at full capacity.
- $145 million negotiated out of long-term control plan and consent agreement based on modeled outcome of inline storage.

## PROJECT DESCRIPTION

Once the 8th largest city in the United States, Buffalo has lost half of its population and most of its industrial base since the 1960s. Before its decline, the city built a massive sewer system to accommodate as many as 750,000 people, but today Buffalo Sewer Authority (BSA) serves just 250,000. This means the collection system has substantial inline storage capacity.

Working with its team of engineers and consultants, BSA identified 16 RTC sites for inline storage and optimal conveyance throughout the city. The sites were chosen for maximum return on investment; from among them, four representative sites were chosen for initial construction. Two of these four sites are now live, while the other two are in design. BSA plans to build and commission all 16 sites by 2020.

The first two inline storage sites, the Bird Avenue RTC and the Lang Avenue RTC, were commissioned in early 2016. Both sites are operated by program logic controllers (PLCs) within BSA's supervisory control and data acquisition (SCADA) system. These PLCs are driven by remote level sensors upstream and



*Any mention of trade names or commercial products does not constitute an endorsement or recommendation for use. EPA and its employees do not endorse any products, services or enterprises.*

downstream of each site, and are presented digitally in the SCADA interface. From March 1 to May 31, 2016, the two sites were studied and tuned to achieve optimal performance. During this period, Lang reduced 4 out of 9 (44 percent) of potential activations, resulting in reduced CSO volume of 1.2 million gallons (64 percent). Bird reduced 14 out of 19 (74 percent) of its potential activations, yielding reduced CSO volume of 12.1 million gallons (64 percent). Both sites were tuned on an ongoing basis, and performance improved with each significant storm during the study period.

Citywide, the program is expected to reduce BSA's CSO volume by 15 to 20 percent, or over 500 million gallons. Based on the modeled outcome of the inline storage program, BSA was able to negotiate $145 million of otherwise needed system improvements out of its long-term control plan and consent agreement with the New York State Department of Environmental Conservation.

Based on the BSA team's experience, the program could yield further operations and maintenance benefits, as well as significant potential for further reductions in overflow volume and activations. As the program develops and all 16 sites are commissioned, the system will benefit substantially from temporal and spatial distribution of rainfall across the urban watershed.



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# Falcon Heights, Minnesota: Predictive Flood Control System

| OWNER |
| --- |
| Capitol Region Watershed District |
| LOCATION |
| Falcon Heights, Minnesota |
| INCEPTION |
| July 2015 |

## KEY FEATURES

- Optimized stormwater management using real-time controls and adaptive logic.
- Doubled flood control capacity of an existing wet pond.
- Reduced risk to nearby residential areas and infrastructure.

## PROJECT DESCRIPTION

Curtiss Pond in Falcon Heights, Minnesota, collects runoff from a 38-acre watershed. A playground and residential area surround the pond. Large storms have caused pond overflows and several feet of standing water in the surrounding area, threatening infrastructure and private property. To eliminate this flooding, which poses an imminent safety concern, the Capitol Region Watershed District designed a network of perforated pipes, 10 feet in diameter, to temporarily store and infiltrate the overflow. However, the physical space for the pipe network was limited.

To eliminate the flooding, the District installed an intelligent retention system that uses weather forecast information to predict the amount of runoff from a watershed and prepare the pond to receive the forecasted water. The system autonomously draws down the pond during dry periods, maximizing available capacity in advance of wet weather. This active control allows for a smaller pond design volume while using its full storage capacity to reduce flood risk.

*"Did you know that innovative technology can automatically check the weather and activate water management structures that protect your neighborhood from flooding? The system will reduce flooding in the park and reduce the risk of damage to surrounding properties."*

**—Capitol Region Watershed District**

An 8-inch butterfly valve was installed to allow the system to control water draining to the infiltration pipe. The system decreased the storage requirement by 226 feet of pipe, effectively increasing storage volume by 58 percent



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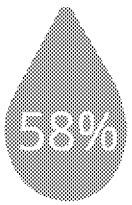
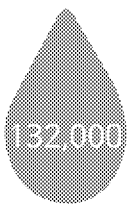
without changing the project footprint. The system also measures temperature and infiltration rates to improve stormwater management during freezing/thawing cycles.




**increase in effective storage**




**gallons managed**

Since deployment in July 2015, the system has successfully collected stormwater runoff from the watershed and prevented the costly flooding of the surrounding area, which limited park use, damaged infrastructure, and created public safety concerns. The system also provides real-time and historical data of site performance. At any time, staff can remotely monitor the system and modify what's happening. This high-efficiency solution has enabled the Capital Region Watershed District to achieve its stormwater management objectives within the constraints of a highly developed urban/suburban area. It also holds potential for expansion to stormwater facilities throughout Falcon Heights to effectively manage storms at the local watershed scale.



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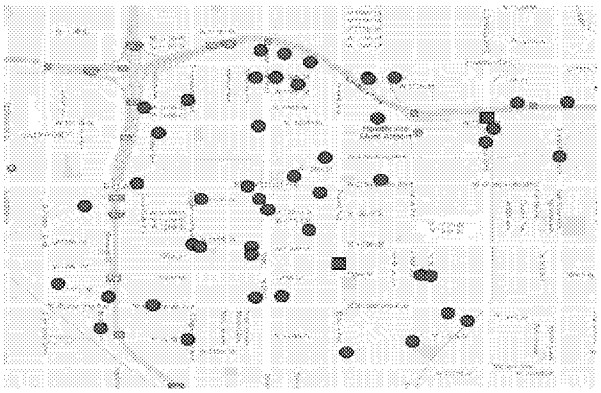
# Hawthorne, California: Real-Time Monitoring to Prevent Sewer Overflows



*Hawthorne installed 50 SmartCover units in their collection system - about 2.5% of all of their manholes - and virtually eliminated overflows.*

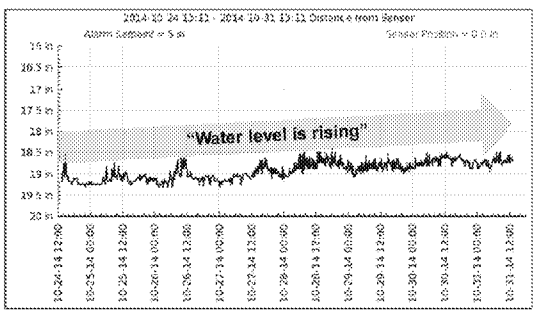
| OWNER |
| --- |
| City of Hawthorne |
| **LOCATION** |
| Hawthorne, California |
| **INCEPTION** |
| 2006 |

## KEY FEATURES

- Real-time control technology provides early warning of pre-flow events.
- Sewer overflows reduced by 99 percent.
- Savings estimated at $2 million in fines and mitigation costs since 2006.

## PROJECT DESCRIPTION

The City of Hawthorne operates a small gravity-only sewer system southwest of the LAX airport. This system includes 94 miles of gravity pipeline, no lift stations, no treatment, and just two full-time collection staff. Before 2006, Hawthorne was experiencing about 10 sewer overflows per year in their sanitary sewer collection system. The city estimated that these spills cost them $400,000 annually in fines, cleanup and mitigation costs, and legal costs.




*The above graph shows a rise in water level, alerting managers to a potential issue.*

In late 2006, the City of Hawthorne positioned 50 real-time remote level monitoring sensors covering 66 of the "hot spots" in the collection system. These systems provide managers real-time early warning of pre-flow events through alarms and through the use of a data analytics tool, used to indicate when pipes were beginning to accumulate dirt; grit; fats, oils, and grease (FOG); or tree roots, thereby changing the daily pattern of water flow in the pipes.

Since the installation of the real-time monitoring system, the City of Hawthorne has experienced only one overflow in its sewer collection system, at a location that was previously unmonitored. This represents a decrease in sewer overflows of 99 percent. Using its two-man crew and the real-time control technology, Hawthorne has been able to virtually eliminate sewer overflows in its collection system, saving more than an estimated $2 million in fines and mitigation costs since 2006.



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# Louisville, Kentucky: Real-Time Control for Integrated Overflow Abatement

**OWNER**

Louisville and Jefferson County Metropolitan Sewer District, Louisville, Kentucky

**LOCATION**

Louisville, Kentucky

**INCEPTION**

2006

**COST**

$21M

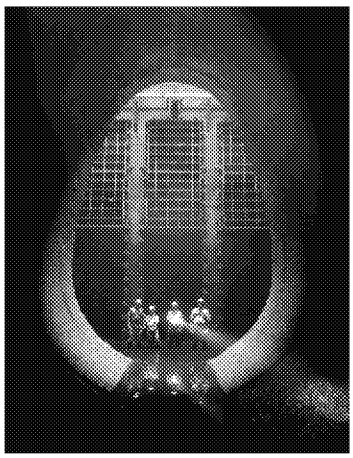
**REFERENCES/LINKS**

Angela Akridge, PE, Chief Engineer
Louisville & Jefferson County
Metropolitan Sewer District
700 West Liberty Street
Louisville, KY 40203-1911
Tel.: 502.540.6136

## KEY FEATURES

- Enhanced sustainability of sewer systems and improved quality of receiving waters from smart use of real-time control (RTC) technology.
- Maximizes conveyance, storage, and treatment capacity, with consistent operational results of capturing 1 billion gallons of combined sewer overflow (CSO) annually.
- Overall cost savings estimated at $117M from the original CSO long-term control plan (LTCP), a 58% reduction in capital investment.

## PROJECT DESCRIPTION



Louisville Metropolitan Sewer District (MSD) operates and maintains a complex wastewater and stormwater system, with more than 3,200 miles of wastewater collection sewer lines, 16 small and regional wastewater treatment plants, over 280 pump stations, and 790 miles of stream water quality monitoring as well as the Ohio River Flood Protection System.

Louisville MSD is one of the nation's early adopters of RTC, applying inline storage since the 1990s and pioneering the application of global optimal and predictive RTC that has been in operation since 2006. The RTC system was a key to maximize the conveyance, storage (inline and office), and treatment capacity to reduce CSO, with consistent operational results of capturing more than 1 billion gallons of CSO annually.



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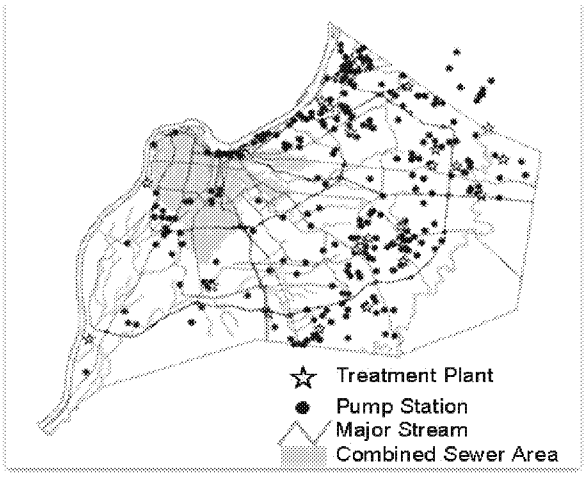
Louisville MSD is mid-way through implementation of a 19-year initiative known as the Integrated Overflow Abatement Plan (IOAP). The vision of the IOAP is to provide a long-term plan to eliminate sanitary sewer overflow (SSO) and other unauthorized discharges and to reduce and mitigate wet weather CSOs in both the combined and separate sewer systems, in an effort to improve water quality in both Louisville Metro streams and the Ohio River.

MSD has a progressive vision for total wastewater system optimization, which includes the control of both inline and offline storage facilities, diversion control within and between the combined and sanitary sewer systems, and maximizing of wastewater treatment throughout the system. RTC is integral to the fulfillment of this vision. Smart use of RTC technology has allowed MSD to enhance the sustainability of their sewer systems while also improving the water quality of receiving waterways.

***Technology Description:*** The global optimal and predictive RTC approach was determined as the most appropriate level of RTC for the Louisville system based on the control objectives and the system hydraulic characteristics. The RTC system includes remote control facilities and a central station. Each remote site includes sensors (flow, level) and a local RTC device (Programmable Logic Controller [PLC] or Remote Terminal Unit [RTU]). Final control elements (e.g., gates, pumps) at each remote control facility are connected to the output side of the PLC (or RTU). The PLC controls the final control elements based on the rules embedded (programmed) into the PLC. These rules are feedback algorithms, where action is based on the difference between a setpoint and the measured variable. Information collected in the field is communicated from the remote stations to the central station via the supervisory control and data acquisition (SCADA) system. The central station manages and coordinates the various modules, including data management and archiving, RTC control algorithms, hydrologic and hydraulic models, and weather forecasting.




As conditions are monitored, acknowledged, and controlled, the RTC system takes into account the distribution of flow in the entire system, both in current conditions and in the future, based on rain forecasts, measurements and sewer simulations in real time. The RTC system provides continuous and strategic adjustment of control devices to optimize flow conveyance, storage, release, and transfer according to the available capacity in the entire system.

***Benefit Cost Analysis:*** The evaluation of RTC feasibility studies of phase 1 implementation identified a relatively low unit cost ranging from $0.006 to $0.021 per gallon of CSO reduction per year by maximizing the existing collection and treatment system. This cost is 4 to 10 times lower than traditional approaches of building additional storage. The overall cost savings was estimated at $117M from the original CSO long-term control plan cost of $200M (a 58% reduction in capital investment).

***Advantages:*** The RTC technology is scalable and flexible. The global optimal and predictive RTC system involves all levels of control—from static to local to global—to provide system-wide optimization. New control sites can be added and control logics can be modified based on performance monitoring as part of adaptive management. The use of an online model reduces the number of sites and extent of the monitoring network required for system-wide optimization.

***Disadvantages:*** The approach relies on online model and weather forecasting to provide predictions of upcoming inflows and their spatial distribution. This requires the calibration and update of the



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hydrologic and hydraulic model to represent the wastewater system adequately. The control strategy and decisions need to account for inaccuracy and unpredictability in weather forecasting.

***Lessons Learned:*** Lessons learned from this project include the following:

- The adoption of RTC technology requires organizational commitment and staff buy-in.
- The utility needs to consider operation and maintenance (O&M) issues and constraints when selecting the appropriate level of RTC implementation.
- It is important to involve system operators early in the planning and design, and to identify and communicate roles and responsibilities at every stage, from design, construction, and commissioning to post-construction performance monitoring.
- Development, implementation, and monitoring performance of standard operating procedures and post-event analysis are critical to properly operate, maintain, and improve the RTC system.

***RTC Project Cost:*** RTC program cost is estimated at $21M to date, including retrofit, construction, monitoring, information technology, etc. The current RTC system includes the use of two stormwater retention basins (over 30 million gallons) for CSO control, multiple inline storages, flow diversions, pump stations, as well as the management of Southwestern outfall, which is an egg-shaped tunnel with a diameter ranging from 24 to 27 feet.

*"Real Time Control is an important component of MSD's long term plan to mitigate untreated combined sewer overflows into Beargrass Creek and the Ohio River. It is a cost effective management strategy to help sustain the resources of our community."*

***Future Projects:*** MSD continues to improve and expand its RTC system as new storage and treatment facilities are constructed under the IOAP.

***Training Needs:*** Web-based training modules on the RTC system were developed and used for continuous training and knowledge transfer. Control site commissioning and start-up provide onsite training opportunities for instrumentation and control (I&C) and O&M staff.



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# Newburgh, New York: Real-Time Control to Monitor Discharges for Reporting/Public Notification

## KEY FEATURES:

- Easier, more reliable, more nimble operations.
- Reduced risk of loss or damage to sensors.
- Reduced cost.

| OWNER |
| --- |
| City of Newburgh |
| LOCATION |
| Newburgh, New York |
| COST |
| $78K for 18 units |

## PROJECT DESCRIPTION

The City of Newburgh replaced its traditional telemetry system with smart controls to provide city staff and the public real-time notification of CSO events and to prepare for increased regulatory requirements for annual reporting and notification.

The City's prior telemetry system used pressure sensors that were required to be located at the bottom of the influent channel, in direct contact with the flow, and in the combined sewer regulator environment. In these locations, the sensors were regularly impacted and damaged or displaced by debris. On numerous occasions under high flow conditions, several entire units were swept away down the CSO and lost at the outfall.

The prior sensors also required expensive calibration equipment and a proprietary consultant to perform the annual calibration of the telemetry system at each installation location. The old telemetry system used a dedicated phone line for each telemetry station, with only a single point of access and control, which was located at the wastewater treatment plant. These hard lines were expensive, had regular loss of communication, and were very difficult or impossible to locate by the utility company when service was required.

With the new telemetry system, all of these problems were avoided. The smart control wireless satellite connectivity proved more reliable than land phone lines, and at a lower cost. Any computer, tablet, or smartphone with internet access can communicate with the telemetry system. There is little calibration needed. When calibration or sensor relocation is required, in-house staff can easily perform the required task with basic tools. The sensors are not in contact with the water, thereby avoiding damage.

***Lessons Learned:*** The new sensors are generally installed hanging from the manhole cover above. At some installation locations, some initial erroneous readings resulted in the discovery that, in some locations within the sewer, plugs of air can cause the sensors to swing. At these locations, a restrained installation of the sensor is required. This has been accomplished in-house with stainless steel angle brackets and associated hardware.

In some sites, initial erroneous readings were caused by low flows with a large distance from the influent channel to the sensor above. This challenge was overcome with the installation of replacement long-range sensors.



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# Philadelphia, Pennsylvania: Real-Time Control to Manage Retention Pond Discharge

## KEY FEATURES

- Retrofit of an existing stormwater management pond with active control technology to increase treatment and reduce wet weather flows.
- Minimization of wet weather discharge for storms up to 2 inches in rainfall depth.
- Integrated system monitoring and reporting capabilities.

| OWNER |
| --- |
| Philadelphia Water Department |
| **LOCATION** |
| Philadelphia, Pennsylvania |
| **INCEPTION** |
| 2016 |
| **COST** |
| Estimated retrofit cost of $53,000 per greened acre |

## PROJECT DESCRIPTION

An existing stormwater management pond (SMP) collecting runoff from 8 acres on private property in the combined sewer area was not meeting Philadelphia Water Department's (PWD's) stormwater management standards. For all areas served by a combined sewer and for which infiltration is infeasible, 100 percent of the runoff from 1.5 inches of rainfall must be routed through an acceptable pollutant-reducing practice and detained in each SMP for no more than 72 hours. Any runoff detained must also be released from the site at a maximum rate of 0.05 cfs per impervious acre. The existing pond was originally designed as an infiltration basin, but does not achieve sufficient infiltration because of errors in the construction process.

A PWD Stormwater Management Incentives Program (SMIP) grant was awarded to fund a facility retrofit to increase treatment and further reduce wet weather flows. The SMP enhancement was achieved through the installation of a continuous monitoring and adaptive control (CMAC) on the existing outlet control structure of the basin. The system includes a level sensor, actuated valve, and integrated software that will provide dynamic control of stormwater storage and discharge above the permanent pool of water in the existing basin.

The stormwater pond contains a permanent pool of 22,500 cubic feet maintained by an outlet structure with a 6-inch orifice. A second, 8-inch orifice is positioned approximately 2 feet above the invert of the lower 6-inch orifice and an overflow weir is positioned approximately 2 feet above the 8-inch orifice. The retrofit involved installing a 6-inch actuated valve on the existing 6-inch orifice, a water level sensor, and the associated communications hardware to connect these to cloud-based control software. The software uses the water level data along with NOAA storm forecasts to determine an optimal valve open percentage based on water quality, storm retention, and flood protection objectives. For this basin, the software was configured to achieve the following logic:

- When a forecasted storm can be fully captured within the basin storage between the permanent pool and the 8-inch orifice, close the 6-inch valve to eliminate wet weather flow.
- After the event, open the valve to release the captured runoff within the 72-hour retention period without exceeding a discharge rate of 0.26 cfs (0.05 cfs per impervious acre).
- When the forecast indicates that an upcoming storm cannot be fully captured, release water at the lowest possible rate to avoid overflowing the riser structure. This logic ensures that the



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0.260 cfs target is only exceeded during large events to mitigate high water levels and discharge rates. Post-event, release any captured storm runoff within the 72-hour retention period without exceeding 0.26 cfs target.

The storage volume available above the current permanent pool of water and below the invert of the 8-inch orifice is 38,000 cubic feet. This volume is larger than the runoff generated by the 2-inch storm event (34,000 cubic feet). Therefore, for all rainfall events up to 2 inches, the CMAC basin is able to fully capture the runoff with no discharge to the combined sewer during the wet weather event. After the event, the valve will slowly but continuously adjust (i.e., open further as the driving head drops) to match the target 0.26 cfs rate until the basin returns to its permanent pool elevation.

In addition to meeting the requirements for stormwater retention credits, the retrofit facility still provides safe passage for larger events. The pond depth and outlet structure configuration were not changed from the existing conditions. When the system is fully functioning, the software logic will open the valve as far as is needed to avoid overtopping the outlet structure, up to fully open for very large events. When the valve is fully open, the retrofit and existing conditions peak flow and maximum water surface elevations are identical. If the CMAC system fails to function properly and the 6-inch valve is closed during a large event, modeling shows that the 100-year event is still safely contained within the basin and will not contribute to local flooding. The CMAC system includes fail-safe features that protect the infrastructure in the event of connectivity or physical hardware failures. The retrofit was installed in November 2016 and has been collecting hydraulic data while adaptively managing the pond discharge.



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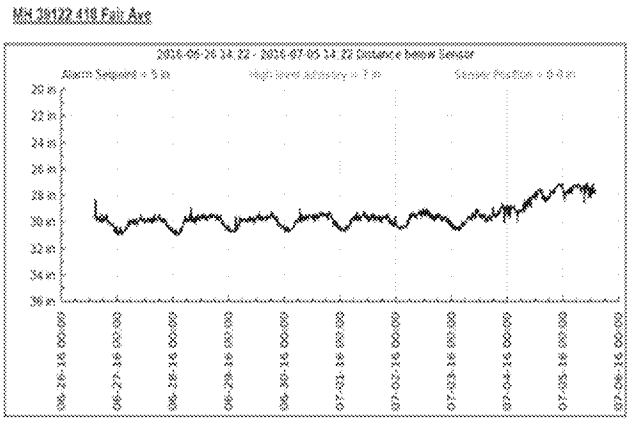
# San Antonio, Texas:
# Real-Time Control for Cleaning Optimization



**Example of a location where the analytic tool indicates a need for cleaning based on water level signature.**

| OWNER |
|---|
| San Antonio Water System |
| **LOCATION** |
| San Antonio, Texas |
| **INCEPTION** |
| Summer 2015 |
| **REFERENCES/LINKS** |
| Jeff Haby, Director, Sewer System Improvements<br>Tamsen McNarie, Director, Operations Support |

## KEY FEATURES:

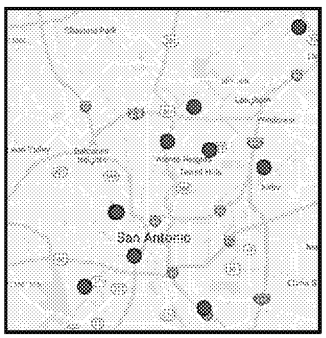
- Decreased cleaning frequency by 94 percent at 10 pilot sites with no increase in spill risk.
- Identified potential savings of $4,000 per location per year.

## PROJECT DESCRIPTION

Blockages or flow restrictions in collection systems are a common cause of sewer overflows. Cleaning the collection system pipes can prevent these overflows. High frequency cleanings (HFC) may be necessary where a utility has repeated overflow problems, typically caused by fats, oils, and grease, root intrusion, or debris collection from stormwater runoffs or other sources.

HFC can reduce near-term risk, and the more frequent site visits can yield timely and valuable information about the site. However, HFC can be costly and capital intensive, adds traffic and operational risk to field staff, and increases wear and tear on pipes.

To help reduce overflows and mitigate the disadvantages of HFC, the San Antonio Water System (SAWS) implemented a pilot project at 10 monthly cleaning locations beginning in the summer of 2015. The pilot used a smart control analytic tool, which automatically scans water flow patterns in a location and detects changes that may signify changing pipe conditions upstream or downstream from the monitored location. The system effectively provides real-time continuous pipe condition assessment, allowing SAWS to use data to determine when to clean a sewer pipe segment rather than using a predetermined cleaning schedule.




**Location of 10 smart control units for SAWS pilot. SAWS is using more than 300 units for other stressed areas in its system.**



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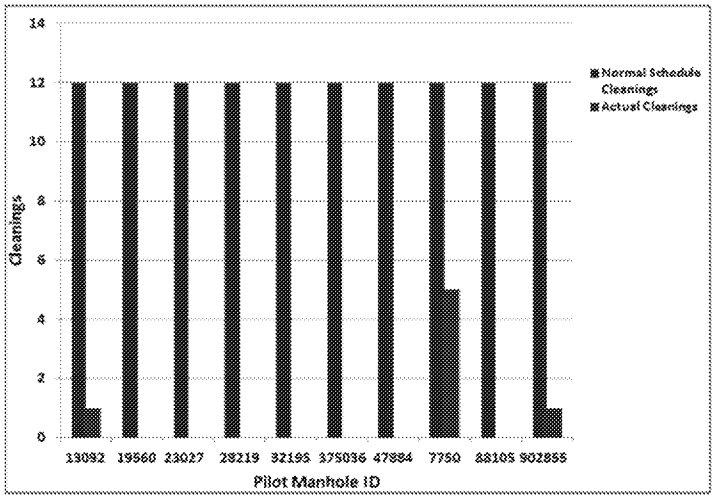
At the 10 sites monitored, cleaning frequency was decreased by 94 percent, while spill risk decreased due to continuous remote monitoring. With the exception of a period in late May/early June of 2016, when San Antonio experienced 16 inches of rain in a week, overwhelming the SAWS system, there were no spills at monitored sites during the pilot period.

SAWS estimated that, net the costs of the monitoring, use of the system for maintenance optimization can save about $4,000 per monitored location per year for sites currently designated for monthly cleaning.




**Cleaning frequency was reduced by 94 percent at 10 pilot locations.**



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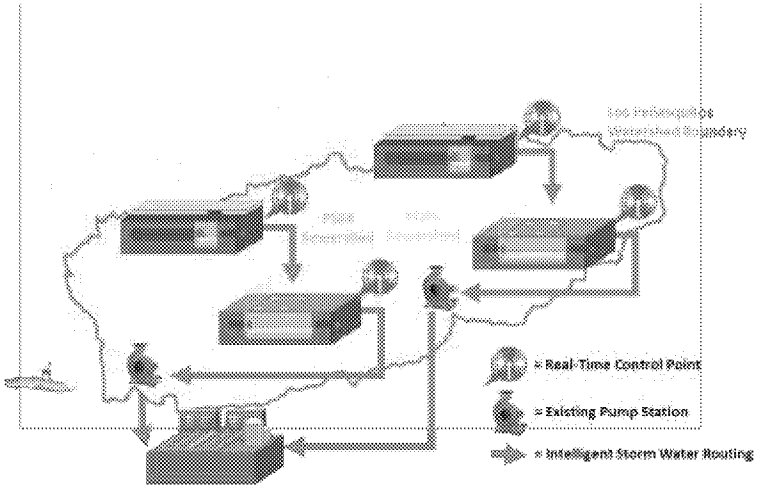
# San Diego, California: Stormwater Harvesting Augmentation Analysis




**OWNER**

City of San Diego, Stormwater Division

**LOCATION**

City of San Diego
various locations

**INCEPTION**

2016

**COST**

$168,900

**REFERENCES/LINKS**

Andrea Demich
(858) 541-4348

## KEY FEATURES

- Optimized stormwater/wastewater management using real-time controls and adaptive logic.
- Cost savings from program coordination.
- Magnitude of water supply augmentation.
- Water quality benefits.

## PROJECT DESCRIPTION

California experienced a historic drought with much of the state reaching D4 "exceptional" conditions on the U.S. Drought Monitor. In response, Governor Jerry Brown declared a state of emergency in January 2014 and established the first statewide mandatory water restrictions in March 2015. Concurrently, significant investments in green infrastructure are needed to address water quality impairments throughout Southern California. Despite the apparent synergy, urban stormwater is still underutilized as a water resource in coastal areas and is often conveyed directly to the ocean without beneficial uses. Synergy between drought resiliency planning and water quality protection could be realized if green infrastructure could be optimized to collect, treat, and distribute urban runoff as a supplemental, local water source.

This work explored and quantified the potential nexus between an emerging stormwater capture program and ongoing efforts to reclaim wastewater as a drinking water resource in San Diego, which currently imports over 80 percent of its water supply. The project considered both (1) the need to pursue water independence in response to prolonged droughts, rising imported water costs, and the city's growing population and (2) the need to plan, construct, and maintain extensive green infrastructure to comply with water quality regulations and flooding issues. As such, it provided valuable data on technological approaches to bolster San Diego's water resiliency while reducing pollution, flooding, spending, and redundancy.



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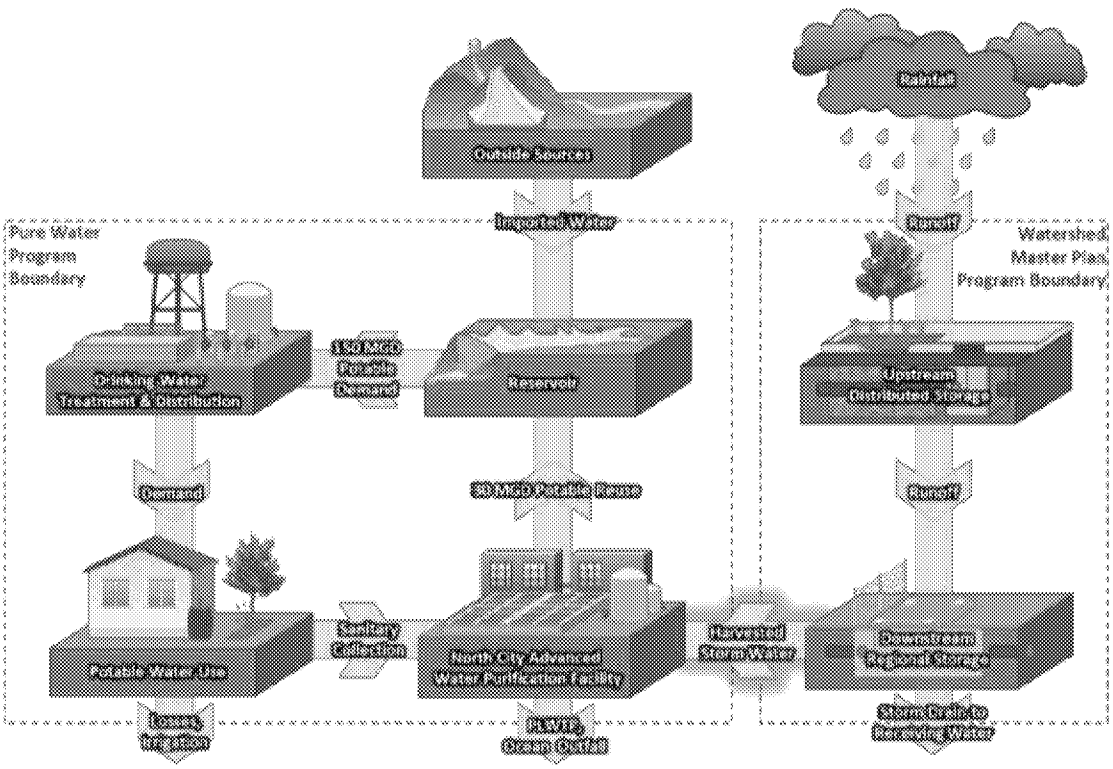
The analysis first defined treatment plant boundary conditions to determine what additional hydraulic and mass loading (from stormwater) the expanding water reclamation program could accommodate. The team leveraged a calibrated watershed model to predict the loading to the plant from raw stormwater and from effluent from the green infrastructure that will be constructed to address water quality regulations. The team then assessed the cost-effectiveness of methods to convey stormwater to the plant, including using the existing sanitary collection infrastructure and implementing a separate storm drain conveyance. Finally, they assessed upstream stormwater control measures—equipped with real-time controls (RTCs)—to optimize the management of stormwater storage and release to the reclaimed water system. The model included various scales of green infrastructure within the two major sewershed areas served by two existing pump plants. The resulting integrated water management analysis synthesized the benefits, costs, and energy demands of various alternatives to inform data-driven decision-making for municipalities with simultaneous water, wastewater, and stormwater stressors.

Analysis of the coordinated approach to water management hinged on simulating the capabilities of RTCs operated by cloud-based adaptive logic for intelligently managing storage and conveyance of water throughout the collection network (i.e., to reduce stormwater overflow to receiving waters while regulating diverted flow not to exceed the capacity of the treatment plant). This was accomplished using a software package to simulate optimization of control setpoints throughout the sewer network. The software identifies when valves, gates, and pumps should be operated to manage overall system performance in response to forecasted runoff and treatment plant capacity. It is well suited to an application where flows and storage must be actively controlled to enforce certain constraints and multiple objectives must be optimized over a long-term simulation. The analysis demonstrated potential cost savings and co-funding opportunities, as well as solutions to create resilient, low-impact communities. The simulations suggested that stormwater harvesting (enabled by RTCs) could substantially augment local water supplies while complying with stormwater quality regulations.



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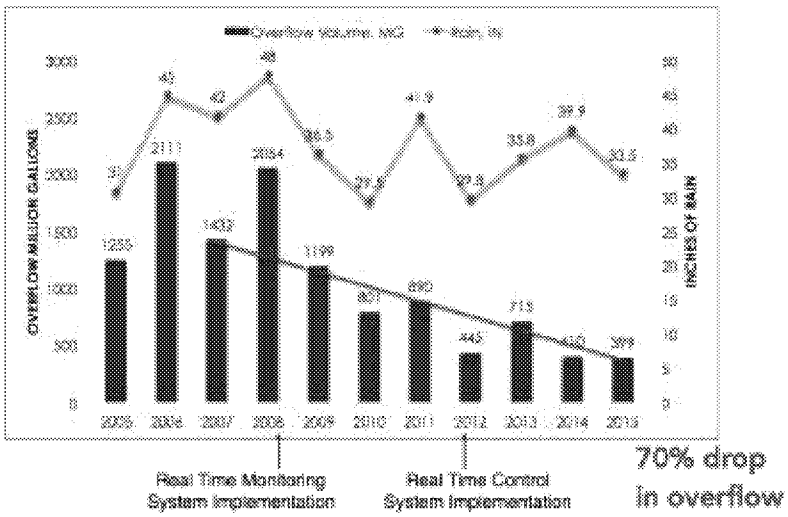
# South Bend, Indiana:
# Real-Time Control and Real-Time Decision Support




**OWNER**

South Bend Department of Public Works

**LOCATION**

South Bend, Indiana

**INCEPTION**

2008–present

**REFERENCES/LINKS**

https://www.southbendin.gov/government/department/public-works

https://www.emnet.net

http://www.greeley-hansen.com

http://pubs.acs.org/doi/abs/10.1021/acs.est.5b05870

## KEY FEATURES

- Uses a real-time decision support system (RT-DSS) to maximize conveyance capacity.
- Eliminated illicit dry weather overflows and reduced total combined sewer overflow (CSO) volume by about 70 percent.
- Reduced the potential cost of the city's long-term control plan (LTCP) by an estimated $300-$400 million.

## PROJECT DESCRIPTION

Before 2008, South Bend, Indiana had one of the largest CSO discharge volumes per capita in the Great Lakes Watershed. With a population of little over 100,000, South Bend generated annual CSO discharge volumes of 1-2 billion gallons and 25-30 dry weather overflows per year. Had the city simply implemented the prescribed projects in its LTCP, the total cost of mitigating its CSO problem would have totaled roughly $800 million.

In 2008, the City of South Bend commissioned a real-time monitoring system of more than 120 sensor locations throughout the city. In 2012, after reviewing data from the system and selecting sites accordingly, the City launched a distributed, globally optimal real-time control (RTC) system. The RTC system consists of nine auxiliary throttle lines with valves governed by an agent-based optimization strategy. Distributed computing agents trade available conveyance capacity in real time, similar to a commodities market.

The system provides information to staff throughout the organization through supervisory control and data acquisition (SCADA) screens for the operators, smart phones and tablets for field staff, and customized websites jointly developed with the city's engineering staff. Operations staff can override automated controls and take over valve and gate operation at any time.



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Since 2012, the City has added additional sensor locations and rain gauges, bringing the total number to 152 sites. It also added automated gates at several stormwater retention basins to better control the timing and rate of stormwater releases into the combined system.

Maximizing conveyance capacity utilization throughout the Saint Joseph interceptor line was the original objective of the RT-DSS. From 2008 through 2014, South Bend eliminated illicit dry weather overflows in the first 12 months and subsequently reduced its total CSO volume by about 1 billion gallons per year, about 70 percent. This program is estimated to reduce the cost of the city's LTCP by $300-$400 million, nearly 50 percent less than the original $800 million estimate and has already surpassed its original target of a 25 percent reduction in CSOs.



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