Visualizing Urban Water Data for Drought Management Across California

Technical Document

A capstone project submitted in partial satisfaction of the requirements for the degree
of Master of Environmental Data Science
for the
Bren School of Environmental Science & Management

By

Tom Gibbens-Matsuyama
Emma Bea Mitchell
Karol Paya
Takeen Shamloo

Committee in charge:
Dr. Naomi Tague
Dr. Carmen Galaz García

Client: California Water Data Consortium

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Signature Page

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The Capstone Project is required of all students in the Master of Environmental Data Science (MEDS) Program. The project is a six-month-long activity in which small groups of students contribute to data science practices, products or analyses that address a challenge or need related to a specific environmental issue. This MEDS Capstone Project Technical Documentation is authored by MEDS students and has been reviewed and approved by:

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EDS 411B INSTRUCTOR

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FACULTY ADVISOR

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DATE

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Abstract

California is known for its susceptibility to drought, caused in part by a misallocation of water resources and an increase in demand. Critical drought related information is reported to multiple state agencies, separating important data and limiting access, leading to the underutilization and poor integration of data into water management. To address this, the California Water Data Consortium developed an open-source portal that consolidates and organizes data from both the Department of Water Resources and the California State Water Resources Board. This project assists the Consortium by creating a governance report, including gap analyses and staff training recommendations, to further clean and maintain the data. The project also creates an online dashboard, making it easy for water managers with limited time or coding experience to analyze the data and identify critical missing values that could lead to misinterpretation. By improving data accessibility and usability, this project aims to strengthen California's drought resilience by providing information that can support coordinated water management.

Executive Summary

California's water crisis, exacerbated by drought, calls for a more coordinated and data-driven approach to water management. Despite legislative efforts such as the Open and Transparent Water Data Act (AB1755), which mandates the integration of water-related data across agencies, the current water data landscape remains fragmented, inconsistently formatted, and difficult to access and interpret. This limits the ability of water resource managers to make informed decisions, particularly in drought preparedness and response.

As part of this partnership, four key datasets have been collected and integrated, comprising self-reported data from local water districts that capture both historical and forecasted information on water production and shortage levels. These include: Actual Historical Production, Forecasted Monthly Water Shortage Level, Forecasted Five-Year Shortage Outlook, and Actual Water Shortage Level.

This capstone project, supported by the California Water Data Consortium and in partnership with key state agencies, including the Department of Water Resources (DWR) and the State Water Resources Control Board (SWRCB), aims to address these challenges through two primary deliverables:

1. A governance report that includes a data gap analysis, documentation of desired improvements, and training recommendations for staff.

2. An interactive web dashboard that enables water managers to visualize and explore water shortage and usage data at the district level without requiring programming expertise.

These tools were designed to increase data transparency, enhance usability, and ultimately support more proactive drought management across California.

Technical Approach

The project followed a five-phase methodology:

- Data Wrangling: Cleaned and prepared several existing water supply and demand datasets using R and documented issues using Quarto.

- Stakeholder Engagement: Conducted interviews with water managers and industry experts to gain insights into water data reporting protocols at the water district level.

- Solution implementation: Designed and developed the interactive web dashboard based on user needs. Conducted a data gap analysis to inform recommendations for improving

data collection and management practices.

- Testing & Feedback: Incorporated user input and iteratively refined deliverables.

- All code and documentation are shared via GitHub, with additional data archived through Dryad and FlowWest's servers to ensure long-term accessibility.

Key Findings

1.0 Governance Report: Data Gap Analysis & Recommendations

The governance report offers a detailed assessment of the current state of four major datasets related to water shortages and production:

- Actual Historical Production

- Forecasted Monthly Water Shortage Level

- Forecasted Five-Year Shortage Outlook

- Actual Water Shortage Level

The project's key findings from the governance report were:

- Data Inconsistencies: All datasets contain missing values, non-standardized formats, and ambiguous variable names.

- Metadata Challenges: Poor documentation makes data interpretation difficult.

- Cross-Dataset Misalignments: Disparities in geographic identifiers and time intervals limit the ability to conduct analyses. To address this, the report includes recommendations for standardizing variables and incorporating additional data sources, such as weather and conservation data to support more effective evaluations in drought management.

2.0 Interactive Web Dashboard

An online dashboard was developed to enable water resource managers to quickly and intuitively explore available data. The dashboard features include:

- Map-based navigation: Users can select their local water district and view region-specific shortage data.

- Filterable data visualization: Dropdown menus allow users to refine the data by water category and date.

- Data summary: Provides data statistics, missing values, and trends.

- Gap identification: Clearly displays where missing or incomplete data may affect interpretation.

This tool bridges the gap between water datasets and actionable insights, allowing non-technical users to explore data without the need to clean and graph the data.

Impact and Future Use

This project strengthens California's drought resilience by:

- Improving data quality: Enabling more robust and consistent data collection and integration across agencies.

- Enhancing accessibility: Allowing stakeholders at all technical levels to explore and interpret water data.

- Enabling proactive planning: Supporting water managers in identifying supply risks and gaps before they become critical.

The tools and reports developed serve not only as immediate resources for water managers but also as blueprints for scalable improvements in water data governance statewide. Future work may involve integrating additional datasets, such as weather and conservation data, expanding training programs for state staff, and enhancing the dashboard's functionality to support broader drought-related analyses.

By prioritizing both technical integrity and user experience, this project represents a significant step forward in turning California's water data into a strategic asset for drought management.

Approach

Our project consists of four main phases:

Phase 1: *Data Exploration & Wrangling* involves collecting, cleaning, and preparing data for analysis.

Phase 2: *Defining Scope & Expectations* is guided by interviews with water managers to establish project objectives and client requirements.

Phase 3: *Prototyping* focuses on developing R-scripts for streamlined data processing and a dashboard for visualization.

Phase 4: *Testing & Feedback* ensures that we incorporate client input and document any data gaps as we progress through all phases of our deliverables.

The detailed steps are outlined in Figure 1 below.

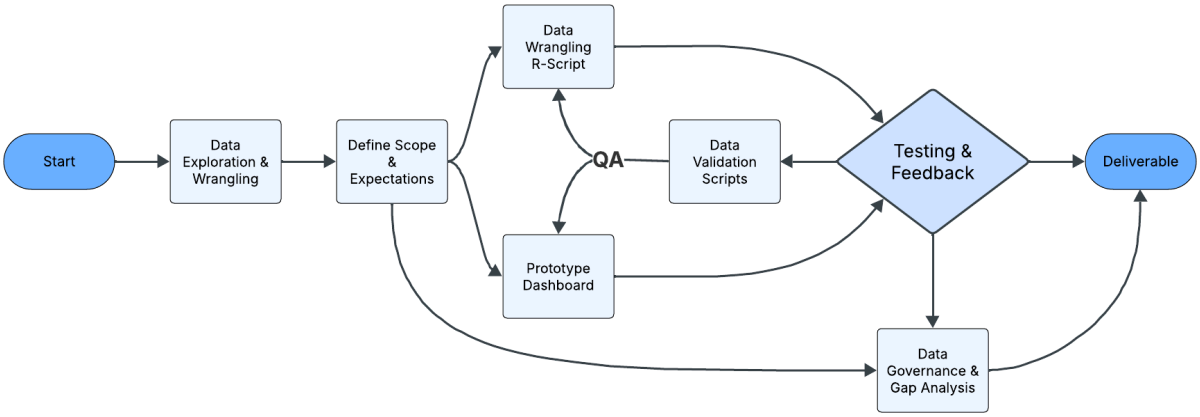


Figure 1: Project implementation workflow.

Methods

1 Governance Report

This report provides the client with a detailed overview of data inconsistencies that pose challenges for water managers in effectively utilizing all available datasets. It also offers recommendations to enhance data reporting practices and proposes training programs for state staff. This governance report was developed through consultation with the client. The final report will be delivered as a Quarto document consisting of the following subcategories: Training Recommendations, a Current Data Gap Analysis, and a Desired Data Gap Analysis

1.1 Training

This section provides internal stakeholders and staff with recommendations in maintaining and updating the deliverables. This is a Quarto document that consists of the technical steps needed to navigate the R code, including data wrangling, unit testing, dashboard building, and performing gap analysis. Libraries used for these consist of tidyverse, janitor, lubridate, shiny, shinydashboard, plotly, tmap, etc.

1.2 Current Gap Analysis

A gap analysis involves identifying and understanding the discrepancies with the current state of each dataset. This includes identifying variables with high numbers of missing values, values that are not the correct type (i.e. negative values when positive should only be present), inconsistent naming conventions, etc. To support this effort, this deliverable was created to help water district staff recognize opportunities to streamline existing practices of data collection and submission to government bodies. Specifically, the current gap analysis is presented as a Quarto document, which outlines data quality issues and corresponding coding solutions within and across four primary datasets: Actual Historical Production, Actual Water Shortage Level, Forecasted Monthly Water Shortage Level, and Forecasted Five-Year Shortage Outlook. To provide context, a brief overview of each dataset is included in Table 1.

Variable, Type, Approximate Size	**Description**
Actual Water Shortage Level, .csv (823 KB)	Monthly water shortage levels for water agencies
Five Year Water Shortage Outlook, .csv (204 KB)	Projected water use and supply of water agencies based on the 5 worst consecutive drought years
Historical Production and Delivery, .csv (89 MB)	Water production/delivery by water type for water agencies
Monthly Water Shortage Outlook, .csv (1MB)	Projected monthly water shortage or surplus for water agencies

Table 1: Research Data Summary

The structure of the gap analysis is as follows:

I. **Dataset Description:**

Each dataset contains a description of collection methods, collection source(s), key variables of interest, and data limitations.

II. Issues:

Each dataset includes identified issues along with corresponding proposed solutions, listed for every issue found. Issues were identified through initial data exploration, cleaning, and ongoing analysis conducted in preparation for the dashboard development. Identified issues ranged from the reorganization of observation names and miscalculated values to missing data likely resulting from improper submission methods. Methods used to identify and resolve solutions were done using dplyr, janitor, and lubridate as these were the main cleaning libraries in R.

III. Solutions:

Each issue mentioned above is followed with code that provides a solution to said issue. It should be noted that not every issue has a direct coding solution. Some solutions may be regarded as a "data checking solution" that consists of unit testing methods for incorporation of more data in the future.

The code used to identify these issues follows a similar format. The following is an example of an issue and a data checking solution for the Five Water Shortage Year Outlook dataset:

Example Issue: Five Year Water Shortage Outlook Dataset

This dataset consists of four main metrics that we are interested in: water supply, water use, water augmentation, and water reduction. In this context, water augmentation refers to a water district receiving water from outside their normal sources, such as buying from another water district. These four variables summed, make up how much water a district is using and has available. In many such cases the total water use is less than or equal to the total water supply. This indicates that a water district has a surplus of water. However, in the other case, where total water use is greater than total water supply, it means that either augmentation, demand reduction or supply are misreported.

Thus,

`total water use = total water supply + total benefit augmentation + total demand reduction.`

To find the rows where this doesn't hold true, let's assume that NA values for supply_augmentation and demand_reduction are 0s. Let's use this logic to find water districts that did not report data.

```
# Replacing NAs with 0s, assuming this as true
five_year_replace_na <- five_year_shortage %>%

  # Mutate existing columns and replace NAs with 0s
  mutate(benefit_supply_augmentation_acre_feet =
           replace_na(benefit_supply_augmentation_acre_feet, 0),
         benefit_demand_reduction_acre_feet =
           replace_na(benefit_demand_reduction_acre_feet, 0))

# Creating a function that calculates supply + demand red + supply aug when Use > Supply
calculate_benefit <- function(df) {
  five_year_replace_na %>%

    # Create new columns
    mutate(total_benefit = ifelse(

      # Use ifelse statement for when use > supply
      water_use_acre_feet > water_supplies_acre_feet,

      # If true, then do the following, If false, assign a 0
      water_supplies_acre_feet + benefit_demand_reduction_acre_feet + benefit_supply_augmentation_acre_feet, 0
    ))
}

# Use the function to reassign the df
five_year_replace_na <- calculate_benefit(five_year_replace_na)

# Let's view the data where total_benefit does not equal total use
five_year_na_filtered <- five_year_replace_na %>%
  filter(total_benefit != 0,
         water_use_acre_feet != total_benefit)
```

Figure 2: Example of an issue and its data checking solution.

1.2.1 R Script

A streamlined R script was developed to simplify the gap analysis data checks and coding solutions. It enables internal staff, stakeholders, and other users to incorporate new data and quickly verify compliance with the best coding practices outlined in the gap analysis.

1.3 Desired Gap Analysis

The intended gap analysis is presented as a second Quarto document that outlines the required data variables, values, and submission formats needed to effectively address client questions in a timely manner. It offers guidance on how state data collection programs should be structured and specifies the types of variables that should be submitted

2.0 Interactive Web Dashboard

A component of the final deliverable consists of the Interactive Web Dashboard. This is where urban water suppliers will be able to gain insights based on the metrics they report and explore trends such as shortages, surplus, reporting completeness, etc.

2.1 Dashboard Components

a) Home Page (Data Overview)
The homepage will be the gateway to this dashboard where the end-user will be able to take a look at information about where our data comes from, our client The California Water Data Consortium, and an overview of the types of operations possible through our dashboard. It will highlight the importance of the presented data and the environmental implications associated with the work being done.

b) Tutorial
The tutorial will aim to instruct our end-users on how to perform the operations available on our dashboard and examples of actions an end-user is expected to do. It will explain each component using a slideshow-style UI, where it will lead the user through the dashboard in a step-by-step walkthrough.

c) Visualizations & Insights
The main component of this dashboard will allow users to select from the multiple datasets compiled by the Consortium based on the annual reporting scheme for Urban Water Suppliers. For more information on our sources, visit the Urban Water Data portal. A search feature will allow users to focus on specific suppliers or organizations, automatically filtering the visualizations and statistics based on the selection. Additional filtering tools will be available to refine the data views such as date ranges or

production/delivery types where applicable. There will be an interactive map of California showing the average documented use vs surplus, produced vs delivered, as well as shortage levels by district. Summary statistics are provided for each selection respective to each dataset, along with a breakdown of missing values corresponding with the variables used to promote transparency and encourage accurate data reporting by suppliers.

The dashboard will be hosted through the FlowWest team on their dedicated R-Shiny server.

2.3 Dashboard Implementation

An additional part of the dashboard setup will be scripts with UI & Server elements, cleaning and filtering of the data, as well as unit testing to ensure the dashboard is working consistently given future additions to the data.

a) Data Wrangling
   The dashboard will have a data wrangling script where all of the data will be imported, filtered, and centralized for use across the web app.

b) UI & Server
   The User Interface (UI) and Server scripts will be where the bulk of the outline and reactive features will be created and processed. All the elements in the UI will be linked to backend components in the Server file per standard R-Shiny practices.

c) Unit Testing
   This last script plays an important part in the longevity of this project. It will contain the basic expected capabilities that this dashboard will need to perform. The goal here is to make sure that with any additions to the dashboard or changes to the various R-scripts outlined in this document, there is a list of protocols that **must run**. These protocols verify both the functionality of the services provided by this product and the accuracy of its results.

Product Description

1.0 Interactive dashboard

The interactive web dashboard was created for the purpose of viewing water shortage data, summary statistics, and data limitations in water districts across California. The intended audience of the dashboard are water managers at both state and local levels. Currently, the data portal housed on the California Natural Resource Agency website contains metadata and downloadable CSV files, but navigation and interpretation of the data may be difficult for water

managers with limited experience in coding or limited time. To solve this issue, the dashboard allows users to view important information about the data without using any programming languages or excel.

The key features of the dashboard are the four different widgets located on the dashboard main page. These four widgets allow the user to visualize and easily interpret the data by showing four different important components; a time series graph representing selected variables in the dataset; an interactive map that shows the location of the water districts and mapping of a variable/variables from the selected dataset; summary statistics showing total values from variables in the dataset; and totals of NA values present in the dataset. All of these widgets are completely customizable, and will change depending on the water district selected, the dataset selected, and the time range selected. The graph, map, summary statistics, and missing values will all change as the selectors are changed. These four components of the dashboard will allow the user to see a brief but accurate overview of the data they are interested in. The first step for users will be to select the org_id, the time range, and the dataset they are interested in. Afterwards the user will use each widget in the workflow below.

Widget One:

On the first widget, the user will pick their dataset of interest. Each dataset is described in detail on the dashboard homepage so users are informed in their selection. They can also pick the date range of interest. The datasets all have different available date ranges, and the selector will be updated depending on the dataset selection. Once both the dataset and date ranges have been selected, the graph representing their selections will be displayed. The graph changes are as follows:

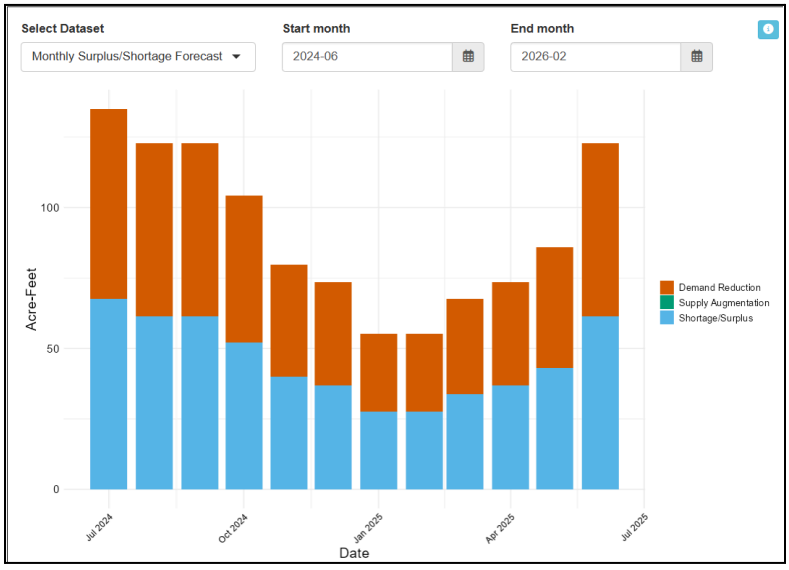


Figure 3: Bar graph of the Monthly Surplus/Shortage Forecasted dataset

When selecting the Monthly Surplus/Shortage dataset, a time series stacked bar plot representing shortage/surplus, supply augmentation, and demand reduction will be displayed.

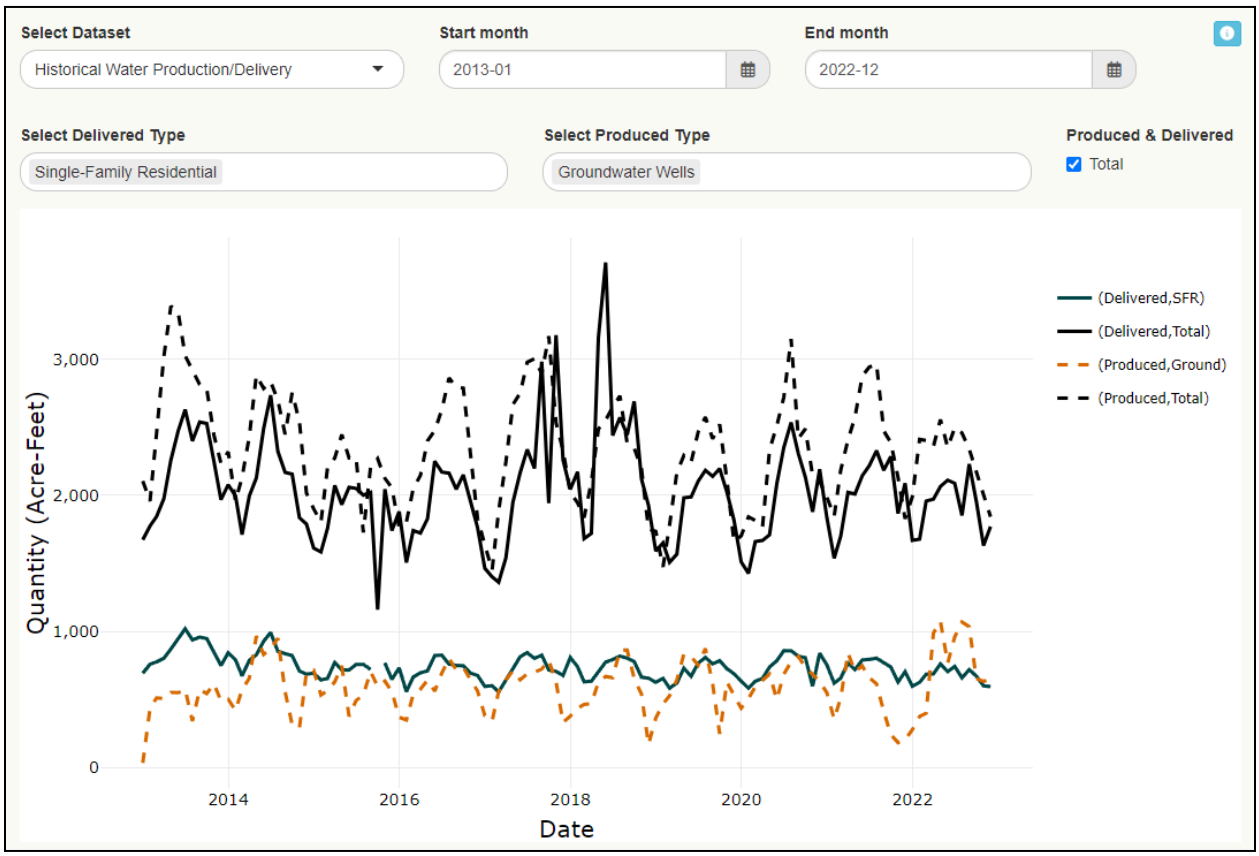


Figure 4: Line graph of the Historical Water Delivery & Production dataset

When selecting the Historical Water Production/Delivery dataset, a new selection will appear. These will ask the user to select the production sources and delivery sectors that the user would like displayed. They can also select Total Produced and Delivered to graph all production sources and delivery sectors. These three selection options can be combined in any way the user wishes. They can be combined, and multiples of each can be selected. The resulting graph is a time series line plot showing acre-feet of the quantity of water in each selected sector/source.

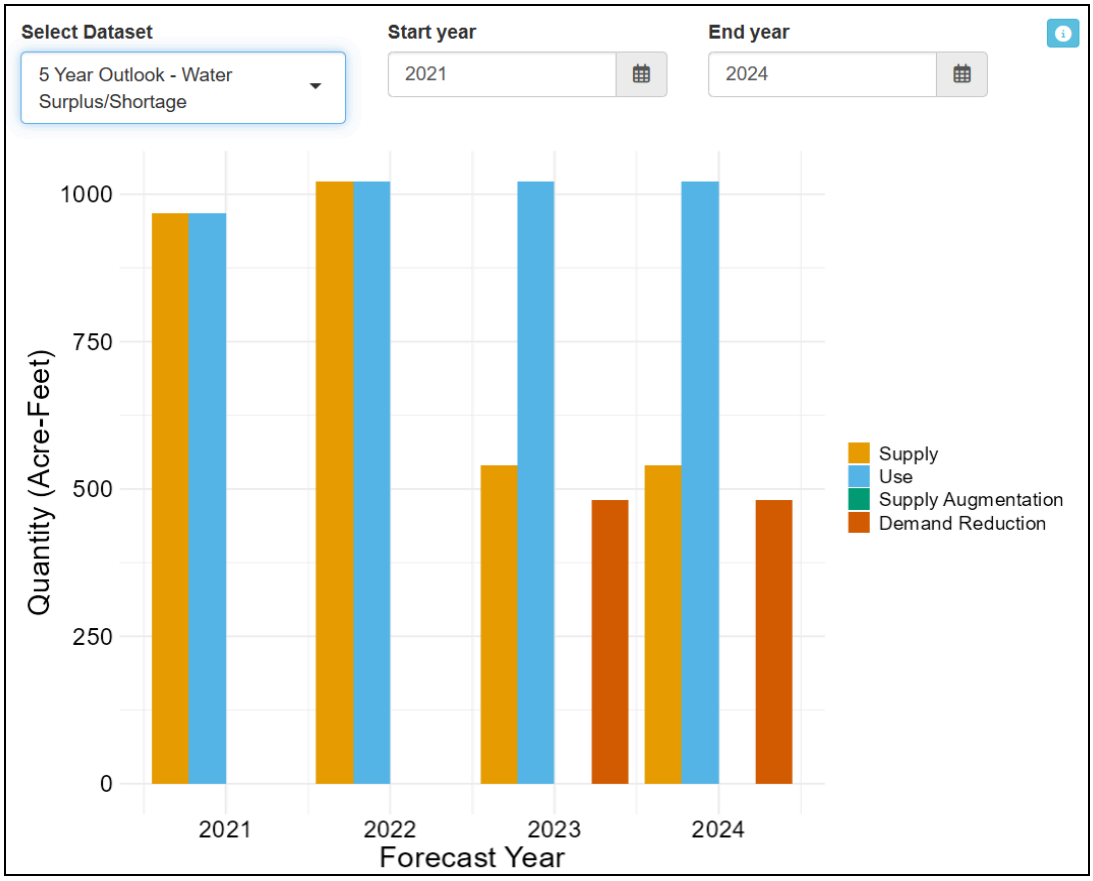


Figure 5: Bar graph of the Five Year Outlook dataset

When the 5 Year Outlook - Water Surplus/Shortage dataset is chosen, a bar chart showing a time series of forecast year and quantity in acre feet of supply, use, supply augmentation, and demand reduction are shown.

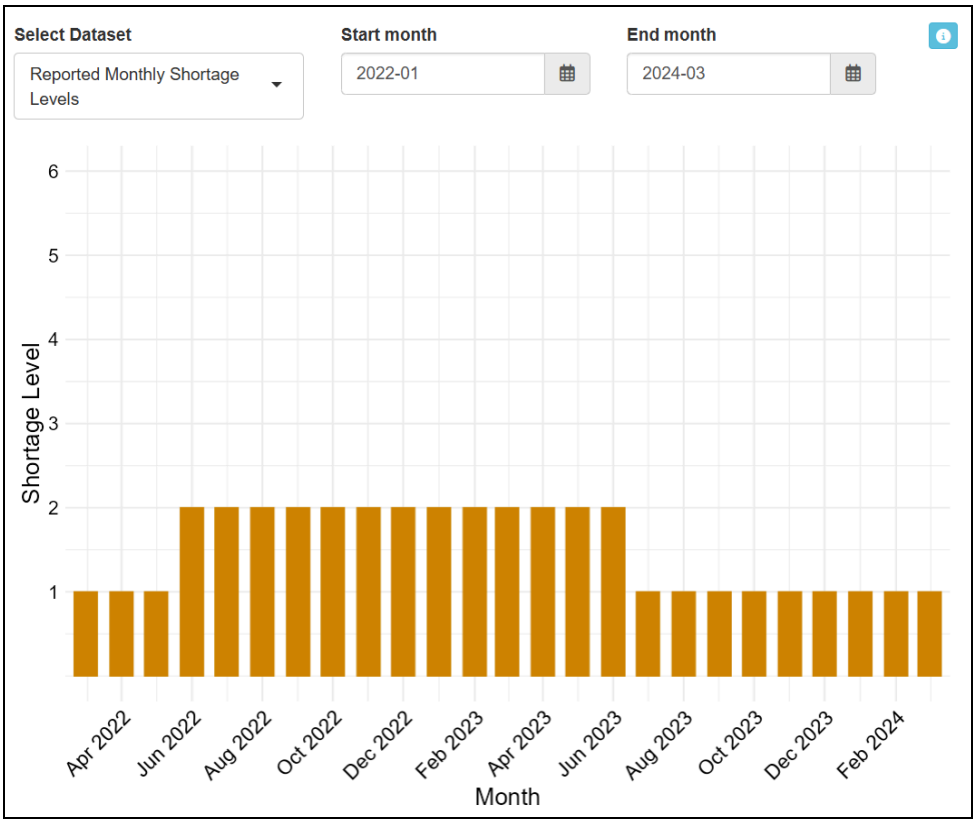


Figure 6: Bar graph of the Reported Monthly Shortage Levels dataset

When the Reported Monthly Shortage Levels are chosen, a bar plot of the shortage levels from one to six will be displayed with a time range representing the range selected by the user.

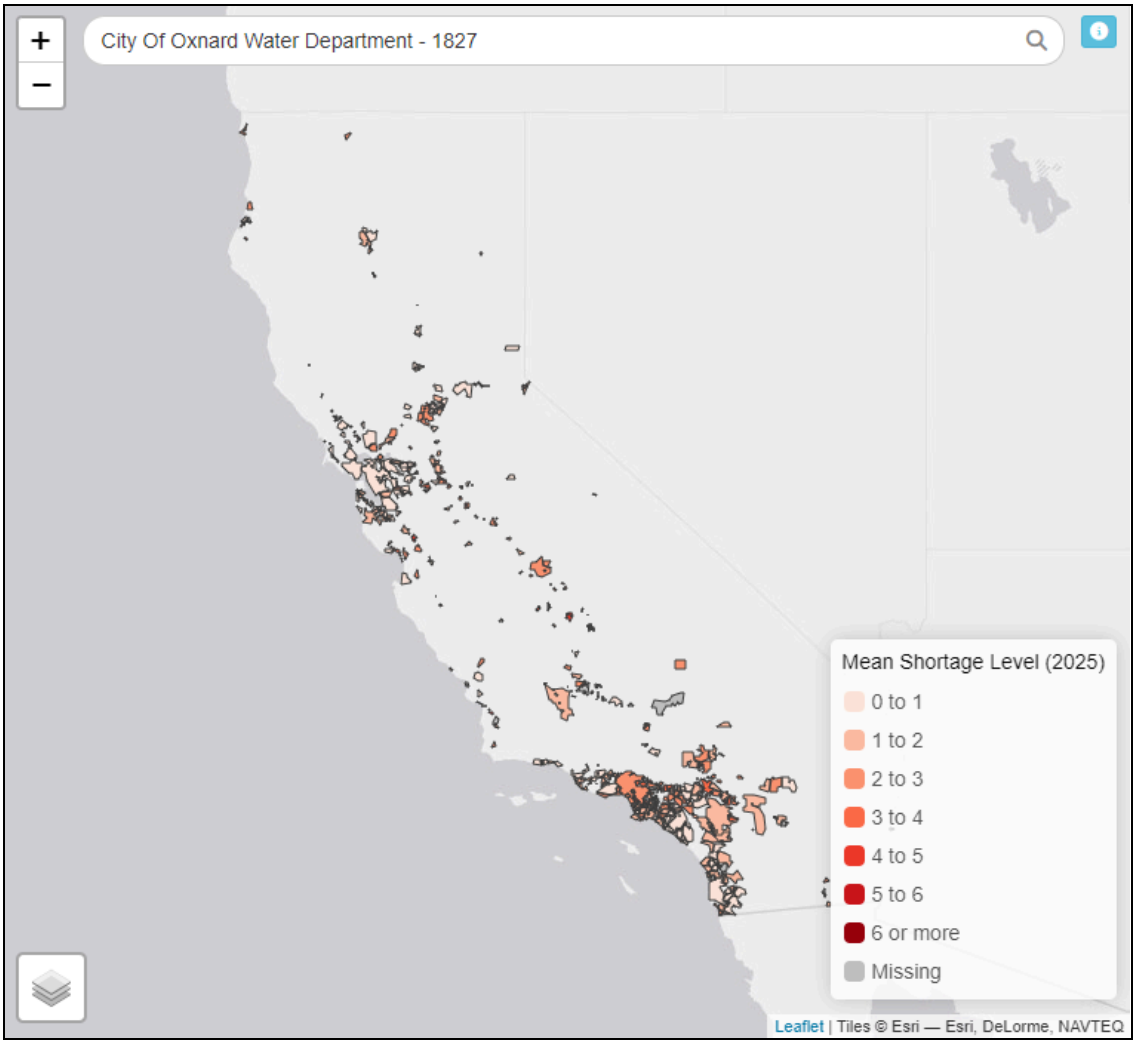


Figure 7: Map of water districts boundaries throughout California

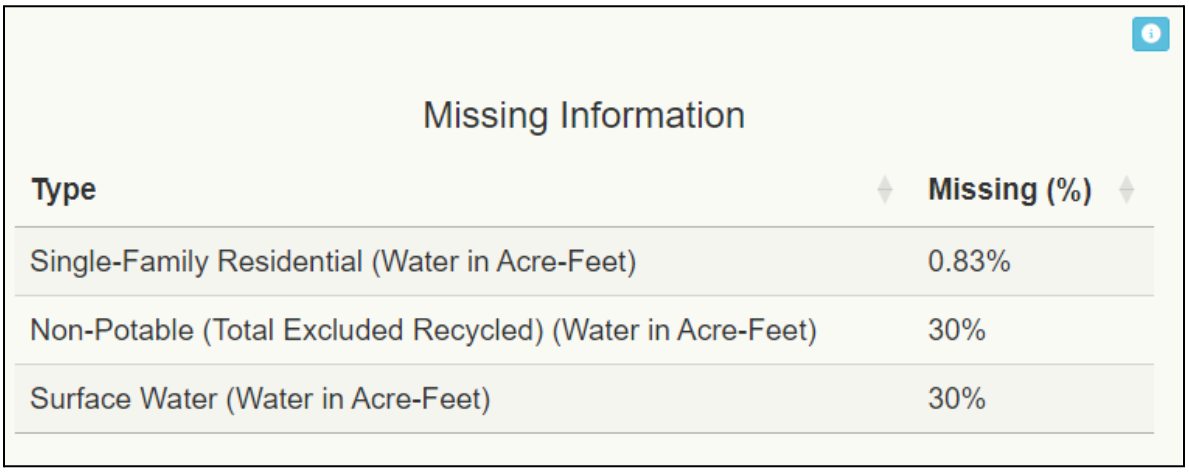
The second widget contains a map of California. As the dataset and org_id selection is changed, the data visualized on the map will change as well. Here, the user can visualize the most recent water shortage data color coded on the map, when selecting the actual shortage level dataset.

Summary Statistics

Produced or Delivered	Type	Total Acre-Feet
Total Produced	—	280,688
Total Delivered	—	243,871
Water Delivered	Single-Family Residential (Water in Acre-Feet)	88,104

Figure 8: Summary statistics in the Historical Water Production & Delivery dataset

The third widget shows the summary statistics of the dataset, location, and time range selected by the user. The statistics shown are unique for each dataset selected, and will change as selected elements change.



Missing Information

Type	Missing (%)
Single-Family Residential (Water in Acre-Feet)	0.83%
Non-Potable (Total Excluded Recycled) (Water in Acre-Feet)	30%
Surface Water (Water in Acre-Feet)	30%

Figure 9: Missing information for the Historical Production & Delivery dataset

The fourth widget shows the amount of NAs present in the selected data. This allows users to understand the gaps in data in their area of interest, and prevents misinformation and misinterpretation of displayed data.

Descriptions of each widget and possible selection will be detailed on the dashboard. The dashboard will also recognize and include information about limitations to the data. It will also link to the gap analyses if users are interested in diving deeper into the limitations.

2.0 Governance Report

The governance report was created for the purpose of state staff, Flow West, and the California Water Data consortium to use to guide future maintenance and updates on the dashboard and data.

2.1 Current data gap analysis

The purpose of the current data gap analysis is to record issues within and between datasets. The analysis describes the issue, solution, and the solution's code if applicable. The analysis can be used to learn about the limitations of the data, or used to update the data based on the recommendations recorded.

2.2 Desired data gap analysis

The purpose of the desired data gap analysis is to record possible data that could be helpful to water managers in their planning, but is not possible with the current data

provided. It will list the data needed to answer various questions and provide recommendations when applicable.

2.3 Staff training

The purpose of the staff training section of the governance report is to detail the technical steps and procedure used to create the dashboard and manage the data. This will act as training recommendations for staff working on dashboard and data maintenance. Training will need to be provided to staff on skills used or considered when hiring.

3.0 App Deployment and Maintenance

This section will detail anticipated problems surrounding maintenance and deployment, along with potential solutions and resources for further troubleshooting.

Deployed by FlowWest. See gap analysis for possible future updates. Tbd on anticipated problems

User Manual

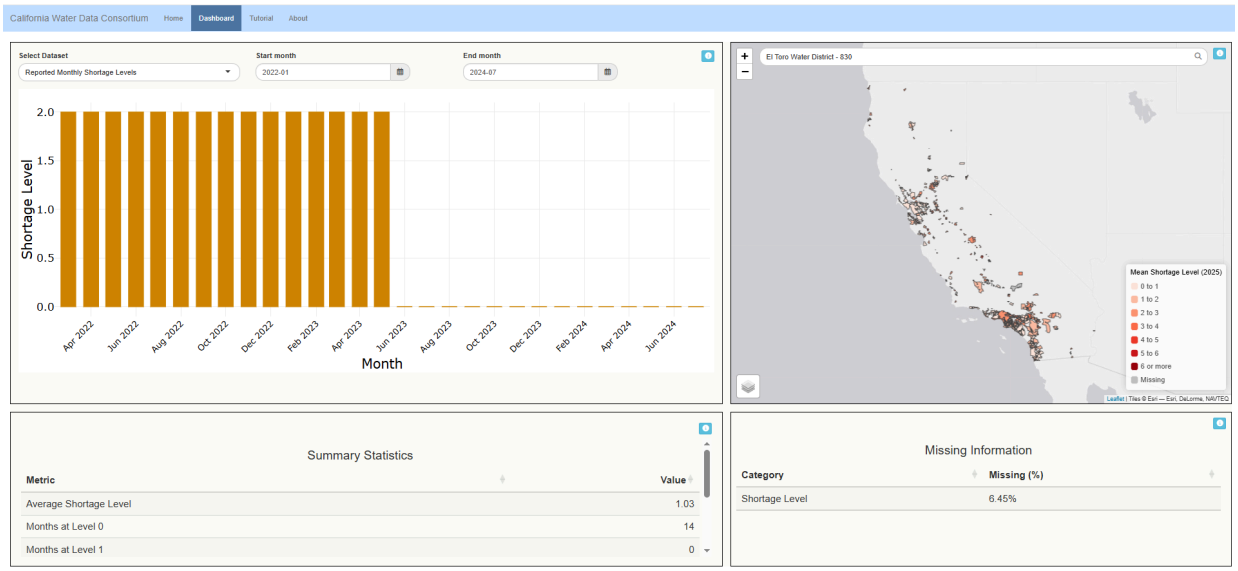


Figure 10: Overview of the dashboard page

The general layout of the dashboard is in four sections/widgets. These four sections include a graph, a map, summary statistics, and the amount of missing information for the data selected.

Figure 11: Dataset selection

When first opening the dashboard, the user will look at the top section. Here is where they will select all the information that they want to see. First, they can select the dataset they are interested in from the select dataset dropdown. Descriptions of what each dataset means can be found in the info button on the top right part of the widget, as well as in more descriptive detail on the home page.

Figure 12: Start and end time range selection

After selecting the dataset, the user will then select the date range that they are interested in. The available date ranges will change depending on the chosen dataset, and the dropdown calendar will reflect those changes.

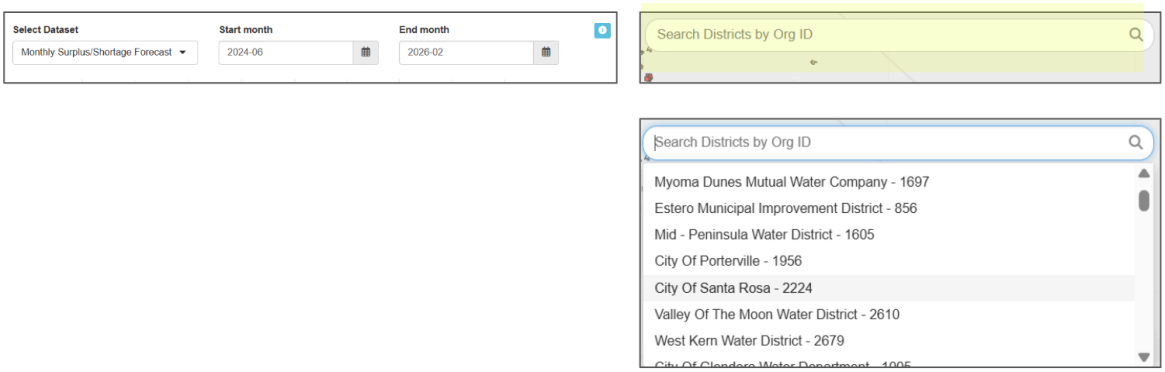


Figure 13: Water district selection through search bar

The user will then select the water district they are interested in. They can search through the name of the district or the organizational ID of the district.

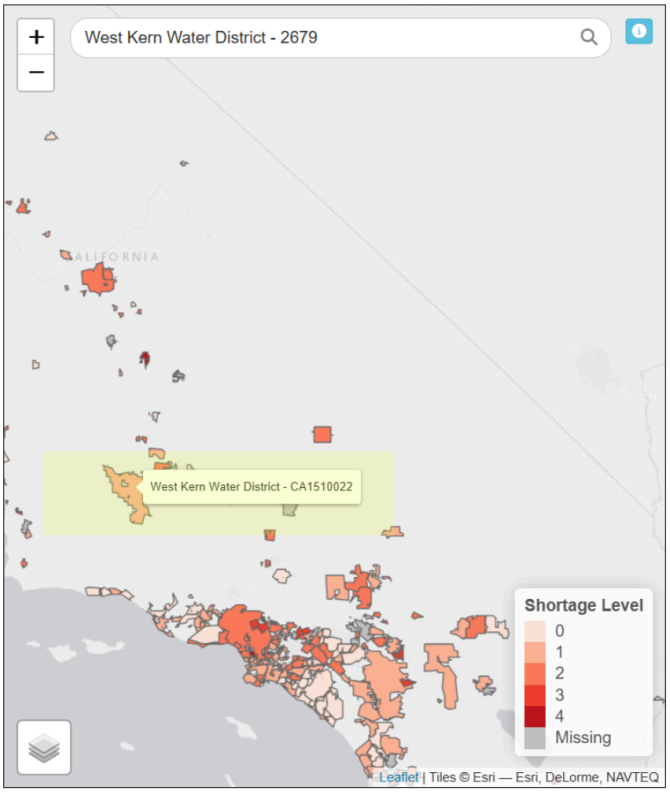


Figure 14: Water district selection through the district boundaries

The user can also select the district through the map. To interact with the map, zoom in or out by using the + or - buttons or use your mouse. When hovering over the district, the name of the district will appear as well as the PWSID (Public Water System ID). When the district is selected, it will automatically populate the search bar with the district chosen.

Once the top row of the dashboard has been filled out, the user can look at the results of their search in 4 different sections.

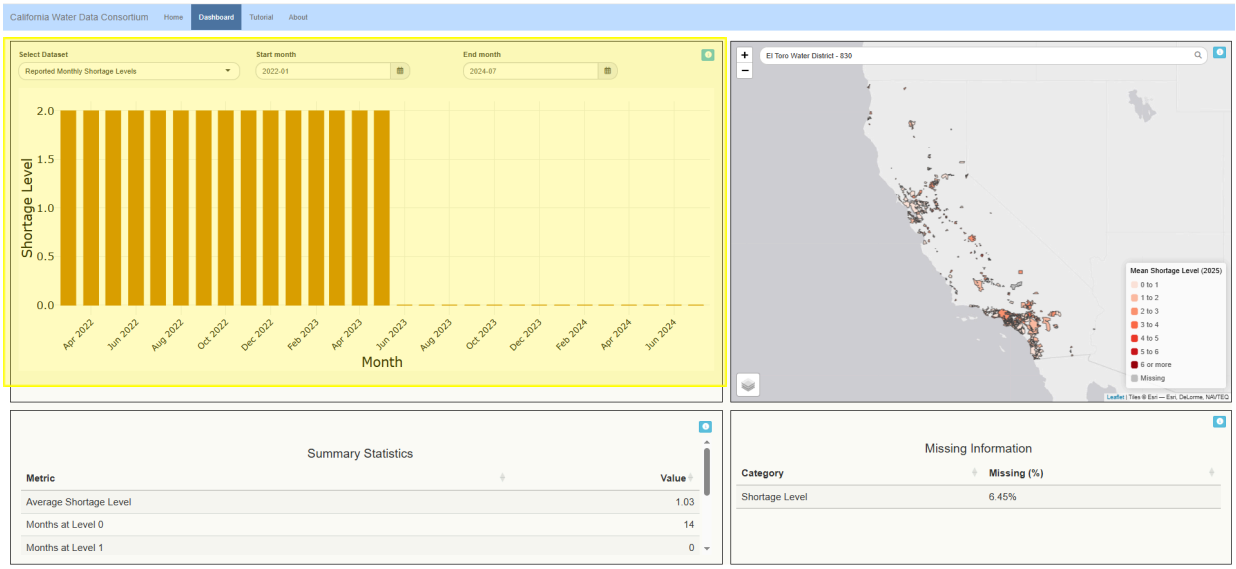


Figure 15: Graph display highlighted

The first widget displays a graph of the data for the selected dataset, date range, and district. For more information on interpretation of the graphs, see the info button on the top right of the widget or see the homepage for more details.

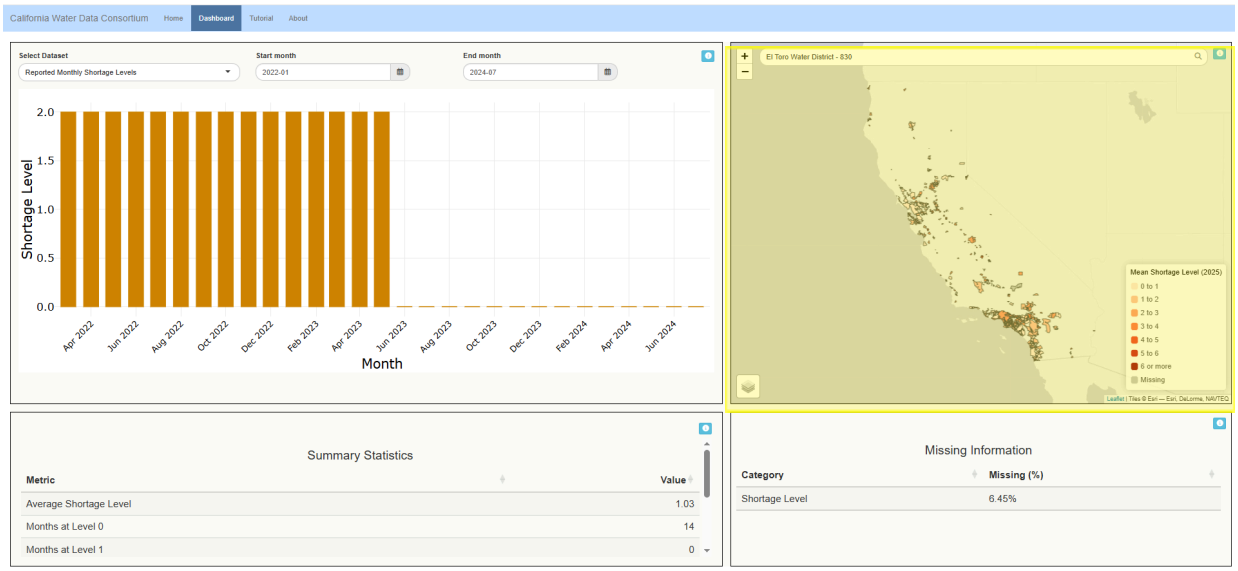


Figure 16: Map display highlighted

The second widget shows a map of California, with color coding representing information based on the dataset selected. To see more information on the map visualization see the info button on the top right of the widget or the home page.

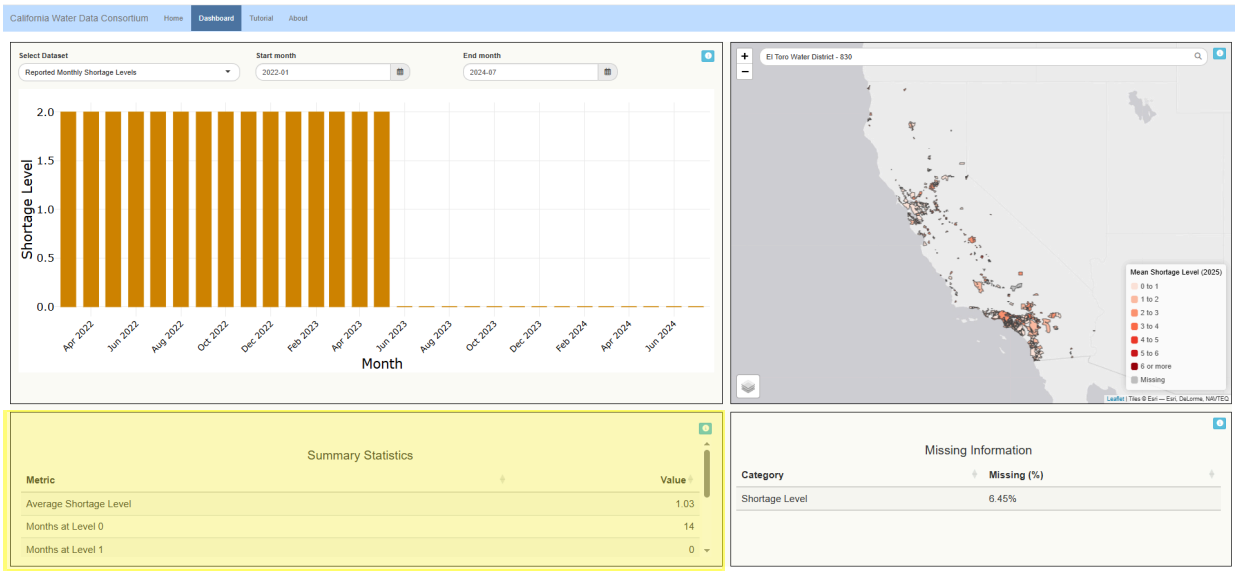


Figure 17: Summary statistics display highlighted

The third widget that a user will look at are the summary statistics. These will also automatically change as the district, date range, data set selection changes. The type of summary statistics shown will be clearly labeled in the widget, and more information can be found with the info button on the top right corner of the widget and home page.

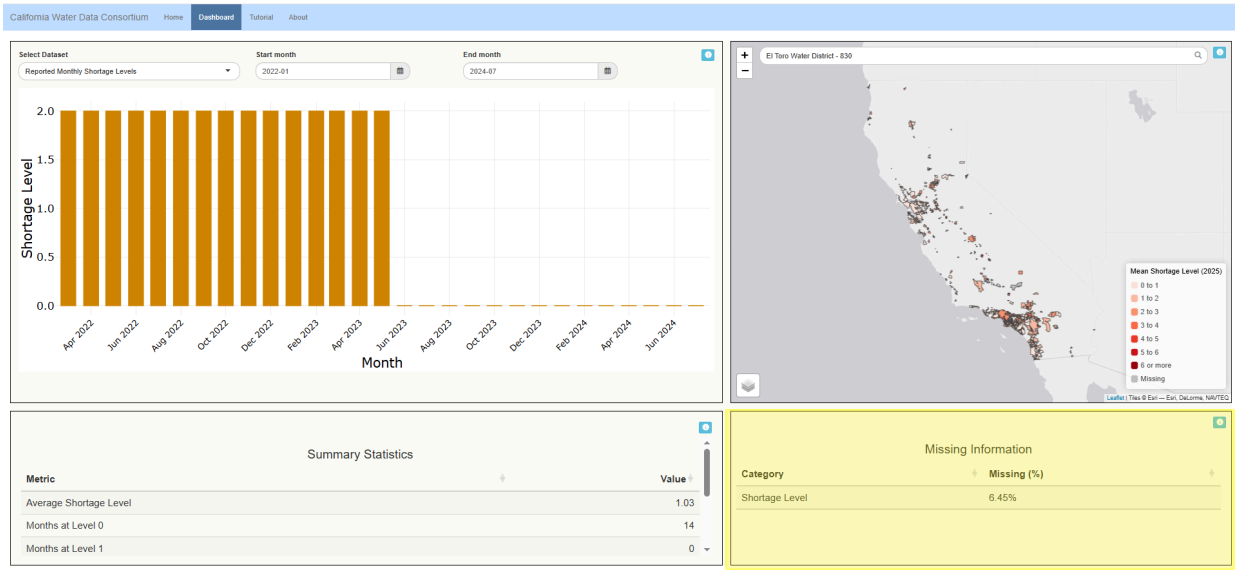


Figure 18: Missing information display highlighted

The last widget a user will look at is the missing information. This will show the amount of NAs present in the data selected. For more information see the info button in the top right corner of the widget or the homepage.

Archive Access

Github Repository

The GitHub Organization, CalDrought, was created to document the code and technical reports for the deliverables. The organization consists of repositories for the dashboard, governance report, and the client's original documentation. Each repository consists of an overarching README.md file that breaks down the purpose, data, and workflow for the documentation.

Data archival is not necessary in this project. No additional data is created.

References

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