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# ALCOSAN’s Water Quality Modeling Approach

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## ABSTRACT

Allegheny County Sanitary Authority, based in Pittsburgh, Pennsylvania, is implementing its Clean Water Plan to manage sewage overflows in compliance with a Federal Consent Decree. ALCOSAN and CDM Smith developed receiving water quality models to support alternative analysis and facility sizing. The technical approach involved statistical calibration for flow and bacteria utilizing an 11,000+ node PCSWMM model. The tributaries were simulated using SWMM and the main rivers using EPA's Environmental Fluid Dynamics Code. Covering 280 miles (451 kms), the model simulates hydrology, river hydraulics, bacteria loading, and temperature-dependent decay. A literature review identified prior studies describing model calibration assessment methods and calibration statistics for flow and nutrients with limited information available for bacteria. ALCOSAN and CDM Smith developed bacteria calibration methods and metrics to objectively assess model calibration suitability for intended purposes. Calibration results for bacteria show a strong fit to observed data, with the root mean square error (RMSE) of the log transformed counts of fecal coliform of between 0.51 and 0.95 and for *E. coli* of 0.57 and 0.83. Since the model simulated bacteria counts were within 1 log of the observed data, the model is suitable for the purpose of forecasting attainment with water quality standards over a typical year.

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# 1. INTRODUCTION

The Allegheny County Sanitary Authority (ALCSOAN) provides wastewater conveyance and treatment services to 83 municipalities, including the City of Pittsburgh. Shown in Figure 1, the service area extends over 310 square miles (499 km$^2$) and serves nearly 900,000 people. ALCOSAN owns and operates 90 miles (145 km$^2$) of interceptor sewers and 25 miles (40 km$^2$) of trunk sewers that convey wastewater to ALCOSAN's treatment plant on Pittsburgh's North Side from over 4,000 miles (3,437 km$^2$) of separate sanitary and combined municipally owned and operated collection sewers. ALCOSAN's interceptor and treatment system were constructed in the 1950's when it was common practice to construct combined (and sanitary) sewer overflow structures that could protect treatment works by discharging excess wet weather flow to local rivers and streams when the system reached its design capacity. ALCOSAN's regional conveyance system currently has 250 combined sewer overflows (CSOs) and 52 sanitary sewer overflows (SSOs) structures. ALCOSAN's municipal collection systems also discharge diluted sewage from numerous additional CSOs and SSOs during wet weather. Collectively, ALCOSAN and municipal CSOs and SSOs contribute to exceedances of water quality standards (WQS) established by the Commonwealth of Pennsylvania (25 Pa. Code § 96.3) (Pennsylvania Code 2024).

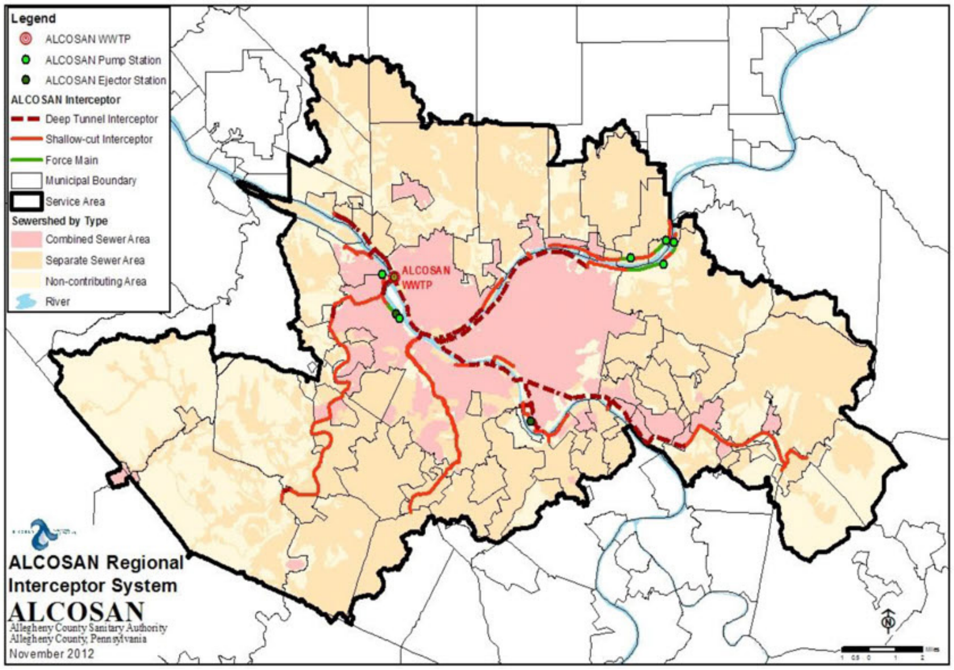


Figure 1 ALCOSAN service area map.

ALCOSAN is currently implementing a phased Clean Water Plan (CWP) to improve receiving water quality by controlling CSO and SSO discharges, as required by a Federal Consent Decree originally entered in 2008, and modified in 2020 (ALCOSAN 2019). The first phase of projects, known as the Interim Wet Weather Plan (IWWP), includes treatment plant upgrades, new regional tunnels, green stormwater infrastructure, and municipal collection system regionalization components. ALCOSAN's approved CWP also includes a second phase of projects known as Final Measures (FM), which includes additional tunnels, conveyance, and storage tanks. CDM Smith serves as ALCOSAN's Program Director for the CWP, working in concert with numerous other ALCOSAN contractors. The CWP is designed to achieve a level of CSO control sufficient to "not preclude the attainment of WQS or the receiving waters' designated uses or contribute to their impairment," consistent with USEPA's CSO Control Policy (USEPA 1994). To support this performance criteria, ALCOSAN and CDM Smith developed a receiving water quality model to forecast water quality conditions after implementation of CWP projects.

## 2. APPROACH TO WATER QUALITY MODELING

The two primary objectives of ALCOSAN's water quality modeling program are: 1) to identify the most cost-effective controls that can meet the requirements of the Consent Decree; and 2) to demonstrate that remaining CSOs will no longer preclude the attainment of WQS. Ideally, the second objective is achieved through post-construction monitoring. However, for ALCOSAN receiving waters, baseline monitoring conducted before the implementation of the CWP identified high dry-weather bacteria levels at tributary and main river sampling locations, indicating that non-CSO pollution sources are contributing to WQS exceedances. As a result, unless other sources are addressed prior to the completion of ALCOSAN's CWP, post-construction monitoring will not provide sufficient information to establish whether ALCOSAN has met its compliance obligations. Under circumstances where "WQS and designated uses are not met in part because of natural background conditions or pollution sources other than CSOs, *a total maximum daily load,* including a waste load allocation and a load allocation, or other means, should be used to apportion pollutant loads" (USEPA 1994). Since it is beyond ALCOSAN's jurisdiction to develop TMDLs, ALCOSAN applied analogous means to apportion pollutant loads. This is achieved via future modeling scenarios that assume model boundary conditions (upstream and dry weather baseflow) and other pollution sources (stormwater runoff) are reduced below WQS. Since ALCOSAN is only responsible for controlling discharges from infrastructure it owns and operates, the water quality model serves as the primary tool for establishing ALCOSAN regulatory compliance end points.

ALCOSAN's water quality models work in tandem with ALCOSAN H&H models and model post-processing WQS assessment tools as depicted in Figure 2. The ALCOSAN and municipal collection systems discharge flow and pollutants to areas receiving waters through over 400 combined and separate sewer outfall locations. The frequency, volume, duration, and pollutant load for overflows from this system were simulated with US Environmental Protection Agency (USEPA) modeling software Storm Water Management Model (SWMM) (USEPA 2022) which simulates stormwater runoff and sanitary sewerage within the collection system. Bacteria concentrations were calculated within SWMM, utilizing nationally derived stormwater Event Mean Concentrations (EMCs) and locally derived observations of sanitary sewage flow. A second SWMM model was used to simulate runoff from the separately sewered areas, as well as runoff from areas which do not contribute to the collection system. This model was also used to simulate the transport and flow of pollutant load through the stream's tributary to the main rivers. The main rivers receiving water model was simulated using Environmental Fluid Dynamics Code (EFDC) software (USEPA 2007). This software simulates the hydrodynamics, decay, and transport of bacteria within the main rivers. The EFDC software includes water temperature based on atmospheric inputs which allows for simulation of temperature-dependent bacteria decay. Temperature variations occur throughout the day and the year and vary by river.

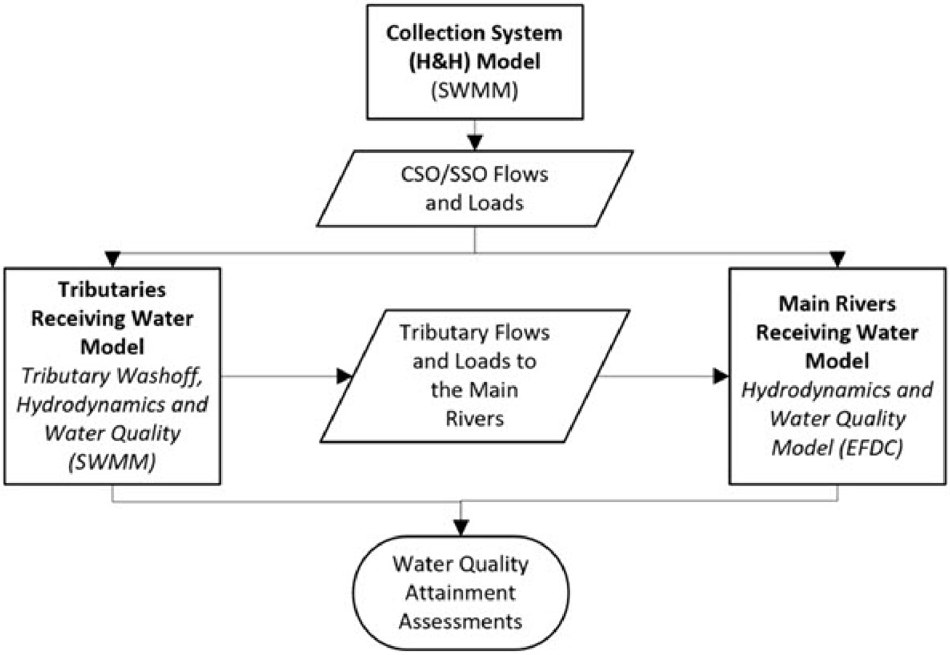


Figure 2 ALCOSAN's suite of H&H and water quality modeling tools.

## 3. WATER QUALITY MODEL CALIBRATION

The receiving water models, both in SWMM and EFDC, were calibrated to continuous observed hydrodynamic data (flow, velocity, and depth) and bacteria counts. The EFDC model was also calibrated to continuous and event temperature data. A literature review of water quality model calibration approaches identified prior studies characterizing the quality-of-fit for river flow and ranges of bacteria decay and resuspension rates but did not provide suggestions for determination of model calibration suitability (Manache et al. 2007; Newport Beach 2009). Previous work in the Scheldt drainage network utilized a simplified network to assess point and non-point sources of *E. coli* and sediment resuspension and provide sediment decay rates but did not suggest methods for assessing model calibration (Ouattara et al. 2013). Analysis of bacteria in southern Lake Michigan beaches provides inactivation rates and mortality rates for *E. coli* (Thupaki et al. 2010). Calibration criteria for rivers focuses on continuous hydrographs and single events for runoff volumes, peak flow rates, and hydrograph shapes (ASCE 1993; Harmel and Smith 2007). Water quality calibration criteria are often limited to nutrients in the statistical assessment using similar metrics to the flow (Engel et al. 2007; Donigian 2002; Moriasi et al. 2007). Water quality modeling of river bacteria uses log transformed data. A study in southwest Bangladesh used root mean square error (RMSE) and skill to provide calibration metrics for *E. coli* and *Entercocci* (Islam 2017), however, the loading to the river was from septic systems and bacteria loading concentrations are several orders of magnitude lower than combined sewer overflows in the ALCOSAN study.

To fill this gap, ALCOSAN and CDM Smith developed bacteria calibration methods and metrics to objectively assess bacteria model calibration suitability for supporting CSO control programs. Calibration included matching an order of magnitude bacteria count to event-based data. Scatter plots of the log of observed and simulated bacteria counts were created for dry weather, a 1-day post-wet weather event, and 3 to 5 days' post wet weather events. The 1-day post-wet weather data was used to verify overall load and transport of the bacteria. The 3 to 5 days' post-wet weather events were used to validate bacteria decay rates. The decay rate for *E. coli* was set to 0.58/day. The root mean square error of the modeled and observed fecal coliform counts were 0.75 for all samples and between 0.51 and 0.58 for post wet weather samples collected 1 to 5 days after a rain event. The model did not match dry weather samples as well with a RMSE of 0.95. This is due to the difficulty in identifying all dry weather sources. For *E. coli*, the RMSE was 0.72 for all samples and 0.57 to 0.64 for post-wet weather samples collected 1 to 5 days after a rain event. The RMSE for dry weather was 0.83.

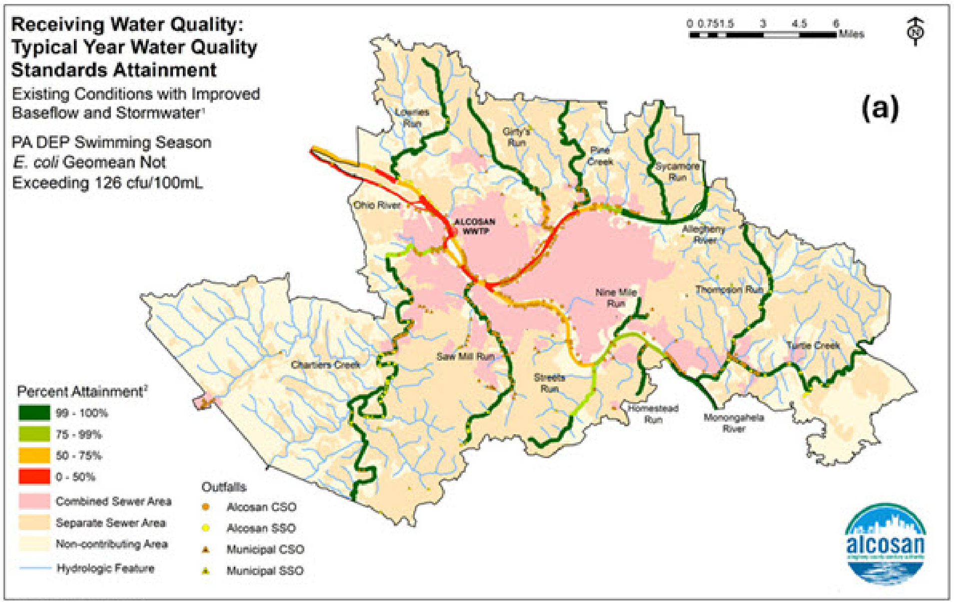
## 4. WATER QUALITY MODELING RESULTS

The validated model was used during the development of the CWP to forecast the water quality benefits of alternative system-wide control strategies and to inform the necessary sizing of proposed facilities. Baseline water quality monitoring of receiving waters identified bacteria as the primary constituent of concern due to significant exceedances of WQS. The relevant water quality criteria protective of water contact recreation include:

- Swimming season (May 1 through September 30)
    - Maximum *E. coli* geometric mean (GM) of 126 colony forming units (CFU) per 100 milliliters (ml) over a 30-day period
    - Maximum *E. coli* statistical threshold value (STV) of not more than 10% of samples collected in a 30-day period over 410 CFU per 100 ml.
- Remainder of the year
    - Maximum fecal coliform geometric mean (GM) of 2,000 CFU per 100 ml based on a minimum of five consecutive samples collected on different days during a 30-day period.

Since attaining WQS is based on the use of in-stream water quality sampling data, ALCOSAN developed a model post-processing sampling algorithm to replicate sampling protocols that would be utilized in the field. The algorithm generated a series of 10,000 random sample groups for each model segment in the swimming season, and for the remainder of the year. Each sample group contained 30 samples randomly selected on different days over a 30-day period. For each model segment, the number of sample groups meeting each criterion was divided by the total number of sample groups (10,000) to calculate the forecasted frequency of WQS attainment. This attainment frequency was considered representative of the probability of attainment with bacteria water quality criteria during a typical year. Attainment of WQS was judged for each model display segment as meeting these criteria in at least 99% of the randomly selected sample sets, which per Pennsylvania Code, is protective of designated surface water uses.

Figures 3a and 3b present the WQS assessment results for existing conditions with non-CSO water pollution sources improved for the swimming season GM and STV water quality criteria, respectively. Since non-CSO sources are improved, these results represent the wet weather impact of ALCOSAN and municipal CSOs and SSOs depicted on each map. The STV criteria is more stringent than the GM and is therefore used to establish the necessary level of CSO control. Figure 3b demonstrates that CSOs are clearly impairing receiving waters. Figures 4a and 4b present WQS assessment results after implementation of the CWP, with municipal CSOs and SSOs controlled and non-CSO sources improved. A comparison of the before and after results demonstrates the significant water quality benefits that will be realized after completing the CWP in parallel with other pollution control programs that will be necessary to address elevated dry weather conditions and stormwater runoff.



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2. Based on simulating collection of 30 samples over 30 days (10,000 iterations)

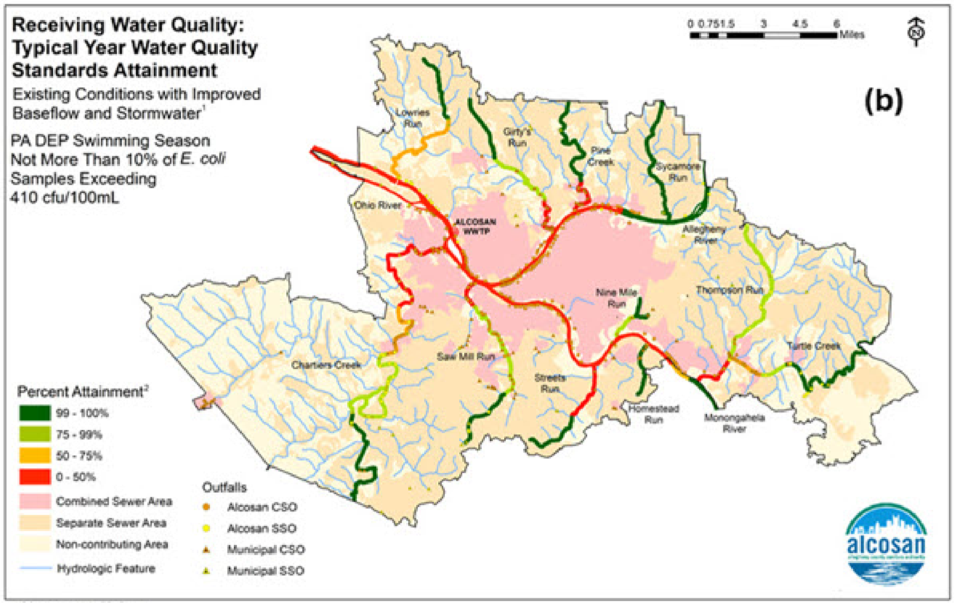

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Figure 3 a) Attainment with GM criterion before CWP; and b) Attainment with STV criterion before CWP.

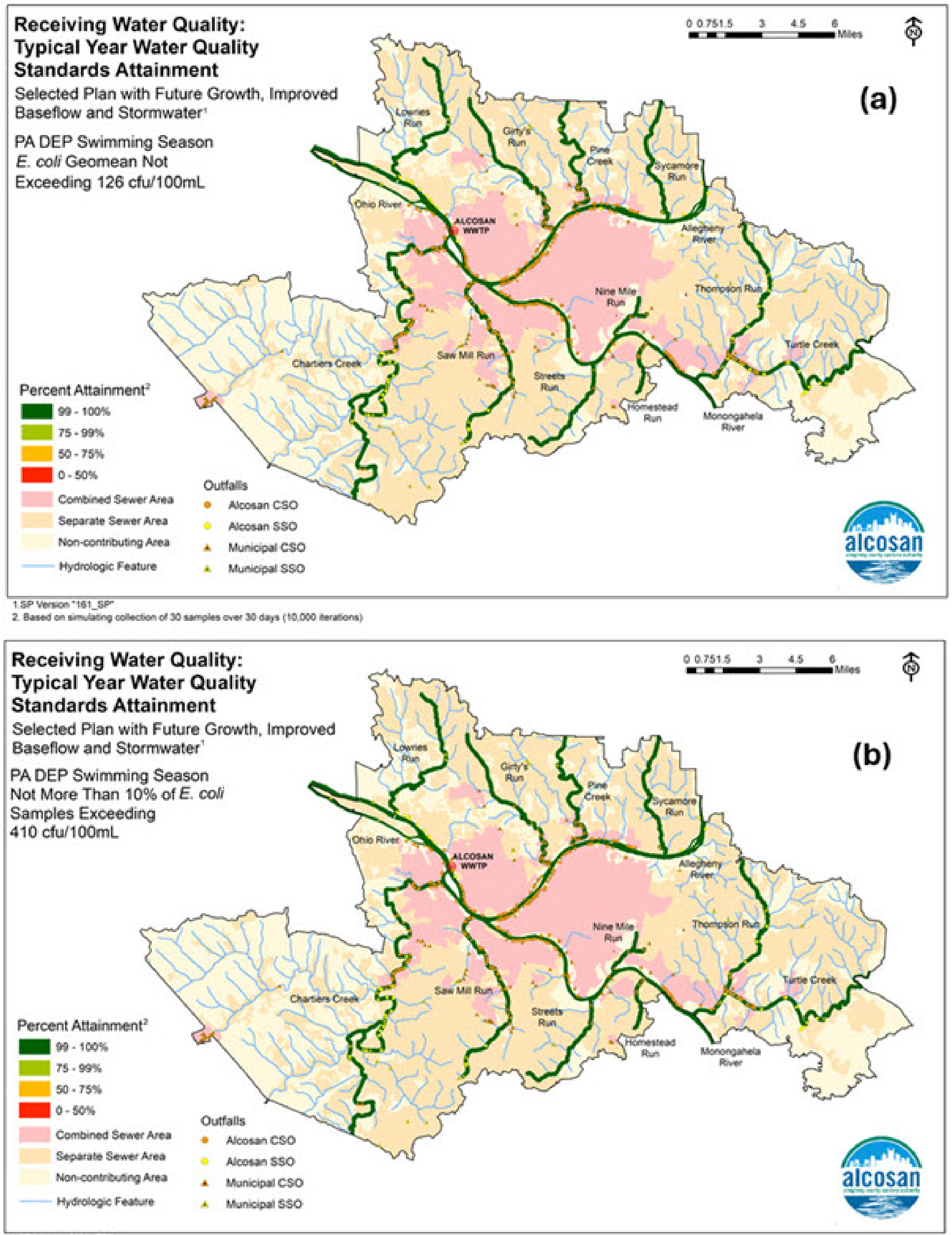

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Figure 4 a) Attainment with GM criterion after CWP; and b) Attainment with STV criterion after CWP.

## 5. DISCUSSION

ALCOSAN's water quality models were developed to serve multiple decision support objectives throughout planning, design, construction, and post-construction monitoring and modeling of the IWWP and FM phases of the CWP. In 2025, ALCOSAN began an interim and post-IWWP construction monitoring plan that will generate additional water quality sampling data characterizing receiving water quality conditions during dry and wet weather. The monitoring data will be used to measure improvements and confirm and/or update bacteria water quality model calibration. After updating the model calibration based on monitoring reflecting post-IWWP conditions, the model will be used to plan and design FM wet weather controls to meet the full objectives of ALCOSAN's Modified Consent Decree.

## 6. CONCLUSIONS

In conclusion, ALCOSAN's comprehensive water quality modeling approach serves as a vital tool in the implementation of their Clean Water Plan (CWP) and is transferrable to other CSO control programs. The integration of advanced hydrologic and hydraulic and receiving water quality models using innovative techniques, such as temperature dependent bacteria decay, quantitative bacteria model calibration statistics, non-CSO pollutant load apportioning, and WQS statistical algorithms that replicate field sampling protocols. Through the development and calibration of these models, ALCOSAN aims to forecast the water quality benefits of various control strategies, ensuring compliance with regulatory standards and the protection of receiving waters. The ongoing calibration and refinement of the models, coupled with extensive post-construction monitoring, further enhance their utility in planning and designing future phases of the CWP. Ultimately, ALCOSAN's commitment to innovative modeling techniques underscores their dedication to achieving significant and sustainable improvements in water quality within the region.

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