Smart
Watershed
Network

Aliso Creek Smart Watershed Network Final Report

Prepared with funding from the Metropolitan Water District of Southern California, Future Supply Action Planning Grant Program

Agreement Number: 189353

Member Agency: Municipal Water District of Orange County

Program Managers: Moulton Niguel Water District and Orange County Public Works

Contents

Tables

Figures

1 Executive Summary

Capture and recovery of urban runoff holds promise for supplementing future local water supply. Captured water can be used for direct local reuse, such as irrigation of the site where runoff is collected. Runoff can also be diverted into the sanitary sewer collection system, reclaimed, and supplied to customers as recycled water. Runoff capture can also help protect receiving waters from runoff impacts, such as water quality. However, there are barriers to expansion of runoff recovery strategies, including capacity issues in the sanitary sewer, elevated salt content in some urban runoff, source control requirements for potential director potable reuse regulations in development and potential negative impacts to receiving waters from flow diversion. There is a need for better information about urban runoff combined with integrated assessment of these data to develop strategies for overcoming these barriers.

This pilot project was a joint effort by Moulton Niguel Water District (MNWD) and Orange County Public Works (OCPW). It sought to help overcome barriers to runoff capture by developing a system for watershed data acquisition and integrated analyses in the Aliso Creek Watershed in Southern Orange County. This project included two primary elements: (1) a permanently deployed watershed monitoring system, and (2) a data management and analysis system. Collectively these systems comprise the Aliso Creek Smart Watershed Network.

Watershed Monitoring System. As part of this project, we piloted the use of the MNWD Advanced Metering Infrastructure (AMI) network to support remote data acquisition and telemetry. We installed water level sensors at 52 locations including outfalls and stream channels, as well as conductivity sensors at 20 of these locations within the Aliso Creek Watershed. These sensors were connected over the AMI network to relay high resolution data to MNWD databases on an ongoing basis. We demonstrated the successful use of the AMI network for this use case. We also gained transferrable lessons learned about sensor compatibility, calibration, and ongoing maintenance. Through the use of AMI gateways for data logging and telemetry, the capital cost of equipment was approximately 75% lower per station than previous flow monitoring and telemetry equipment used for this similar purpose.

Data Management and Analysis System. As part of this project, we developed a pipeline for the sensor readings relayed over the AMI network, providing automated quality control and connections to the permanent repositories for these data. This pipeline built on existing data management systems used by MNWD and OCPW. The system also integrated additional data beyond those from the watershed monitoring system, including water usage data, precipitation data, and other watershed monitoring stations. We then developed a cloud-based analytical space to perform data management and analysis functions. The user facing work product is the Smart Watershed Network Dashboard. This dashboard allows users to explore and analyze the federated datasets and evaluate runoff capture scenarios. The source code for both the front-end dashboard and back-end web service components of this system was developed under an open-source license and can serve as a template and starting point for similar efforts.

Collectively, the Smart Watershed Network serves as a key tool to overcome barriers to implementing a runoff capture project. The system is acquiring a growing body of high-resolution data to help characterize water and salt balance during both dry and wet weather. The custom dashboard enables managers to efficiently set up queries and scenarios to derive meaning from these data, including maintaining the temporal and spatial relationship between datasets. This system is a living tool because users are able to update saved analyses with new data with very limited effort. New stations and parameters can be added as the watershed system is expanded, and the system is extensible to support additions to the toolbox. Case study uses of this system have yielded initial insights into planning of runoff capture projects and are detailed in this report.

2 Introduction

2.1 Background

Urban runoff recovery refers to capturing runoff from the storm sewer system, during dry and/or wet weather, and putting this water to beneficial use. This can reduce peak flows in the stormwater system, improve water quality, and assist with flood protection. Captured water can be a new source of local water supply. This can be achieved through direct use of stored water to meet local irrigation needs or via diversion of captured water to the regional sanitary sewer collection system where it is routed to water reclamation facilities to become recycled water. This project focuses on data acquisition and analysis to help managers explore the water supply and watershed protection benefits associated with potential runoff capture strategies. It also provides datasets that can support other management decisions.

Aliso Creek Watershed. The Aliso Creek Watershed is a 35 square mile coastal watershed that ultimately discharges to the Pacific Ocean at Aliso Beach. More than 70 percent of the watershed is developed, and much of the balance is preserved as parkland. The watershed contains portions of the cities of Aliso Viejo, Dana Point, Laguna Beach, Laguna Hills, Laguna Niguel, Laguna Woods, Lake Forest, and Mission Viejo and unincorporated Orange County. These municipalities are enrolled in the San Diego Regional Municipal Separate Storm Sewer System (MS4) Permit (Order No. R9-2013-0001, as amended by Order Nos. R9-2015-0001 and R9-2015-0100). The watershed contains over half of the Moulton Niguel Water District ("MNWD" or "District") service area (Figure 1).

Aliso Creek experiences a range of water quality impairments. As typical of urban streams, it experiences unnatural levels of both dry and wet weather runoff to the stream, which can alter flow regimes, impair water quality, and cause stream erosion. Urban runoff contains a range of pollutants that can cause water quality impairments. The South Orange County Watershed Management Area (SOC WMA) Water Quality Improvement Plan (WQIP) (2018)[1] identifies unnatural water balance as a high priority issue and identifies a range of strategies to help correct unnatural water balance, among them urban runoff diversion systems. Additionally, Aliso Creek is impaired for fecal indicator bacteria and other pollutants found in urban runoff. Runoff capture has the potential to help improve flow regimes in the creek while reducing pollutant loading.

---

[1] https://ocgov.app.box.com/v/SDR-WQIP-Clearinghouse/folder/155231558270

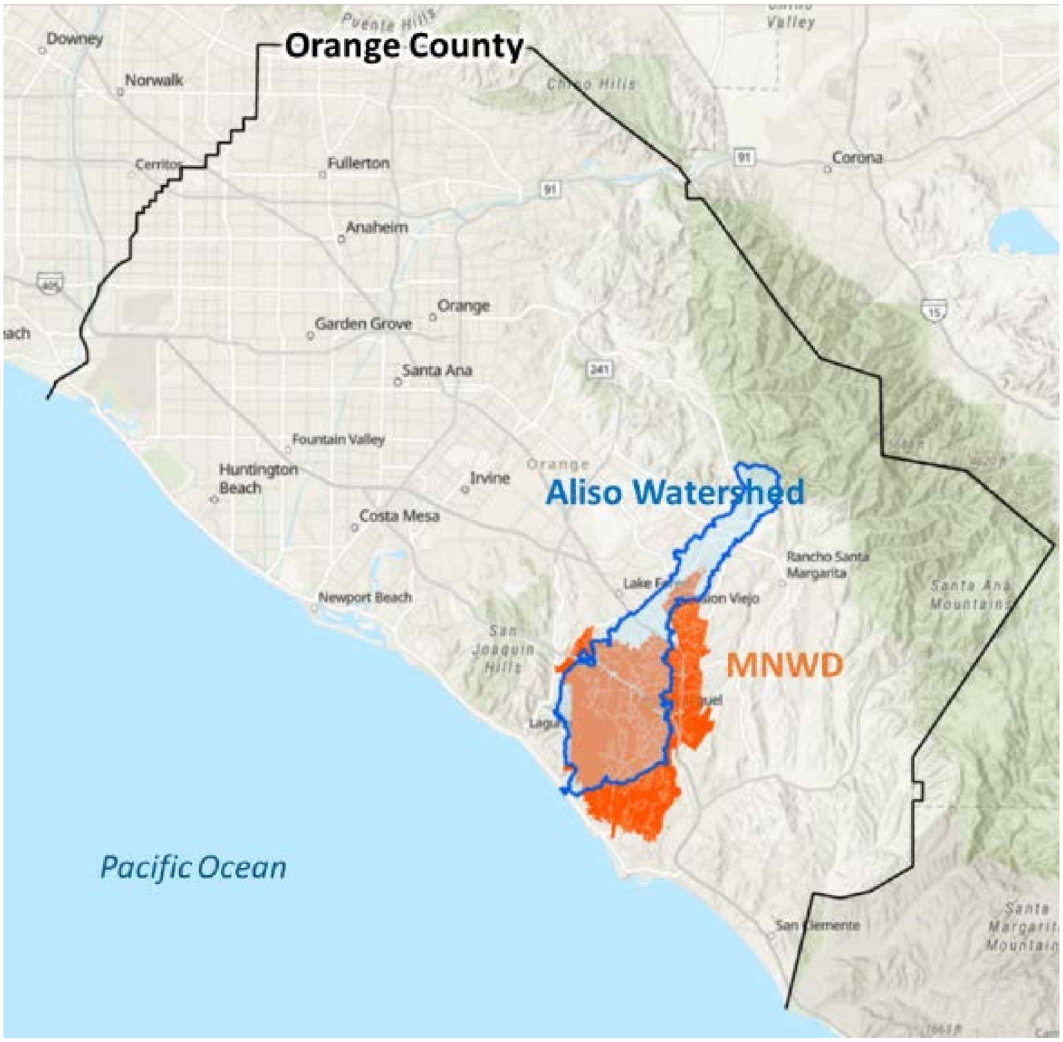


Figure 1. Study area of the Aliso Watershed and the MNWD service area

Water Resource Recovery Potential. Based on prior monitoring performed by the SOC WMA, there is considerable water available for potential recovery. Dry weather flows at major storm drain outfalls are estimated to be 3,200 acre-feet per year (AFY) (or 4.2 cfs)[2]. Much of this water may be needed to support stream function and would not be suitable for diversion, however through a more detailed characterization of flow sources and regimes, it may be possible to identify areas where low flow diversion from storm drain outfalls would have a net benefit to stream health while augmenting local water supply. Total average annual discharge in Aliso Creek is approximately 11,000 AFY including baseflows and storm flows[3], of which a substantial portion could be available for capture and diversion before reaching the stream.

---

[2] Baseline Unnatural Flow to Inland Receiving Waters: Analysis of Outfall Data from 2010 to 2020. https://ocgov.app.box.com/v/SDR-WQIP-Clearinghouse/file/912979272682

[3] South Orange County Flow Ecology Special Study. https://ocgov.app.box.com/v/SDR-WQIP-Clearinghouse/folder/154810835223

As a result of effective water conservation measures, MNWD currently has approximately double the wastewater treatment capacity of the current dry weather wastewater flows it sends to wastewater treatment plants. In 2017, MNWD recorded average dry wastewater flows of 10.8 million gallons per day (MGD), with current capacity of approximately 22.7 MGD (resulting in an available capacity of approximately 13,300 AFY). Total water (recycled water and potable water) demand in the MNWD was approximately 28,000 AFY in fiscal year 2019-2020[4]. If the District were to divert and recover one third of the combined dry weather and wet weather runoff volume, this volume would represent around 13% of MNWD's total water demands.

Barriers to Urban Runoff Recovery. Recovery of urban runoff during both dry and wet weather represents an opportunity for MNWD and other agencies in Southern California to increase local water supplies. However, before stormwater or urban runoff can be fully developed as a new resource, agencies must understand the interactions of various environmental, social, and regulatory factors which influence the viability and success of a potential project. Specific barriers to broader implementation include:

- **Capacity Issues.** Sanitary sewer collection systems can experience inflow and infiltration during wet weather that can temporarily increase flows in the conveyance system and to the treatment plant. Intentional routing of stormwater during these periods may need to be limited to avoid overwhelming the conveyance system or water reclamation facilities.
- **Total dissolved solids (TDS) issues.** Water recycling systems often need to be carefully managed for increases in TDS associated with using water multiple times. Some systems may operate near the upper limits specified in their operating permits. Dry weather runoff tends to contain elevated TDS. Depending on levels of TDS in runoff compared to TDS levels in recycled water, capture of this runoff could improve TDS conditions or degrade TDS conditions. In comparison, stormwater is often lower in TDS than dry weather runoff.
- **Receiving water impacts.** Runoff and seepage to streams (whether natural or unnatural) may play an important role in sustaining current riparian ecosystems. Capturing and removing water could have a negative impact on these receiving waters. The SOC WMA permittees conducted the Flow Ecology Special Study (see Footnote 3) to develop tools to assess this question.
- **Data integration.** Evaluation of the factors above requires data from multiple spatial and temporal scales. Additionally, data needs to be processed and analyzed in an integrated way to help develop strategies for overcoming these barriers.

This Smart Watershed Network project aims to help overcome barriers to urban runoff recovery by providing real-time, high resolution watershed data combined with an integrated decision support tool.

2.2 Study Objectives

The Smart Watershed Network is intended to provide information and tools to evaluate the sustainable use of urban runoff and stormwater as a potential water supply within the Aliso Creek Watershed. The project is intended to help improve resiliency of the region's water supply by providing a new resource to look at the urban water balance to identify potential resource recovery projects. The project advances the field of knowledge in urban runoff recovery and provides a methodology and tools that can be applied to water agencies throughout the region.

---

[4] MNWD 2020 Urban Water Management Plan: https://www.mnwd.com/wp-content/uploads/2021/12/2020-Urban-Water-Management-Plan.pdf

Specific research objectives of this project include:

- **Pilot the use of AMI network for watershed monitoring**. The AMI network was built to support high-resolution monitoring of customer water usage. This project includes novel use of the District's AMI network to evaluate flows in the storm drain system and creek. This project is intended to serve as a pilot demonstration to provide lessons learned and transferrable findings about this use of the existing network.
- **Fill key data gaps to support urban runoff recovery planning.** This project includes a high-resolution network of permanently deployed flow and conductivity monitoring stations. These data are intended to help refine understanding of water and salt balance in the system to help support resource recovery and other management actions.
- **Provide tools to support decision making.** This project produced a full-scale working example of how datasets and analysis algorithms can be combined into a single platform to support a range of different research and planning use cases pertaining to urban runoff recovery.
- **Provide transferrable lessons learned.** This project is intended to provide transferrable lessons learned to other water agencies and watershed management groups who have similar management goals and may be considering similar systems.

2.3 Overview of Work Performed and Accomplishments

In order to realize urban runoff recovery as a reliable water supply source, runoff flowrates, flow patterns, and water quality need to be better characterized at an outfall and watershed level. To help meet study objectives, this project produced two primary work products:

1. Procurement and installation of a permanently deployed, continuous flow monitoring network at outfalls and major confluences within the storm drain network connected via MNWD's existing AMI network. This also included probes to continuously monitor conductivity as an indication of dissolved solid (salt) content at a subset of stations. This work product is described further in Section 4.
2. Development of a cloud-based data management, integration, and analytics space to support planning and decision making based on watershed data feeds and applied algorithms. The analytical scripts, algorithms and visualizations determined to be effective for managing and interpreting data can be directly adopted or serve as a template for other agencies. Software developed as part of this Project is under an open-source license. This work product is described further in Section 5.

In this report, we document the development of these work products. We also present case studies and findings in Section 6 and 7, respectively.

2.4 Summary of Findings

This section provides a high-level preview of findings. Additional findings specific to the work products are discussed in Section 4 (pertaining to monitoring system deployment) and Section 5 (pertaining to digital infrastructure elements), and overall findings are presented in Section 7. In summary, through this work we found:

(1) It is feasible to perform watershed modeling by utilizing the AMI network. This approach required considerable effort to set up the digital connections between different data systems. However, it resulted in considerable cost savings in monitoring equipment.

(2) There are considerable challenges in maintaining a distributed monitoring network, regardless of the telemetry and data management solution used. The risks of vandalism and challenges maintaining sensor calibration will require ongoing attention.

(3) An integrated data analysis space serves as an efficient solution to explore various critical relationships between data. This type of network produces a very large quantity of data for which the temporal and spatial relationships are critical to derive meaning. The data management and analysis tools produced in this project allowed more efficient detection of meaningful relationships.

(4) An efficient scenario analysis system can support evaluation and optimization of potential runoff recovery scenarios. For example, there are many parameters, such as storage volume, diversion rate, and timing of diversion that can influence performance.

2.5 Study Team and Roles

This section identifies the study team members and provides an overview of their roles in this project.

Municipal Water District of Orange County (MWDOC) – *Lead Member Agency*. MWDOC was the lead member agency and administered the grant.

Moulton Niguel Water District (MNWD)– *Program Manager*. MNWD served as the lead program manager for this project. MNWD directed the work of the study consultant team. MNWD staff also directly supported the deployment of sensors connected to the AMI network and development of data management work products. MNWD is a retail water provider that delivers high-quality drinking water, recycled water and provides wastewater services to more than 170,000 customers in Laguna Niguel, Aliso Viejo, Mission Viejo, Laguna Hills, Dana Point, and San Juan Capistrano.

Orange County Public Works (OCPW) – *Co-Program Manager*. OCPW served as the co-program manager. OCPW procured sensors, contracted with study consultants and directed the work of this team. OCPW staff directly contributed to monitoring site selection, sensor deployment, and development of data management work products. OCPW leads the South Orange County Stormwater Program. This program represents the 11 stormwater permittees in South Orange County, including planning, compliance, monitoring, and assessment functions for this group.

Geosyntec Consultants – *Lead Consultant*. Geosyntec led the consultant team for this project. In addition, Geosyntec led the data management system design, algorithm development, and data analysis tools in collaboration with MNWD, OCPW, and ESA Sitka. Geosyntec was contracted to OCPW.

NV5 (formerly Alta Environmental). *Lead Monitoring Consultant*. NV5 was the lead consultant for the deployment of the field monitoring equipment. NV5 worked with MNWD and OCPW to develop equipment specifications, select sites, and perform installation, calibration, and maintenance of monitoring equipment. NV5 was contracted to OCPW.

ESA Sitka (formerly Sitka Technology Group) – *Technology Sub-Consultant*. ESA Sitka supported development of data management systems and led development of the web-based user interface for the Smart Watershed Network dashboard. ESA Sitka was subcontracted to Geosyntec Consultants.

3 Study Design and Execution

3.1 Task Breakdown

The Smart Watershed Network Work Plan was divided into five tasks designed to provide a workflow for producing the primary work products of this effort.

Task 1: Select Monitoring Sites. This task included selection of flow monitoring sites and verification of the ability to feasibly access and install equipment. As a result of this task, 60 sites were selected as candidate flow monitoring sites, and 20 of those were selected to additionally include conductivity monitoring equipment. OCPW and Geosyntec led the selection of sites to align with major (priority) stormwater outfalls and key intermediate points and confluences in the stream network. NV5 and OCPW screened these sites for suitability for equipment deployment. This resulted in selection of 52 sites for flow monitoring and 20 sites for conductivity monitoring.

Task 2: Develop Digital Infrastructure. This task involved establishing the automated data processes necessary to transmit the sensor data from the field instruments into a cloud-based data storage and analysis space. This included software processes to receive and compile data, clean data, and transmit data between different data repositories. As a result of this task, each of the Smart Watershed Network's multiple data sources have a fully automated process for loading the data into the centralized analysis environment.

Task 3: Procure and Install Equipment. In this task, the project team procured, installed, and calibrated the sensor equipment for the sites identified in Task 1. As a result of this task 52 flow monitoring stations were installed throughout the watershed, each transmitting continuous data via the AMI network. Each flow monitoring station was calibrated to convert sensor signals to water depth. Additionally, NV5 developed a site-specific flow rating table for each site to convert water level to flowrates. Conductivity probes were also installed at 20 of the locations.

Task 4: Data Analysis and Scenario Evaluation. This task involved building on the capabilities of the digital infrastructure established in Task 2 to support data access, visualization, and analysis. The project team developed custom software to perform user-specified data analyses and visualize results. The project team also developed a user interface. As a result of this task, all of the time series data and analytical capabilities are available in a single web-based dashboard that enables users to view spatial and temporal relationships between the various time series data streams, evaluate regressions and relationships between the data, and conduct evaluations of diversion scenarios at any monitoring location within the watershed.

Task 5: Research Findings and Project Report. This task involved development of case studies of the Smart Watershed Network to showcase how the tool functions and the type of analysis it can help provide. It also involved development of this final report and an associated summary presentation.

3.2 Schedule Summary

This section contains key schedule milestones and a discussion of adjustments from the original schedule.

3.2.1 Project Milestones

Task 1: Select Monitoring Sites.

- Draft inventory of monitoring sites: March 2020
- Field inspections to assess feasibility as part of equipment installation: April-May 2020

Task 2: Develop Digital Infrastructure.

- Data pipeline development: May-August 2020.
- First pilot sensors relaying data over the AMI network to MNWD databases: October 2020 (dependent on Task 3 milestones)
- Full automation of data pipeline described in Section 5.1: December 2020

Task 3: Procure and Install Equipment.

- Finalize equipment specifications and start procurement: May 2020
- First round of sensor installations: August-October 2020
- Sensor inspection and maintenance: January-June 2021
- Finalize head-vs-flow rating tables: March-June 2021
- Apply all head-vs-flow rating tables: September 2021
- Conductivity sensor installations: October-November 2021

Task 4: Data Analysis and Scenario Evaluation.

- Development of data analysis and scenario evaluation engine: Progressive development from July 2020 through October 2021
- Beta release of Smart Watershed Network web dashboard: October 2021
- Updated release of Smart Watershed Network dashboard: February 2022
- Case study analyses: February 2022

Task 5: Research Findings and Project Report

- Draft project report: April 2022
- Final project report and summary presentation: TBD.

3.2.2 Discussion of Schedule Modifications

The original schedule submitted with the Future Supply Action Planning (FSAP) grant proposal assumed project startup in February 2019. Actual project startup occurred in December 2019 based on contracting timelines. Additionally, the COVID-19 pandemic and equipment troubleshooting resulted in some delays in equipment procurement and installation. The tasks in the project build on each other, therefore delayed start and delayed installation has required that completion of other tasks be delayed.

We encountered a data resolution error in the AMI software that resulted in the transmitted numbers being overly rounded such that they were not meaningful. This delayed calibration of the water level sensors and development of flow rating tables. This required a period from August 2020 to March 2021 for this error to be resolved and tested by the AMI software provider. This further delayed the schedule for subsequent tasks that depended on calibrated flow data.

The full suite of monitoring data (with calibration and water level to flowrate translation) began to be available in the Smart Watershed Network in September 2021. This milestone was originally anticipated in early 2020. With delays, there was relatively limited period of record available as of late 2021 with which to perform case studies. In light of this, we requested an extension to the contract. This adjusted the contract end from December 2021 to December 2022.

3.3 Cost Summary

3.3.1 Costs Incurred and Fund Disbursements

As part of this study, we incurred costs for professional services firms and equipment procurement. Table 1 summarizes the budgeted cost, incurred cost, and funds dispersed. This does not account for the considerable in-kind contribution by MNWD and OCPW staff to help manage and perform this project.

Table 1. Summary of costs incurred and dispersed[1]

Cost	Procured By:	Budgeted Cost in Grant Proposal	Incurred Cost	Funds Dispersed
Professional Services Contracts				
Geosyntec (Prime) with ESA Sitka (Sub)	OCPW	$169,735	Pending completion	Pending completion
NV5	OCPW	$115,788	Pending completion	Pending completion
California Data Collaborative	MNWD	$0 (in-kind by MNWD)	$6,600	$6,600
Kisters/Hydstra	OCPW	$0 (in-kind by OCPW)	$10,000	$0
Equipment				
AMI Gateways (MNWD)	MNWD	$18,000	$18,000	$18,000
Sensors and power supplies.	OCPW	$86,520	$100,240	$0
Sum		$411,508	Pending completion	Pending completion

1. Costs incurred and funds dispersed are approximate. Final project accounting will be completed in the Fall of 2022, at which time this table will be updated prior to final submission.

3.3.2 Comparison of Planned and Actual Budget

There were three primary areas where costs exceeded the planned budget:

- Additional effort was needed by OCPW and MNWD to interface with their existing software systems. OCPW hired Kisters to implement customizations to the Hydstra database to perform automated data imports. This was necessary so that it could support the Smart Watershed Network and serve as the primary data repository for the acquired data. This was procured as part of an established agreement with Kisters. MNWD hired the California Data Collaborative to develop custom scripts to process and transmit the acquired data from the AMI network. This work occurred within their existing data management system that is used for their water meter data.

- Through the course of the project, we learned that the conductivity sensors require an enhanced power supply compared to the base power supply budgeted for the monitoring sites. This resulted in greater equipment costs incurred.
- Due to data resolution issues, vandalism, and other issues, additional field effort was required by NV5 compared to the original budget.

4 Work Product: Watershed Monitoring System

The first primary product of the Smart Watershed Network project was to develop an instrumentation network of permanently deployed continuous monitoring sensors to characterize wet weather and dry weather flow volume and salinity. These continuous data streams enable the project to begin to fill key data gaps regarding flow variability, flow magnitude, relationships between base flow, urban runoff, and salt content, and how each of these varies throughout the watershed. The watershed monitoring system is defined to include the sensors, power supplies, and field communication to relay the sensor data to the MNWD AMI system. Transmittal and analysis of the data after reaching the AMI system is covered in Section 5.

The following sections describe how monitoring locations were selected for instrumentation, the instrumentation equipment installation process and logistics, and the lessons learned from this effort that are transferrable to future efforts.

4.1 Monitoring Locations

OCPW and Geosyntec identified 60 candidate sites, including major outfall locations, and selected in-stream locations. These locations were selected by County monitoring staff and Geosyntec staff who are familiar with the storm drain assets and the drainage network. The candidate monitoring locations were primarily major outfalls defined by their diameter or largest rectangular dimension (36-inch and larger). These sites provide insight to the direct flows generated by the immediately adjacent upstream urban drainage area. The team also identified candidate locations within stream channels. These locations focused on areas around confluences and intermediate points between other flow monitoring locations.

The OCPW and NV5 teams performed field visits to the candidate sites to assess suitability for monitoring. Key factors evaluated as part of this screening included: solar coverage, AMI network coverage, and presence of a defined and stable cross-section. Via this screening, several of the candidate in-stream and outfall locations were deemed unsuitable for equipment installation. The team was able to install and calibrate water level sensors at 52 monitoring stations in the Aliso Creek Watershed. The permanently installed flow monitoring stations include 13 in-stream locations and 39 major outfall locations and are shown below in Figure 2.

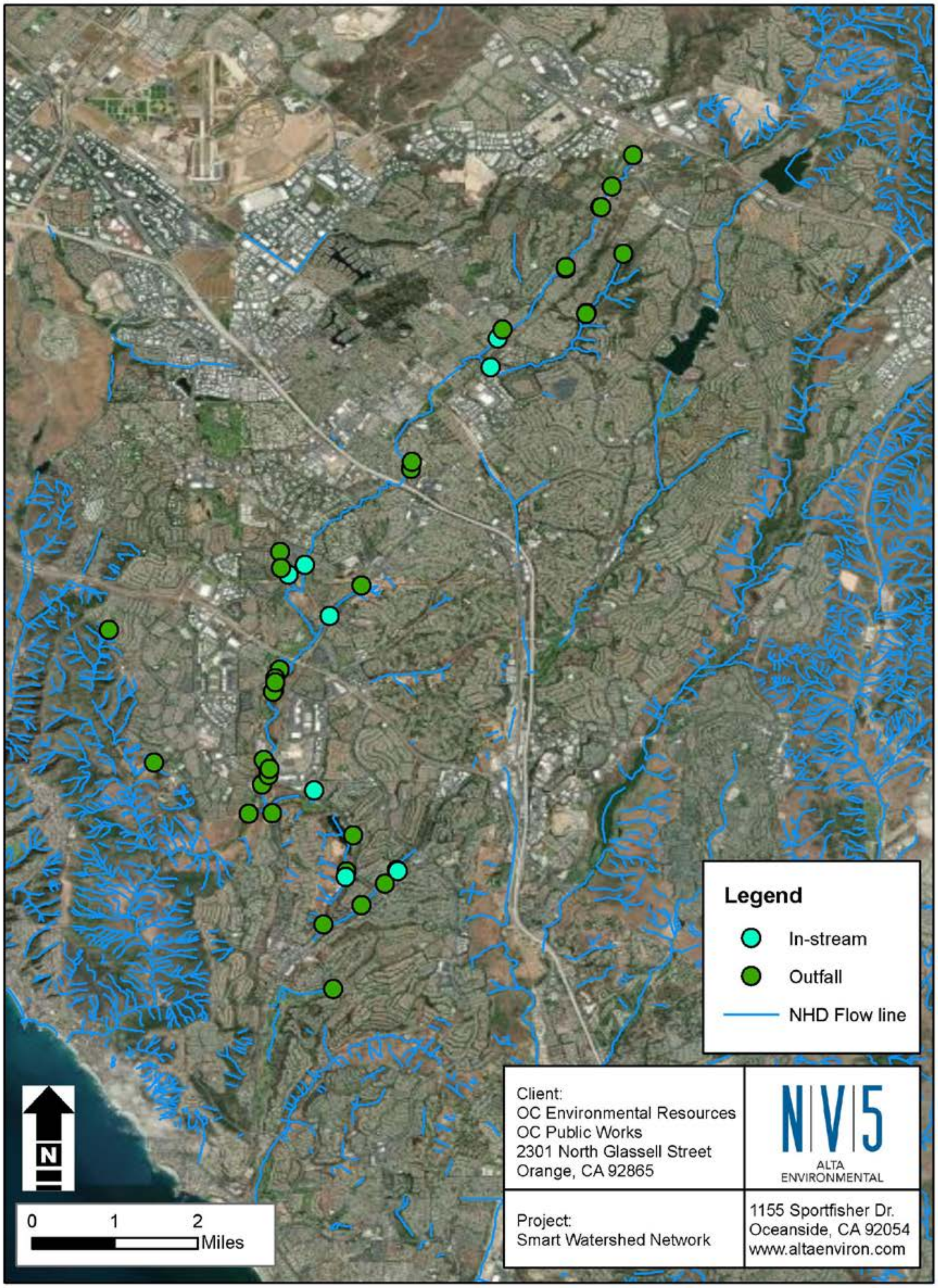


Figure 2. Smart Watershed Network flow monitoring locations

In addition, 20 of these sites have suitable configurations for installation of conductivity probes. These probes must remain continuously submerged to function properly. The locations with conductivity probes installed are shown below in Figure 3.

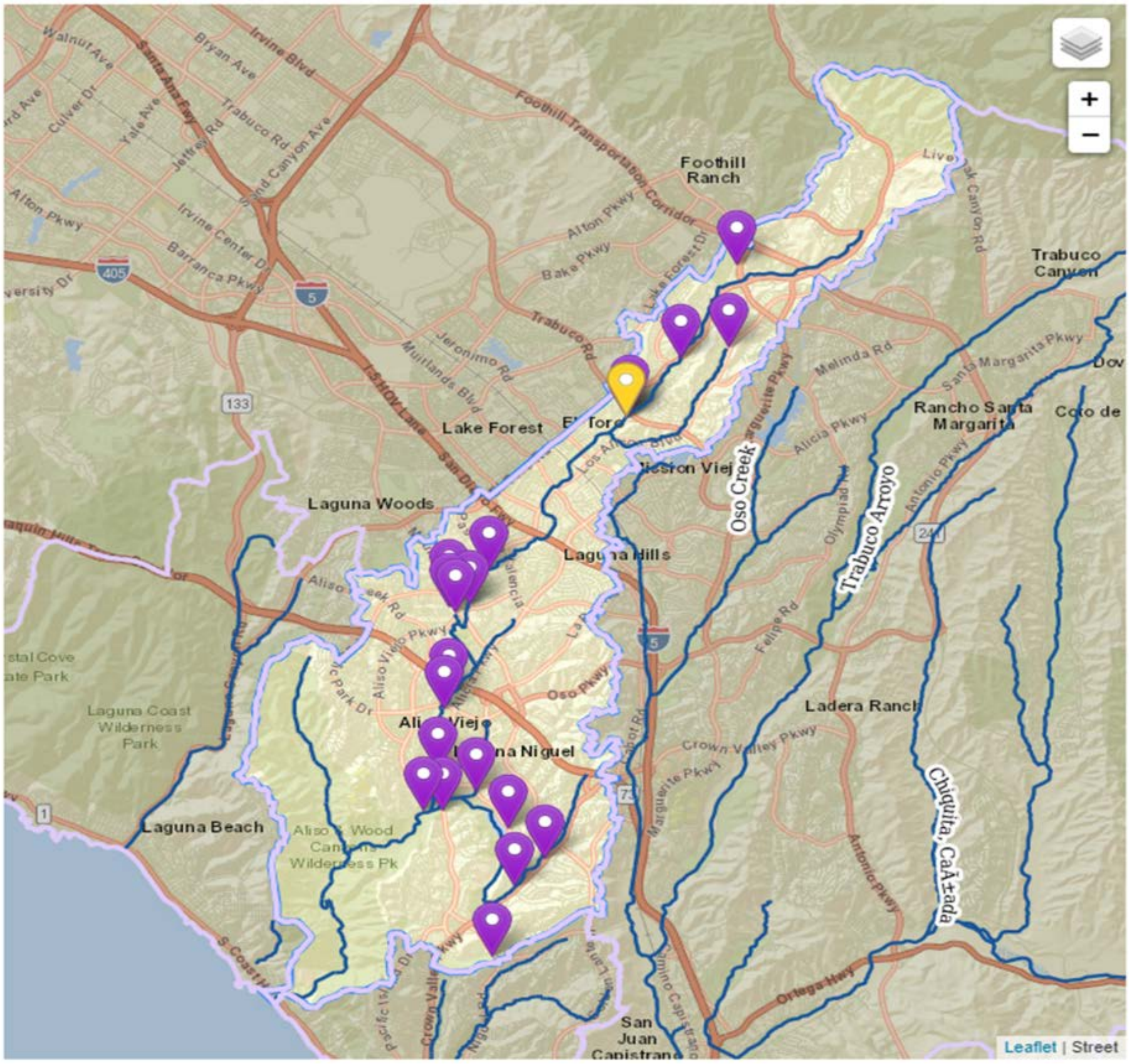


Figure 3. Smart Watershed Network conductivity monitoring locations (screen grab from the SWN Dashboard)

Figure 4 and Figure 5 show examples of in-stream monitoring stations. Figure 6 and Figure 7 show examples of outfall monitoring stations.

Figure 4. Example of in stream installation with smart gateway and pressure transducer.

Figure 5. Example of in stream installation with smart gateway and pressure transducer.

Figure 6. Example of outfall installation with smart gateway, solar panel, regulator and battery enclosure, and downward looking ultrasonic sensor.

Figure 7. Example of outfall installation with smart gateway, solar panel, regulator and battery enclosure, and downward looking ultrasonic sensor.

4.2 Equipment Configuration

As part of this project, NV5 pilot tested a range of sensors and supporting equipment to develop a final parts list to successfully install the continuously deployed flow and conductivity monitoring stations connected to MNWD's AMI network.

The final set of equipment specified, procured, and installed includes:

- Sensus Smart Gateway units
- Global Water WL705 ultrasonic water level sensors
- Global WL400 water level sensors (submersible pressure transducers)
- Xylem EC1500 electrical conductivity sensors
- Tycon Systems RPDC RemotePro outdoor remote power systems (for stations with ultrasonic sensors only)

In the original equipment design, the Sensus Smart Gateway units are typically able to provide two sensors with enough battery capacity to power both sensors as well as transmit their data into the AMI network for two years of continuous deployment before requiring battery replacement. The pilot testing process identified that the ultrasonic sensors demand more power than the Sensus Smart Gateways could provide. This was because the ultrasonic sensors need to be continually powered on in order to provide a reliable reading instead of being powered up periodically by the Smart Gateway to obtain a reading. As such, supplemental power systems needed to be procured. This required additional equipment costs and procurement time. It also required additional field effort to install, secure, and connect the equipment.

4.2.1 Water Level Sensors

NV5 installed and calibrated 52 water level sensors throughout the Aliso Creek watershed as part of the Smart Watershed Network effort. These sensors included 13 in-stream locations, which employed Global WL400 water level sensors (submersible pressure transducers) and 39 major outfall locations, which typically employed Global Water WL705 ultrasonic water level sensors. One exception to this is for site J01-9273-1 for which a pressure transducer sensor was placed within an outfall.

The installation and calibration process for the flow monitoring sensors included:

- Obtain water level measurements at the time of install and inspection
- Apply offsets and conversions to translate the raw sensor readings to an estimate of water level (depth from bottom). For example, the ultrasonic sensors report the distance from the sensor to the water surface. Therefore, to determine water depth, this requires measurement of the height of the sensor above the bottom of the conduit.
- Develop water level versus flow rating table. This was developed using Manning's equation and was calibrated to the observed flow depth and discharge during field visits. The flow rating tables were each field validated using at least 3 in-situ measurements of water level and flow rate.

Appendix A provides additional detail regarding the installation and calibration of sensors. Section 5.1.2 also provides more information about how the conversions from sensor measurements to flow estimates were implemented in the data pipeline.

4.2.2 Conductivity Sensors

Conductivity sensors (Xylem EC1500) were installed in selected locations where the probe could be continuously submerged. This included 8 in-stream locations and 12 outfall locations. These sensors were factory calibrated prior to delivery and field verified using a reference solution during installation. Each sensor was found to be within the manufacturers specified accuracy during the calibration check.

4.3 Lessons Learned and Transferrable Findings

Upon installation of the watershed monitoring system, NV5 visited the sites around three times on average to perform inspections and check sensor calibration. Procurement, installation, and maintenance of the watershed monitoring system led to several key lessons learned which may be transferrable beyond this watershed.

4.3.1 Continuous Watershed Monitoring via the AMI Network

The Smart Watershed Network project successfully leveraged the AMI network for transmitting continuous watershed monitoring data. The AMI network is an upgraded water meter technology that proactively detects leaks, improves operations and enables customers to monitor hourly water usage. The Smart Watershed Network project demonstrates that it is possible to leverage this existing telemetry network for other types of sensors, including water level and conductivity, by using the Sensus Smart Gateways. The AMI network relies on radio frequency (RF) communications, which require much less power than cell-based transmission equipment.

The data from watershed monitoring sensors comes in different conventions than water meter data. Therefore, it was necessary to set up a separate data parsing routine within the MNWD data management system to separate these data streams from the remainder of the AMI data streams.

This project experienced an unusual error in the AMI software that resulted in excessive rounding of the signals sent from the water level sensors over the AMI network. This may have been due to the use of a new type of sensor with smart gateway or due to the relative newness of the smart gateway product. This posed a significant issue for this project that took several months to correct. We do not believe this is an inherent issue with AMI networks, though it does serve as an example of the types of troubleshooting that may be needed when expanding the use of an existing system.

4.3.2 Method of Flow Measurement

Open channel flow measurement is challenging in general, particularly when measurements need to span multiple orders of magnitude. Low flows are often less than 0.1 cfs, with water depths less than 2 inches, while storm flows can greatly exceed 100 cfs in some locations, with water levels up to several feet. As part of this project, we considered different solutions.

The most precise methods for flow measurement involve the use of pre-calibrated inline weirs or flumes combined with water level measurement. However, this approach can reduce the capacity of pipes and can greatly increase installation effort . Additionally, this approach can require greater maintenance associated with sediment and debris accumulation. Breakaway weirs are a possibility, but that requires additional maintenance at each site after each storm event, and the device cannot provide flow data during the event once the breakaway is triggered.

Area-velocity meters can measure the depth and velocity of water without requiring a weir or flume. However, these can require greater power than simple water level sensors and have minimum submergence depths that may not be met in many cases. They also tend to be more expensive than water level sensors.

This project team selected ultrasonic sensors for most outfalls to balance the equipment cost, maintenance requirements, and measurement precision. Ultrasonic sensors require less maintenance and are less prone to fouling caused by algae and damage caused by large storm events than submerged sensors since they are not within the flow. However, without the use of a weir or flume, the estimate of flow is very sensitive to the measurement precision of the equipment and the accuracy of the rating table, particularly for low flows. As a result, we believe the estimates of low flow are relatively uncertain. This uncertainty is likely acceptable for establishing trends and making comparisons between monitored locations, but the absolute magnitude of flow estimates should be regarded as approximate. To keep these sensor readings as accurate as possible the project team recommends field maintenance and calibration of the equipment during quarterly visits as well as some as-needed effort based on monthly reviews of the data. Quarterly maintenance and calibration check at all 52 of the SWN sites requires approximately 3-4 days of field work for a crew of two.

Pressure transducers were selected for stream monitoring locations as these sites typically provide permanent submergence and many of these sites did not have overhead options for mounting an ultrasonic sensor. Much of the same limitations apply to these sensors as discussed in the paragraph above.

4.3.3 Sensor Calibration and Rating Table Development

Sensor calibration and rating table development poses a challenge for any monitoring program. In this case, it was complicated somewhat by the telemetry and data management structure of the AMI system. Ideally field teams are able to view the sensor signal in the field at the time that in-situ water level measurements are obtained. However, the AMI gateways do not provide a field read-out, so the comparison of sensor reading to field measurement could not be recorded in real-time. Rather, data transmitted over the AMI network needed to be obtained after the fact and compared against the field measurements recorded earlier. This resulted in greater effort. For future similar efforts, it would be helpful to set up a system for real-time interrogation of sensor measurements before beginning the sensor calibration step.

4.3.4 Equipment Costs

This project leveraged the Sensus Smart Gateway units to save cost on field monitoring equipment. Each Sensus Smart Gateway is capable of 2 channel data logging and transmission and is equipped with a power supply that is typically able to power the Gateway device and the data sensors for a two-year period. This project used the two channels to measure flow with either a pressure transducer sensor or an ultrasonic sensor, and conductivity with a probe. As discussed earlier, the ultrasonic sensors have higher power requirements than the Gateway is able to provide, so for each site equipped with an ultrasonic sensor the team installed a supplemental power supply with solar panel.

One of our hypotheses in this pilot project was that this method of monitoring would be less expensive compared to other available approaches due to the lower cost of telemetry equipment and lower power supply. Table 2 reports the costs per station for the hardware used in this project. Table 3 summarizes the equipment costs for the default flow monitoring and telemetry equipment that OCPW has used for the last 7 years if this was scaled up to serve all 52 locations in the Smart Watershed Network. The default OCPW system is portable and can be relocated to different monitoring locations, which is an advantage not as readily offered by the AMI gateways. However, the data logger and telemetry system are much more expensive than the AMI gateway which performs similar functions.

Note that we did not account for the initial effort to configure the AMI network and MNWD databases to handle these data. This is a necessary upfront cost to allow the AMI network to be used in this way.

Table 2. Cost components of field equipment used in pilot project

Element	Count	Unit Cost
Sensus Smart Gateway (data logging, transmission and base power supply)	52	$292
Supplemental Solar Power Supply for Stations with Ultrasonic Level Sensors	39	$180
Pressure Transducer (Global Water WL400)	13	$455
Ultrasonic Sensor (Global Water WL705)	39	$670
Conductivity Probe (Xylem EC1500)	20	$1,700
Total	--	$88,249

Table 3. Cost components of OCPW default monitoring and telemetry solution (hypothetical)

Element	Count	Unit Cost
HACH FL900 Data Logger with batter supply and cellular telemetry	52	$6,240
Cellular Data Plan (annual)	52	$180
Pressure Transducer	13	$455
Ultrasonic Sensor	39	$1,250
Conductivity Probe	20	$1,700
Total	--	$427,700

4.3.5 Vandalism, Maintenance, and Repair

In most locations, the monitoring equipment is accessible or visible to the public. It was not possible to armor all sensor cables nor enclose equipment in a tamper-proof box. The AMI telemetry equipment needs to be able to access the RF network. Additionally, solar panels (which were necessary for sites with ultrasonic sensors) needed to be located where they have solar exposure. Over the course of the 18 months since installation, several of the sites have been vandalized, including cut cables, stolen equipment, or broken solar panels. The rates of vandalism are not necessarily higher than other monitoring efforts conducted by OCPW. However, the permanent deployment of this system results in a greater chance that vandalism will occur over the lifespan of the equipment.

As discussed above, maintenance is needed to keep rating tables up to date over time. OCPW has begun to implement long-term systems to meet this need, including collecting in-situ measurements of water level and flowrate at the time of twice-yearly outfall inspections. These observations can be used to apply rating table updates over time.

Overall, this system will require substantial ongoing investment to ensure that monitoring stations remain operational and provide reliable data over time.

5 Work Product: Data Management and Analytic Tools

As the second key work product, the Smart Watershed Network project team developed a cloud-based data management, integration, and analytics space to support planning and decision making based on watershed data feeds and applied algorithms. The analytical scripts, algorithms and visualizations determined to be effective for managing and interpreting data can be directly adopted or serve as a template for other agencies. Software developed as part of this project was developed under an open-source license.

5.1 System Elements and Data Connections

The Smart Watershed Network incorporates data from many sources and presents the sensor data from field stations in an integrated cloud-based analysis environment that supports analyses across multiple datasets. To accomplish this, the project team built multiple software processes and data workflows. An overview of the system data sources is shown in Figure 8 (the numbers in Figure 8 align with the numbers in the list below).

The key components of the system include:

1. **Anonymized Water Usage Data.** Anonymized water usage and budget metrics are automatically aggregated to the OCPW regional subbasin spatial layer. This regional subbasin layer also serves as the system for determining the drainage area that flows to each of the monitoring stations.
2. **Field Sensor Data Pipeline.** The sensor measurements from the watershed monitoring system are transmitted over the AMI network and prepared via a data pipeline such that they are available to enter into the OCPW Hydstra database.
3. **Other OCPW Monitoring Data.** This includes existing data resources from the OCPW ALERT telemetry system, including regional stream flow monitoring and precipitation monitoring stations.
4. **OCPW Hydstra Database.** The OCPW Hydstra database is the system of record for the existing hydrologic monitoring performed by OCPW. This is used as the permanent repository for the Smart Watershed Network station. Hydstra provides tools for querying the time series records available at each monitoring station.
5. **Data Integration and Analysis Environment.** A cloud-based data integration and analysis environment was developed to collect the data from each of the various data sources and to

provide a unified application programming interface (API) to access the federated data, run analyses, and review results.

6. **Smart Watershed Network Dashboard.** This website serves as the primary user interface for the Smart Watershed Network data resources and analysis functionality from which authenticated users can view the monitoring locations on a web map, interact with the various data streams, perform analyses, run scenarios, and download data.

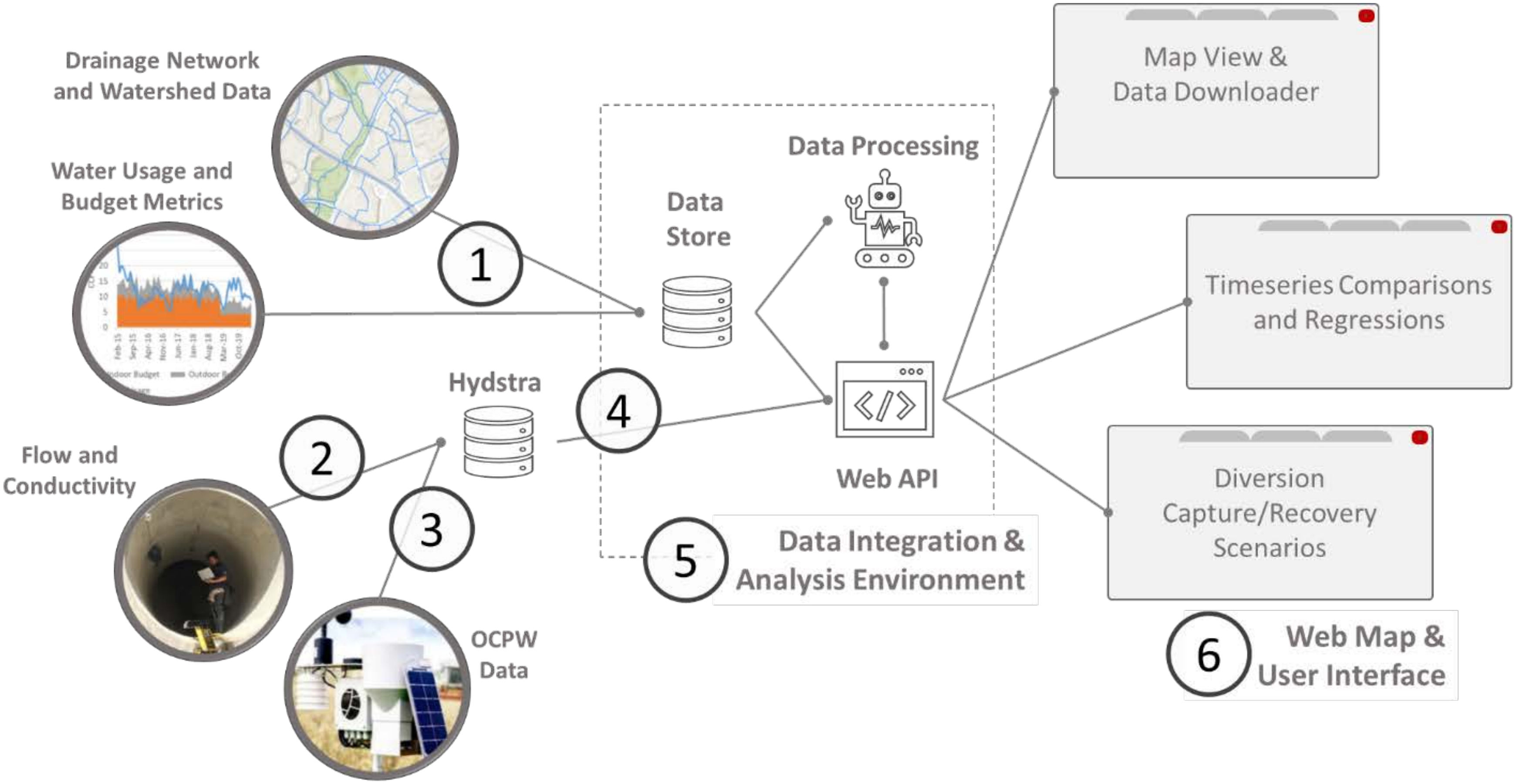


Figure 8. Smart Watershed Network data sources, processes, and destinations.

The following sections describe each of the numbered data sources and digital infrastructure components identified in Figure 8.

5.1.1 MNWD Anonymized Water Usage Data

The first numbered element in Figure 8 refers to the monthly water usage data collected by MNWD for water customers throughout the District. These water usage and water budget data are collected and processed on MNWD's secure system and anonymized and spatially aggregated to protect privacy.

The secure calculation space maintained by MNWD computes multiple metrics, including metered usage and water budget for both indoor and outdoor uses. Their system combines these metrics to form estimates of indoor usage, outdoor usage, and an estimate of outdoor budget overage. This estimated outdoor budget overage metric is used by the Smart Watershed Network as a proxy for potential irrigation overspray, or "estimated urban drool". MNWD has been able to calculate these metrics back to 2015.

The usage metrics data are spatially aggregated within regional subbasins delineated and maintained by OC Survey[5] which manages, edits, and publicly shares the GIS information for the drainage network, watersheds, and regional subbasins for Orange County. The regional subbasin layer is composed of neighborhood sized drainage delineations with a nominal size of about 40 acres. Each delineation feature in the dataset has both a unique identification field and the unique identification field of its next downstream regional subbasin feature. MNWD's anonymized water usage and budget metrics are aggregated within these regional subbasins prior to being posted to a secure FTP as a flat-file csv. This process occurs on a monthly cycle. MNWD also posts a snapshot of the regional subbasin GIS layer that was used to aggregate the data.

The monthly MNWD usage metrics (csv file) and the regional subbasins snapshot (geojson file) are retrieved from the secure FTP each month and loaded into the central cloud-based data analysis environment (See Section 5.1.5).

These two resources are used in the tool to display accumulated water usage metrics for the regional subbasins upstream from each monitored location. In the example shown below in Figure 9 the tributary area to a field monitoring station is shown with orange fill on the web map on the left. The aggregated MNWD usage metric for estimated urban drool from the upstream regional subbasins is displayed on the right. In this example we see the seasonal cycling of the estimated urban drool.

---

[5] https://ocgis.com/arcpub/rest/services/Environmental_Resources/RegionalSubbasins/FeatureServer

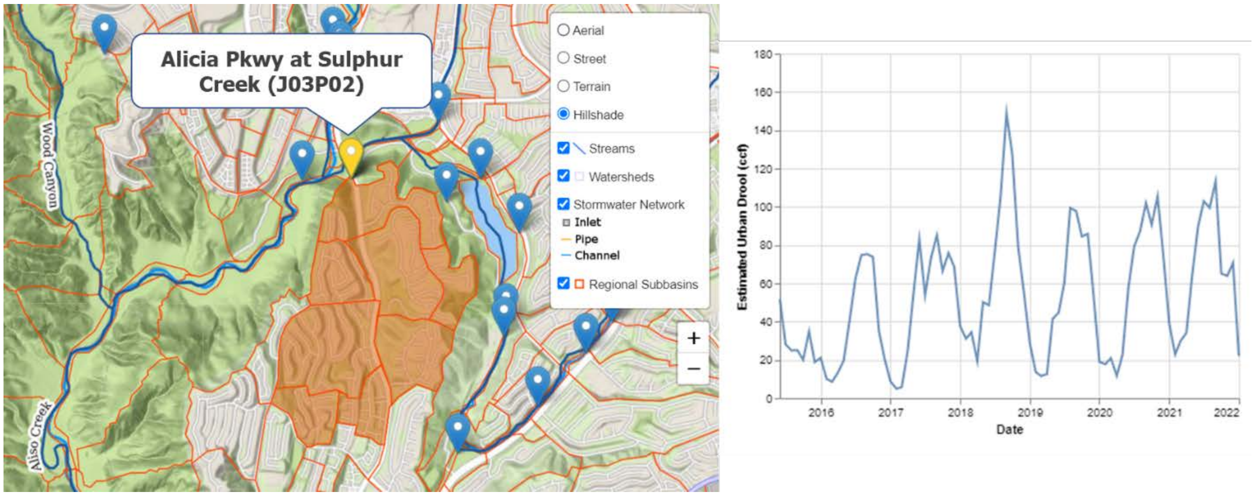


Figure 9. Tributary drainage area to the J03P02 field monitoring station, with MNWD metrics[6].

5.1.2 Field Sensor Data Pipeline

The project team has developed an automated data pipeline to receive the data transmitted by the Sensus Smart Gateway units, clean the data, append it to a staging database, and allow permissioned access to the data by other components of the system. Specifically, this pipeline starts with the AMI network and ends when the cleaned data are imported in the OCPW Hydstra database. The Sensus to Hydstra Data Pipeline includes the following steps:

- MNWD and Sensus developed a custom daily report containing the 15-minute resolution water level data and conductivity readings reported by the Smart Watershed Network stations. This report is maintained separately from water usage data also transmitted over the AMI network.
- MNWD and the California Data Collaborative developed a script that receives the Sensus report, parses, cleans, and appends it to a master database of Smart Watershed Network sensor readings on an Amazon S3 bucket. This script was built by adapting a similar script that MNWD uses to parse and clean water meter readings that are also relayed over the AMI network.
- Hydstra and OCPW developed an automated scheduled routine to import the new raw sensor data from the Amazon S3 bucket to the OCPW Hydstra database (See Section 5.1.4).

The Sensus to Hydstra Data Pipeline is identical for all three sensor data streams (ultrasonic, pressure, and conductivity), but there are notable differences in the way that the raw sensor data is transformed into useful units of measure within Hydstra. The following sections focus on the differences in the data management process once the raw data has been through the Sensus to Hydstra Data Pipeline.

5.1.2.1 Ultrasonic water level sensors

Ultrasonic water level sensors are positioned on the top inside surface of large diameter outfall pipes. They continuously emit ultrasonic pulses and measure the return time to measure the distance to the free water

---

[6] https://swn.yachats.sitkatech.com/time-series-analysis?json={"start_date":"2015-06-01", "end_date":"2022-01-01", "timeseries":[{"variable":"urban_drool", "site":"J03_9221_1","interval":"month", "weather_condition":"both","aggregation_method":"tot"}, {"variable":"mnwd_meter_count","site":"J03_9221_1","interval":"month","weather_condition":"both","aggregation_method":"tot"}]}

surface within the pipe below the instrument. The raw sensor information is then loaded into Hydstra each day via the Sensus to Hydstra Data Pipeline described above.

The Hydstra database is responsible for translating the raw instrument reading from the ultrasonic sensor into volumetric flowrate by applying field collected numeric offset values recorded during the installation process and by applying the site-specific rating table for the instrument and location. The conversion is made by a series of measurements, calibrations, and rating tables recorded in the field and stored in the Hydstra database for each site.

First, the physical position of the sensor is carefully measured and logged in the field and loaded into the Hydstra database. These measurements were made during installation and can be updated if changes or repairs are needed as the project team continues to maintain the instrumentation. Figure 10 below indicates the installation offset measurements required to fully document the position of the instrument within the outfall pipe.

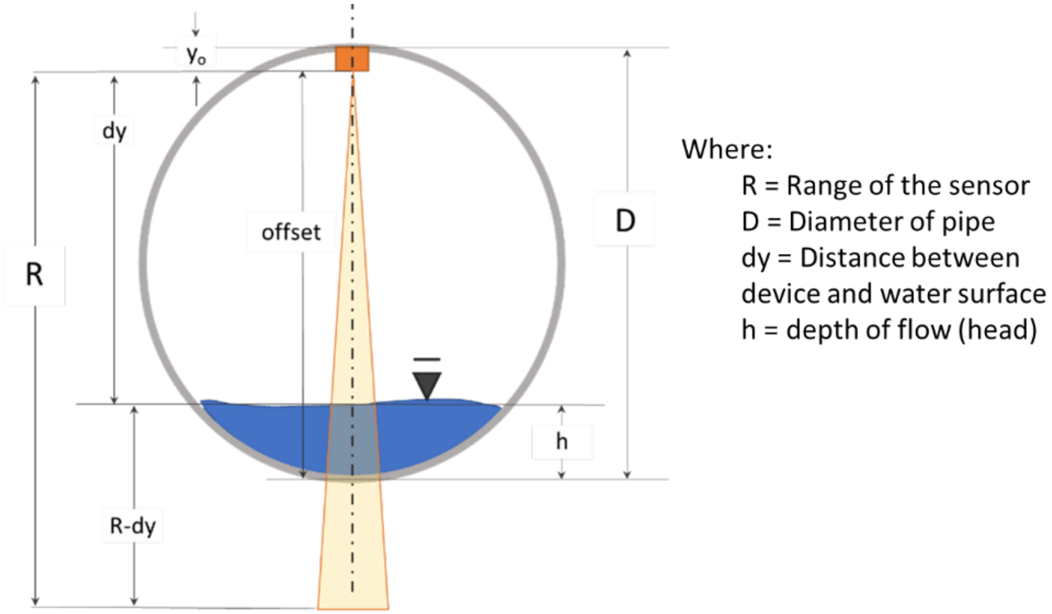


Figure 10. Ultrasonic sensor field installation offset measurements

The installation offset measurements enable the system to translate the raw instrument reading into a measurement of distance to water and then, again using these offsets, into flow depth in inches.

The field teams also establish calibrated rating tables for each flow sensor location using the outfall diameter and slope to convert the observed water level into volumetric flowrate using Manning's Equation. Flow rating tables are stored within the County's Hydstra Database. Each of the 39 ultrasonic sensors has a unique rating table similar to the one shown below in Figure 11.

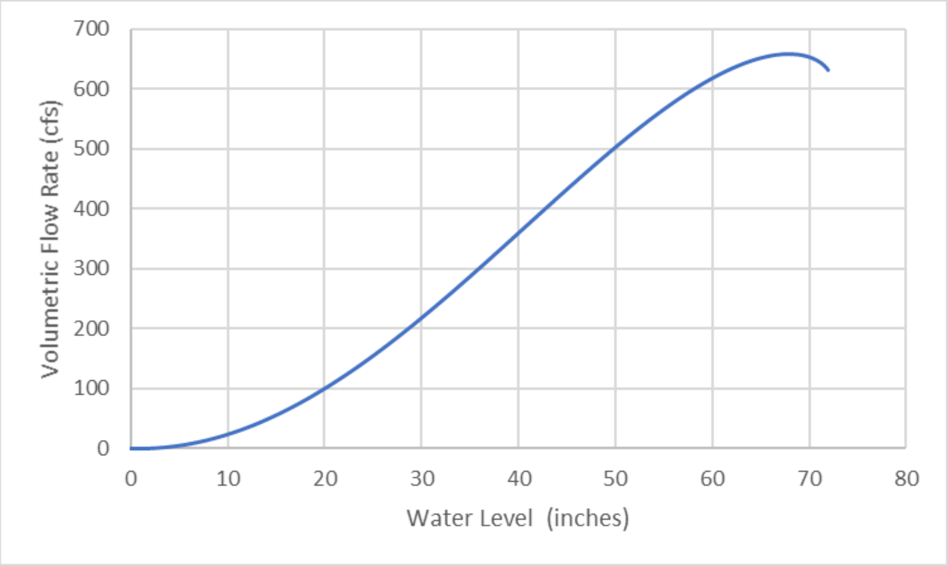


Figure 11. Water level to volumetric discharge rating table for ultrasonic sensors at Alicia Pkwy at Sulphur Creek (J03P02) station ID: J03-9221-1

Once the installation offset measurements and field calibrated rating tables are entered into the Hydstra database, the system is ready to convert nightly csv uploads of raw ultrasonic sensor data into volumetric discharge values by applying both the installation offsets and the calibrated rating table. The Hydstra Database provides both the distance to water (inches) variable and the volumetric discharge (cfs) variable for each ultrasonic sensor site installed in the Smart Watershed Network. This relationship is demonstrated by Figure 12 below which compares the translated sensor reading of distance to water into volumetric flowrate for a storm event occurring in February 2022.

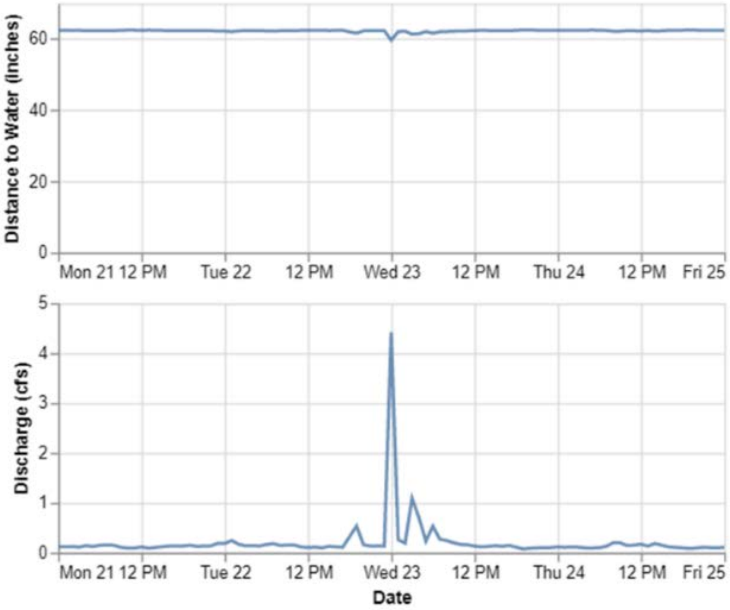


Figure 12. Distance to water and volumetric discharge at Alicia Pkwy at Sulphur Creek (J03P02) for a storm event occurring on February 22-23, 2022 [7]

5.1.2.2 Submersible pressure transducers

The submersible pressure transducers were installed predominantly in in-stream locations throughout the Aliso Creek Watershed. These sensors are placed along the channel bottom and continuously transmit the changes in water pressure above the sensor as the depth of flow varies with time. The raw sensor information is then loaded into Hydstra each day via the Sensus to Hydstra Data Pipeline described above.

Field teams record field calibration and installation offset measurements for each pressure transducer to correct for the as-installed sensor position. These installation offset measurements are stored in the OCPW Hydstra database and allow the database to convert the pressure readings from the instrument into depth of flow.

For each site, field teams also establish field verified rating tables based on the channel cross section and slope, which to convert the observed water level into volumetric flowrate using Manning's Equation. These rating tables are also stored within the County's Hydstra database. Each of the 13 deployed pressure transducer water level sensors has a unique rating table like the one shown below in Figure 13.

---

[7] https://swn.yachats.sitkatech.com/time-series-analysis?json={"start_date":"2022-02-21","end_date":"2022-02-25","timeseries":[{"variable":"distance_to_water","site":"J03_9221_1","interval":"hour","weather_condition":"both","aggregation_method":"mean"},{"variable":"discharge","site":"J03_9221_1","interval":"hour","weather_condition":"both","aggregation_method":"mean"}]}

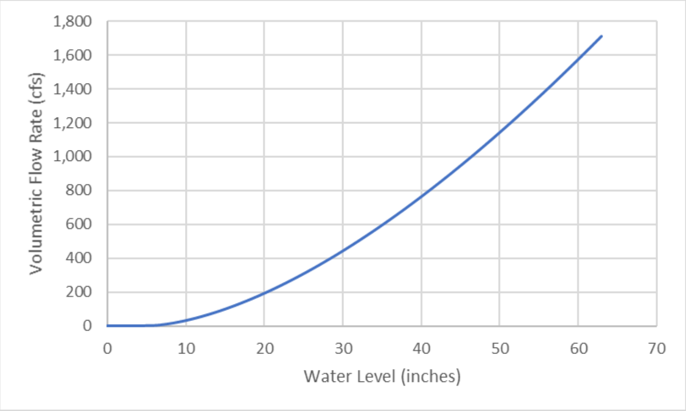


Figure 13. Water level to volumetric discharge rating table for pressure transducer sensor at the Aliso Creek at Aliso Creek Rd station.

Once the installation offset measurements and field calibrated rating tables are entered into the Hydstra database, the system is ready to convert nightly csv uploads of raw pressure transducer data into volumetric discharge values by applying both the installation offsets and the calibrated rating table. The Hydstra database provides both the raw water level (inches) variable and the volumetric discharge (cfs) variable for each ultrasonic sensor site installed in the Smart Watershed Network. This relationship is demonstrated by Figure 14 below which compares the translated sensor reading of water depth into volumetric flowrate for a storm event occurring in February 2022.

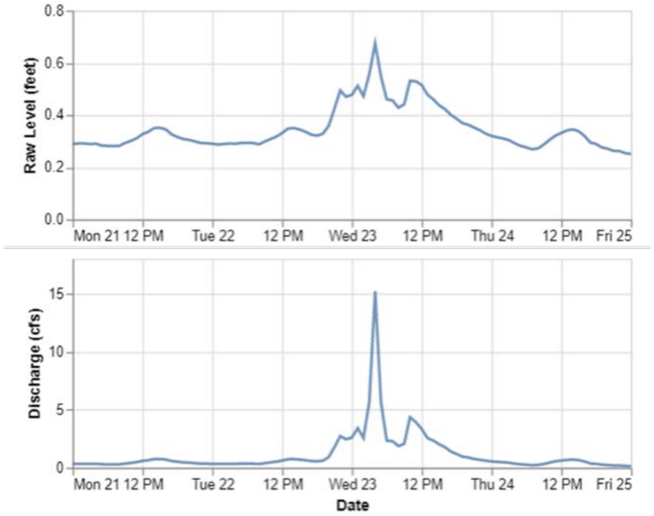


Figure 14. Raw water level and volumetric discharge at Aliso Creek at Aliso Creek Rd for a storm event occurring on February 22-23, 2022[8]

---

[8] https://swn.yachats.sitkatech.com/time-series-analysis?json={"start_date":"2022-02-21","end_date":"2022-02-25","timeseries":[{"variable":"raw_level","site":"ALISO_ALISO_CK_RD","interval":"hour","weather_condition":"both","aggregation_method":"mean"},{"variable":"discharge","site":"ALISO_ALISO_CK_RD","interval":"hour","weather_condition":"both","aggregation_method":"mean"}]}

5.1.2.3 Conductivity Sensors

Conductivity sensors were installed in locations where the probe could be continuously submerged. This included 8 in-stream locations and 12 outfall locations. These sensors were factory calibrated prior to delivery and field verified using a reference solution during installation. Each sensor was found to be within the manufacturer's specified accuracy during the calibration check. The raw sensor information is loaded into Hydstra each day via the Sensus to Hydstra Data Pipeline described above. Hourly conductivity is shown along with hourly discharge for the same storm event in February 2022 in Figure 15.

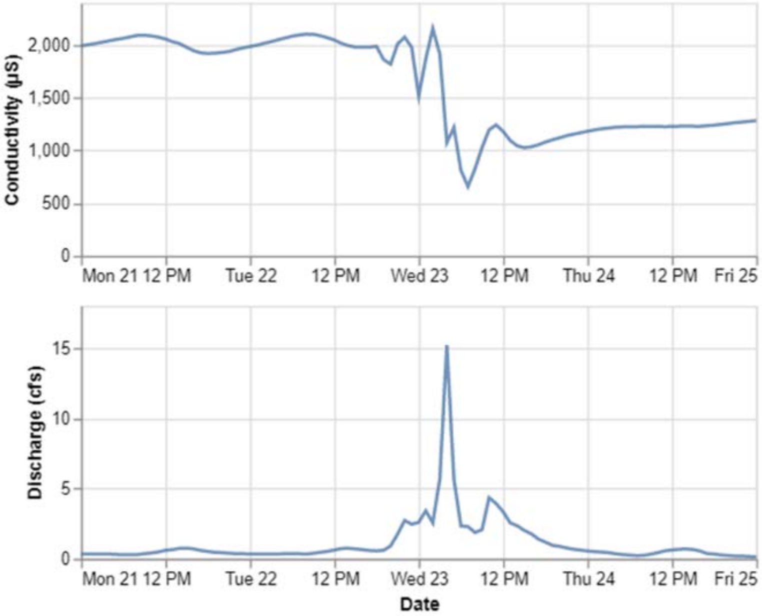


Figure 15. Conductivity and volumetric discharge at Aliso Creek at Aliso Creek Rd for a storm event occurring on February 22-23, 2022[9]

5.1.3 OCPW Data Sources

OCPW operates a network of rainfall and stream gage stations located throughout Orange County, which compose the Automated Local Evaluation in Real Time (ALERT) system. OCPW shares these data publicly via their online Hydrology Data Portal[10], which also includes USGS maintained stream gauge data as well as historical precipitation data from weather stations in the National Center for Environmental Information (NCEI) Cooperative Observer Network (COOP). Each of these streams of telemetry data were available prior to the initiation of the Smart Watershed Network project and the data connections and workflows needed for updating and loading new sensor data have been established for many years. These data resources are all publicly available for review and download via the County's Hydrology Data Portal or by directly querying the County's underlying Hydstra database.

---

[9] https://swn.yachats.sitkatech.com/time-series-analysis?json={"start_date":"2022-02-21","end_date":"2022-02-25","timeseries":[{"variable":"conductivity","site":"ALISO_ALISO_CK_RD","interval":"hour","weather_condition":"both","aggregation_method":"mean"},{"variable":"discharge","site":"ALISO_ALISO_CK_RD","interval":"hour","weather_condition":"both","aggregation_method":"mean"}]}

[10] http://hydstra.ocpublicworks.com/web.htm

5.1.4 OCPW Hydstra Database

OCPW utilizes a Hydstra database to house and manage various time series data streams. This database is a high-performance time series data archival tool that supports workflows for managing hydrological monitoring stations and establishing transformations such as applying data offsets to account for the as-installed positioning of the sensor and registering rating curves to relate flow depth to volumetric flow rate.

The Hydstra database is managed by trained OCPW staff who work with the field teams to register all the necessary metadata for each monitoring site. For the purpose of this project, the Hydstra database includes the relevant installation offset measurements, rating tables, and the geographic coordinates for the monitoring station. It also includes tags indicating that a site is part of the Smart Watershed Network so that it can be identified for inclusion in the Data Integration and Analysis Environment (See Section 5.1.5).

The Hydstra database is the system of record for all continuous monitoring stations within the Smart Watershed Network. This system provides the Data Integration and Analysis Environment and the Web Map and User Interface with important station metadata, including:

- Station name, ID, and description
- Geographic location of each station in geojson format for use in a web map
- List of available time series variables at each station (discharge, water level, conductivity, precipitation)
- Period of data availability for each data variable

Hydstra also provides powerful data aggregation and resampling tools that allow users to retrieve time series data for a certain station, variable, and time period, and to specify that the continuous data be aggregated to hourly, daily, or monthly time intervals by either taking the mean, sum, minimum, or maximum value for the values within the interval. These capabilities for data aggregation are exposed via the Hydstra web API. We built on these capabilities for this project instead of developing new data aggregation routines.

5.1.5 Data Integration and Analysis Environment

The data integration and analysis environment (referred to by the software development team as "Lyra")[11] is an open-source cloud-based web service written in Ppython. We also refer to this as the "back-end web service" in this report. This back-end web service provides integrations with the various project data streams and provides a unified API for accessing and processing the data. In general, there are several core capabilities provided by this back-end web service as part of the Smart Watershed Network, including:

- **Maintain synchronicity** with the primary data systems of record.
- **Provide fully integrated data access** for both the MNWD usage metrics and Hydstra time series data streams and their metadata, such as spatial coordinates, data availability (variables), and date range.

---

[11] https://github.com/Geosyntec/lyra

- **Orient the project data streams on the landscape** and provide the resources (data and computational) necessary to relate these time series data streams to one another and to the landscape.
- **Provide analytical functions** capable of operating on the timeseries metrics, including spatial comparisons, variable comparisons, regressions and relationships, and diversion simulations.
- **Provide a unified API** for all capabilities, including viewing and retrieving data streams, their metadata, and triggering advanced analytical functions. This API supports the front-end user interface available on the Smart Watershed Network Platform website.

In support of these project requirements the back-end web service is composed of three principal components each deployed within a Microsoft Azure Cloud application:

1. A Python-based web server and data analysis functions, with a single unified API
2. Data storage services, including a Microsoft SQL Server database and an Azure FileShare
3. Suite of background data management tasks (written in Python) which run scheduled jobs to retrieve or update data.

The following sections discuss how these software components integrate with the data resources from MNWD (Section 5.1.1) and from the OCPW Hydstra database (Section 5.1.3) to produce a unified data retrieval and analysis service to support the web map and user interface discussed in the next section.

5.1.5.1 Unified Query and Analysis API

The back-end web service is responsible for providing a consistent API for handling requests from the front-end Smart Watershed Network Dashboard. These requests include continuous data sources (such as discharge, conductivity, precipitation) from Hydstra or the MNWD metered usage database. The requests also include a description of the analyses to be performed on these datasets. The unified query and analysis API effectively serves as the “conductor” of the back-end web service. It receives requests of various types from the front-end dashboard, queries datasets needed to fulfill the request, conducts analyses on these datasets, and packages the results from these analyses to send back to the frontend dashboard.

Section 5.2 describes the inputs needed for each type of request in greater detail. Results from the back-end web service can be returned in various formats, including:

- CSV files to support further desktop analysis
- JSON data that is available for other analysis tools (e.g., PowerBI, or other web services)
- Interactive chart specifications (as JSON) which leverage the VegaLite data visualization grammar for producing interactive web graphics.

The following sections provide more information on how this unified API integrates with the main data sources.

5.1.5.2 MNWD Integration

The MNWD anonymized water usage metrics (csv file) and accompanying regional subbasins snapshot (geojson file) are prepared and shared via secure FTP by MNWD each month following their billing cycle. The back-end web service runs an automated job each month to retrieve the files from the secure FTP and copy them into the Azure FileShare. The usage metrics data are then uploaded into the SQL database so that they can be queried, aggregated, and returned through the web application. The regional subbasins file is then loaded into the back-end web service so that it can be retrieved as a static file by the front-end dashboard.

These two resources are used in the tool to display accumulated water usage metrics for the regional subbasins upstream from each monitored location. The back-end web service provides utility functions for tracing the subbasins upstream from each monitoring location and aggregating the usage metrics stored in the database. This allows the usage metrics data to be compared to other monitoring time series data at the Smart Watershed Network monitoring locations such as conductivity and volumetric discharge rate by using the regional subbasin identifier of the monitoring station.

Once loaded into the database, the back-end web service queries these aggregated metric usage time series data just like the time series data from the continuous datasets. This allows for a consistent querying and data retrieval pattern for all of the project variables.

5.1.5.3 Hydstra Integration

The OCPW Hydstra database is the system of record for the continuously monitored time series data obtained via the Smart Watershed Network as well as other hydrologic records maintained by OCPW. Hydstra databases provide a web based JSON API to retrieve the data from each monitoring station. The Smart Watersheds Network back-end web service interfaces with the Hydstra JSON API to retrieve the applicable data for each station. The back-end web service translates the simpler API inputs provided by the Smart Watershed Network Dashboard to the more detailed inputs needed for the Hydstra API.

Each night the back-end web service retrieves the station metadata from the Hydstra API to build up a Smart Watershed Network station data manifest, including the station location, the variables available at each station and the time frame for which data exists for each variable. The back-end web service also associates each monitoring station with the nearest OCPW rainfall monitoring station to aid with determination of dry versus wet weather conditions. In addition, the back-end web service intersects each station location with the regional subbasin layer to determine which subbasin contains the station and associates each gauge with a list of upstream regional subbasins to facilitate the linkage between the MNWD meter usage database and the continuous data monitoring station. This data availability manifest is compiled into GeoJSON format and is made available as a web-map ready endpoint to support the Smart Watershed Network Dashboard.

5.1.6 Smart Watershed Network Dashboard - Web Map and User Interface

The Smart Watershed Network Dashboard (front-end dashboard) includes a web map and user interface (referred to by the software development team as “Nebula”).[12] This component is also open-source software, loosely coupled with the back-end web service described above. This website provides the main user-facing interface for the data exploration and analysis tools, including time series analysis, regression analysis, and diversion scenario modeling.

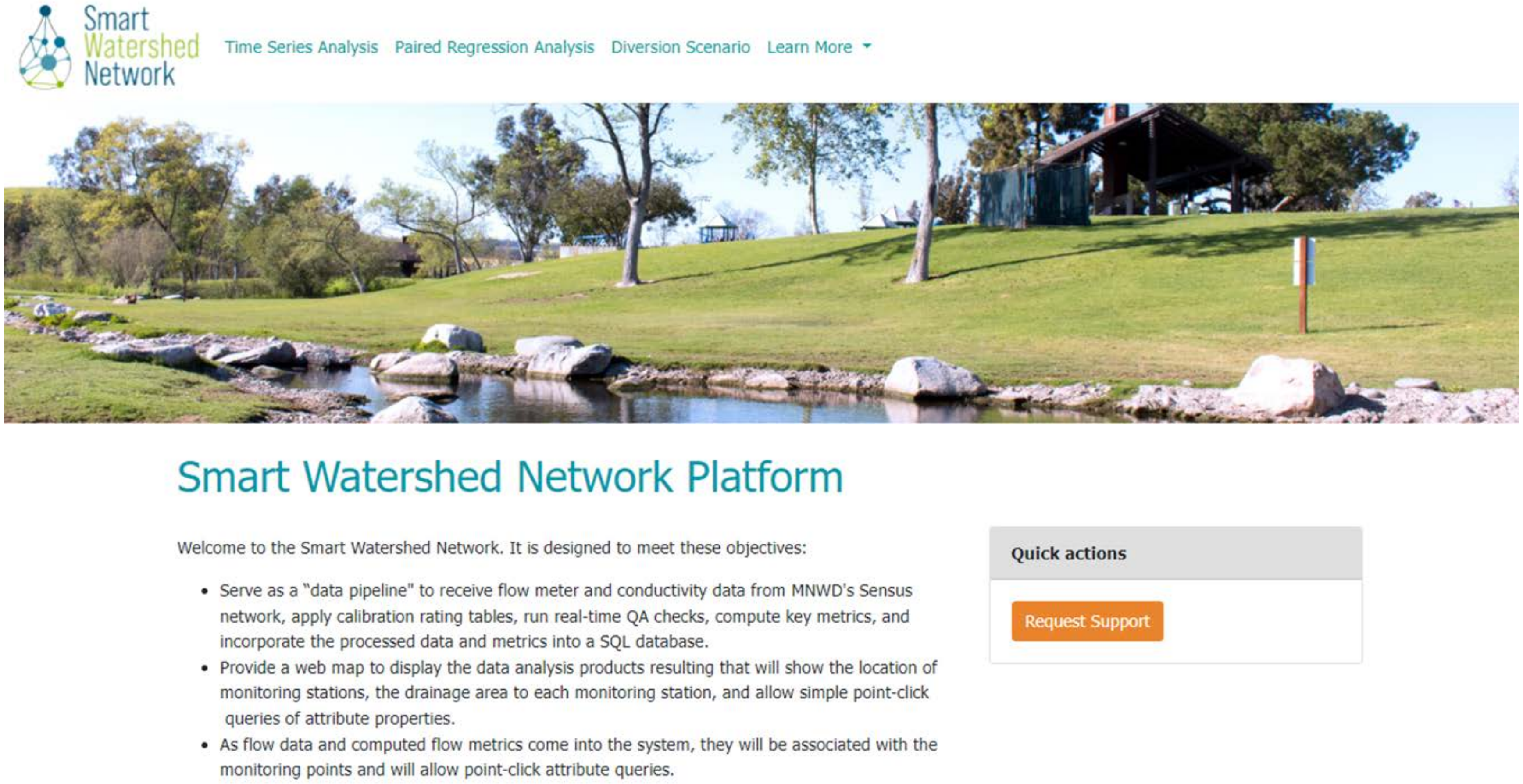
Each of the tools is composed of a web map that displays each of the applicable monitoring stations as well as the key metadata about each station, including the time series variables that are associated with

---

[12] https://github.com/sitkatech/nebula

each monitoring station and the date range for which the data is available. The web map also supports searches for specific stations and filtering the stations by available data types.

Once a station is selected, users can review the station metadata, select an available variable for analysis, and then configure and execute one of the supported analysis functions. These functions and their inputs and outputs are discussed in more detail in Section 5.2. Figure 16 through Figure 19 show examples of the Smart Watershed Network Dashboard.

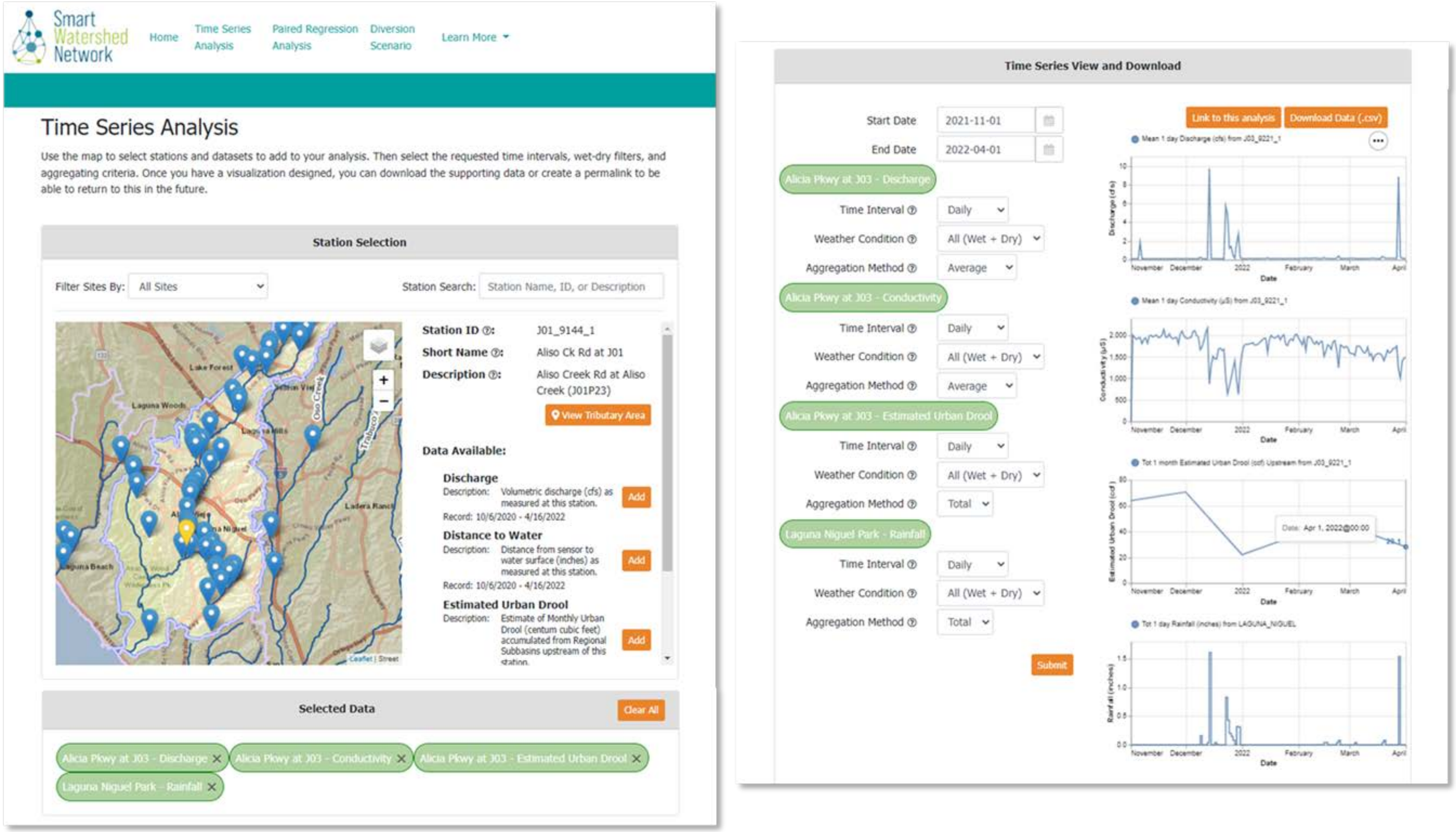


Smart Watershed Network Platform

Welcome to the Smart Watershed Network. It is designed to meet these objectives:

- Serve as a "data pipeline" to receive flow meter and conductivity data from MNWD's Sensus network, apply calibration rating tables, run real-time QA checks, compute key metrics, and incorporate the processed data and metrics into a SQL database.
- Provide a web map to display the data analysis products resulting that will show the location of monitoring stations, the drainage area to each monitoring station, and allow simple point-click queries of attribute properties.
- As flow data and computed flow metrics come into the system, they will be associated with the monitoring points and will allow point-click attribute queries.

Figure 16. Smart Watershed Network Dashboard - Home Page



Time Series Analysis

Use the map to select stations and datasets to add to your analysis. Then select the requested time intervals, wet-dry filters, and aggregating criteria. Once you have a visualization designed, you can download the supporting data or create a permalink to be able to return to this in the future.

Station Selection

Filter Sites By: All Sites

Station Search: Station Name, ID, or Description

Station ID ⓘ: J01_9144_1

Short Name ⓘ: Aliso Ck Rd at J01

Description ⓘ: Aliso Creek Rd at Aliso Creek (J01P23)

View Tributary Area

Data Available:

Discharge
Description: Volumetric discharge (cfs) as measured at this station.
Record: 10/6/2020 - 4/16/2022

Distance to Water
Description: Distance from sensor to water surface (inches) as measured at this station.
Record: 10/6/2020 - 4/16/2022

Estimated Urban Drool
Description: Estimate of Monthly Urban Drool (centum cubic feet) accumulated from Regional Subbasins upstream of this station.

Selected Data

Alicia Pkwy at J03 - Discharge ✕
Alicia Pkwy at J03 - Conductivity ✕
Alicia Pkwy at J03 - Estimated Urban Drool ✕
Laguna Niguel Park - Rainfall ✕

Time Series View and Download

Start Date: 2021-11-01
End Date: 2022-04-01

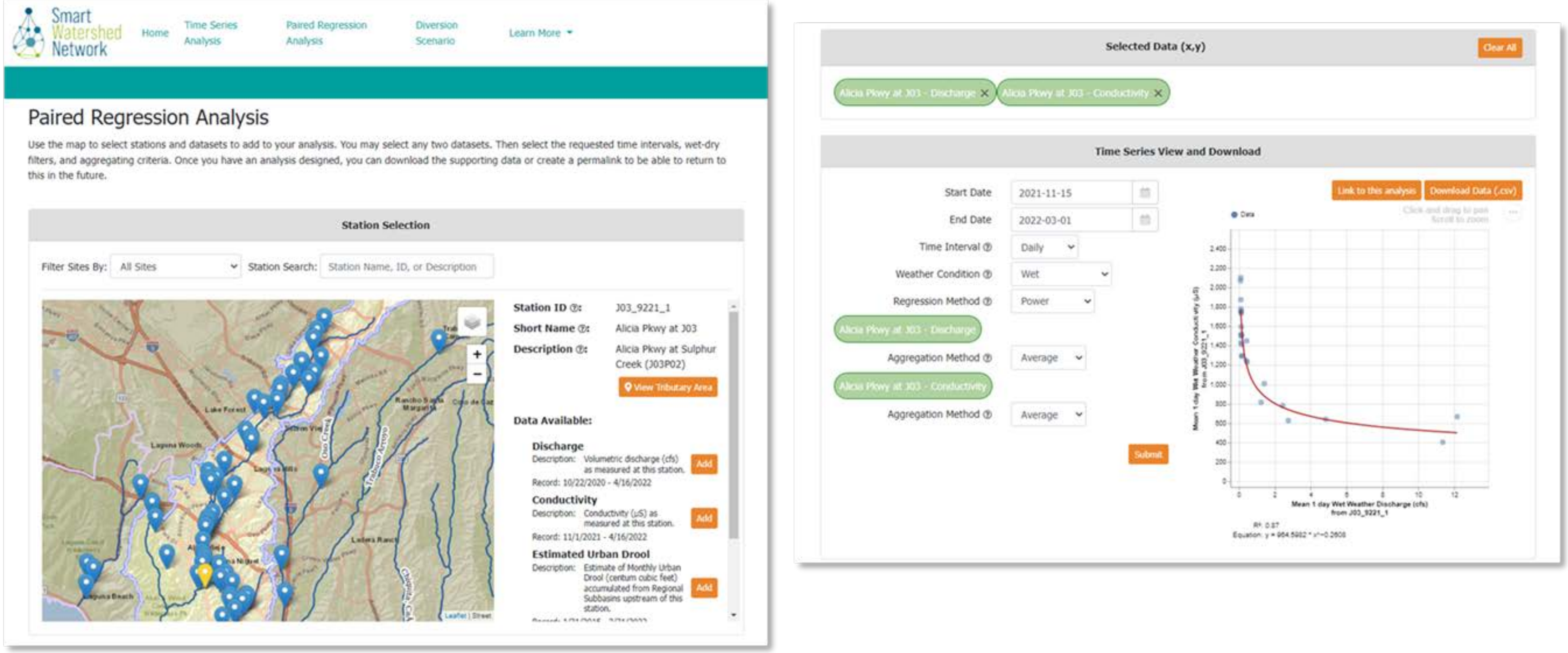
Alicia Pkwy at J03 - Discharge
Time Interval ⓘ: Daily
Weather Condition ⓘ: All (Wet + Dry)
Aggregation Method ⓘ: Average

Alicia Pkwy at J03 - Conductivity
Time Interval ⓘ: Daily
Weather Condition ⓘ: All (Wet + Dry)
Aggregation Method ⓘ: Average

Alicia Pkwy at J03 - Estimated Urban Drool
Time Interval ⓘ: Daily
Weather Condition ⓘ: All (Wet + Dry)
Aggregation Method ⓘ: Total

Laguna Niguel Park - Rainfall
Time Interval ⓘ: Daily
Weather Condition ⓘ: All (Wet + Dry)
Aggregation Method ⓘ: Total

Figure 17. Smart Watershed Network Dashboard – Time Series Analysis Tool Overview



Paired Regression Analysis

Use the map to select stations and datasets to add to your analysis. You may select any two datasets. Then select the requested time intervals, wet-dry filters, and aggregating criteria. Once you have an analysis designed, you can download the supporting data or create a permalink to be able to return to this in the future.

Station Selection

Filter Sites By: All Sites
Station Search: Station Name, ID, or Description

Station ID ⓘ: J03_9221_1
Short Name ⓘ: Alicia Pkwy at J03
Description ⓘ: Alicia Pkwy at Sulphur Creek (J03P02)

Data Available:

Discharge
Description: Volumetric discharge (cfs) as measured at this station.
Record: 10/22/2020 - 4/16/2022

Conductivity
Description: Conductivity (µS) as measured at this station.
Record: 11/1/2021 - 4/16/2022

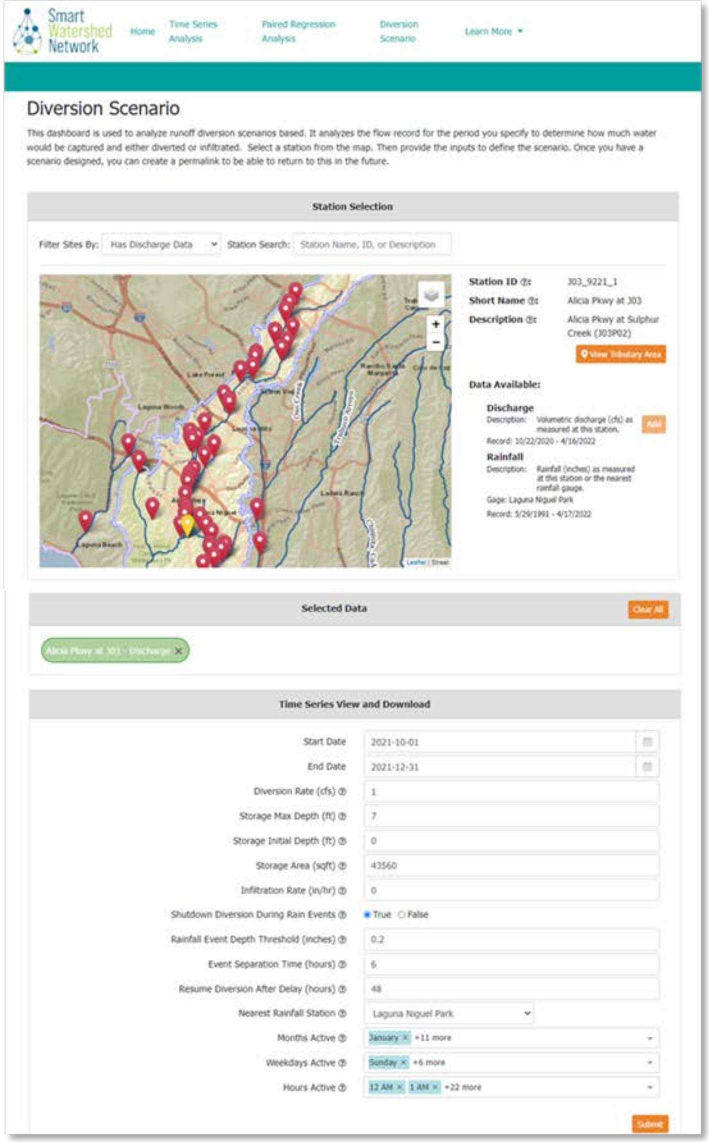
Estimated Urban Drool
Description: Estimate of Monthly Urban Drool (centum cubic feet) accumulated from Regional Subbasins upstream of this station.

Selected Data (x,y)

Time Series View and Download

Start Date: 2021-11-15
End Date: 2022-03-01
Time Interval ⓘ: Daily
Weather Condition ⓘ: Wet
Regression Method ⓘ: Power
Alicia Pkwy at J03 - Discharge
Aggregation Method ⓘ: Average
Alicia Pkwy at J03 - Conductivity
Aggregation Method ⓘ: Average

Figure 18 Smart Watershed Network Dashboard – Regression Analysis Tool Overview



Diversion Scenario

This dashboard is used to analyze runoff diversion scenarios based. It analyzes the flow record for the period you specify to determine how much water would be captured and either diverted or infiltrated. Select a station from the map. Then provide the inputs to define the scenario. Once you have a scenario designed, you can create a permalink to be able to return to this in the future.

Station Selection

Filter Sites By: Has Discharge Data
Station Search: Station Name, ID, or Description

Station ID: J03_9221_1
Short Name: Alicia Pkwy at J03
Description: Alicia Pkwy at Sulphur Creek (J03P02)

Data Available:

Discharge
Description: Volumetric discharge (cfs) as measured at this station.
Record: 10/22/2020 - 4/16/2022

Rainfall
Description: Rainfall (inches) as measured at this station or the nearest rainfall gauge.
Gage: Laguna Niguel Park
Record: 5/29/1991 - 4/17/2022

Selected Data

Alicia Pkwy at J03 - Discharge ✕

Time Series View and Download

Start Date: 2021-10-01
End Date: 2021-12-31
Diversion Rate (cfs): 1
Storage Max Depth (ft): 7
Storage Initial Depth (ft): 0
Storage Area (sqft): 43560
Infiltration Rate (in/hr): 0
Shutdown Diversion During Rain Events: ● True ○ False
Rainfall Event Depth Threshold (inches): 0.2
Event Separation Time (hours): 6
Resume Diversion After Delay (hours): 48
Nearest Rainfall Station: Laguna Niguel Park
Months Active: January × +11 more
Weekdays Active: Sunday × +6 more
Hours Active: 12 AM × 1 AM × +22 more

Scenario Summary Table

Label	Units	Value	Description
Total Inflow Volume	cuft	3,965,346	Total volume entering the diversion during the scenario.
Total Diverted Volume	cuft	1,860,415	Total volume diverted during this scenario.
% of Inflow Diverted	%	46.9%	Diverted volume as percentage of inflow volume.
Total Infiltrated Volume	cuft	0	Total volume infiltrated during this scenario.
% of Inflow Infiltrated	%	0.0%	Infiltrated volume as percentage of inflow volume.
Total Bypassd Volume	cuft	1,800,011	Total volume bypassed during this scenario.
% of Inflow Bypassd	%	45.4%	Bypassed volume as percentage of inflow volume.

Figure 19. Smart Watershed Network Dashboard – Diversion Scenario Analysis Tool Overview

5.2 Data Analysis Tools

Each of the data analysis tools created for the Smart Watershed Network Dashboard include a web map selection interface to provide spatial context for the monitoring station. Users can select one or more station and variable combinations (depending on the analysis tool) as inputs, and then configure and execute the analysis. These analyses support three primary use cases:

- Data exploration, review/QA, and spatial comparisons are supported by the time series analysis tool
- Relationship discovery between pairs of stations and/or variables is supported by the regression analysis tool
- Simulating a flow management and diversion scenario for a given station over a portion of its monitored history is supported by the diversion scenario analysis tool

Each tool provides the user with:

- A tailored input interface to help users build their query
- An interactive chart of the analysis results to enable the user to continue to explore and understand the results
- A link to download the data shown on the interactive chart
- A permanent link (“permalink”) to the analysis that can be copied, stored, and shared with other permissioned users of the Smart Watersheds Network analysis tools.

The following sections provide additional detail about each analysis tool.

5.2.1 Time Series Analysis Tool

The time series data analysis tool supports users in reviewing data availability, assessing temporal trends, and assessing potential relationships between different stations and variables. These analysis tools enable users to compare time series data streams sourced from either the MNWD user metrics database or the Hydstra database. These comparisons can be composed of any combination of variables (discharge, conductivity, estimated urban drool, precipitation) and between any number of monitored sites.

For each time series variable, the time series analysis tools allow for temporal aggregation on user defined intervals, including hourly, daily, monthly, and yearly aggregation. This helps distinguish longer-term trends from shorter-term variability. For some timeseries, a weather filter is also included to help isolate wet weather and dry weather response. The specific time series analysis capabilities related to continuously monitored datasets available in Hydstra and the monthly water usage metrics available from MNWD are detailed below.

Timeseries Analysis of Continuous Data – Hydstra. For continuously monitored datasets that are accessible with Hydstra, the timeseries analysis tool enables several capabilities.

> Temporal aggregation – Each of the Hydstra data streams can be aggregated to hourly, daily, monthly, or yearly time series of the variable. The time series enables users to take the average, minimum, or maximum value for each interval for the continuous flow and salinity data. For precipitation, the time series tools allow users to take the sum for each interval.

Weather condition – Each monitoring location in the Hydstra database is assigned a reference rainfall gauge. This allows users to filter time series to wet conditions, dry conditions, or both (no filter). Wet conditions are determined by the analysis tools by collecting the daily reference rainfall gauge results for the requested period and checking if that day has more than 0.1 inches of rainfall or is within 3 days of such a day with more than 0.1 inches of rainfall.

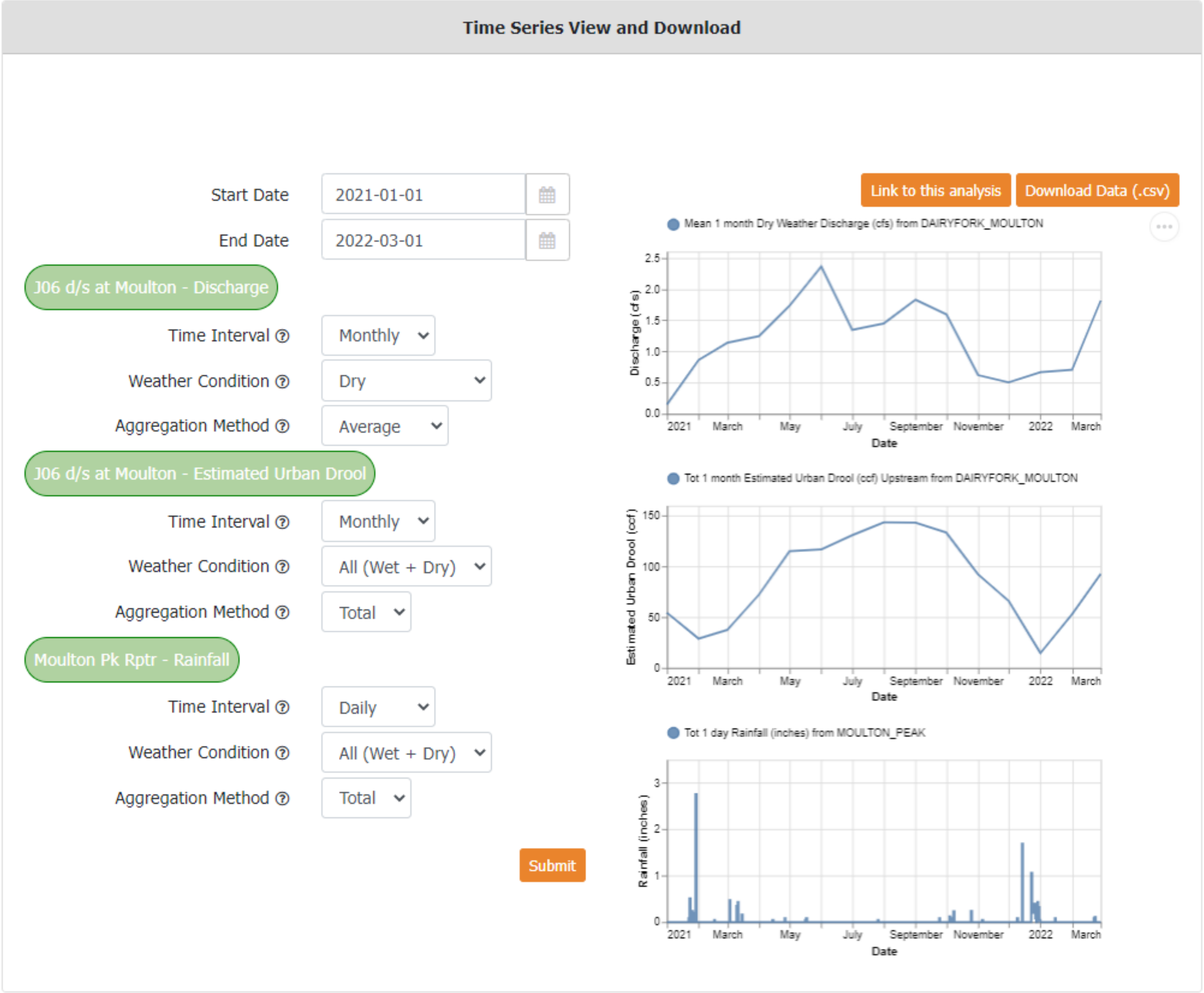
Timeseries Analysis for Monthly Metered Usage Metrics – MNWD. The Smart Watershed Network Dashboard currently shares the metric for estimated urban drool (measured in centum cubic feet, or ccf) from the MNWD usage metrics database. Other MNWD usage metrics may be exposed by the tool at a future time if needed. As previously described, the MNWD usage metrics are provided as a monthly value per regional subbasin. The time series analysis tools enable both temporal and spatial aggregation of the MNWD metrics so that these data can be compared to the time series datasets recorded at continuous monitoring locations.

Temporal aggregation – The MNWD usage metrics exposed in the tool can be aggregated to monthly and yearly intervals. For the estimated urban drool metric, the tool allows users to take the sum of the values within each interval.

Spatial aggregation – The time series analysis tools keep track of the regional subbasins upstream from each of the monitoring locations, and automatically aggregate the MNWD usage metrics upstream. This allows the MNWD usage metrics to be compared to other time series variables in the system.

Weather condition –MNWD usage metrics are monthly and are thus unable to be filtered by weather condition. If a user requests either ‘wet’ or ‘dry’ conditions for one of these metrics, the system will ignore the selection and return results without applying the filter and notify the user that the filter could not be applied to the data set.

Figure 20 provides an example timeseries analysis of monthly average flowrate for dry weather conditions only plotted with monthly total estimated urban drool. It also includes daily precipitation at a nearby gage for reference.



Start Date 2021-01-01

End Date 2022-03-01

J06 d/s at Moulton - Discharge

Time Interval Monthly

Weather Condition Dry

Aggregation Method Average

J06 d/s at Moulton - Estimated Urban Drool

Time Interval Monthly

Weather Condition All (Wet + Dry)

Aggregation Method Total

Moulton Pk Rptr - Rainfall

Time Interval Daily

Weather Condition All (Wet + Dry)

Aggregation Method Total

Figure 20. Example timeseries analysis comparing monthly average dry weather flow versus monthly estimated urban drool[13].

5.2.2 Regression Analysis Tool

The regression analysis tool allows a user to select any pair of time series in the platform and perform a regression analysis. For a regression analysis to be possible, the time series pair must share the following input parameters: Start date, end date, aggregation interval, weather condition (wet, dry, or both; this selection is ignored if one of the datasets is an MNWD usage metric, as described above), and regression method.

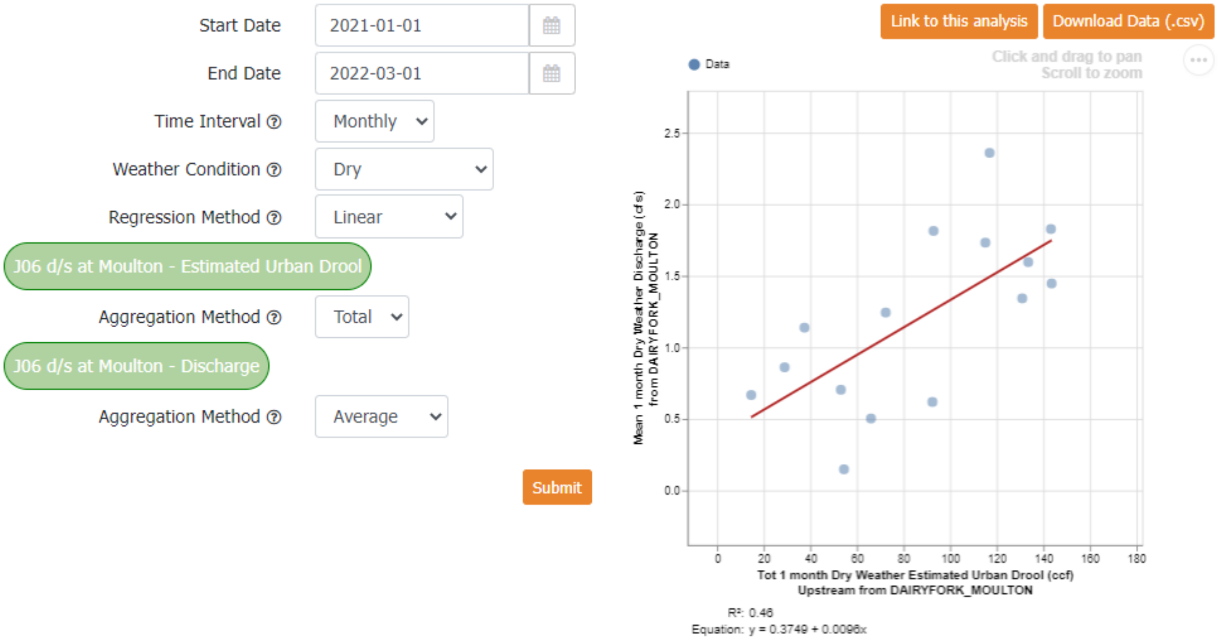
The regression analysis tool allows users to select multiple methods of establishing a two-dimensional regression. Linear fit regression is the default, but the system includes exponential fit, logarithmic fit,

---

[13] https://swn.yachats.sitkatech.com/time-series-analysis?json={"start_date":"2021-01-01","end_date":"2022-03-31","timeseries":[{"variable":"discharge","site":"DAIRYFORK_MOULTON","interval":"month","weather_condition":"dry","aggregation_method":"mean"},{"variable":"urban_drool","site":"DAIRYFORK_MOULTON","interval":"month","weather_condition":"both","aggregation_method":"tot"}, {"variable":"rainfall","site":"MOULTON_PEAK","interval":"day","weather_condition":"both","aggregation_method":"tot"}]}

polynomial (cubic) fit, quadratic fit, and power fit functions as well. The regression analysis tool displays a plot of the best fit function and the scatter plot data along with the fit function equation and its R^2 value.

Figure 21 provides an example regression analysis between monthly average dry weather flowrate and monthly total estimated urban drool (the same two timeseries shown in Figure 20).



Start Date: 2021-01-01
End Date: 2022-03-01
Time Interval: Monthly
Weather Condition: Dry
Regression Method: Linear
J06 d/s at Moulton - Estimated Urban Drool
Aggregation Method: Total
J06 d/s at Moulton - Discharge
Aggregation Method: Average

R²: 0.46
Equation: y = 0.3749 + 0.0096x

Figure 21. Example regression analysis comparing monthly average dry weather flow versus monthly estimated urban drool.[14]

5.2.3 Diversion Scenario Analysis Tool

The diversion scenario analysis tool enables users to estimate the diversion capture performance of a wide variety of diversion configurations and operational regimes. This tool can be used on any monitoring station in the Smart Watershed Network that reports volumetric discharge. The analysis uses a level pool routing algorithm to calculate the inflow volume and subtract the infiltration, diversion, and bypass volumes for each hourly timestep of the selected monitoring site discharge time series. This algorithm is shown graphically in Figure 22 below.

---

[14] https://swn.yachats.sitkatech.com/paired-regression-analysis?json={"start_date":"2021-01-01","end_date":"2022-03-01", "interval":"month","weather_condition":"dry","regression_method":"linear","timeseries":[{"variable":"urban_drool","site":"DAIRYFORK_MOULTON","aggregation_method":"tot"}, {"variable":"discharge","site":"DAIRYFORK_MOULTON","aggregation_method":"mean"}]}

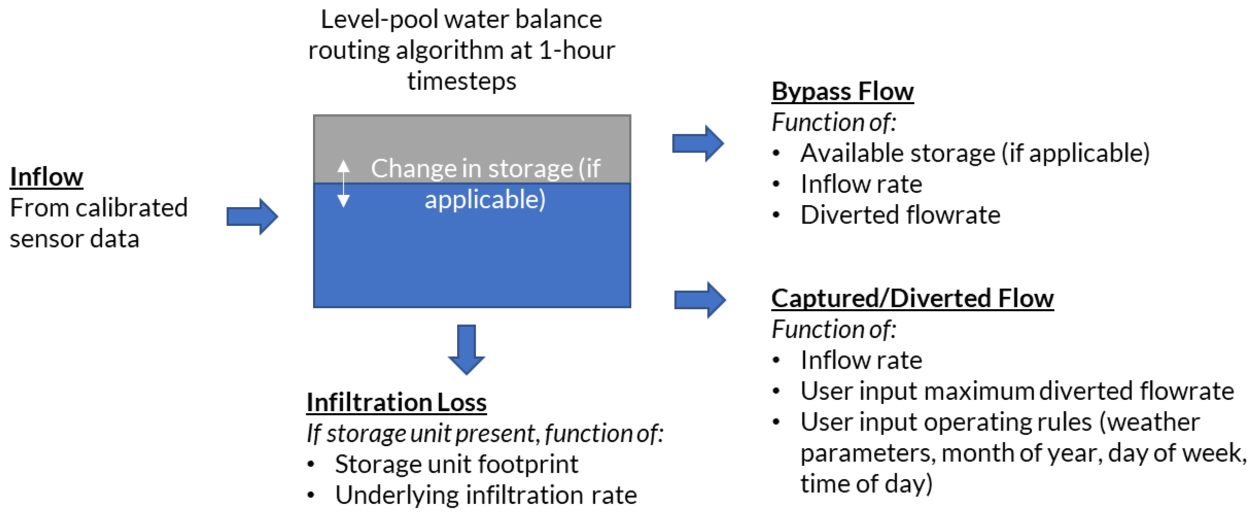
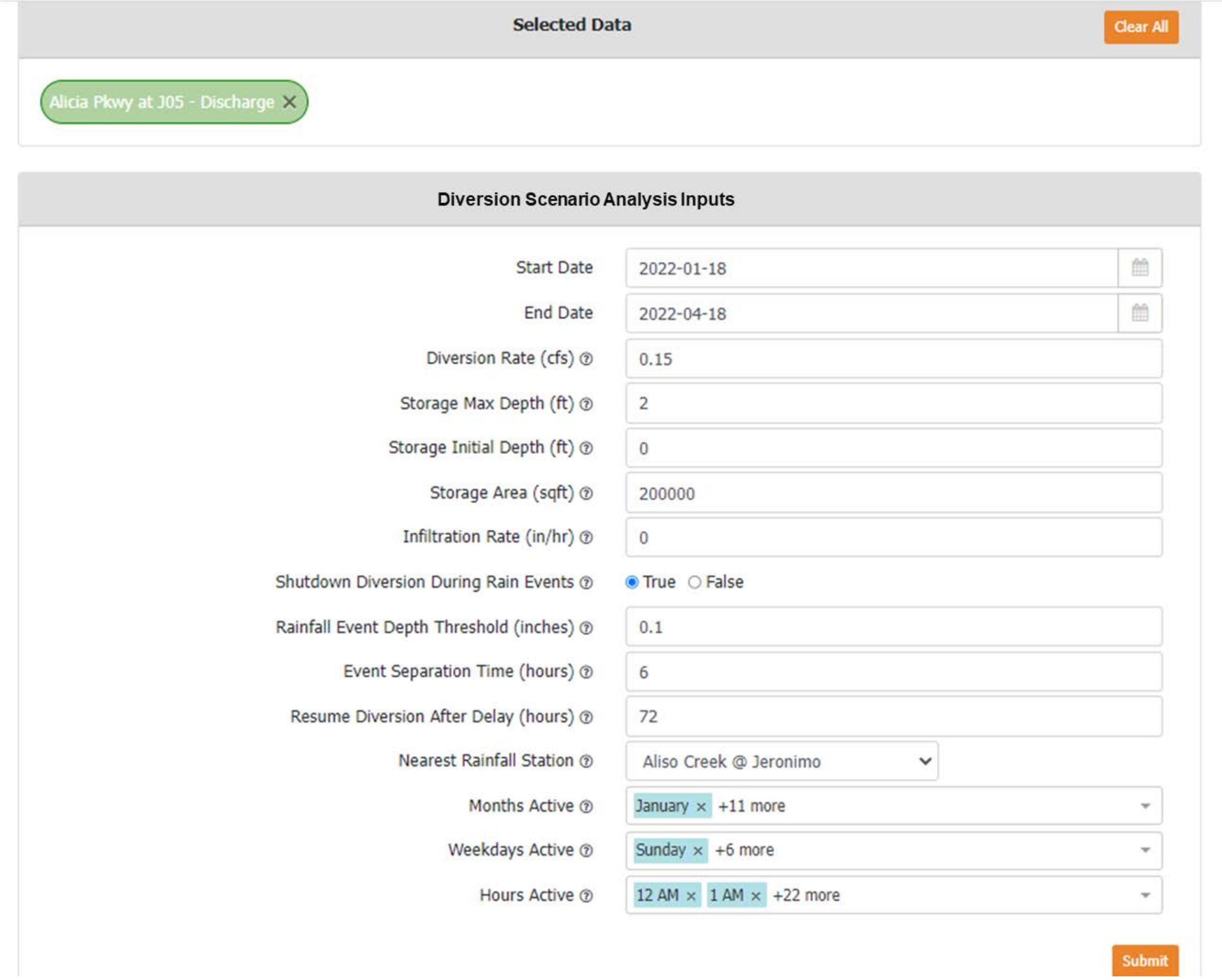


Figure 22. Conceptual diagram of diversion scenario analysis algorithm

Users can simulate complex diversion configurations including setups with inline storage capacity with either lined or unlined (infiltrating) basin bottoms. The tool also supports complex operational behaviors like triggering wet weather shut down behavior, configuring the types of rainfall events that should trigger a shutdown, and adjusting the delay after which to resume diversion operations. Users can also configure the months of the year, days of the week, and hours of the day that the diversion is operational.

Figure 23 shows a screen capture of the user-defined inputs for the diversion scenario analysis tool. Example results are included in the case studies in Section 6.1.3.



Selected Data

Alicia Pkwy at J05 - Discharge ✕

Diversion Scenario Analysis Inputs

Start Date	2022-01-18
End Date	2022-04-18
Diversion Rate (cfs)	0.15
Storage Max Depth (ft)	2
Storage Initial Depth (ft)	0
Storage Area (sqft)	200000
Infiltration Rate (in/hr)	0
Shutdown Diversion During Rain Events	● True ○ False
Rainfall Event Depth Threshold (inches)	0.1
Event Separation Time (hours)	6
Resume Diversion After Delay (hours)	72
Nearest Rainfall Station	Aliso Creek @ Jeronimo
Months Active	January × +11 more
Weekdays Active	Sunday × +6 more
Hours Active	12 AM × 1 AM × +22 more

Figure 23. Example user-defined inputs for the diversion scenario analysis tool

5.3 Lessons Learned and Transferrable Elements

5.3.1 Integration with Existing Institutional Data Systems

As part of early system design phases, we explored various different potential options for system architecture for the data management and analysis space. Ultimately, we made the decision to design the system around existing data management systems in use by MNWD and OCPW. In this system, data flow from the MNWD AMI system to the MNWD AWS cloud, similar to the system for the remaining AMI data from the District's water meters. This helps make this part of the pipeline familiar to the MNWD data team, supporting ongoing maintenance over time. A simple SFTP linkage allows the relevant data to be imported into the OCPW Hydstra system. But once there, the data resides in an environment familiar to the OCPW data team. This environment already supports the kind of sensor calibration and rating table operations used for other OCPW hydrologic monitoring data. This environment also serves as the permanent repository for the data, addressing the question of ongoing storage management.

This structure allows the Smart Watershed Network analysis engine and interface to be relatively lightweight and relatively easy to keep in sync with the underlying datasets. It primarily federates data rather than duplicating datasets or serving as the long-term repository of these datasets. As the underlying datasets expand, this system will not require ongoing updates to stay in sync.

Overall, this architecture required somewhat more time and effort to build than other alternatives. This was primarily due to the need to coordinate various entities in developing the pipeline and work with multiple different tools and environments. However, we believe this will result in lower cost and greater durability of the system over the long term.

5.3.2 System Reliability

There are numerous “stops” for the data in the data pipeline. Additionally, the system is referencing underlying datasets that are continually being updated. Each dynamic dataset and “stop” in the pipeline represent a potential point of failure. We addressed this concern via careful planning upfront and adaptive adjustments during the period of the pilot project. Most systems have been stable. We did encounter some edge cases in some datasets that had not been envisioned. This prompted adjustments to the code base to be more tolerant of data anomalies such that they trigger localized flags instead of causing updates to fail. We also encountered a period where data were not flowing freely from the AMI network. This caused no data loss but caused a delay in updating the records to the Smart Watershed Network dashboard. For a system used to make real-time decisions, this type of issue would be of significant concern. However, as this system is primarily used for longer-term research and planning, this type of temporary delay is tolerable.

We envision the need for ongoing monitoring of data connections periodically, similar to other systems that MNWD and OCPW operate. We do not envision that this data system will be a greater burden to maintain than other systems these organizations maintain.

5.3.3 Use of VegaLite Library

The VegaLite library includes pre-packaged options for interactive charts. In the Smart Watershed Network architecture, the back-end web service is responsible for assembling VegaLite packages to send back to the front-end dashboard. The dashboard then renders these without modifications. We believe this significantly reduced overall costs compared to sending full datasets to the front end and developing custom code to render these data to visualizations. It also avoids having duplicate datasets stored in the back-end web service and the front-end web application. Each VegaLite chart built by the back-end web service includes one or more interactive elements, including tooltips on data points, panning and zooming the chart axes, highlighting datasets by selecting the legend, date-range data filtering.

The minor consequence of this decision is that each update to the analysis and visualization requires a round-trip to the back-end web service to produce a new VegaLite package. However, update times are typically on the scale of a few seconds. Additionally, this helps ensure that an analysis is driven by the latest datasets each time it is refreshed.

5.3.4 Efficiency and Functionality Gains

The most common system for outfall flow monitoring in this region has been to deploy temporary field units, perform periodic manual uploads of datasets to Hydstra, and then access the data via the Hydstra interface. Hydstra includes various temporal aggregation functions. Data can be downloaded for local analysis by individual users. In comparison to this baseline, we have realized a few key efficiency and functionality gains by combining multiple systems and developing a custom analysis environment:

- **Integration of datasets**. The system brings together MNWD and OCPW datasets, including tabular and spatial datasets. It enables the use of spatial proximity and relationships to form more meaningful queries.
- **Simpler user inputs.** Compared to the Hydstra API, the system allows inputs that are simpler and more meaningful to end users who do not have as much knowledge of the Hydstra data structure. The system input structure also works for querying either the MNWD database or the Hydstra database which made it more efficient to build the front-end dashboard query interface.
- **Weather filters.** The system includes custom code that assigns wet vs. dry weather tags to data based on analysis of a proximate precipitation gage. This analysis helps isolate dry weather processes from wet weather processes. It otherwise requires an off-system analysis to apply.
- **Standardized analysis functions.** The analyses performed by the system are relatively simple and could be performed by a competent technical professional using a range of software tools. The benefit this system offers is that these are standardized and integrated directly with the underlying system of record, making them very efficient to set up and execute and consistent between different users of the system. This also greatly reduces the chance of quality control issues associated with data management.
- **Ability to share results in an editable and refreshable format.** The system allows users to send permalinks to each other to share analysis results. This allows the recipient to replicate the same analysis or adjust the inputs and perform a similar analysis. It also allows a saved analysis to be easily refreshed with new data in the future. This functionality is not supported in normal forms of results sharing, such as sending spreadsheets.

5.3.5 Transferrable Aspects of Source Code

All source code is open source and freely available for other parties to learn from or contribute to. Aspects of this source code that are likely most transferrable include:

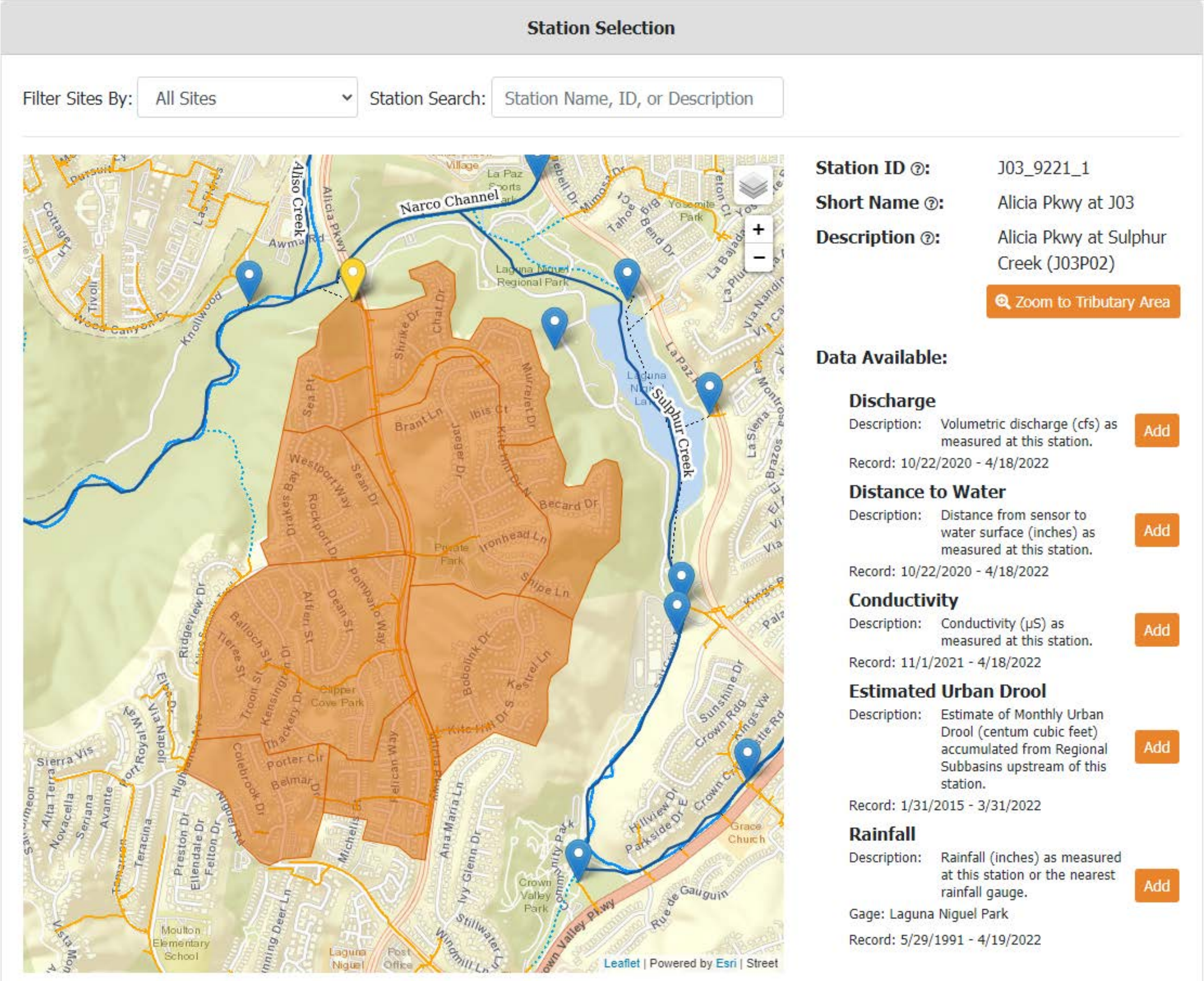
- API programming. This was specifically customized to serve as the interface between the front-end dashboard and the data analysis environment. It can serve as an example of how this layer of the system is built and the role it plays in the system.
- Analysis tools. These tools are targeted at the management questions underlying this project. They should be generally transferrable. The Python codebase can also be refactored for other datasets and questions.
- Web dashboard. We put considerable thought into the user experience and workflows for efficiently defining meaningful analysis questions. This aspect would be transferrable.

At a detailed level, some of the code is specific to the configuration of OCPW's Hydstra database and their data conventions, and the same for MNWD data. Therefore, any deployment of a system for a different watershed group would require customization of these components. However, Hydstra is a fairly common system, so some of these components could likely be transferred with relatively limited adjustment.

6 Urban Runoff Capture Analysis

6.1 Case Studies

The following sections include case studies to demonstrate the analysis tools built into the Smart Watershed Network Dashboard. Each of these case studies focuses on an outfall near where Alicia Parkway crosses Sulphur Creek. This outfall was chosen to demonstrate the Smart Watershed Dashboard capabilities in these case studies because it has a predominantly residential development pattern, few existing upstream impoundments, and had good quality observations for all available variables for multiple consecutive months. Figure 24 shows the outfall drainage area to the case study outfall. Figure 25 shows a photograph of this outfall from the field level.



Station ID: J03_9221_1
Short Name: Alicia Pkwy at J03
Description: Alicia Pkwy at Sulphur Creek (J03P02)

Data Available:

Discharge
Description: Volumetric discharge (cfs) as measured at this station.
Record: 10/22/2020 - 4/18/2022

Distance to Water
Description: Distance from sensor to water surface (inches) as measured at this station.
Record: 10/22/2020 - 4/18/2022

Conductivity
Description: Conductivity (µS) as measured at this station.
Record: 11/1/2021 - 4/18/2022

Estimated Urban Drool
Description: Estimate of Monthly Urban Drool (centum cubic feet) accumulated from Regional Subbasins upstream of this station.
Record: 1/31/2015 - 3/31/2022

Rainfall
Description: Rainfall (inches) as measured at this station or the nearest rainfall gauge.
Gage: Laguna Niguel Park
Record: 5/29/1991 - 4/19/2022

Figure 24. Tributary Area to Outfall J03-9221-1

Figure 25. Inpsection Photo of Outfall J03-9221-1

6.1.1 Time Series Comparison Case Study

In this section we identify trends and potential relationships in data streams by plotting multiple time series datasets together over a given time period. This example also uses the weather condition filter to identify conductivity readings that likely occurred during wet or dry weather.

Figure 26 compares hourly discharge, hourly conductivity and total daily precipitation depth for the outfall monitoring station Alicia Pkwy at Sulphur Creek (J03_9221_1) from mid-November through February. Conductivity readings that were recorded during wet weather (within 72 hours of a storm event greater than 0.1 inches) are shown in blue and readings that were recorded in dry weather conditions are shown in orange.

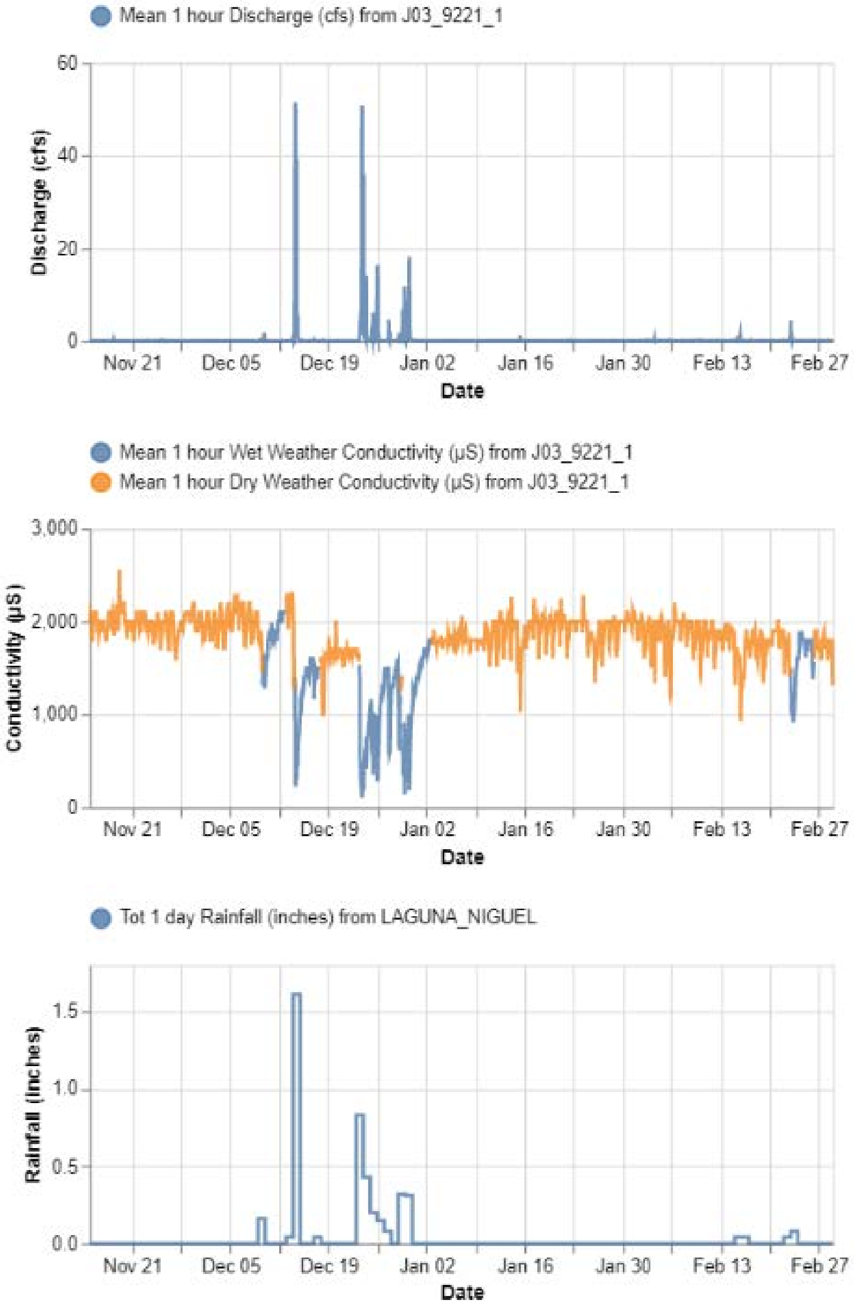


Figure 26. Discharge, conductivity and precipitation at Alicia Pkwy at Sulphur Creek (J03_9221_1) station from Nov 15-March 01 2022. [15]

---

[15] https://swn.yachats.sitkatech.com/time-series-analysis?json={"start_date":"2021-11-15","end_date":"2022-03-01","timeseries":[{"variable":"discharge","site":"J03_9221_1","interval":"hour","weather_condition":"both","aggregation_method":"mean"},{"variable":"conductivity","site":"J03_9221_1","interval":"hour","weather_condition":"wet","aggregation_method":"mean"},{"variable":"conductivity","site":"J03_9221_1","interval":"hour","weather_condition":"dry","aggregation_method":"mean"},{"variable":"rainfall","site":"LAGUNA_NIGUEL","interval":"day","weather_condition":"both","aggregation_method":"tot"}]}

During this time period typical dry weather flows at this station have conductivity in the 1,600-2,200 µS/cm, but during large or prolonged rainfall events the conductivity varies much more widely.

This pattern of sustained high conductivity during dry periods and variability during wet periods could indicate a relationship between measured flowrate and conductivity that is worth exploring further in the Regression Analysis tool. The timeseries tool can be used to rapidly explore and compare monitoring datasets to identify time periods and locations where discharge rate appears to be related to conductivity.

6.1.2 Relationship between Conductivity and Discharge Case Study

In this section we investigate the relationship between conductivity and discharge that was identified in the previous section. This tool allows us to easily compare data points which co-occur, such as comparing the average conductivity measured for a given hour with the average discharge rate observed for the station.

A wet weather regression analysis for the Alicia Pkwy at Sulphur Creek (J03_9221_1) station for the Nov 15-March 01, 2022 time period is shown in Figure 27 below. This analysis presents the hourly average wet weather readings of discharge rate and conductivity at the site and fits a power function to the data.

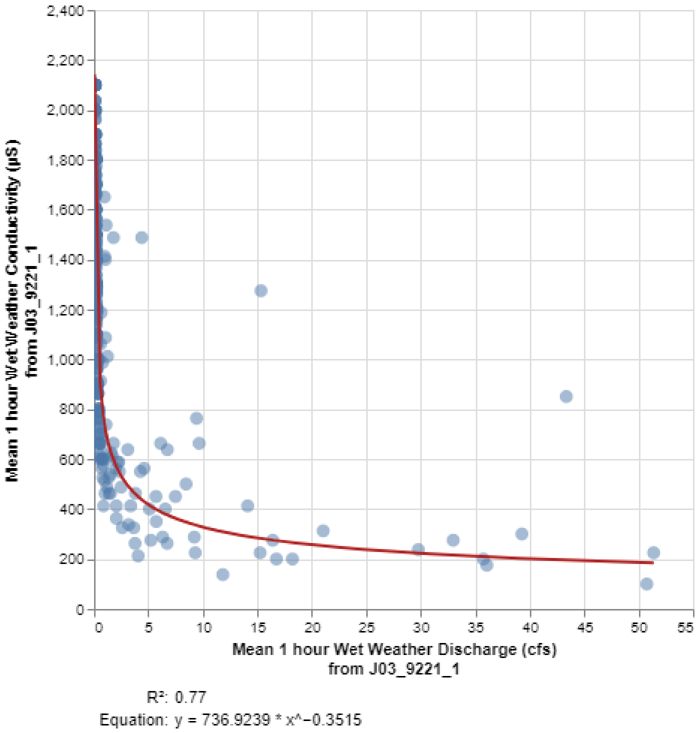


Figure 27. Relationship between discharge and conductivity during wet weather conditions for the Alicia Pkwy at Sulphur Creek (J03_9221_1) station from Nov 15 to March 01, 2022 [16]

---

[16] https://swn.yachats.sitkatech.com/paired-regression-analysis?json={"start_date":"2021-11-15","end_date":"2022-03-01", "interval":"hour","weather_condition":"wet","regression_method":"pow","timeseries":[{"variable":"discharge","site":"J03_9221_1","aggregation_method":"mean"}, {"variable":"conductivity","site":"J03_9221_1","aggregation_method":"mean"}]}

From these scatter data and fit function, it is apparent that during wet conditions with flow regimes lower than approximately 2.5 cfs, there is a lot of variability in the measured conductivity, but for flows between 5 cfs and 55 cfs the conductivity is relatively stable between 200-400 µS/cm throughout the whole range of wet weather discharge values.

The wet weather trend differs markedly from the trend for the same site and time period during dry weather conditions. The same discharge and conductivity variables are plotted for dry weather conditions (more than 72 hours after a rain event greater than 0.1 inches) in Figure 28 below.

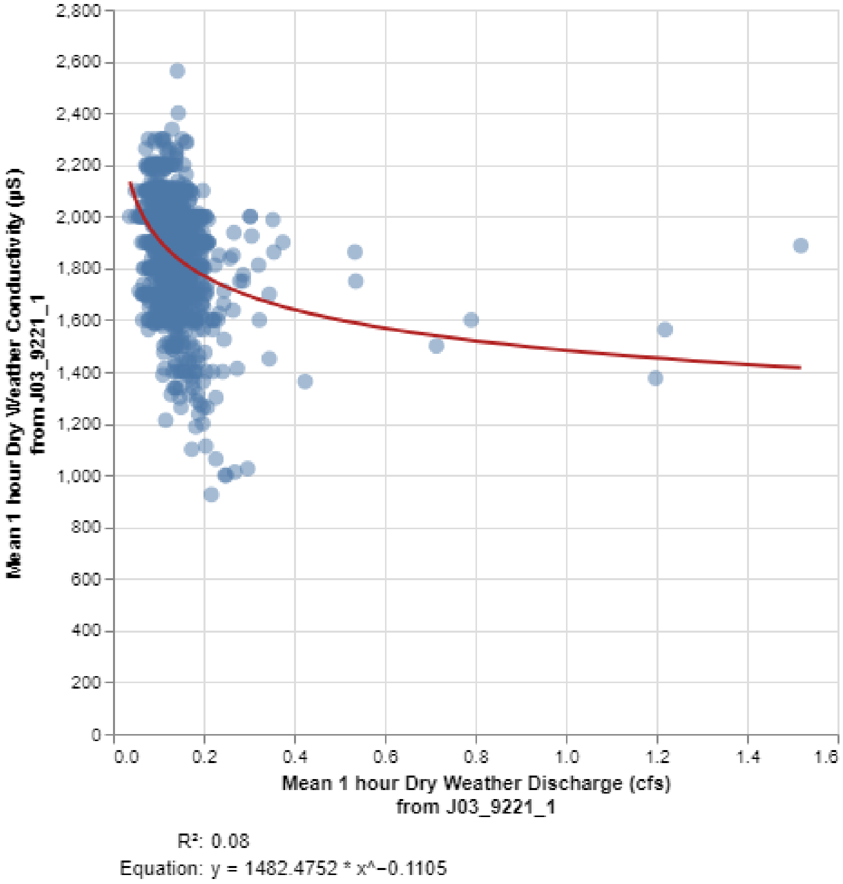


Figure 28. Relationship between discharge and conductivity during dry weather conditions for the Alicia Pkwy at Sulphur Creek (J03_9221_1) station from Nov 15 to March 01, 2022 [17]

In dry weather conditions the flow regime for this station is very low, less than 2 cfs, but the central tendency of the measured conductivity is approximately 1,800 µS/cm.

Assessing the wet and dry condition regressions together reveals three key findings:

1. Wet weather conditions with discharges larger than 2 cfs typically have reasonably stable conductivity at this station. For planning purposes, it may be reasonable to use a conductivity

---

[17] https://swn.yachats.sitkatech.com/paired-regression-analysis?json={"start_date":"2021-11-15","end_date":"2022-03-01", "interval":"hour","weather_condition":"dry","regression_method":"pow","timeseries":[{"variable":"discharge","site":"J03_9221_1","aggregation_method":"mean"}, {"variable":"conductivity","site":"J03_9221_1","aggregation_method":"mean"}]}

value 400 μS/cm for flows occurring at over 2 cfs for this station. For the time period monitored, flowrates over 2 cfs only occurred during wet weather conditions.

2. As flow regimes transition from dry weather to wet weather (about 0.2 to 2 cfs), the relationship between conductivity and discharge rate is very sensitive to the discharge rate.
3. Dry weather condition flows at this station are tightly clustered between very low discharge rates from 0.05 cfs to 0.2 cfs. Conductivity measured for these flows is likely best estimated by a single average value for both discharge and conductivity. For planning purposes, dry weather flow discharge rates at this station are typically observed at 0.15 cfs and conductivity is typically measured at roughly 1,800 μS/cm.

The regression analysis tool allows rapid exploration of these relationships to aid planners and managers in decision making and in identifying opportunities to implement site specific flow diversion strategies.

6.1.3 Diversion Scenario Case Studies

In this section, we explore three diversion case studies for the same outfall inspected in the sections above. The case studies include:

1. **Dry weather diversion.** The diversion operates during dry weather only, without storage. The diversion rate is set to accommodate the typical diurnal peak flowrate during dry weather. This is a common scenario for existing diversion systems in South Orange County.
2. **Full-time diversion.** The diversion operates during both dry and wet weather, without storage, at a diversion rate five times higher than the first scenario. Note: This scenario is not necessarily advisable but is presented as a hypothetical example for comparison.
3. **Capture and delayed diversion.** The diversion operates during dry weather only but has storage for capture and delayed diversion of wet weather runoff.

Scenario 1: Dry Weather Diversion

This is a simple scenario informed by the timeseries analysis feature presented above. Based on inspection of the results from Figure 29, the diversion rate is set to 0.2 cfs to capture the typical diurnal peak flow. The diversion is shut down whenever rain event depth exceeds 0.2 inches, and for the 48 hours that follow.

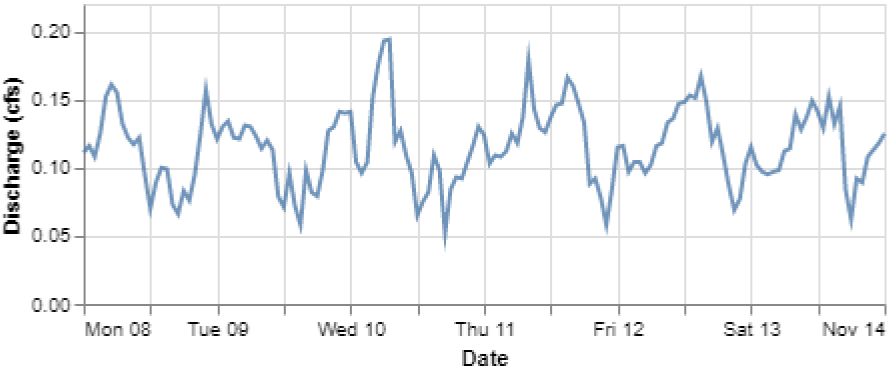


Figure 29. Typical dry weather flow in November at the Alicia Pkwy at Sulphur Creek (J03_9221_1) station.

This scenario diverts nearly all flow during dry weather but does not divert wet weather runoff. Therefore, the percent of water captured during the wet season is rather low (about 23% for the period from Oct 1, 2021 to Jan 15, 2022). Figure 30 shows the diversion scenario dashboard with time series results.

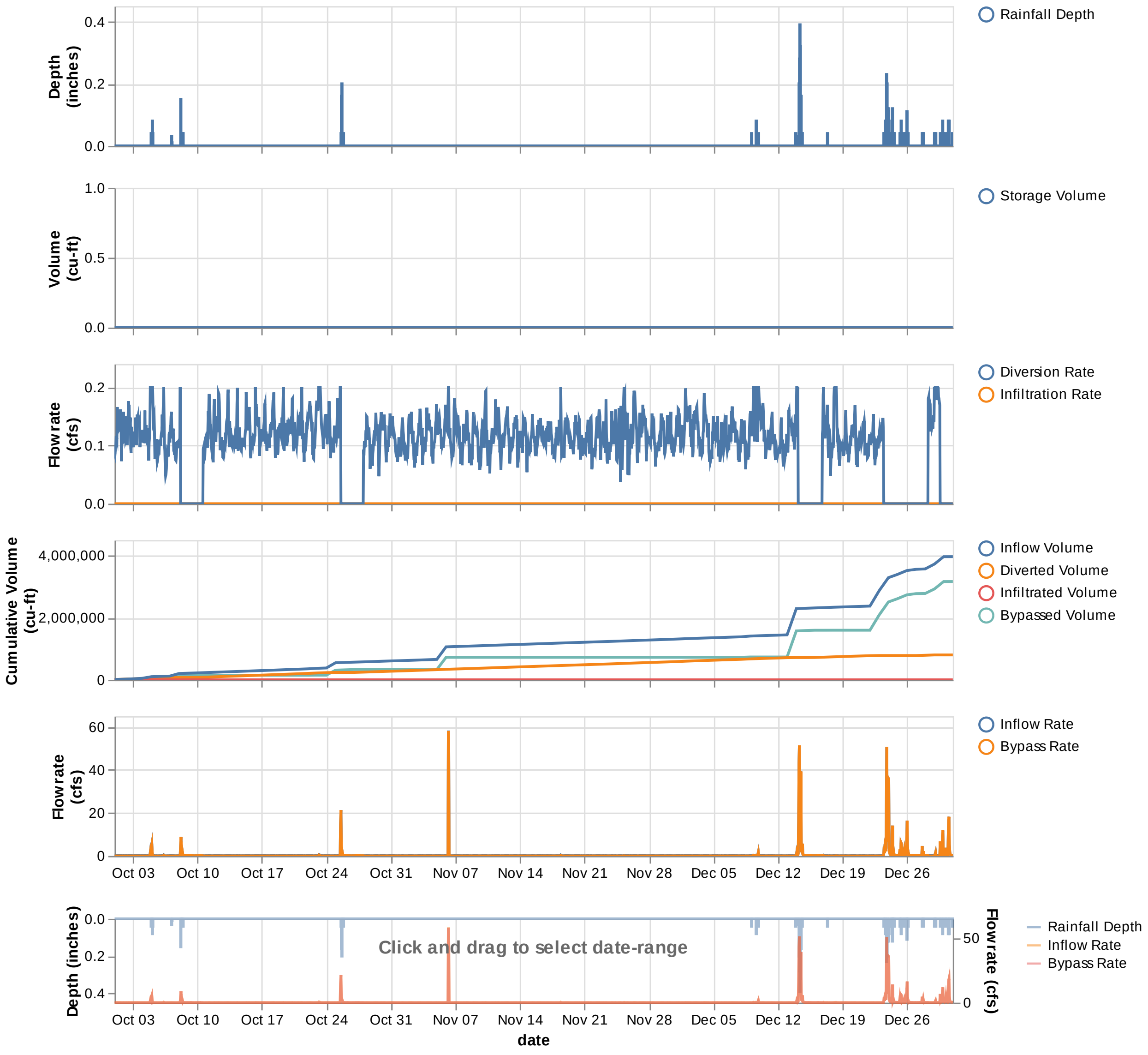


Figure 30. Diversion scenario 1 at the Alicia Pkwy at Sulphur Creek (J03_9221_1) station from October through December[18].

---

[18] https://swn.yachats.sitkatech.com/diversion-scenario?json={"start_date":"2021-10-01","end_date":"2021-12-31","site":"J03_9221_1","diversion_rate_cfs":0.2,"storage_max_depth_ft":0,"storage_initial_depth_ft":0,"storage_area_sqft":0,"infiltration_rate_inhr":0,"rainfall_event_shutdown":true,"rainfall_event_depth_threshold":0.2,"event_seperation_hrs":6,"after_rain_delay_hrs":48,"nearest_rainfall_station":"LAGUNA_NIGUEL","diversion_months_active":[1,2,3,4,5,6,7,8,9,10,11,12],"diversion_days_active":[6,0,1,2,3,4,5],"diversion_hours_active":[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23]}

Scenario 2: Full-time Diversion

This is a hypothetical scenario where the diversion rate is increased to allow some flows from small storms. The diversion rate is set to 1 cfs and is not shut down under any condition. This may pose a risk to sewer system capacity and may not be advisable. It is presented for illustration purposes only.

This continues to divert all dry weather but enables some diversion of wet weather runoff. For the same period as scenario 1, the system now diverts about 36% of total runoff volume.

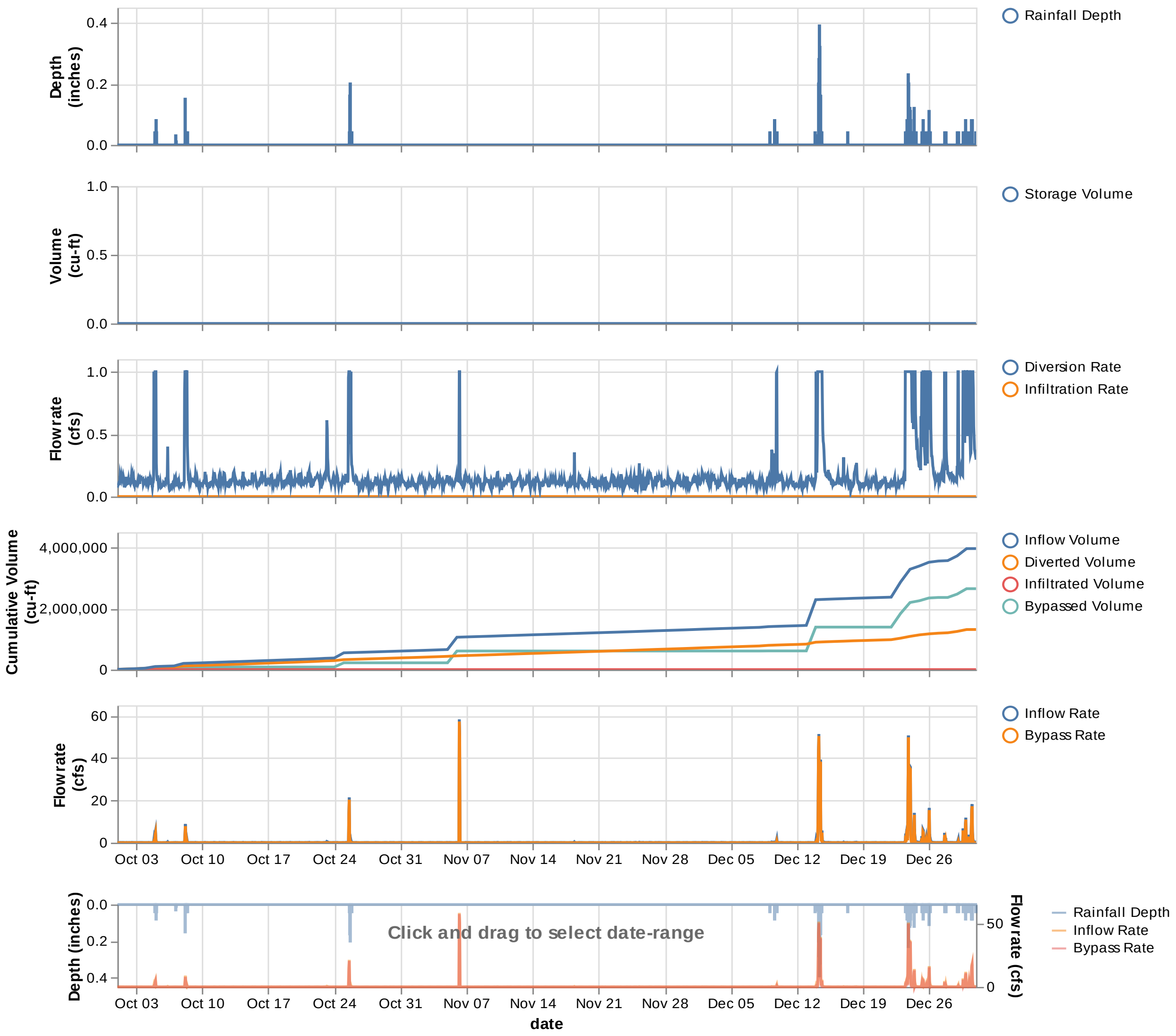


Figure 31. Diversion scenario 2 with higher diversion rate and no wet weather shutdown at the Alicia Pkwy at Sulphur Creek (J03_9221_1) station from October through December[19]

---

[19] https://swn.yachats.sitkatech.com/diversion-scenario?json={"start_date":"2021-10-01","end_date":"2021-12-31", "site":"J03_9221_1","diversion_rate_cfs":1,"storage_max_depth_ft":0,"storage_initial_depth_ft":0,"storage_area_sqft":0, "infiltration_rate_inhr":0,"rainfall_event_shutdown":false,"rainfall_event_depth_threshold":0.2,"event_seperation_hrs":6, "after_rain_delay_hrs":48,"nearest_rainfall_station":"LAGUNA_NIGUEL","diversion_months_active":[1,2,3,4,5,6,7,8,9,10,11,12],"diversion_days_active":[6,0,1,2,3,4,5],"diversion_hours_active":[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23]}

Scenario 3: Capture and Delayed Diversion

This scenario involves construction of a storage tank upstream of the outfall. The diversion is set to shut down under the same wet weather criteria as Scenario 1. After the 48-hour shutdown period, water is diverted to the sewer at 0.5 cfs. This is half of the rate diverted in Scenario 2. This diversion rate is set to exceed the average dry weather flow rate so that stored water can drain while new dry weather flows come into the storage tank. The storage volume was set to capture the runoff from around 0.25 inches of rain on the watershed. The watershed is estimated to be about 570 acres with a runoff coefficient of about 0.3, equating to a 3.5 ac-ft storage feature.

This configuration served as our base configuration for Scenario 3, and the results from this base configuration are shown below in Figure 32. We also explored various permutations on this scenario with greater diversion volume, greater storage volume and without a wet weather shutdown.

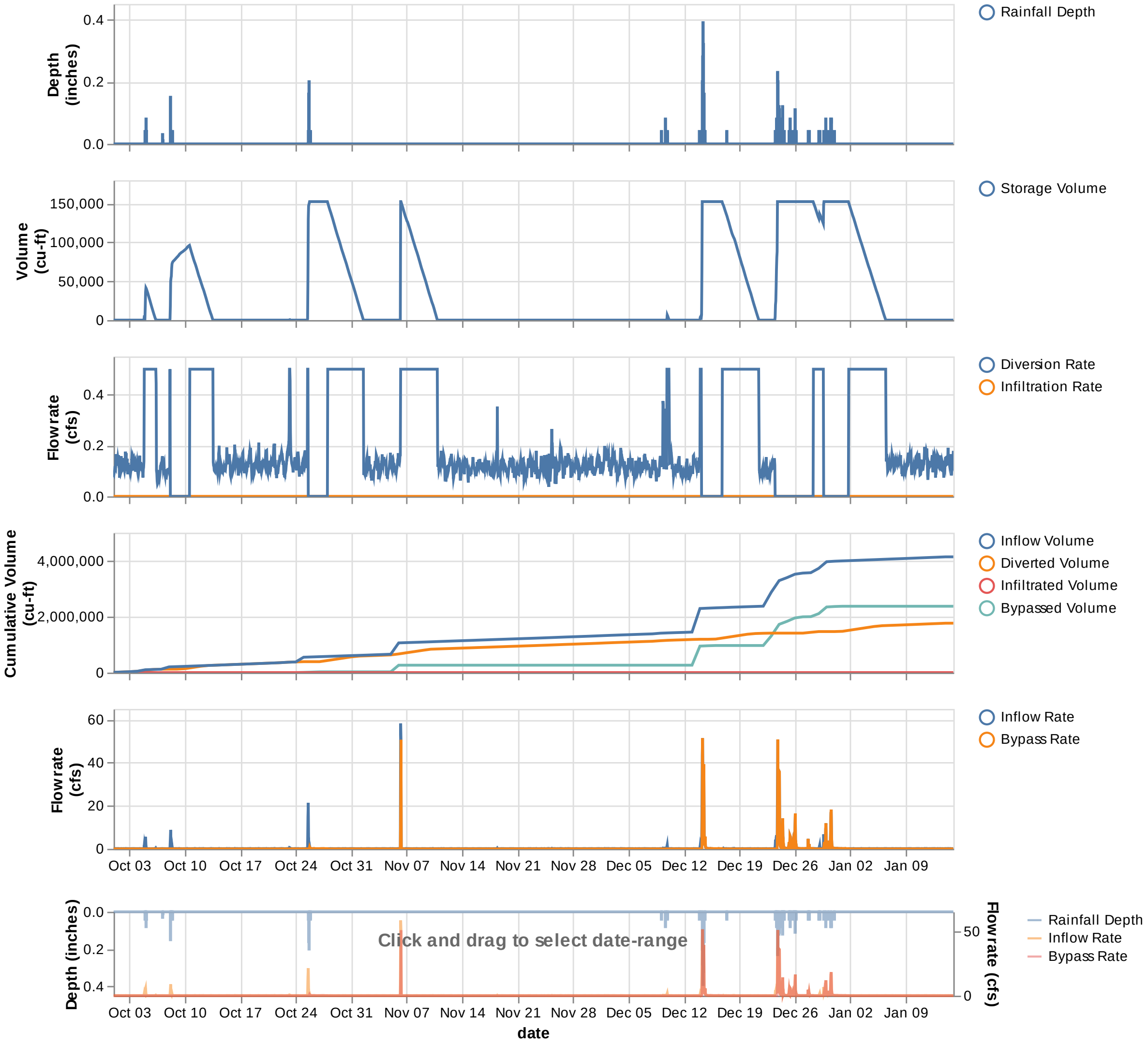


Figure 32. Diversion scenario 3 with 0.5 cfs diversion rate and 3.5 ac-ft of storage at the Alicia Pkwy at Sulphur Creek (J03_9221_1) station from October 2021 through January 15 2022[20]

---

[20] https://swn.yachats.sitkatech.com/diversion-scenario?json={"start_date":"2021-10-01","end_date":"2022-01-15","site":"J03_9221_1","diversion_rate_cfs":0.5,"storage_max_depth_ft":3.5,"storage_initial_depth_ft":0,"storage_area_sqft":43560,"infiltration_rate_inhr":0,"rainfall_event_shutdown":true,"rainfall_event_depth_threshold":0.2,"event_seperation_hrs":6,"after_rain_delay_hrs":48,"nearest_rainfall_station":"LAGUNA_NIGUEL","diversion_months_active":[1,2,3,4,5,6,7,8,9,10,11,12],"diversion_days_active":[6,0,1,2,3,4,5],"diversion_hours_active":[0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,22,23]}

Table 4. Scenario parameters and results (Oct 1, 2021 through Jan 15 2022)

Input/Result	Scenario 1	Scenario 2	Scenario 3				
			Base	Base + double diversion rate	Base + double storage volume	Base + double storage, double diversion rate	Base + full time diversion
Operating Rule	Dry only	Full time	Dry only	Dry only	Dry only	Dry only	Full time
Operating delay	48 hrs	NA	48 hrs	48 hrs	48 hrs	48 hrs	NA
Storage Volume	0	0	3.5 ac-ft	3.5 ac-ft	7 ac-ft	7 ac-ft	3.5 ac-ft
Diversion Rate	0.2 cfs	1 cfs	0.5 cfs	1 cfs	0.5 cfs	1 cfs	0.5 cfs
% of Inflow Diverted	23%	36%	43%	44%	52%	56%	52%
Approx. dry weather volume diverted, ac-ft	22	22	22	22	22	22	22
Approx. wet weather volume diverted, ac-ft	0	12	19	20	28	31	28
Approximate conductivity of diverted water, μS/cm	1800	1290	1150	1130	1020	980	1020

1 – It is assumed that water diverted beyond Scenario 1 is wet weather runoff.

2 – Based on the results of conductivity versus flow regression analysis in Section 6.1.2, we estimated dry weather flow to have a conductivity of 1,800 μS/cm an wet weather flow to have a conductivity of 400 μS/cm.

Scenario 3 demonstrates how a user of the Smart Watershed Network can rapidly iterate on the design and operational parameters of a diversion opportunity to meet site specific objectives. The results of this scenario indicate that a large amount of storage at this location is needed to increase the total amount of volume diverted. This finding is largely due to the time period of the simulation, which contains a couple of large rainfall events in December. These large rain events account for much of the total inflow volume, most of which is bypassed by the simulated diversion system design. As the Smart Watershed Network gathers more data from the sensor network, users of the tool will be able to assess their diversion designs on a wider variety of inflow conditions by selecting a longer time period for the simulation or by selecting a different time period to assess performance during certain inflow or seasonal conditions. By using the Smart Watershed Network permanent links provided by the tool, users can revisit a saved diversion scenario design at a future date to re-evaluate the scenario using inflow data for a new period.

6.1.4 Case Study Observations

The Smart Watershed Network Case studies demonstrate how the analysis tools built for this project address several key project objectives.

In the time series comparison case study, we demonstrated how the tool can help highlight trends in the sensor data. This included comparing the hourly discharge and conductivity sensor readings at the same station, comparing those data to a precipitation data recorded at a nearby gage, and identifying the conductivity readings that occurred during wet weather conditions and dry conditions by plotting them in different colors. This analysis revealed an apparent trend in the conductivity data wherein the conductivity appeared to be higher and steadier during dry weather conditions and appeared to become lower and more varied during wet weather conditions. The time series analysis tool is the easiest way to explore the data streams of the Smart Watershed Network both spatially and temporally and to identify potential relationships in the data that may warrant further investigation or analyses.

In the second case study we further explored the relationship between discharge and conductivity that we identified in the time series comparison. This case study demonstrated the regression analysis tool and allowed for a more detailed relationships to be explored. This analysis helped establish typical wet and dry weather conductivity values for the monitoring station that are useful for planning purposes.

In the third case study we assessed six diversion scenarios for the monitoring station with three overall management strategies: operate diversion only during dry weather, operate during both wet and dry weather, and operate with a storage tank. Using the Smart Watersheds Network diversion scenario analysis tool, we were able to explore these iterations rapidly and efficiently. This kind of scenario analysis can help a project planner determine optimal tradeoffs between storage, diversion rates, and operating rules. This case study focused on only a subset of the available record to help better visualize the results. A longer period of record can be explored. Additionally, as the system continues to accumulate data from each monitoring station it will be possible to revisit the relationships revealed in these case studies over longer time periods or to investigate diversion operations during a particular weather event or season.

7 Project Summary

7.1 Assessment of Study Objectives

Objective 1: Pilot the use of AMI for watershed monitoring. The project met this objective. Section 4 provides a description of the monitoring equipment and lessons learned from this part of the project.

Objective 2: Fill key data gaps to support urban runoff recovery planning. This objective was partly completed. Due to delays in procurement, installation, and AMI software configuration, we were only able to obtain about 18 months of data within this study, with shorter periods for some stations and sensor types. However, the system continues to collect more data, so it will continue to serve as a stronger resource to fill gaps as time goes on.

Objective 3: Provide tools to support decision making. The project met this objective via the web dashboard and analysis framework that was produced. Section 5 describes this system and the capabilities of the tools to support decisions. Section 6 provides case study applications of these tools.

Objective 4: Provide transferrable lessons learned. This objective was met. Section 4 and 5 provide lessons learned for both the watershed monitoring system and the data management and analysis components. Section 7.2 summarizes key research findings.

7.2 Research Findings

7.2.1 Key Accomplishments

This project demonstrated the viability of leveraging the AMI network for continuous watershed monitoring. We demonstrated compatibility between AMI gateways and off-the-shelf water level and conductivity sensors, and we were successful in establishing a reliable remote data transmission link to return the sensor data to the MNWD data repository. By using this method of telemetry, the cost of equipment was around 75% less per station than the default flow monitoring approach that has been used by OCPW to date.

The Smart Watershed Network project demonstrated the viability of an integrated analysis space that is continually updated with new data from multiple sources. The system enables key data visualization and analysis tasks directly within the web dashboard without the need to download data and perform off-system analyses. This greatly streamlines common data analysis tasks. It has been tailored to the key management questions faced by MNWD and municipal stormwater permittees.

This project has obtained up to 18 months of continuous data at around 50 stations. The system is running in a fully automated and unattended manner, so additional data are being acquired every day. Ongoing maintenance of this network is anticipated to be needed to maintain sensor calibrations, fix or replace damaged sensors, and ensure data connectivity. The system is on track to enable large-scale, long-term acquisition of valuable data.

7.2.2 Key Lessons Learned and Transferrable Findings

Lessons learned and transferrable findings are summarized in Section 4.3 (watershed monitoring system) and Section 5.3 (data management and analysis tools). The following bullets summarize the most important findings from these sections.

Watershed Modeling System

- After working through initial glitches in AMI software, the connectivity between the sensors and the MNWD database was reliable. This serves as a proof of concept that the AMI network can be adapted to serve watershed monitoring purposes.
- We identified several sensors that may be compatible with the AMI gateways, and we demonstrated that the selected sensors were indeed compatible.
- Power demands for some sensors exceeded what the AMI gateway could supply. This was primarily because some sensors needed to be powered on continuously instead of being powered on to collect a reading only. This required a supplemental solar power system. The cost of the supplemental system was modest; however, the need for a solar panel exposed the systems to greater visibility and potential for vandalism.
- Vandalism was an issue at several sites. This can be a common issue for watershed monitoring deployment. The rates of occurrence were not necessarily higher than other monitoring campaigns. However, the permanent nature of this system means that the risk of vandalism is higher over the life of the system.
- Open channel flow monitoring is imprecise, particularly at low flows. The monitoring design prioritized low maintenance requirements over the precision and accuracy of readings. The data are useful for evaluating trends but have considerable uncertainty in terms of quantifying absolute magnitudes.
- As discussed above, the equipment costs were around 75% lower per station than the default monitoring approaches used by OCPW to date. Much of this saving came via the low cost of the AMI gateways (which provide both data logging and telemetry) compared to the current OCPW equipment used for data logging and telemetry.
- We anticipate a significant level of effort will be needed to maintain the continuously deployed field monitoring network, including maintaining sensor calibration and rating tables, repairing damaged or stolen equipment, and periodically replacing or maintaining power supplies.

Data Management and Analytical Tools

- Through this project, we explored the existing systems that MNWD and OCPW use to manage AMI data and hydrologic monitoring data, respectively. Both agencies have well-established systems and tools for managing large datasets. This helped inform the approach for the design of the Smart Watershed Network.
- One major decision was to build on top of the existing data management systems in use by MNWD and OCPW instead of developing a parallel system. This may have required more time and effort to coordinate between different IT groups to create new connections. However, we believe it will reduce costs and maintenance effort over the long-term. This design avoids duplicating large (and growing) datasets in more places than necessary. It also utilizes systems that the owning organizations are invested in and that their staff are familiar with.
- Applying and updating sensor calibrations and rating tables is a key task to convert raw sensor readings into meaningful data. We leveraged the existing functionality in the Hydstra database for

this aspect, which provides a standard and reliable method. However, this step will still require substantial investment on an ongoing basis, coordinated with field visits, to maintain the calibration of these sensors. A more streamlined approach for this would be beneficial.

- Despite the number of components and connections in the data pipeline and analysis system, we found that it was reliable, with minimal downtime. When a connection did break, the data was still preserved and could be populated automatically to the "downstream" components when the connection restored. This report explains the purpose of each component of this pipeline. It can serve as a reference for how such a system can be configured elsewhere.
- We believe the analysis environment and tools developed as part of this project provide greater efficiency, standardization, and improved quality control compared to alternative data management and analysis paradigms. Of significant importance:
    - The system provides a one-stop location for all the data needed to support analysis, always up to date with the latest obtained data. There is no need to manually compile records from multiple sources and append new records periodically.
    - The system packages the common analyses needed to evaluate storm drain flows and stormwater capture scenarios. These can be performed in minutes or less, in a standardized way across various users.
    - The system promotes sharing and collaboration by allowing users to share live links to their analyses and enabling the recipient to make edits and update these analyses with the latest data.

7.2.3 Effectiveness of System to Reduce Barriers to Future Supply

The Smart Watershed Network has the potential to reduce barriers to runoff capture through both data acquisition (filling gaps in existing datasets) and data exploration (making practical sense of data obtained). This can translate to three practical use cases.

Understanding of water and salt balance in the watershed drainage network. The sensor network developed in this pilot project is substantially more spatially and temporally robust than any previous monitoring effort in this watershed. The growing body of long-term datasets and the efficient analysis tools will allow managers to better understand the relative sources of flow at different points in the watershed and the salt content of the water. As additional critical locations are identified, they can be added to the network. This promises to serve as valuable tool to understand where excess water with relatively low salt content can potentially be diverted for local water supply.

Understanding of storm runoff response. It is possible to perform hydrologic calculations to estimate stormwater volumes. However, these calculations have significant uncertainty due to the spatial heterogeneity of the watershed and uncertainty in hydrologic parameters. The direct monitoring approach facilitated by the Smart Watershed Network can help improve understanding of how much runoff is generated from more frequent smaller rainfall events, as well as how the salt content changes in these events. From initial datasets obtained, we see a clear pattern of reduced salt content in even small storm events, suggesting that diversion of water during small storms would have a beneficial diluting effect for the recycled water system. The Smart Watershed Network provides a basis to quantify these benefits more discretely.

Balancing stormwater capture goals with capacity limitations. The diversion scenario analysis tool operates directly on monitoring data to help answer "what if" questions related to stormwater capture. It can help assess the runoff flowrates in storms of different sizes to assess the risk posed to the capacity of the sanitary sewer collection system. It can also help evaluate the effect of storage and operating rules. For example, through the addition of storage, how much additional water could be captured? If a post-storm shutdown period is needed, how much does this reduce the amount of water captured? These efficient analyses can help guide planning and benefit quantification to help formulate candidate projects.

Overall, the utility and value of this tool will increase with time as more data is loaded into the system. We expect this to lead to increasingly robust understanding of relationships between key variables like flow, conductivity, wet vs dry weather conditions, and an ever-improving characterization of the spatial variability due to the variety of human activities, needs, and environments upstream of the monitoring stations.

7.2.4 Potential Uses for Aliso Creek Watershed Management Efforts

This section outlines two potential uses we foresee as part of ongoing watershed management efforts led by municipal stormwater permittees.

Dry weather flow source identification and abatement. Since around 2015, the SOC WMA Permittees have performed focused studies on dry weather flow magnitudes, patterns, and likely sources. This is part of an overall strategy to identify and abate illicit discharges and correct unnatural flow regime issues in regional creeks. Our experience with these studies has helped guide some of the functionality of the Smart Watershed Network. We envision that this tool will help support MS4 Permittees in a few ways:

- The system will provide longer-term, synchronous datasets to help better understand seasonal and climatic influences on dry weather flow. While some of the prior monitoring efforts performed in the WMA have spanned more than a year, this is not commonly available. Additionally, a one-year period is not long enough to be able to assess flow patterns across different water years.
- The system will enable more streamlined data compilation and access. Previous flow monitoring studies have depended on periodic data download, quality control, and static analysis. This system provides access to data within one day after acquisition, giving users a better tool to help plan, implement, and assess the effectiveness of flow source identification and abatement efforts.
- The system enables a more direct linkage between water usage records and urban runoff measurements. This can help identify the locations and times of year when there is greater potential opportunity and need to capture runoff.

Stormwater capture planning. Stormwater capture has the potential to be an important strategy for watershed protection and pollutant load reduction. The Smart Watershed Network enables efficient scenario analyses to help plan these types of projects in coordination with MNWD. Many of the same questions applicable to MNWD are also applicable to MS4 Permittees evaluating projects. Additionally, this can help MS4 Permittees assess the flow control benefits to the creek that could come from stormwater capture.

7.2.5 Opportunity for Ongoing Improvements

Through this project, the research team and trial user groups have developed additional ideas about improvements that could be made after completion of the pilot project. These are outlined below:

Enable more automated processes for updating flow rating tables based on in-situ measurements. The current process for updating a flow sensor calibration and rating table requires field teams to record their observations on a paper form, analyze the rating table in the office, and submit the table to OCPW for manual insertion into the Hydstra database. This type of update should be a fairly routine maintenance update, yet it involves multiple steps of data handoffs and depends on staff people with expertise in Hydstra to make the update. A future improvement to the system would be to automate this process so that field teams could prepare their rating table and post it to an SFTP from which it would be loaded into Hydstra automatically. This would require fewer staff people to be involved in this routine update and would help the update to be made to the system as quickly as possible.

Develop a data quality alert system to notify relevant parties if a site appears to be experiencing data issues. This system could be built into the Smart Watershed Network Dashboard to identify stations with periods of missing, erroneous, or unexpected values, potentially indicating an issue with the data pipeline and alerting the respective data manager or indicating that the station equipment itself has been damaged and alert a repair and maintenance team.

Enable the ability to evaluate more types of regression relationships. Future improvements may enable a user to add paired datasets from another station to the regression chart to see if two sites have similar relationships between the same pair of variables. It may also be interesting to view multi-parameter regressions as a grid of paired regression charts each displaying a relationship between two different variables. This would allow a user to compare the relative importance of correlations between many variables with a single query.

Enhance the diversion scenario tool to estimate the conductivity of the diverted flow using the conductivity sensor data for the same station. At twenty of our flow monitoring stations, it should be possible to form a volume-weighted estimate of conductivity for the diverted flow. This was not included in the current diversion scenario dashboard because it is only possible at certain flow monitoring sites.

Enable relationships between variables to be applied to diversion scenario to estimate the conductivity of the diverted flow. This would allow for an estimate of the conductivity at sites that do not have conductivity monitoring sensors.

Refine operational parameters of the diversion scenarios, such as the ability to specify a different diversion rate in different times of the year, or the ability to specify a partial (fractional) diversion.

7.3 Broader Applicability to Southern California Watersheds

Urban runoff recovery is of broad interest across Southern California. Low flow diversions have been in use for decades in some areas to recover excess irrigation and protect receiving water quality. Over the last 10 years, there has been an increased focus on stormwater capture to augment local water supply. The Los Angeles Department of Water and Power developed a Stormwater Capture Master Plan[21] in 2015 that explored the opportunity for stormwater capture. It focused primarily on projects and programs to enhance groundwater recharge. The County of San Diego led development of the San Diego Region Stormwater Capture Feasibility Study[22] in 2018 to explore the feasibility of stormwater capture in the region. This included assessment of groundwater recharge, local reuse, and regional water recycling. The Las Virgenes Water District led a project funded by the FSAP grant program to specifically study the diversion of urban runoff into existing wastewater collection and recycling systems. The "Phase 2 White Paper: Tapping into Available Capacity in Existing Infrastructure to Create Water Supply and Water

---

[21] https://www.ladwp.com/ladwp/faces/wcnav_externalId/a-w-stormwatercapturemp

[22] https://projectcleanwater.org/download/swcfs-report-november-2018/

Quality Solution"[23] (2021) presented the results of this analysis and identified recommendations for how to increase the integration of stormwater and wastewater systems to expand the use of both dry and wet weather diversions.

Some of the recommendations put forth by the Phase 2 White Paper are relevant to the Smart Watershed Network and its potential broader applicability. The Phase 2 White Paper found that:

> There is a need for "An efficient data management system is needed to store the flow monitoring and pump data in one repository for the monitoring and system evaluation purposes."
>
> There is a need to "Improve dry weather diversion flow monitoring approach." including "The real-time monitoring of flows at these facilities can help inform the decisions for real-time operations of diversions and sanitary sewer systems. The quality and temporal resolution of data needs to be improved to better understand the operations of dry weather diversion and the types of improvements needed for the infrastructure to accommodate wet weather runoff."
>
> There is a need to "Implement real-time monitoring of the sewer levels and the system at critical locations to help inform the depth of flow in the sewer to allow flows to be diverted from the dry weather diversions. The real-time flow monitoring of sewers can provide better control and operation of diversions… Where multiple diversion locations compete for limited capacity, SCADA-enabled diversion systems can be integrated to manage the timing of discharges to share the capacity."

These needs and recommendations are directly aligned with the purposes of the Smart Watershed Network. We anticipate being able to utilize this system to help address both the planning and operational needs associated with future stormwater capture projects. We believe that this pilot demonstration can serve as useful reference and starting point for other water districts and watershed groups who see the need for a similar data acquisition and management system, such as identified in the Phase 2 White Paper. The software developed as part of this effort is open source and freely distributed.

More generally, this project demonstrated the use of the AMI network for watershed monitoring purposes, including the potential to substantially reduce data logging and telemetry costs via this approach. Many water districts are expanding AMI networks for metering of customer water usage and could consider the expanded use of this system for watershed monitoring. We expect that the details of integrating with the AMI network will depend on the AMI service provider. This project used the Sensus AMI network.

To our knowledge, many other organizations use Hydstra to store hydrologic data. The data management and analysis system we built as part of this project utilizes and enhances the functionality of Hydstra. This can serve as a reference implementation, including open-source code that is freely distributed.

Finally, the technical findings from the Aliso Creek Smart Watershed Network likely have some transferability to other watersheds. For example, the consistent correlations between conductivity and flowrate found in this watershed could likely support estimates in other watersheds if local data are not available.

---

[23] https://socalwater.org/wp-content/uploads/Stormwater_Capture_White_Paper_Phase_2_August-2021.pdf