TECHNICAL MEMORANDUM | AUGUST 2023

# EAST BAY PLAIN SUBBASIN CHARACTERIZATION TASK 4A, ISOTOPIC ANALYSIS – SURFACE WATER-GROUNDWATER INTERACTION

PREPARED FOR

EAST BAY MUNICIPAL UTILITIES DISTRICT

PREPARED BY

LSCE TEAM

# TABLE OF CONTENTS



## LIST OF TABLES

## LIST OF FIGURES

## LIST OF ACRONYMS AND ABBREVIATIONS

| Acronym | Meaning |
|---|---|
| $^{222}Rn$ | disolved radon |
| baseflow | extent and location of groundwater |
| bgs | Below ground surface |
| cfs | Cubic feet per second |
| DO | dissolved oxygen |
| DWR | California Department of Water Resources |
| EBMUD | East Bay Municipal Utility District |
| EBP | East Bay Plain |
| EC | electrical conductivity |
| ft | feet |
| GDE | groundwater dependent ecosystem |
| GMWL | Global Meteoric Water Line |
| GSP | groundwater sustainability plan |
| IRIS | isotope ratio infrared spectroscopy |
| LLNL | Lawrence Livermore National Laboratory |
| MCL | maximum contaminant level |
| NTU | nephelometric turbidity units |
| ONO | Oakland North CDEC station |
| Prop 68 | Proposition 68 |
| RWQCB | Regional Water Quality Control Board |
| SMC | sustainable management criteria |
| TDS | total dissolved solids |
| TM | technical memorandum |
| USEPA | U.S. Environmental Protection Agency |
| VSMOW | Vienna Standard Mean Ocean Water |

# Executive Summary

Surface water-groundwater interaction in the East Bay Plain (EBP) Subbasin was identified as a key data gap during Groundwater Sustainability Plan (GSP) development. East Bay Municipal Utility District (EBMUD) obtained a Proposition 68 (Prop 68) Grant from the California Department of Water Resources (DWR) for the EBP Subbasin. This Technical Memorandum (TM) presents the results of Task 4A in the DWR Prop 68 Grant, which included collection of synoptic streamflow measurements and analysis of stream water samples for geochemical and isotopic tracers to better understand stream discharge rates, gaining and losing stream reaches, and sources of water to streams. San Pablo Creek, in the northern portion of the subbasin, and San Leandro Creek, in the southern portion, were chosen based on their relatively large watershed size and on the presence of potential Groundwater Dependent Ecosystems (GDEs). San Leandro Creek was sampled at four locations below Lake Chabot, and San Pablo Creek at five locations below San Pablo Dam. Both streams were sampled at baseflow and just before and during runoff events in February and March, 2021.

Combined results of field parameters, dissolved radon, stable isotopes of oxygen and hydrogen, and tritium are interpreted to characterize and quantify the sources of water that generate streamflow and to identify locations of groundwater inflow. Isotopic tracers reveal that San Leandro Creek is losing along much of its course below Lake Chabot. Evaporated Lake Chabot water recharges shallow groundwater downstream of the dam for a distance of greater than 10,000 feet (ft), but the stream becomes intermittent in lower reaches, with urban drainage providing the limited flow between events and during baseflow. During precipitation events, quick flow (runoff) is the main source of water in the creek. Imported water contributes to flow at downstream locations, making up nearly all of the flow during dry periods and a small percentage of the flow during events.

The overall stability and low variability in isotopic tracer concentrations along San Pablo Creek indicate significant groundwater interaction with the stream along much of its course below San Pablo Reservoir. The stream is perennial and gaining at most locations and most times. Total dissolved solids (TDS) are generally about twice as high in San Pablo Creek as in San Leandro Creek, and sources of dissolved ions to San Pablo Creek are likely geogenic and not anthropogenic. Tritium results for San Pablo Creek indicate that the groundwater has resided in the subsurface for up to 20 years before entering the stream, suggesting relatively long flow paths to the stream. An isotopically distinct (and low TDS) imported stream water component, possibly released via irrigation return or leaky infrastructure, is evident at locations below the I-80 culvert on San Pablo Creek. Groundwater pumping in the alluvium and stream alluvial terraces upstream of I-80 is likely to decrease groundwater inflow to San Pablo Creek and may adversely affect GDEs, especially during periods of low streamflow.

Additional data will be developed to build on the present study. In particular, neither San Leandro Creek nor San Pablo Creek is gaged, so water fluxes cannot be determined, including the flux of imported water that reaches the bay. New stream gages are planned for installation and monitoring as part of GSP implementation tasks, along with periodic synoptic stream surveys. Another future task to fill data gaps involves drilling shallow wells adjacent to the streams for monitoring of water levels. These shallow wells could also be sampled for the same tracers applied in this study, revealing flow direction and water sources over seasonal hydrographs.

# 1. INTRODUCTION

East Bay Municipal Utility District (EBMUD) obtained a Proposition 68 (Prop 68) Grant from the California Department of Water Resources (DWR) for the East Bay Plain Subbasin that includes tasks for installation of five nested monitoring well sites, long-term regional aquifer testing at two locations, collection of stream water samples for isotope analysis (this study), and collection of groundwater samples for isotope analysis. This Technical Memorandum (TM) presents the results of Task 4A in the DWR Prop 68 Grant, which included collection of synoptic streamflow measurements and analysis of stream water samples for isotopes.

## 1.1. Background

Surface water-groundwater interaction in the East Bay Plain (EBP) Subbasin and surrounding watersheds was identified as a key data gap during Groundwater Sustainability Plan (GSP) development. Improving the understanding of surface water-groundwater interaction has important implications for developing an accurate hydrogeologic conceptual model and water budgets, assessment of the GSP sustainable management criteria (SMC) for surface water depletion, and for future evaluation of impacts to potential groundwater dependent ecosystems (GDEs). The EBP Subbasin GSP describes several tasks that are intended to fill existing data gaps related to surface water-groundwater interaction, including ithe nstallation of additional stream gages and ongoing stream stage and discharge monitoring, conducting synoptic stream surveys, installation of shallow wells adjacent to streams, and stream isotope studies. These studies will initially focus on the major streams in the EBP Subbasin that have greatest potential for surface water-groundwater interaction: San Pablo Creek, Wildcat Creek, and San Leandro Creek (the majority of San Lorenzo Creek within the EBP Subbasin is lined and will not be studied as closely as the other major creeks).

The various tasks described above to fill data gaps will be initiated over the first five years of the GSP implementation period. Results of all these tasks will be analyzed and presented as part of the first Five-Year GSP Update Report in 2027. This TM describes results and preliminary conclusions from the first task to be implemented in improving the understanding of surface water-groundwater interactions in the EBP Subbasin. Ultimately, the results of all tasks described in the GSP will be analyzed together to ensure the GSP moves forward with consistent conclusions regarding surface water-groundwater interactions that are based on all the studies proposed to be conducted to fill data gaps.

## 1.2. Purpose

The purpose of this study was to apply a combination of synoptic streamflow measurements and collection of stream water samples analyzed for isotopes and other constituents to better understand stream discharge rates, gaining and losing stream reaches, and sources of water to the stream. LSCE Team members Dr. Jean Moran and Dr. Ate Visser[1] conducted streamflow measurements and water quality sampling in one stream in the northern portion of the Subbasin (San Pablo Creek) and one stream in the southern portion of the Subbasin (San Leandro Creek). Neither stream has significant stream gaging data, and there has been little prior investigation of stream dynamics or surface water-groundwater interaction on either stream.

## 1.3. Application of Isotopes

When physical data such as stream discharge and groundwater levels are lacking, isotopic and geochemical tracer data collected from streams can be applied to advance the understanding of surface water-groundwater interaction. Stable isotopes of the water molecule ($^{1}H$, $^{2}H$ and $^{16}O$, $^{18}O$) vary in precipitation due to fractionation in water cycle processes. Infiltration and transport via groundwater homogenize these isotopic signals; however, shallow and deeper groundwater typically have distinct isotopic signatures that can be used to quantify these components in stream water. In addition to stable isotopes of oxygen and hydrogen, field water quality parameters (e.g., specific conductance and temperature) provide additional information about water flow paths and enhanced statistical definition of end members used in surface water-groundwater mixing analysis. Dissolved radon ($^{222}Rn$) is produced in subsurface sediments and allows quantification of the extent and location of groundwater (baseflow) inputs to streamflow. Radon has a high solubility in water but transfers to the gas phase over a relatively short distance in surface water bodies, making it useful for pinpointing locations of groundwater input to streams. The LSCE Team used radon to identify gaining and losing reaches and seasonal changes in groundwater inflow to the creeks targeted for study. Tritium results were used to study the age of water contributed by the headwater catchment and the groundwater discharging in the investigated stream reach and for comparison of the mean ages between runoff and baseflow time periods. Tritium results from a downstream location allow estimation of the mean age of streamflow near the outlet to San Francisco Bay.

[1] Dr. Jean Moran is a Professor in the Department of Earth and Environmental Sciences at California State University – East Bay, and Dr. Ate Visser is an Isotope Hydrologist at Lawrence Livermore National Laboratory.

# 2. SAMPLING AREAS AND RATIONALE FOR SITE SELECTION

The sampling sites for this study included four locations along San Leandro Creek below Lake Chabot and above the channelized (straightened, constructed) reach, and five locations along San Pablo Creek below San Pablo Dam and above the channelized (straightened, constructed) reach. Upstream reaches include parkland and open space, while downstream reaches are densely developed with many culverts, bridges and small control features. However, both streams are mostly 'daylighted,' with (mostly non-native) riparian vegetation lining and surrounding incised stream banks.

The entire San Pablo Creek watershed encompasses 42 square miles. However, San Pablo Dam effectively disjoins the upper, 31 square-mile watershed above the dam from the lower, 11.2 square-mile drainage area below the dam because of limited releases from the dam. Several tributaries enter San Pablo Creek between Kennedy Grove (below the dam) and the I-80 culvert, the three most significant being Castro Creek, Wilkie Creek, and Appian Creek on the north side of the main stem. Although these tributaries all have catchment areas of less than 1 square mile, their discharges could contribute significantly to the total discharge in San Pablo Creek in the absence of streamflow from San Pablo Dam releases. Eight small tributaries enter the creek from the south side.

Sites were chosen along San Pablo and San Leandro Creeks using two criteria:

1) locations where groundwater-surface water exchange is likely to occur and potentially lead to recharge of the Subbasin or to groundwater discharge to the creek at a potential GDE area, and
2) locations that are accessible and suitable for measuring stream discharge and collecting stream water samples.

Criteria (1) considerations point to daylighted reaches with natural bed material, mainly below the Hayward Fault and within the alluvial fans (also known as depositional cones) (**Figure 1**) and above the downstream reaches that are channelized (**Figure 2**). The depth to the water table along the two streams is generally shallow (less than 30 feet below ground surface (bgs); **Figure 3**) and does not rule out the presence of GDEs. Much of the non-channelized portion of San Pablo Creek is identified as potential GDE (**Figure 4**). Criteria (2) considerations point to locations with public access, where sinuosity is relatively low and stream banks are indurated. Also, San Pablo Creek has three perennial tributaries below the dam – Appian Creek, Wilkie Creek, and Castro Creek. These are not gaged or otherwise monitored for streamflow and affect flow in the mainstem by unknown amounts, so two locations are downstream of the lowest tributary, Appian Creek. San Leandro Creek does not have tributaries below Lake Chabot, but inflow from the urban drainage system contributes flow to both creeks. The sampled locations that best met these two criteria are shown in **Figures 5 and 6**.

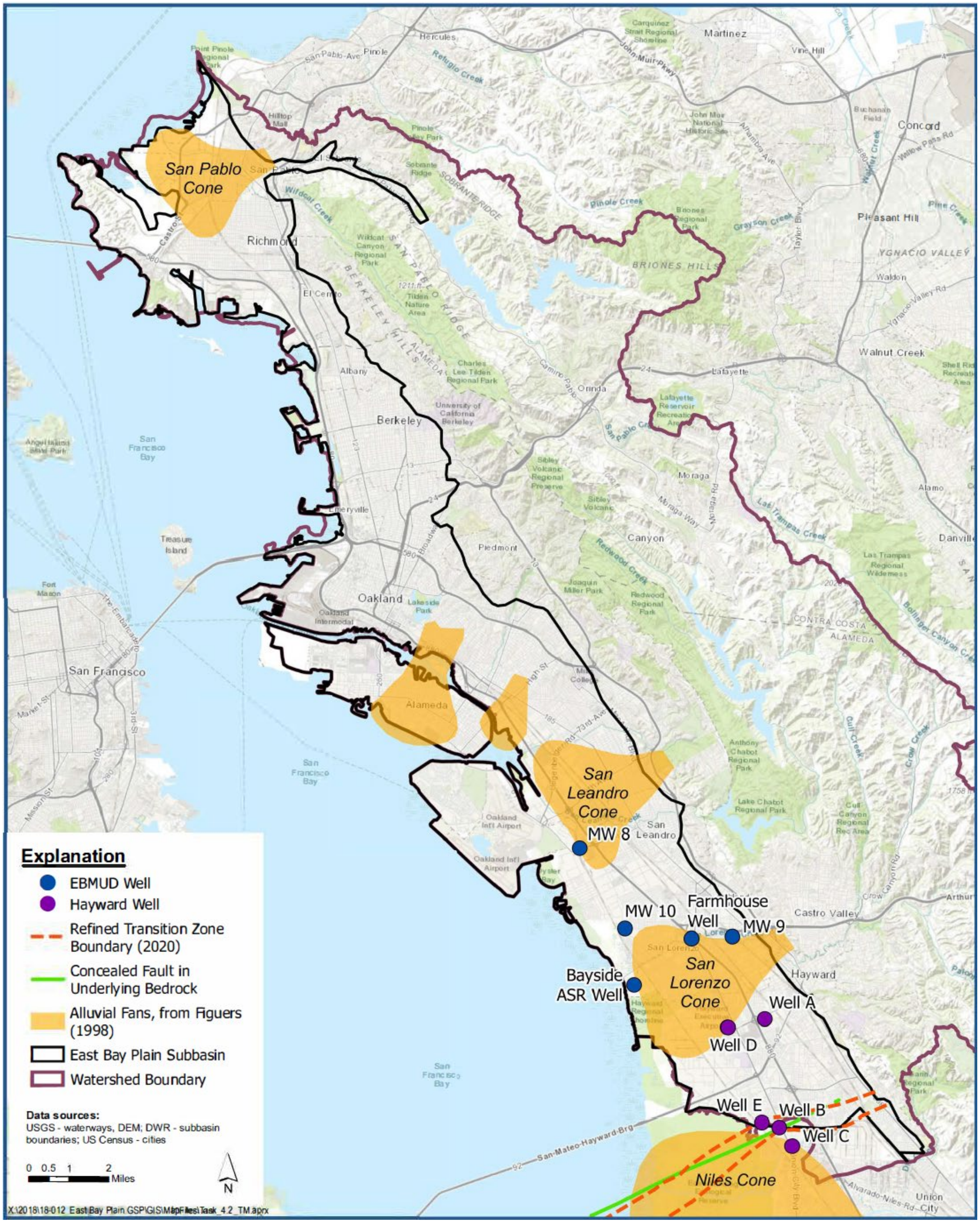



**Figure 1. Depositional Cones of the Major Creeks in the EBP Subbasin**


**Figure 2. Lining of Stream Channels**

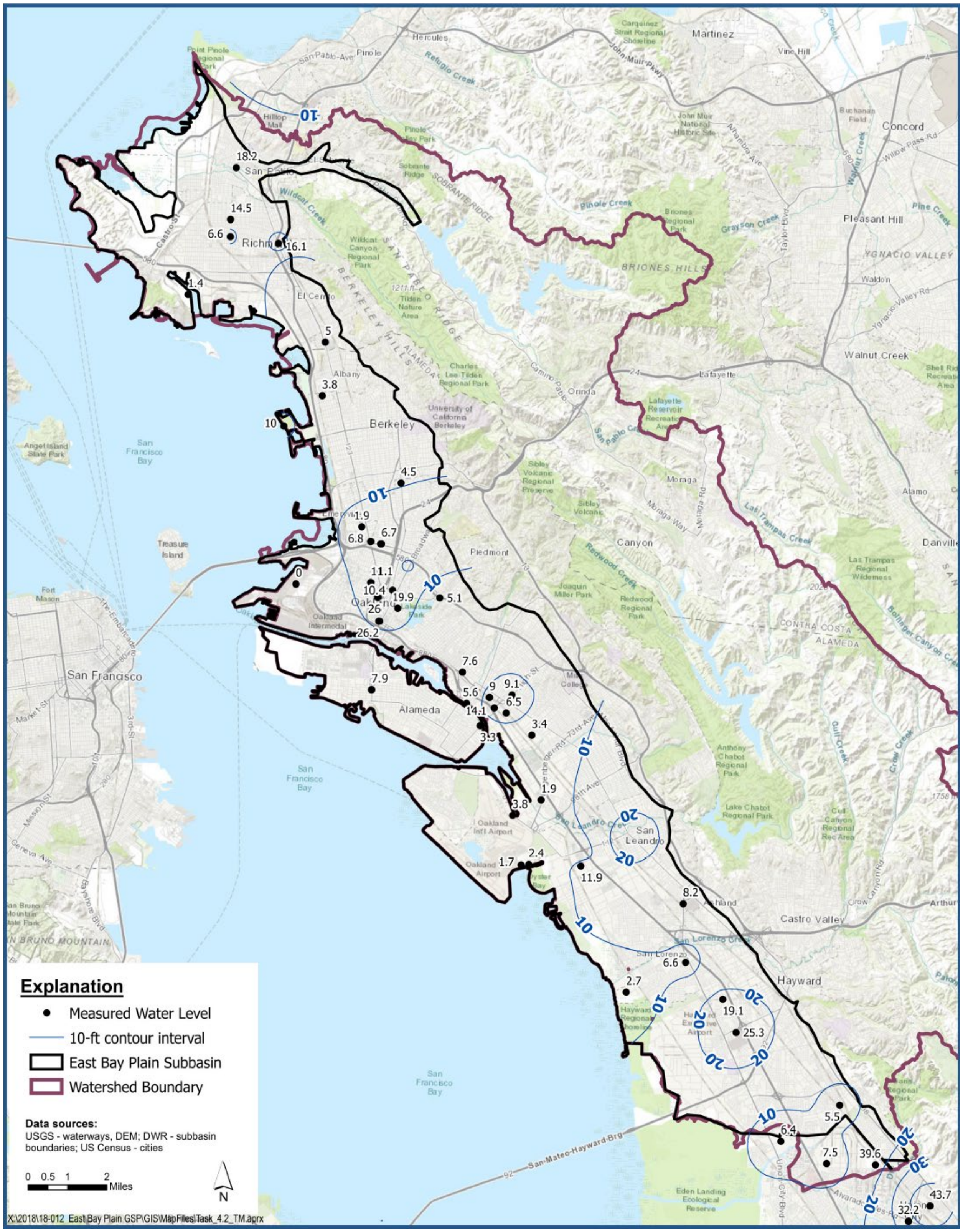



**Figure 3. Depth to Water Table - Fall 2014**

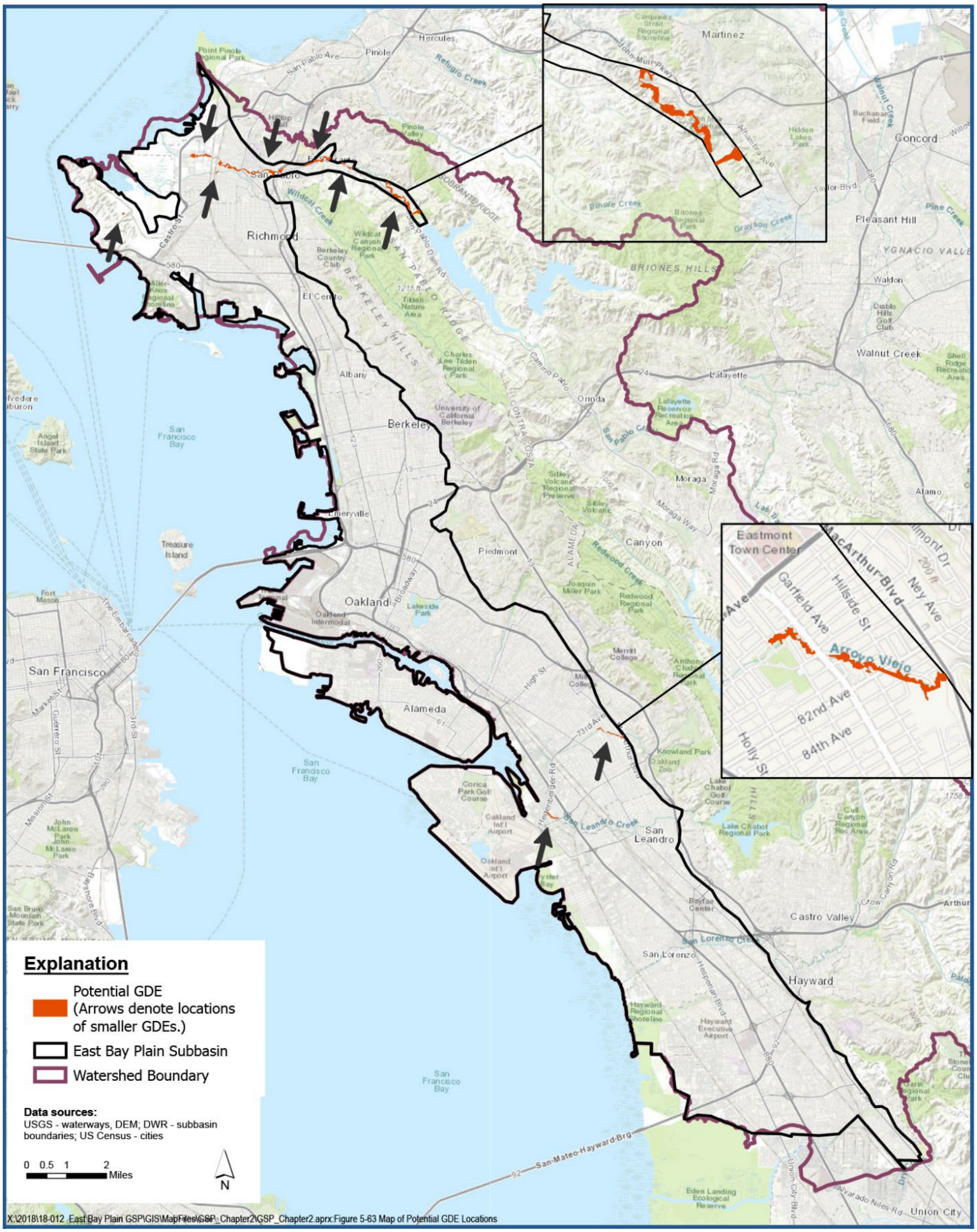



**Figure 4. Potential GDEs**

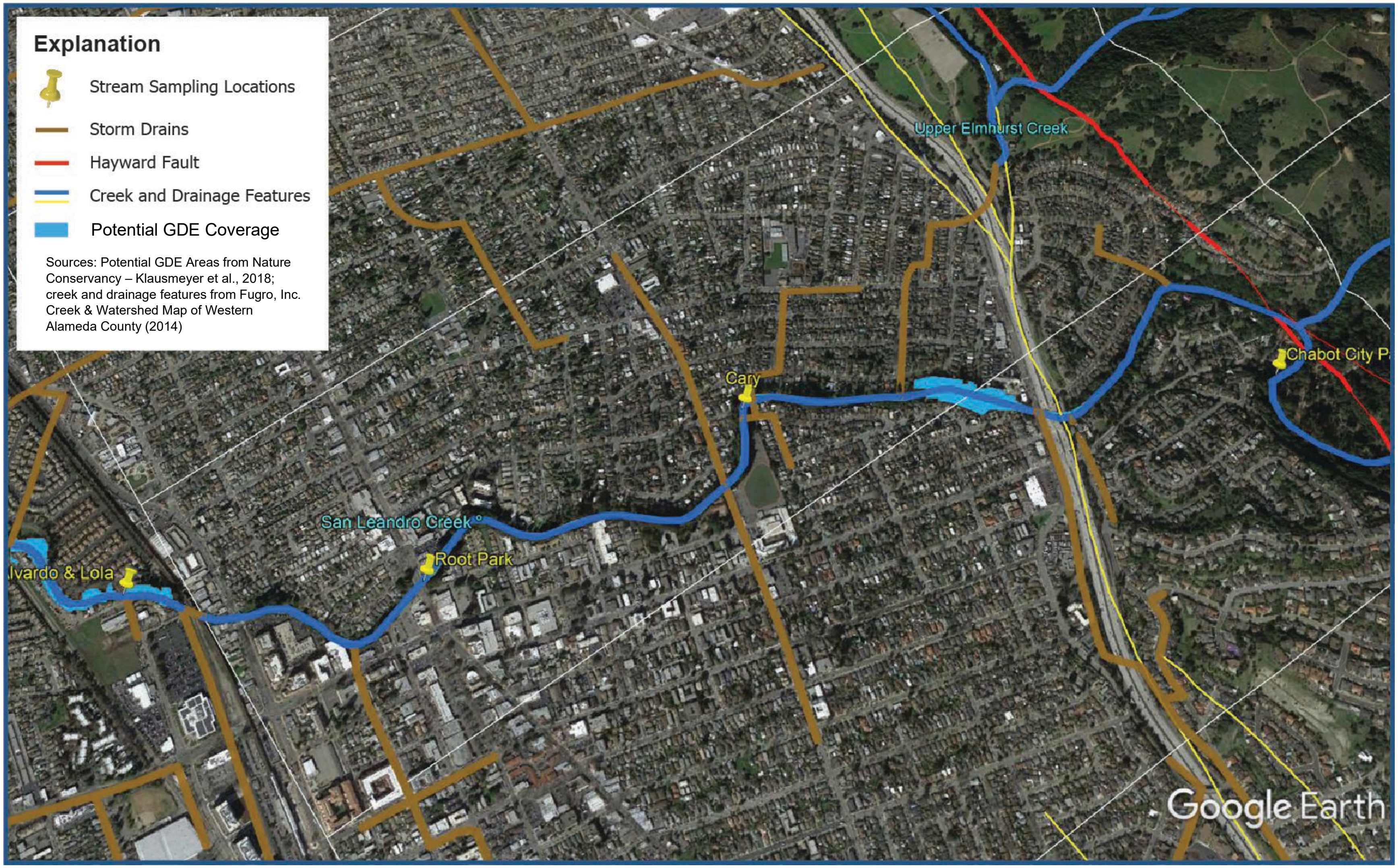



**Figure 5. San Leandro Creek Sampling Locations**

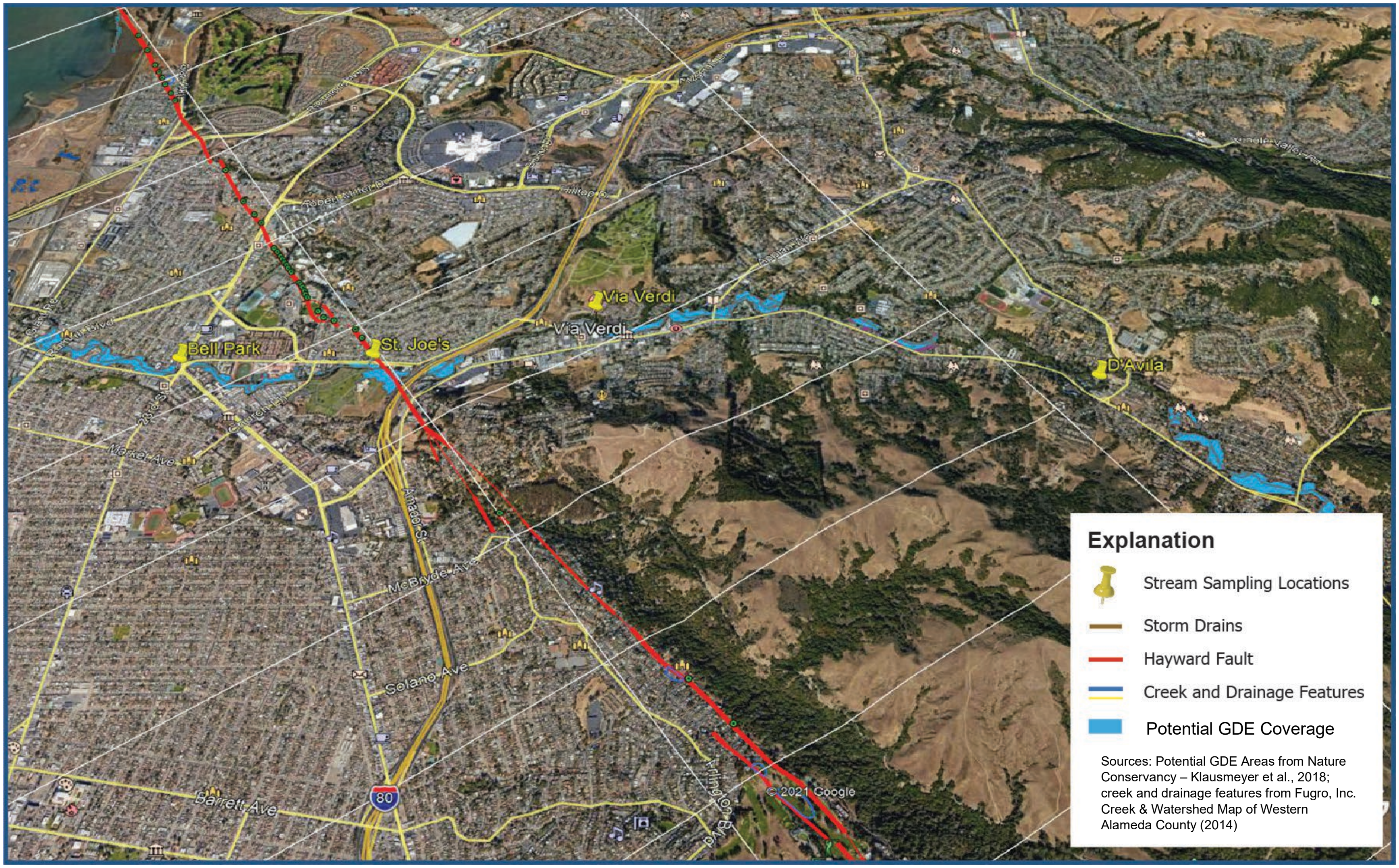



**Figure 6. San Pablo Creek Sampling Locations**

# 3. SAMPLE COLLECTION PROCEDURES AND STREAM DISCHARGE MEASUREMENTS

The following activities were conducted to better understand gaining and losing stream reaches, sources of water to streams, and stream discharge rates:

- Collection of stream samples from San Leandro and San Pablo Creeks
- Collection of precipitation samples
- Synoptic streamflow measurements

In 2021, stream samples were collected and stream discharge was measured at the locations along San Leandro and San Pablo Creeks shown in **Figures 5 and 6**. Streams were sampled four times each, as shown on **Table 1:** once just before and during a stormflow event, once during a second stormflow event, and once during late spring baseflow. A few additional samples at select stream locations were collected on October 31, 2020 and July 23, 2021, and later analyzed. Precipitation samples were also collected for analysis at the locations noted in **Table 2a**. The synoptic streamflow measurements consisted of stream discharge measurements at the four locations along each stream on the same days as when water samples were collected.

## 3.1. Water Sample Collection and Analyses

Samples collected from the streams were analyzed for stable isotopes and radon. Field parameters were measured at stream sampling locations *in situ*. Precipitation samples were analyzed for stable isotopes. The procedures for collecting the samples and analyzing them are described below.

### *3.1.1. Field Water Quality*

A Thermo Orion water quality meter was used to record field water quality parameters: pH, temperature, electrical conductivity, dissolved oxygen (DO), and oxidation-reduction potential. The pH and DO probes were calibrated before each day of use. Probes were submerged in the creek water until a stable reading was noted. An Oakton T-100 turbidity meter was used to record turbidity in nephelometric turbidity units (NTU).

### *3.1.2. Stable Isotopes and Radon*

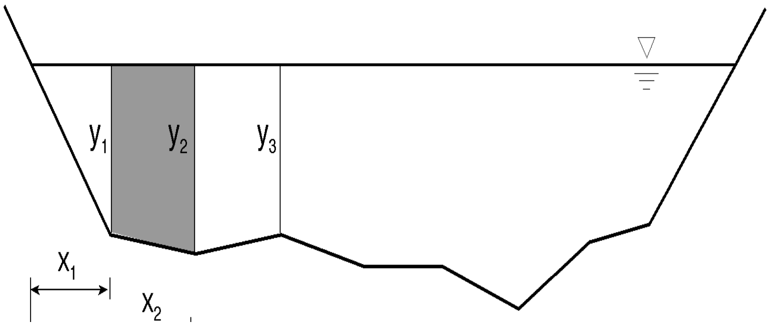
Grab samples were collected from flowing (not stagnant) water, directly into sample bottles. Stable isotope and radon samples were collected from each of the four (San Leandro Creek) or five (San Pablo Creek) locations. Precipitation samples were collected for stable isotope analysis at the locations and on the dates indicated in **Table 2a**. Glass containers were set out in the open prior to rain events and collected at time intervals such that there was no opportunity for evaporation. In three cases, as indicated on the table, rain was collected from puddles during or just following the rain event. For Radon, 250 ml glass bottles were filled with the container submerged a few centimeters below the water surface and capped tightly under water with no headspace to preserve the dissolved gas. Samples were transported on ice in a cooler back to the laboratory. Samples were analyzed for $^{222}Rn$ within two days of collection. Additionally, tritium samples were collected from the upstream and downstream location in each creek during one storm event and during baseflow.

For stable isotopes, a 30 ml glass bottle (clear, French-square type) with Qorpak™ polyseal-lined cap was triple rinsed with sample water, then filled just below the threads on the bottle. No preservatives are required, but the cap is tightly closed. Samples can be stored indefinitely at room temperature. The 2H/1H and 18O/16O ratios were measured on a Picarro L-2130i cavity ring down isotope ratio infrared spectroscopy (IRIS) water isotope analyzer at Lawrence Livermore National Laboratory (LLNL). Hydrogen and oxygen stable isotope values are reported in δ notation: $\delta = (R_{sample}/R_{standard} - 1)$, where $R_{sample}$ and $R_{standard}$ are the $^{2}H/^{1}H$ or $^{18}O/^{16}O$ ratios for the sample and standards, respectively, and values are reported in per mil (parts per thousand, ‰). Water vapor δ values are calibrated to the Vienna Standard Mean Ocean Water (VSMOW) scale by analyzing liquid water standards at the beginning and end of each sample set.

For tritium, a 1-liter glass bottle (e.g., Pyrex with orange polypropylene plug seal cap) is filled with the water sample to just below the threads. No preservatives are required. Samples can be stored indefinitely at room temperature. Tritium samples are analyzed at LLNL via the helium-ingrowth method.

## 3.2. Stream Discharge

Stream discharge was measured using the velocity-area method. Discharge is measured by integrating the area and velocity of each point across the stream; that is, the stream is divided into sections based on where velocity and stage height measurements were taken in the cross-section of the stream. By multiplying the cross-sectional area (width of section x stage height) by the velocity, one can calculate the discharge for that section of the stream (Equation 1). The discharge from each section is added to determine the total discharge of water from the stream (Equation 2). Water velocity was measured using a Global FP111 water flow probe. The probe averages the water velocity over a vertical section while it is moved up and down slowly over the vertical water column.




An example of the velocity-area stream gaging cross-sectional set up, where x is the distance between verticals, and y is the depth of a vertical.

$$q = w\left(\frac{y_1 + y_2}{2}\right)\left(\frac{v_1 + v_2}{2}\right)$$

*Equation 1*

Equation 1 is used to calculate the discharge of each section, where q is the discharge of each section, w is the width of the section, y is the depth of each vertical, and v is the velocity at each vertical.

$$Q = \sum_{i=1}^{n} q_i$$

*Equation 2*

Equation 2 is used to calculate the stream discharge (Q), the sum of all the section discharge values (q).

**Table 1. 2021 Stream Sampling**

| Stream | San Pablo Creek | | | San Leandro Creek | | |
|---|---|---|---|---|---|---|
| Location | Identifier distance downstream | Base Flow Feb 10 &, May 14 | Stormflow Event Feb 12 & Mar 10 | Identifier distance downstream | Base Flow Feb1 & May 14 | Stormflow Event Feb 2, Mar 10 |
| 1 | Kennedy 0 ft | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ | Chabot 0 ft | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ |
| 2 | D'Avila 10,131 ft | $^{2}H$, $^{18}O$, $^{222}Rn$ | $^{2}H$, $^{18}O$, $^{222}Rn$ | Cary 6,512 ft | $^{2}H$, $^{18}O$, $^{222}Rn$ | $^{2}H$, $^{18}O$, $^{222}Rn$ |
| 3 | Via Verdi 22,681 ft | $^{2}H$, $^{18}O$, $^{222}Rn$ | $^{2}H$, $^{18}O$, $^{222}Rn$ | | | |
| 4 | St. Joe's 27,554 ft | $^{2}H$, $^{18}O$, $^{222}Rn$ | $^{2}H$, $^{18}O$, $^{222}Rn$ | Root 10,252 ft | $^{2}H$, $^{18}O$, $^{222}Rn$ | $^{2}H$, $^{18}O$, $^{222}Rn$ |
| 5 | Bell Park 31,903 ft | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ | Alvarado/Lola 13211 ft | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ | $^{2}H$, $^{18}O$, $^{222}Rn$, $^{3}H$ |

Notes: Locations, dates, and distances along San Pablo and San Leandro Creeks, downstream of EBMUD reservoirs, and types of samples collected from each location during baseflow and stormflow events.

| Table 2a. Summary of Precipitation Samples Collected for Isotope Analysis | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Station ID | Location | Sample Type | Date | Time | Isotope Analyses | | | |
| 113617 | Oakland | Rain | 3/5/21 | 23:00 | d18O | d2H | d17O | dExcess |
| 113618 | Oakland | Rain | 3/6/21 | 0:00 | d18O | d2H | d17O | dExcess |
| 113619 | Oakland | Rain | 3/6/21 | 1:00 | d18O | d2H | d17O | dExcess |
| 113620 | Oakland | Rain | 3/9/21 | 19:00 | d18O | d2H | d17O | dExcess |
| 113621 | Oakland | Rain | 3/9/21 | 20:00 | d18O | d2H | d17O | dExcess |
| 113622 | Oakland | Rain | 3/9/21 | 21:00 | d18O | d2H | d17O | dExcess |
| 113623 | Oakland | Rain | 3/9/21 | 22:00 | d18O | d2H | d17O | dExcess |
| 113624 | Oakland | Rain | 3/9/21 | 23:00 | d18O | d2H | d17O | dExcess |
| 113625 | Oakland | Rain | 3/10/21 | 2:00 | d18O | d2H | d17O | dExcess |
| 113626 | Oakland | Rain | 3/10/21 | 8:00 | d18O | d2H | d17O | dExcess |
| 113627 | Oakland | Rain | 3/10/21 | 14:00 | d18O | d2H | d17O | dExcess |
| 113628 | Oakland | Rain | 3/10/21 | 22:00 | d18O | d2H | d17O | dExcess |
| 113629 | Oakland | Rain | 3/11/21 | 8:00 | d18O | d2H | d17O | dExcess |
| 113630 | Oakland | Rain | 3/14/21 | 23:00 | d18O | d2H | d17O | dExcess |
| 113614 | Alv & Lola | Rain | 2/2/21 | 0:00 | d18O | d2H | d17O | dExcess |
| 113615 | Cary | Puddle | 2/2/21 | 0:00 | d18O | d2H | d17O | dExcess |
| 113599 | Chabot Park | Puddle | 2/2/21 | 8:30 | d18O | d2H | d17O | dExcess |
| 113603 | Kennedy | Puddle | 2/13/21 | 0:00 | d18O | d2H | d17O | dExcess |
| 113586 | Chabot Park | Rain | 3/10/21 | 9:45 | d18O | d2H | d17O | dExcess |
| 113585 | Kennedy Grove | Rain | 3/10/21 | 13:40 | d18O | d2H | d17O | dExcess |
| 113604 | Livermore | Composite | 2/2/21 | 0:00 | d18O | d2H | d17O | dExcess |
| 113598 | Livermore | Rain | 2/10/21 | 0:00 | d18O | d2H | d17O | dExcess |
| 113596 | Livermore | Rain | 3/10/21 | 10:50 | d18O | d2H | d17O | dExcess |
| 113593 | Livermore | Rain | 3/10/21 | 16:30 | d18O | d2H | d17O | dExcess |
| 113600 | CSUEB | Rain | 2/2/21 | 0:00 | d18O | d2H | d17O | dExcess |

# 4. RESULTS

## 4.1. Precipitation Data

The precipitation samples were analyzed for the isotopes indicated in **Table 2b** at LLNL. These data were used in the interpretation of stream isotope results as described further in the following sections.

**Table 2b. Summary of Precipitation Isotope Analysis Results**

| Station ID | Location | Sample Type | Date | Time | Isotope Analyses (per mil) | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | d18O | d2H | d17O | dExcess |
| 113617 | Oakland | Rain | 3/5/21 | 23:00 | -6.59 | -34.49 | -3.44 | 18.23 |
| 113618 | Oakland | Rain | 3/6/21 | 0:00 | -8.25 | -51.02 | -4.31 | 14.96 |
| 113619 | Oakland | Rain | 3/6/21 | 1:00 | -8.91 | -58.24 | -4.66 | 13.02 |
| 113620 | Oakland | Rain | 3/9/21 | 19:00 | -9.85 | -59.55 | -5.14 | 19.21 |
| 113621 | Oakland | Rain | 3/9/21 | 20:00 | -9.36 | -56.93 | -4.89 | 17.94 |
| 113622 | Oakland | Rain | 3/9/21 | 21:00 | -9.95 | -60.86 | -5.20 | 18.77 |
| 113623 | Oakland | Rain | 3/9/21 | 22:00 | -8.32 | -47.67 | -4.34 | 18.93 |
| 113624 | Oakland | Rain | 3/9/21 | 23:00 | -10.20 | -59.74 | -5.34 | 21.85 |
| 113625 | Oakland | Rain | 3/10/21 | 2:00 | -9.53 | -55.37 | -4.98 | 20.83 |
| 113626 | Oakland | Rain | 3/10/21 | 8:00 | -8.67 | -47.19 | -4.52 | 22.13 |
| 113627 | Oakland | Rain | 3/10/21 | 14:00 | -9.83 | -54.56 | -5.14 | 24.04 |
| 113628 | Oakland | Rain | 3/10/21 | 22:00 | -8.51 | -52.90 | -4.44 | 15.15 |
| 113629 | Oakland | Rain | 3/11/21 | 8:00 | -8.49 | -54.38 | -4.44 | 13.53 |
| 113630 | Oakland | Rain | 3/14/21 | 23:00 | -4.40 | -12.97 | -2.27 | 22.22 |
| 113614 | Alv & Lola | Rain | 2/2/21 | 0:00 | -3.98 | -15.79 | -2.06 | 16.07 |
| 113615 | Cary | Puddle | 2/2/21 | 0:00 | -4.08 | -15.52 | -2.12 | 17.12 |
| 113599 | Chabot Park | Puddle | 2/2/21 | 8:30 | -4.23 | -17.15 | -2.23 | 16.67 |
| 113603 | Kennedy | Puddle | 2/13/21 | 0:00 | -5.20 | -34.82 | -2.74 | 6.79 |
| 113586 | Chabot Park | Rain | 3/10/21 | 9:45 | -7.82 | -43.69 | -4.17 | 18.86 |
| 113585 | Kennedy Grove | Rain | 3/10/21 | 13:40 | -5.03 | -32.85 | -2.72 | 7.38 |
| 113604 | Livermore | Composite | 2/2/21 | 0:00 | -4.55 | -22.12 | -2.40 | 14.29 |
| 113598 | Livermore | Rain | 2/10/21 | 0:00 | -8.42 | -62.51 | -4.43 | 4.82 |
| 113596 | Livermore | Rain | 3/10/21 | 10:50 | -8.67 | -53.01 | -4.56 | 16.32 |
| 113593 | Livermore | Rain | 3/10/21 | 16:30 | -5.41 | -27.55 | -2.88 | 15.70 |
| 113600 | CSUEB | Rain | 2/2/21 | 0:00 | -4.35 | -18.79 | -2.28 | 16.03 |

## 4.2. Field Water Quality Parameters

Results of field water quality parameters are shown in **Table 3** and in **Figures 7 and 8**. Existing basic water quality data are limited (RWQCB, 2007; The Watershed Project, 2018), and were related to assessing fish habitat. Field parameters, including pH, temperature, and dissolved oxygen, are within expected ranges and unremarkable with respect to temporal or spatial variability. Dissolved oxygen was below Regional Water Quality Control Board (RWQCB) basin plan objectives of 7 mg/L at two locations on San Pablo Creek during baseflow sampling on May 14, 2021. Previous monitoring on San Leandro Creek at Chabot Park and Root Park revealed dissolved oxygen concentrations below 7 mg/L during the dry season (RWQCB, 2007). Turbidity values are low even during event sampling but are perhaps much higher during peak flows. Sediment transport is limited by the upstream dams on both creeks.

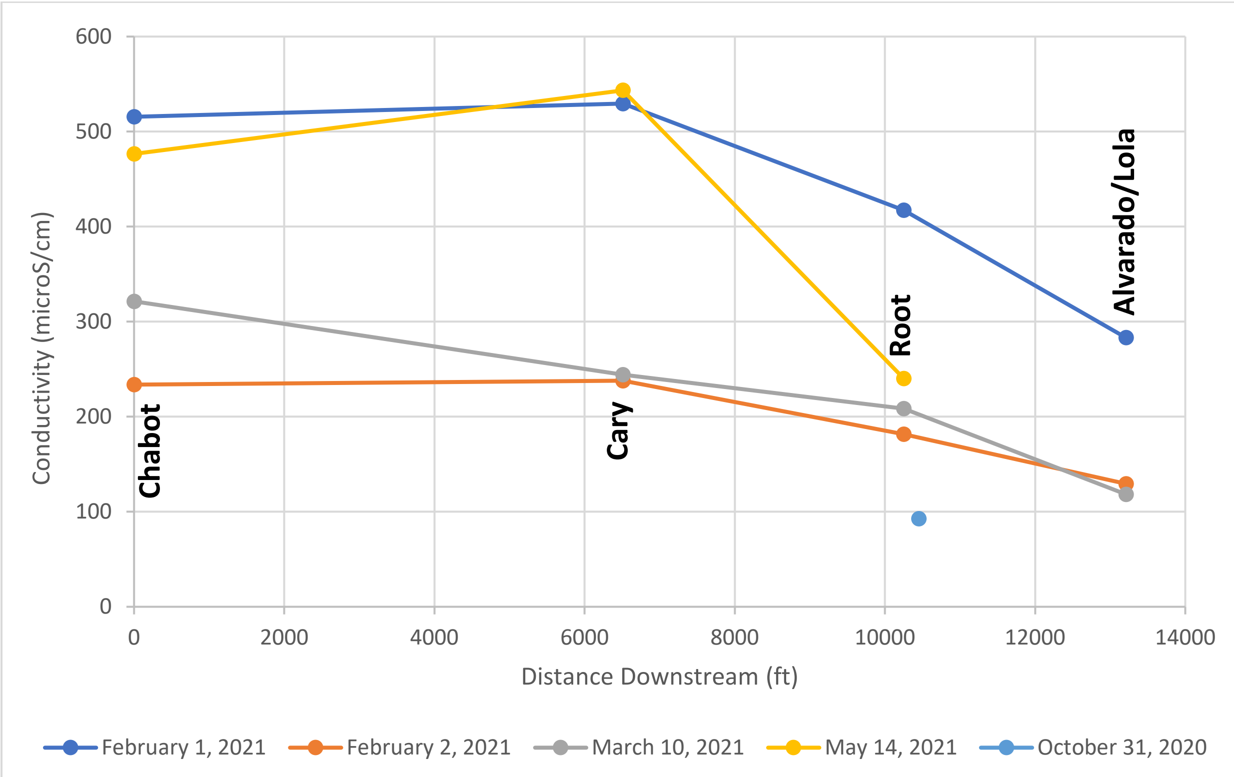
Electrical conductivity results from San Leandro Creek show the expected pattern of significantly lower values during runoff events (February 2, 2021; March 10, 2021) compared to a prior event (February 1, 2021) or during baseflow (May 14, 2021). Interestingly, when water is in isolated pools at downstream locations at low flow (near Root Park, 10,450 ft downstream of Lake Chabot Dam on October 31, 2020, and at Root Park on May 14, 2021), Electrical Conductivity (EC) is quite low, suggesting a lower total dissolved solids (TDS) water source, distinct from the other locations on the same date (discussed further below). Furthermore, on all dates, EC decreases at the two downstream locations, indicating input of lower TDS water over the study reach.

**Table 3. Summary of Stream Field Parameter Data for East Bay Plain Subbasin**

| Station Number | LLNL ID | Sample ID | Date | Time | Location Description | Creek | Latitude | Longitude | Distance from Station Number 1 (feet) | Turbidity (NTU) | EC (µS/cm) | TDS from EC (mg/L) | pH | Temp (deg C) | ORP (mV) | DO (mg/L) | Bottles |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | NA | Root | 10/31/2020 | 9:00 | bridge at Root Park | San Leandro Creek | 37.726874 | -122.157493 | 10,252 | | | | | | | | |
| | 113573 | Ped Br near Root | 10/31/2020 | 9:42 | at outlet of drainage into San Leandro Creek, under a pedestrian bridge near Root Park | San Leandro Creek | 37.725432 | -122.159486 | 10,452 | 0.4 | 92.64 | 59 | 6.67 | 18 | 83.6 | | SI, 3H, Rn |
| 1 | 113574 | Kennedy Grove | 10/31/2020 | 11:30 | below San Pablo Dam in Kennedy Grove | San Pablo Creek | 37.946206 | -122.266427 | 0 | 3.6 | 917.8 | 587 | 7.78 | 11.1 | 23.2 | | SI, 3H, Rn |
| 4 | 113572 | St. Joe's | 10/31/2020 | 12:05 | at Fordam intersection | San Pablo Creek | 37.962933 | -122.332659 | 27,554 | 2.6 | 1199 | 767 | 8.1 | 12.6 | 5.9 | | SI, Rn |
| 4 | 113602 | Alv-Lola | 2/1/2021 | 11:30 | Alvarado St Bridge near Lola | San Leandro Creek | 37.726611 | -122.166098 | 13,211 | | 283.1 | 181 | 7.09 | 10.3 | 57 | 5.73 | SI, Rn |
| 3 | 113601 | Root | 2/1/2021 | 12:05 | bridge at Root Park | San Leandro Creek | 37.726874 | -122.157493 | 10,252 | | 417.3 | 267 | 7.3 | 9.7 | | 7.28 | SI, Rn |
| 2 | 113606 | Cary | 2/1/2021 | 13:10 | pedestrian bridge at the end of Cary St | San Leandro Creek | 37.731102 | -122.148223 | 6,512 | v. low | 529.5 | 339 | 7.83 | 11.3 | 20.2 | 9.38 | SI, Rn |
| 1 | 113605 | Chabot City Park | 2/1/2021 | 14:00 | near bridge at Estudillo in Chabot Park | San Leandro Creek | 37.731948 | -122.131843 | 0 | v. low | 515.6 | 330 | 7.69 | 10.4 | | 8.71 | SI, Rn |
| 4 | 113594 | Alv-Lola | 2/2/2021 | 9:10 | Alvarado St Bridge near Lola | San Leandro Creek | 37.726611 | -122.166098 | 13,211 | 9.2 | 129.4 | 83 | 7.23 | 11.8 | 53.2 | 8.18 | SI, Rn |
| 3 | 113613 | Root | 2/2/2021 | 10:12 | bridge at Root Park | San Leandro Creek | 37.726874 | -122.157493 | 10,252 | 11.7 | 181.5 | 116 | 6.87 | 11.5 | 75 | 8.87 | SI, Rn |
| 2 | 113576 | Cary | 2/2/2021 | 10:51 | pedestrian bridge at the end of Cary St | San Leandro Creek | 37.731102 | -122.148223 | 6,512 | 12.0 | 237.9 | 152 | 7.5 | 10.7 | 39 | 9.22 | SI, Rn, 3H |
| 1 | 113612 | Chabot City Park | 2/2/2021 | 11:53 | near bridge at Estudillo in Chabot Park | San Leandro Creek | 37.731948 | -122.131843 | 0 | 3.0 | 233.6 | 150 | 7.62 | 10.5 | 33.1 | 8.42 | SI, Rn |
| 5 | 113611 | Bell Park | 2/10/2021 | 10:15 | below bridge on San Pablo Ave | San Pablo Creek | 37.96267 | -122.345786 | 31,903 | 4.5 | 1101 | 705 | 7.61 | 10.7 | 32 | 8.22 | SI, Rn |
| 4 | 113610 | St. Joe's | 2/10/2021 | 10:45 | at Fordam intersection | San Pablo Creek | 37.962933 | -122.332659 | 27,554 | 2.9 | 1197 | 766 | 7.88 | 10.1 | 19.5 | 9.21 | SI, Rn |
| 3 | 113578 | Via Verdi | 2/10/2021 | 10:50 | at E end of detour | San Pablo Creek | 37.966526 | -122.318017 | 22,681 | 7.1 | 1277 | 817 | 7.8 | 9.9 | 23.7 | 7.99 | SI, Rn |

| Table 3. Summary of Stream Field Parameter Data for East Bay Plain Subbasin | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station Number | LLNL ID | Sample ID | Date | Time | Location Description | Creek | Latitude | Longitude | Distance from Station Number 1 (feet) | Turbidity (NTU) | EC (µS/cm) | TDS from EC (mg/L) | pH | Temp (deg C) | ORP (mV) | DO (mg/L) | Bottles |
| 2 | 113608 | D'Avila | 2/10/2021 | 11:30 | D'Avila at LaHonda | San Pablo Creek | 37.961237 | -122.283327 | 10,131 | 4.6 | 1285 | 822 | 7.62 | 9.9 | 32.8 | 8.27 | SI, Rn, 3H |
| 1 | 113609 | Kennedy Grove | 2/10/2021 | 12:40 | below San Pablo Dam in Kennedy Grove | San Pablo Creek | 37.946206 | -122.266427 | 0 | 7.2 | 1640 | 1,050 | 7.42 | 9.6 | 43.3 | 7.29 | SI, Rn |
| 1 | 113607 | Kennedy Grove | 2/12/2021 | 8:00 | below San Pablo Dam in Kennedy Grove | San Pablo Creek | 37.946206 | -122.266427 | 0 | 4.6 | 1411 | 903 | 7.19 | 9.1 | 38.9 | 8.25 | SI, Rn |
| 2 | 113616 | D'Avila | 2/12/2021 | 9:00 | D'Avila at LaHonda | San Pablo Creek | 37.961237 | -122.283327 | 10,131 | 9.6 | 787.9 | 504 | 7.49 | 10 | 23.9 | 8.13 | SI, Rn, 3H |
| 3 | 113579 | Via Verdi | 2/12/2021 | 9:30 | at E end of detour | San Pablo Creek | 37.966526 | -122.318017 | 22,681 | 8.9 | 912.3 | 584 | 7.63 | 10 | 17 | 8.31 | SI, Rn |
| 4 | 113595 | St. Joe's | 2/12/2021 | 10:00 | at Fordam intersection | San Pablo Creek | 37.962933 | -122.332659 | 27,554 | 9.1 | 749 | 479 | 7.57 | 10.1 | 19.9 | 8.96 | SI, Rn |
| 5 | 113597 | Bell Park | 2/12/2021 | 10:30 | below bridge on San Pablo Ave | San Pablo Creek | 37.96267 | -122.345786 | 31,903 | 9.9 | 718 | 460 | 7.33 | 10.2 | 31.9 | 8.48 | SI, Rn |
| 4 | 113588 | Alv-Lola | 3/10/2021 | 8:00 | Alvarado St Bridge near Lola | San Leandro Creek | 37.726611 | -122.166098 | 13,211 | 15.4 | 118.3 | 76 | 7.36 | 9.7 | 43.1 | 8.92 | SI, Rn, 3H |
| 3 | 113589 | Root | 3/10/2021 | 8:45 | bridge at Root Park | San Leandro Creek | 37.726874 | -122.157493 | 10,252 | 8.9 | 208.6 | 134 | 7.52 | 9.1 | 36.7 | 9.02 | SI, Rn |
| 2 | 113577 | Cary | 3/10/2021 | 9:00 | pedestrian bridge at the end of Cary St | San Leandro Creek | 37.731102 | -122.148223 | 6,512 | 9.2 | 244.1 | 156 | 8.08 | 9.3 | 5 | 9.62 | SI, Rn |
| 1 | 113587 | Chabot City Park | 3/10/2021 | 9:45 | near bridge at Estudillo in Chabot Park | San Leandro Creek | 37.731948 | -122.131843 | 0 | 4.6 | 321.4 | 206 | 7.58 | 8.9 | 33 | 9.52 | SI, Rn, 3H |
| 5 | 113582 | Bell Park | 3/10/2021 | 11:00 | below bridge on San Pablo Ave | San Pablo Creek | 37.96267 | -122.345786 | 31,903 | 19.5 | 536.4 | 343 | 6.98 | 9 | 64.2 | 9.92 | SI, Rn, 3H |
| 4 | 113592 | St. Joe's | 3/10/2021 | 11:30 | at Fordam intersection | San Pablo Creek | 37.962933 | -122.332659 | 27,554 | 19.9 | 507.4 | 325 | 6.77 | 9.6 | 73.5 | 10.04 | SI, Rn |
| 2 | NA | D'Avila | 3/10/2021 | 12:00 | D'Avila at LaHonda | San Pablo Creek | 37.961237 | -122.283327 | 10,131 | | | | | | | | |
| 3 | 113580 | Via Verdi | 3/10/2021 | 12:30 | at E end of detour | San Pablo Creek | 37.966526 | -122.318017 | 22,681 | 10.8 | 639.2 | 409 | bad | 9.4 | bad | 9.66 | SI, Rn (lg bottle) |
| 1 | 113591 | Kennedy Grove | 3/10/2021 | 13:40 | below San Pablo Dam in Kennedy Grove | San Pablo Creek | 37.946206 | -122.266427 | 0 | 3.3 | 1142 | 731 | bad | 8.8 | bad | 9.62 | SI, Rn, 3H |
| 4 | | Alv-Lola | 5/14/2021 | 8:00 | Alvarado St Bridge near Lola | San Leandro Creek | 37.726611 | -122.166098 | | NA | | | NA | NA | NA | NA | NA |
| 3 | | Root | 5/14/2021 | 8:30 | bridge at Root Park | San Leandro Creek | 37.726874 | -122.157493 | 10,252 | 4.2 | 240.1 | 154 | 6.04 | 15 | 92.8 | 8.16 | SI, Rn, 3H |
| 2 | | Cary | 5/14/2021 | 9:00 | pedestrian bridge at the end of Cary St | San Leandro Creek | 37.731102 | -122.148223 | 6,512 | 6.5 | 543.4 | 348 | 6.23 | 14.1 | 82.5 | 7.26 | |
| 1 | | Chabot City Park | 5/14/2021 | 9:30 | near bridge at Estudillo in Chabot Park | San Leandro Creek | 37.731948 | -122.131843 | 0 | 0.7 | 476.4 | 305 | 6.53 | 13.4 | 65.5 | 7.7 | SI, Rn, 3H |

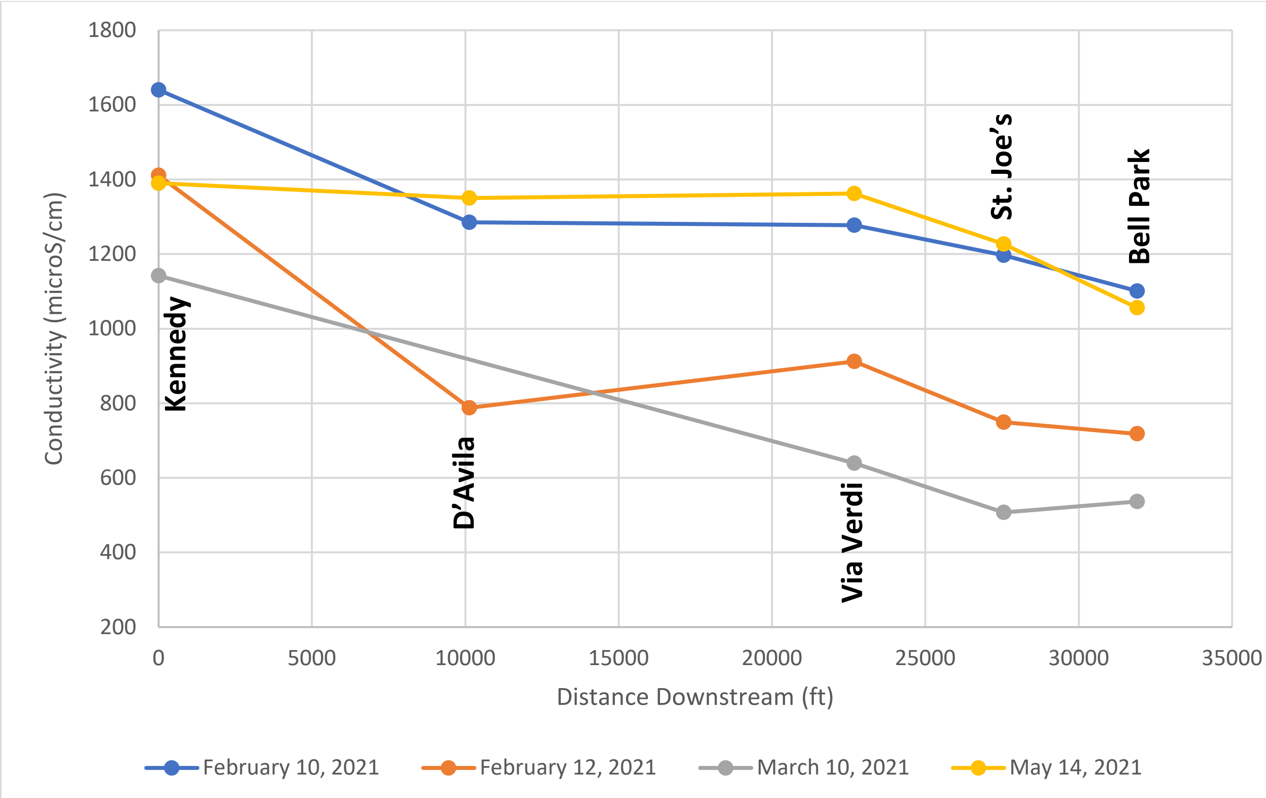
| Table 3. Summary of Stream Field Parameter Data for East Bay Plain Subbasin | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Station Number | LLNL ID | Sample ID | Date | Time | Location Description | Creek | Latitude | Longitude | Distance from Station Number 1 (feet) | Turbidity (NTU) | EC (µS/cm) | TDS from EC (mg/L) | pH | Temp (deg C) | ORP (mV) | DO (mg/L) | Bottles |
| 1 | | Kennedy Grove | 5/14/2021 | 10:50 | below San Pablo Dam in Kennedy Grove | San Pablo Creek | 37.946206 | -122.266427 | 0 | 7.4 | 1390 | 890 | 6.7 | 12.4 | 56.2 | 6.89 | SI, Rn, 3H |
| 2 | | D'Avila | 5/14/2021 | 11:45 | D'Avila at LaHonda | San Pablo Creek | 37.961237 | -122.283327 | 10,131 | 2.2 | 1350 | 864 | 6.89 | 13.7 | 46.6 | 5.7 | SI, Rn |
| 3 | | Via Verdi | 5/14/2021 | 13:15 | at E end of detour | San Pablo Creek | 37.966526 | -122.318017 | 22,681 | 3.0 | 1362 | 872 | 6.73 | 14.2 | 53.1 | 8.43 | SI, Rn |
| 4 | | St. Joe's | 5/14/2021 | 13:50 | at Fordam intersection | San Pablo Creek | 37.962933 | -122.332659 | 27,554 | 2.5 | 1227 | 785 | 7.25 | 12.7 | 27.3 | 7.85 | SI, Rn |
| 5 | | Bell Park | 5/14/2021 | 14:00 | below bridge on San Pablo Ave | San Pablo Creek | 37.96267 | -122.345786 | 31,903 | 18.8 | 1056 | 676 | 6.47 | 13.5 | 69.3 | 8.05 | SI, Rn |
| 4 | NA | Alv-Lola | 10/31/2021 | 10:20 | Alvarado St Bridge near Lola | San Leandro Creek | 37.726611 | -122.166098 | 13,211 | NA | | | NA | NA | NA | NA | NA |




Note: Sampled prior to a runoff event (Feb 1), during runoff events (Feb 2, March 10), and during baseflow (May 14).

## Figure 7. Conductivity in San Leandro Creek

EC values on San Pablo Creek are generally more than twice as high as those observed on San Leandro Creek. Again, observed values are lower during the two runoff events (February 12, 2021 and March 10, 2021) than prior to the runoff event (February 10, 2021) or at baseflow (May 14, 2021), as expected. Values reach levels below the secondary maximum contaminant level (MCL) for TDS (500 mg/L) only during the runoff events (a low value of 325 mg/L is equivalent to 503 µS/cm on March 10 at the St. Joseph's location). And, in a pattern similar to that observed in San Leandro Creek, EC is consistently lowest at the two most downstream locations, indicating input of lower TDS water over the lower reach.

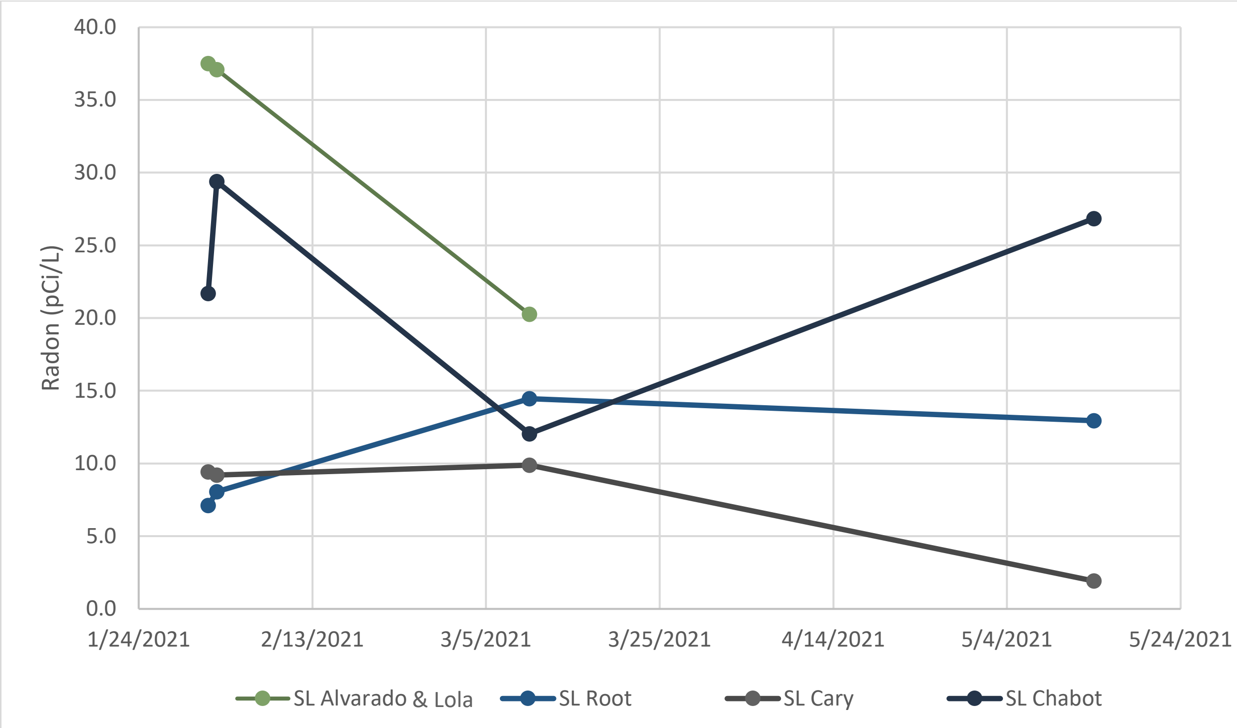



Note: Sampled prior to a runoff event (Feb 10), during runoff events (Feb 12 and Mar 10), and during baseflow (May 14).

## Figure 8. Conductivity in San Pablo Creek

The high TDS levels in San Pablo Creek are consistently above thresholds set by the U.S. Environmental Protection Agency (USEPA) for support of aquatic life (<500 µS/cm). The sources of dissolved ions to San Pablo Creek are likely geologic and not anthropogenic, although the urbanized watershed enhances the rate of runoff and contributions of particulate matter. In addition to the results from San Pablo Creek, the Wilkie Creek and Castro Creek tributaries to San Pablo Creek were visited on July 23, 2021, and EC was measured at 1720 µS/cm and 1419 µS/cm, respectively, even higher than values in the main stem. Similarly high EC values have been recorded in small creeks in the Berkeley hills (Temescal Creek watershed and Caldecott inlet; Lovelace, 2018), and in San Lorenzo Creek at very low flow, but not in upper Wildcat Creek, Codornices Creek, San Leandro Creek, or Redwood Creek in the upper San Leandro watershed (Beitz, 2014). Since the high values are observed consistently along the course of San Pablo Creek and in some tributaries, the dissolved solids are likely to come from a natural, sedimentary source, possibly the (Tertiary) Plio-Miocene sedimentary sequences that are pervasive in the San Pablo watershed. These formations are not as prevalent to the south, where Cretaceous Great Valley sequence formations dominate the landscape. A high proportion of groundwater inflow to San Pablo Creek, discussed further below, is also a likely contributing factor.

## 4.3. Dissolved Radon



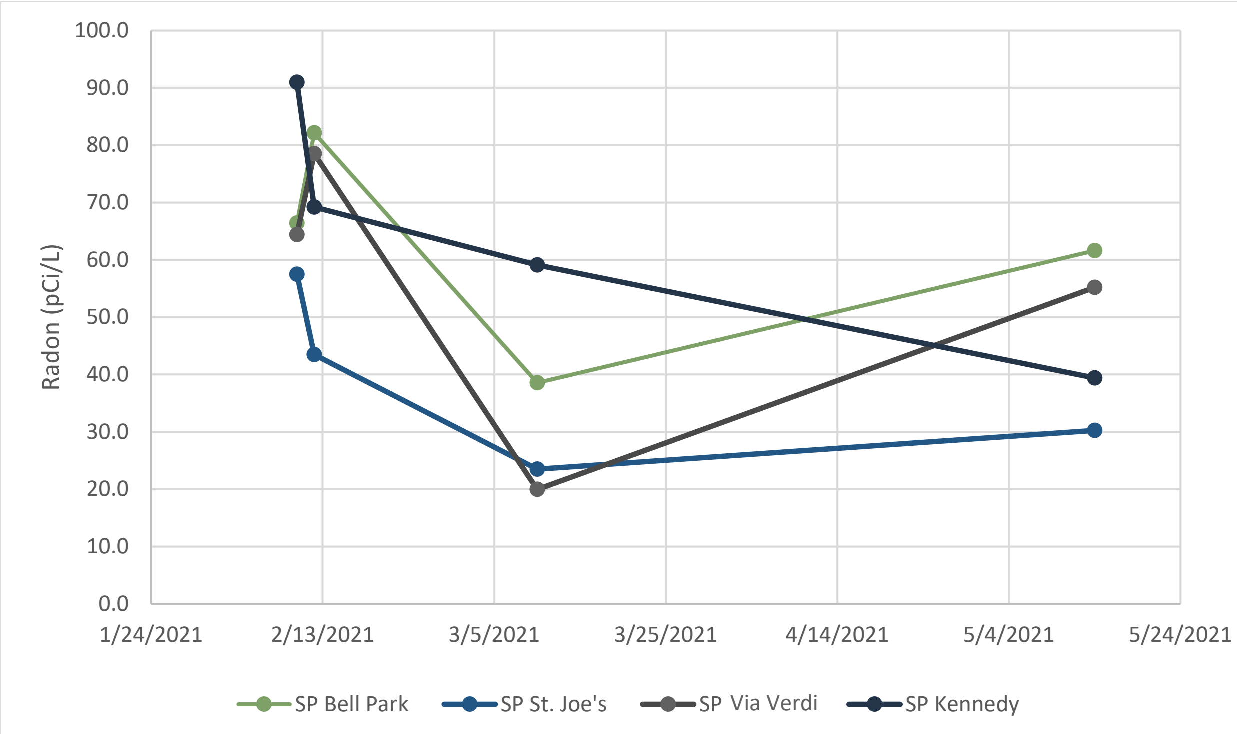

Note: Sampled prior to a runoff event (Feb 10), during runoff events (Feb 12 and Mar 10), and during baseflow (May 14).

### Figure 9. Dissolved Radon in San Leandro Creek

Results of dissolved radon ($^{222}Rn$) analysis are shown in **Table 4** and **Figures 9 and 10**. Some values observed in San Leandro Creek are near or below the method detection limit of approximately 10 pCi/L. Only the downstream (Alvarado & Lola) and upstream (below Lake Chabot) locations show evidence for a small component of groundwater inflow; overall, losing conditions are prevalent along San Leandro Creek based on radon results.

Compared to San Leandro Creek, observed values on San Pablo Creek are generally two times higher, with relatively low values at three locations during the March 10, 2021 runoff event, suggesting a significant component of overland flow during the event, or possibly more turbulent stream conditions leading to loss of radon. In February, all locations show elevated $^{222}Rn$, indicating groundwater inflow, with small decreases during the event (on February 12) at two locations (Kennedy Grove and St. Joseph's Cemetery) and small increases at two locations (Via Verdi and Bell Park). The relatively high radon concentrations indicate that gaining conditions are prevalent along San Pablo Creek.

| Table 4. Summary of Stream Radon Data for East Bay Plain Subbasin | | | |
|---|---|---|---|
| **Sample ID** | **Date** | **Location Description** | **Corrected Mean (pCi/L)** |
| Kennedy | 10/31/2020 | below San Pablo Dam in Kennedy Grove | 33.3 |
| Pedestrian Bridge near Root Park | 10/31/2020 | at outlet of drainage into San Leandro Creek, under a pedestrian bridge near Root Park | 7.3 |
| St. Joe's | 10/31/2020 | San Pablo Creek at Fordam intersection | 42.5 |
| Alv-Lola | 2/1/2021 | Alvarado St Bridge near Lola | 37.5 |
| Cary | 2/1/2021 | pedestrian bridge at the end of Cary St | 9.4 |
| Chabot City Park | 2/1/2021 | near bridge at Estudillo in Chabot Park | 21.7 |
| Root | 2/1/2021 | bridge at Root Park | 7.1 |
| Alv-Lola | 2/2/2021 | Alvarado St Bridge near Lola | 37.1 |
| Cary | 2/2/2021 | pedestrian bridge at the end of Cary St | 9.2 |
| Chabot City Park | 2/2/2021 | near bridge at Estudillo in Chabot Park | 29.4 |
| Root | 2/2/2021 | bridge at Root Park | 8.1 |
| Bell Park | 2/10/2021 | below bridge on San Pablo Ave | 66.4 |
| D'Avila | 2/10/2021 | D'Avila at LaHonda | 34.9 |
| Kennedy | 2/10/2021 | below San Pablo Dam in Kennedy Grove | 91.0 |
| St. Joe's | 2/10/2021 | at Fordam intersection | 57.5 |
| Via Verdi | 2/10/2021 | at E end of detour | 64.4 |
| Bell Park | 2/12/2021 | below bridge on San Pablo Ave | 82.1 |
| D'Avila | 2/12/2021 | D'Avila at LaHonda | 44.8 |
| Kennedy | 2/12/2021 | below San Pablo Dam in Kennedy Grove | 69.2 |
| St. Joe's | 2/12/2021 | at Fordam intersection | 43.5 |
| Via Verdi | 2/12/2021 | at E end of detour | 78.5 |
| Alv-Lola | 3/10/2021 | Alvarado St Bridge near Lola | 20.3 |
| Bell Park | 3/10/2021 | below bridge on San Pablo Ave | 38.6 |
| Cary | 3/10/2021 | pedestrian bridge at the end of Cary St | 9.9 |
| Chabot City Park | 3/10/2021 | near bridge at Estudillo in Chabot Park | 12.0 |
| Kennedy | 3/10/2021 | below San Pablo Dam in Kennedy Grove | 59.1 |
| Root | 3/10/2021 | bridge at Root Park | 14.5 |
| St. Joe's | 3/10/2021 | at Fordam intersection | 23.5 |
| Via Verdi | 3/10/2021 | at E end of detour | 20.0 |
| Bell Park | 5/14/2021 | below bridge on San Pablo Ave | 61.6 |
| Cary | 5/14/2021 | pedestrian bridge at the end of Cary St | 1.9 |
| Chabot City Park | 5/14/2021 | near bridge at Estudillo in Chabot Park | 26.8 |
| D'Avila | 5/14/2021 | D'Avila at LaHonda | 32.3 |
| Kennedy | 5/14/2021 | below San Pablo Dam in Kennedy Grove | 39.4 |
| Root | 5/14/2021 | bridge at Root Park | 12.9 |
| St. Joe's | 5/14/2021 | at Fordam intersection | 30.3 |
| Via Verdi | 5/14/2021 | at E end of detour | 55.2 |




Note: Sampled Prior to a Runoff Event (February 10), During Runoff Events (February 12 and March 10), and During Baseflow (May 14).

**Figure 10. Dissolved Radon in San Pablo Creek**

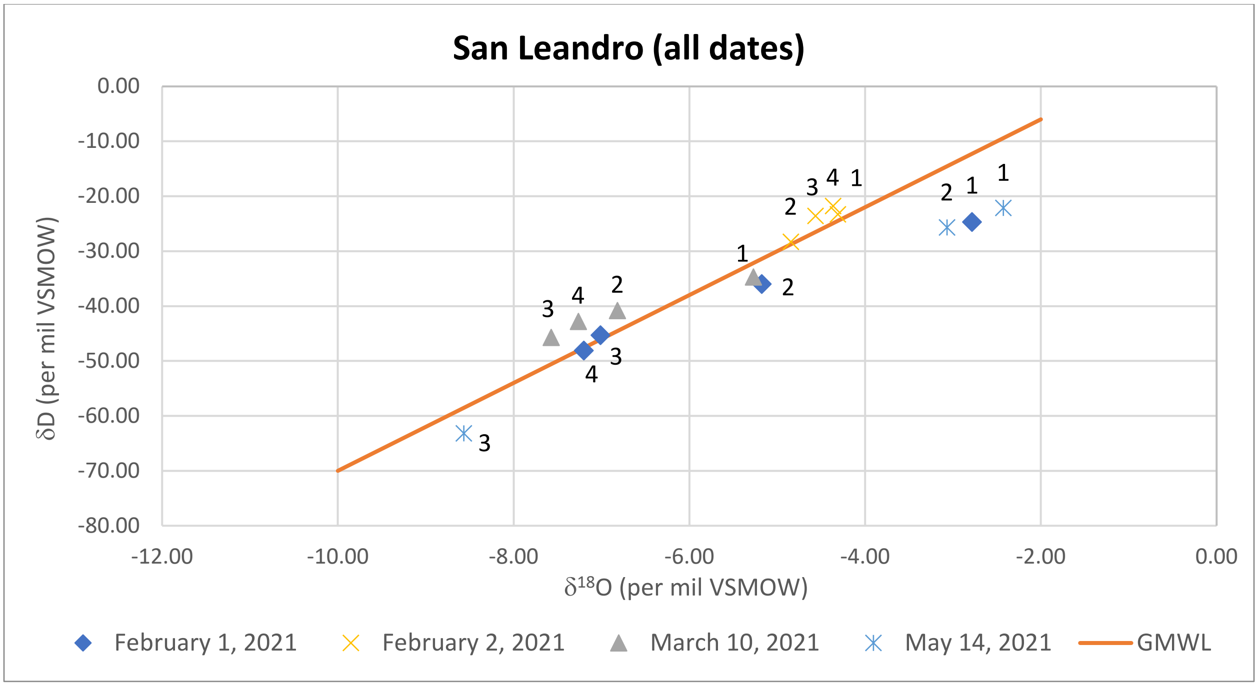
## 4.4. Stable Isotopes and Tritium

Stable isotopes are interpreted using knowledge of the isotopic signatures of 'end members', the different sources of water that combine to produce flow in the streams. The end member signatures are in turn related to where (mainly distance from the ocean and elevation) the precipitation formed and whether there was significant evaporation after condensing as precipitation. In addition, while individual rainstorms tend to vary considerably in their stable isotope signatures due to differing vapor sources and transport pathways, groundwater tends to have a homogenous isotopic signature due to mixing and slow movement through the vadose zone and aquifer. In addition to locally derived runoff and groundwater inflow, imported water from the Mokelumne River watershed is a possible source of water that may reach streams via the urban storm drain system or as groundwater, either from excess irrigation return flow or leaky water/wastewater conveyance lines. This imported water has a distinctly lighter (more negative) isotopic signature than locally derived water. While stable isotope results from wells in the East Bay (GSP Appendix 2.A.a) do not show much evidence for the presence of imported water in groundwater, few of the wells sampled are from the shallow aquifer (where an imported water component is most likely to occur) that may be connected to streamflow. A recent study by Grande et al. (2020) revealed that excess irrigation of imported water at Tilden Golf Course in

Berkeley (in the bedrock watershed upstream of EBP Subbasin) comprised up to 25% of the total flow in Wildcat Creek downstream of the golf course.

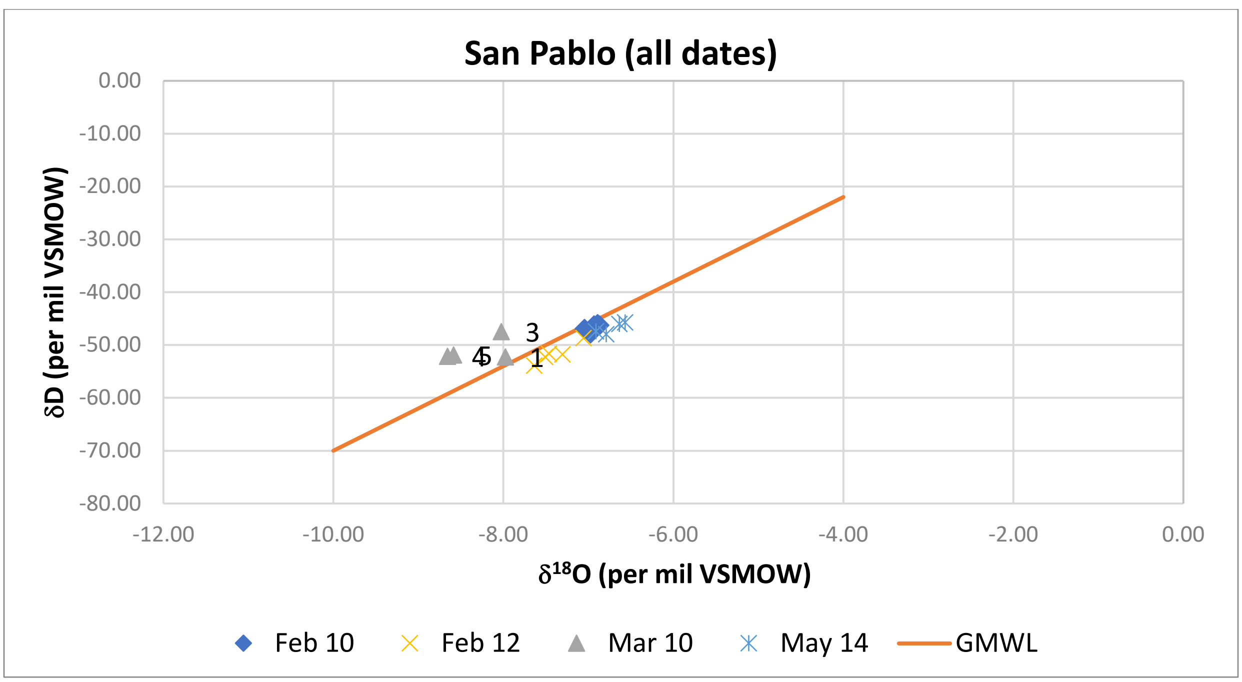
Plotting the results from San Leandro Creek and San Pablo Creek along with the Global Meteoric Water Line (GMWL; **Figures 11 and 12**) highlights the larger range observed in San Leandro Creek compared to San Pablo Creek, and the locations on San Leandro Creek that show an evaporated signature, falling below the GMWL. On February 1 (prior to the February 1-2 event) and during baseflow on May 14, the upstream locations on San Leandro Creek (1 and 2, below Lake Chabot and Cary) show the signature of water left behind after significant evaporation in Lake Chabot. The February 2 samples all closely reflect the signature of the precipitation event on February 1-2. The lighter isotopic composition of the sample from Root Park (3) suggests a contribution of imported Mokelumne River water, which is consistent with the low conductivity of the same sample (**Figure 7**). Root Park and Alvarado & Lola appear to reflect the East Bay Plain groundwater signature, as they are similar to the tightly clustered baseflow samples collected from San Pablo Creek.

Release records from Lake Chabot and from San Pablo Reservoir (ebmud.com/water/about-your-water/water-supply/water-supply-reports/reservoir-releases/) indicate regular releases from Lake Chabot of between 0.2 cubic feet per second (cfs) and 1.0 cfs, while releases from San Pablo Reservoir are very limited and did not take place over the study period. Because of the evaporated signature, stable isotopes provide a tracer of water from Lake Chabot, appearing at the two upstream locations during periods of low flow in San Leandro Creek (February 1, May 14, and to a lesser degree on March 10). This evaporated water does not reach the Root Park location or below. (No samples were collected from the reservoirs.)




Note: Plotted Along with the Global Meteoric Water Line (GMWL), Sampled at Four Downstream Locations: 1=Below Lake Chabot, 2=Cary St, 3=Root Park, 4=Alvarado & Lola

## Figure 11. Stable Isotope Results from San Leandro

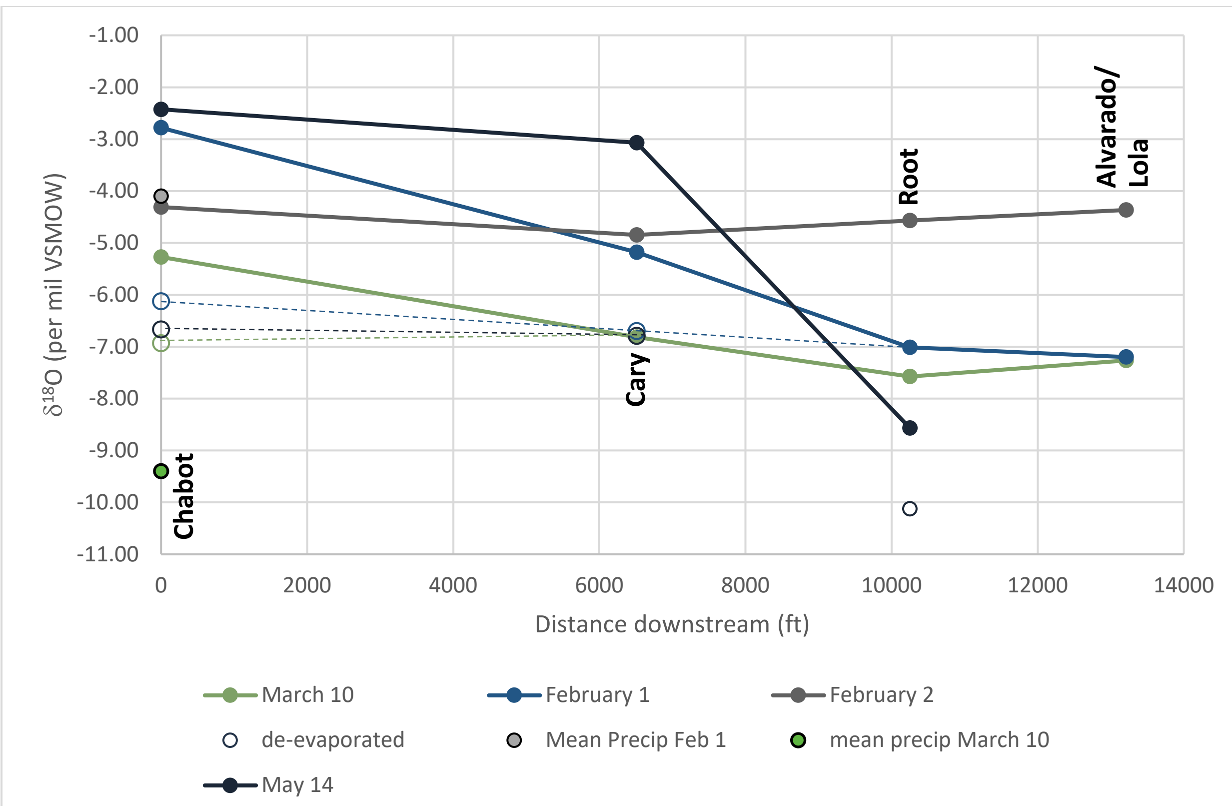



Note: Plotted Along with the Global Meteoric Water Line (GMWL), Sampled at Four or Five Downstream Locations: 1=Kennedy Grove, 2=D'Avila, 3=Via Verdi, 4=St. Joe's, 5=Bell Park; (stable isotopes were not sampled at location 2 on March 10)

## Figure 12. Stable Isotope Results from San Pablo

Results for the different sampling locations along San Pablo Creek cluster tightly for each date, and in a tighter overall range than the San Leandro samples. The February 12 and March 10 precipitation events were similar in composition to the mean precipitation or groundwater component reflected by the February 10 pre-event and May 14 baseflow samples. Stable isotopes of San Pablo Creek are not affected by releases from San Pablo reservoir with an evaporated signature. The lower variability observed in San Pablo Creek samples likely reflects the predominance of groundwater inflow, which has lower variability because of spatial and temporal integration of the source water signal during percolation and groundwater transport.

On **Figure 13**, which shows the pattern in the oxygen isotope ratios with distance downstream on San Leandro Creek, open symbols show the result of a calculation that reverses the evaporation trend (using a slope of 5 toward the GMWL; Gibson et al., 2008), revealing the original oxygen isotope ratio prior to evaporation.




Note: Open Symbols Represent a Calculation of the Original Isotopic Signature Prior to Evaporation.

**Figure 13. $\delta^{18}O$ Results for San Leandro Creek and Individual Precipitation Samples for the February 1-2 and March 10 Events**

Looking in more detail at results from San Leandro Creek (**Figure 13**), one sees that during the February 1-2 runoff event, the stable isotope pattern shifts drastically during the event, becoming uniformly heavy ($\delta$18O ≈ -4.5‰) and closely resembling the value of a February 2 precipitation sample from the Lake Chabot Park location (gray symbols). This result indicates that San Leandro Creek flow is dominated by recent runoff of local precipitation, and that groundwater inflow is minimal during the runoff event. The March 10 event had isotopically lighter precipitation (that varied spatially and temporally during the event – **Figures 15 and 16**), and flow in the stream becomes isotopically lighter than February 1 values, but not as light as the volume-weighted mean for precipitation in Oakland over the event. This finding indicates that event water is observed in the stream, but it is mixed with pre-event water that dampens short-term variability.

On all dates except February 2, stream water becomes isotopically lighter at downstream locations, signaling inflow of a component of isotopically lighter water, likely imported water. In fact, $\delta$18O values are lighter at downstream locations compared to upstream locations on both streams, and all dates (with the exception of the February 2 event on San Leandro Creek). The local spatial pattern in precipitation typically shows the 'continental effect' whereby heavier isotopes are distilled out of rain clouds first as they move from the ocean inland, resulting in lighter and lighter isotopes in precipitation with distance inland. The fact that lighter isotopes are observed downstream (closer to the bay in a pattern opposite the expected continental effect pattern), indicates that the increasing component of water at downstream locations is likely the isotopically light imported water supplied by EBMUD. This effect is most pronounced in the May 14 sample from Root Park.

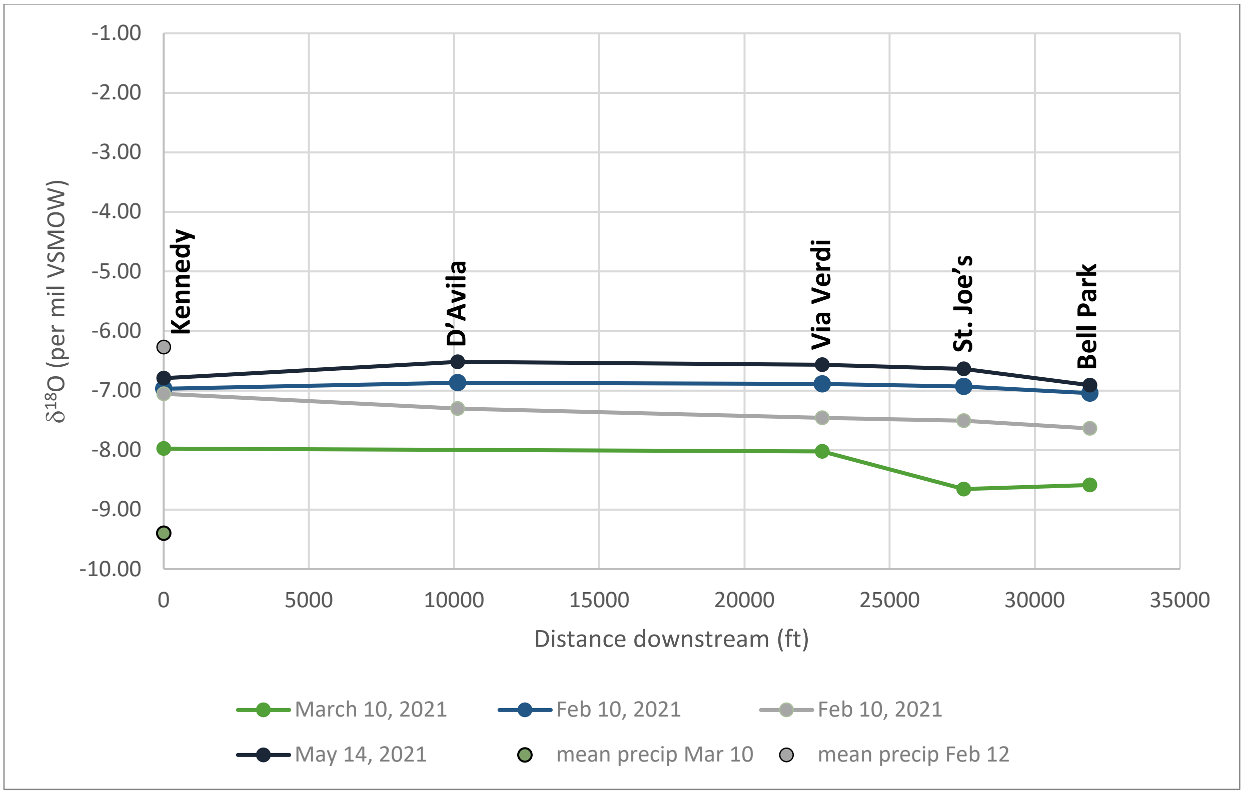



**Figure 14. $\delta^{18}O$ Results for San Pablo Creek and Individual Precipitation Samples the February 10-12 and March 10 Events**

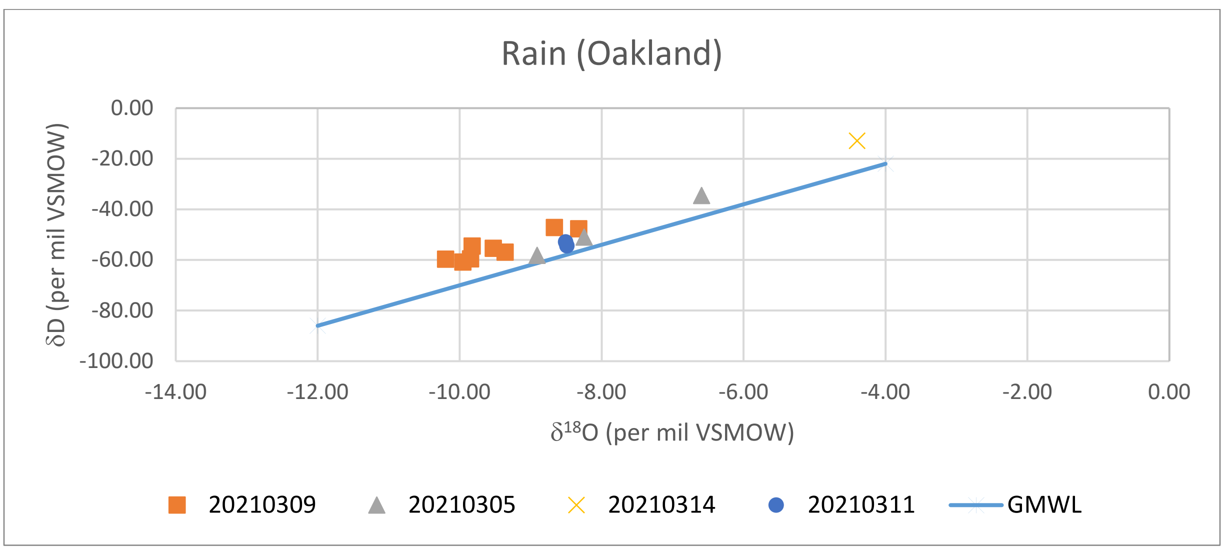
Downstream variation of $\delta^{18}O$ in San Pablo Creek is less pronounced. The constant February 10 signature likely reflects the long-term mean precipitation as it is mixed in groundwater. A precipitation sample from the smaller February 12 event was heavier (-6.3 ‰) than the pre-event samples, but the creek samples trend towards lighter signatures. The larger March 10 event was isotopically lighter (-9.4 ‰); this is reflected in lighter $\delta^{18}O$ values in all samples but is most pronounced in the two most downstream locations. The lighter signatures observed at downstream locations on all dates may also reflect a component of imported water, which also show decreased EC at the same locations (**Figure 8**).

Mixing calculations that allow quantification of the fractions of different water sources (end members) to a stream water sample are sensitive to the chosen end member values (**Table 5**). 'Event' end members, based on $\delta^{18}O$ values in precipitation collected during the event, often vary considerably over short distances and short times. A volume-weighted $\delta^{18}O$ value for precipitation was calculated for the March 10 event, using measured values from multiple precipitation samples collected at one location in Oakland over the course of the event, prior to stream sampling (**Figure 15**). Using the record of precipitation from the Oakland North CDEC station (ONO), the end member value is -9.4‰. The February 2 and February 12 events $\delta^{18}O$ end member values are based on individual rainwater samples collected just prior to stream sampling at Chabot Park on

February 2 ($\delta^{18}O$ = -4.1‰) and Kennedy Grove on February 12 ($\delta^{18}O$ = -6.3‰), respectively. A second end member is the imported water from the Mokelumne River watershed. Although the isotopic signature of this end member is less variable than that of precipitation, it also may vary temporally and spatially depending on natural processes in the Mokelumne watershed and possible mixing with other water sources in the EBMUD distribution system. A $\delta^{18}O$ value of -11.6‰ was chosen based on repeated measurements of irrigation water at Tilden Golf Course (Grande et al., 2020). Thirdly, the stream may carry pre-event water that is locally derived water that moves slowly through the unsaturated and saturated zones to the stream. This integrated component is typically observed at baseflow and is relatively constant. In the case of San Leandro Creek, this component may not be observed, as the stream is mainly losing, and releases from Lake Chabot are the obvious component at low flow. In San Pablo Creek, upstream locations on May 14 (unlikely to contain imported water or event water) have $\delta^{18}O$ values of approximately -6.8‰, and this value is used as the 'baseflow' end member. It is close to values that were determined using averages of multiple measurements of $\delta^{18}O$ at baseflow in upper Wildcat Creek ($\delta^{18}O_{baseflow}$ = -6.6‰; Grande et al., 2020) and Upper Redwood Creek ($\delta^{18}O_{baseflow}$ = -6.8‰; Beitz, 2014). It should be noted that the larger the difference in end member values, the more robust the quantification of the components in the mixture. The end-member values are listed in **Table 5** and used in the equations below to calculate fa and fb (the fraction of event or baseflow water and the fraction of imported water, respectively). Results of mixing calculations are shown in **Table 6** (San Pablo Creek) and **Table 7** (San Leandro Creek).

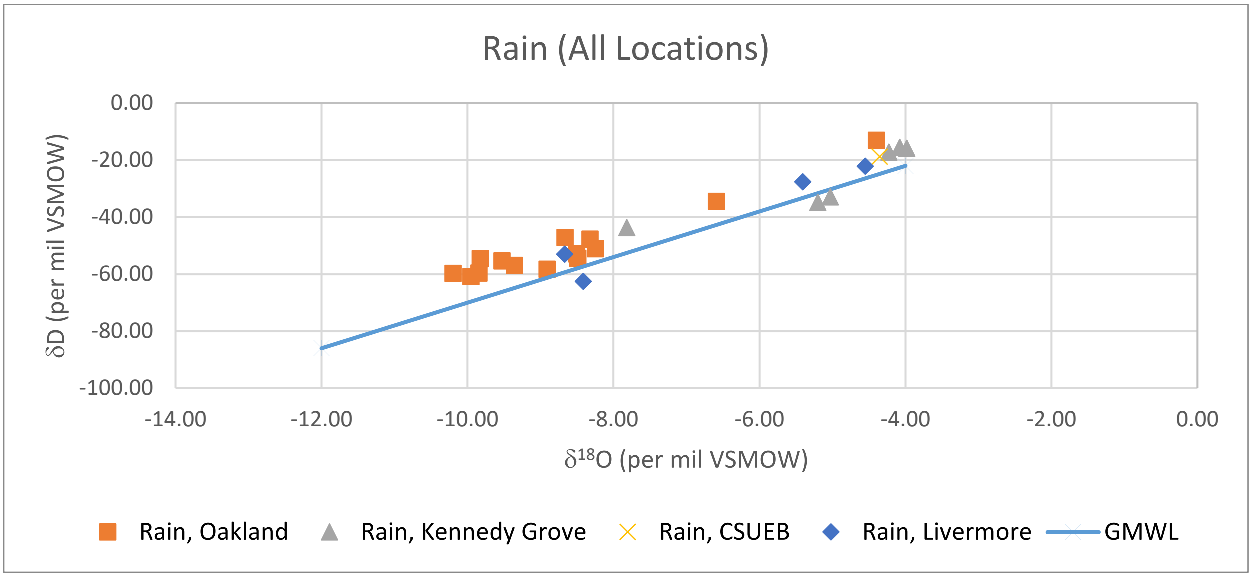
$$\delta^{18}O_{\text{Stream}} = (\delta^{18}O_{\text{Event or Baseflow}} * f_a) + (\delta^{18}O_{\text{Imported}} * f_b), \text{ and } f_a + f_b = 1$$

$$EC_{\text{Stream}} = (EC_{\text{Baseflow}} * f_a) + (EC_{\text{imported}} * f_b)$$




Note: Precipitation in Oakland on different dates between March 5-14, 2021, plotted along with the Global Meteoric Water Line (GMWL)

## Figure 15. Stable Isotope Values for Oakland Precipitation Samples




Note: Collected at Different Locations Across the Bay Area from March 5-14, 2021, Plotted Along with the Global Meteoric Water Line (GMWL)

## Figure 16. Stable Isotope Values for All Precipitation Samples

| Table 5. End-Member Values for $\delta^{18}O$ for Different Sources of Water | | | |
|---|---|---|---|
| **End-member** | **Date** | **$\delta^{18}O$** | **EC (µS/cm)** |
| Precipitation | Feb 12 | -4.1 | NM |
| | Feb 12 | -6.3 | NM |
| | Mar 10 | -9.4 | NM |
| Baseflow (San Pablo) | | -6.8 | 1400 |
| Lake Chabot releases | | -3.0 | 500 |
| Imported water | | -11.6 | 100 |

NM = not measured

| Table 6. End-Member Mixing Calculations for San Pablo Creek | | | | | |
|---|---|---|---|---|---|
| Date | Location | % Event Water | % Pre-event | % Imported | Value measured in stream |
| 10 Feb | Kennedy Grove | 0 | 100 | 0 | -6.87 |
| 10 Feb | Bell Park | 0 | 95 | 5 | -7.04 |
| 12 Feb | Kennedy Grove | ~0 † | NC | NC | -7.05 |
| 12 Feb | Bell Park | NC* | NC* | 13* | -7.64 |
| 10 Mar | Kennedy Grove | 48 | 52 | 0 | -7.95 |
| 10 Mar | Bell Park | NC | NC | 17* | -8.58 |
| 14 May | Kennedy Grove | 0 | 100 | 0 | -6.79 |
| 14 May | Bell Park | 0 | 98 | 2 | -6.91 |

*calculated as mixture of Kennedy Grove water on February 12 or March 10 and imported water

† $\delta^{18}O_{event}$ results in a small negative value

NC = not calculated

By May 14, San Leandro Creek is intermittent with isolated pools, and the pool at Root Park shows an evaporated signature. Calculating the unevaporated value of $\delta^{18}O$ results in a value of -10.1‰, close to the assumed end member value for imported water and indicating that 83% of the water present in the stream at that time and location is imported (**Table 7**). A sample from below Root Park, taken from drainage inflow to the streambed on October 31, 2020, had a $\delta^{18}O$ value of -12.5‰, even lighter than the end member value used in the calculations, and indicating the presence of only unevaporated, imported water.

| Table 7. End-Member Mixing Calculations for San Leandro Creek | | | | | |
|---|---|---|---|---|---|
| **Date** | **Location** | **% Event Water** | **% Pre-event** | **% Imported** | **Value measured in stream** |
| February 1 | Below Lake Chabot | 0 | 100 | 0 | -2.78 |
| February 1 | Root Park | 0 | 96 | 4† | -7.01 |
| February 2 | Below Lake Chabot | 100 | 0 | 0 | -4.31 |
| February 2 | Root Park | NC* | NC* | 6* | -4.57 |
| March 10 | Below Lake Chabot | 35 | NC | NC | -5.27 |
| March 10 | Root Park | NC †† | NC †† | NC †† | -7.57 |
| May14 | Below Lake Chabot | 0 | 100 | 0 | -2.73 |
| May14 | Root Park | 0 | 17 | 83 | -10.1 |

† calculated as mixture of pre-event (-6.8) water and imported water (no water from Lake Chabot)

*calculated as mixture of February 1 event water and imported water

††complex mixture of isotopically light event water, baseflow, and imported water

NC = not calculated

EC measurements provide further evidence for the presence of a component of imported water at downstream locations. For example, if pre-event (baseflow) EC is approximately 500 μS/cm on San Leandro Creek and approximately 1400 μS/cm on San Pablo Creek, and imported water EC is 100 μS/cm (Grande, 2020), then conservative mixing would indicate that 23% of the San Pablo Creek streamflow is imported water on February 10 at Bell Park, and 26% is imported water on May 14; 20% of the San Leandro Creek streamflow is imported water at Root Park on February 1, and 65% is imported water on May 14. These should be considered rough estimates (especially during events) because of potential variability in end members, but the consistent patterns of decrease in both EC and $\delta^{18}O$ at downstream locations on both creeks highlight the presence of imported water.

Tritium ages can be calculated from the sample concentration ($3H_{sample}$) as 17.8 years × $\ln(3H_{in}/3H_{sample})$ if the initial concentration of tritium in precipitation ($3H_{in}$) is known. Tritium in Oakland precipitation is estimated at 11.6 pCi/L based on research in Tilden Park (Grande et al., 2020). However, mixing between different water sources can complicate age calculations. The tritium value of imported water is expected to be 8.6 pCi/L due to the aging of water in the Mokelumne watershed (Harms et al., 2014; Grande et al., 2020; Thaw et al., 2020).

Tritium values in San Leandro Creek on March 10 (**Figure 17**) confirm that recent runoff is the dominant water source for streamflow, both upstream and downstream. During baseflow in May, the tritium value at Chabot (11.4 pCi/L) indicates there is still a large component of recent precipitation, whereas the value at Root Park (9.5 pCi/L) is consistent with an 83% contribution of imported water with lower tritium.

In contrast to San Leandro Creek, San Pablo Creek appears to produce streamflow with a considerable groundwater age. The contribution of event water at Kennedy Grove is estimated at 48% based on the $\delta^{18}O$ value, and the groundwater end-member in the mixture (52%) is estimated to have a tritium value of approximately 3 pCi/L to result in a sample value of 7.1 pCi/L. A tritium value of 3 pCi/L corresponds to a water age of approximately 20 years. Old water is commonly found in steep natural terrain, with the majority of water storage in the unsaturated zone and long, deep flow paths that connect to the stream network when activated by precipitation events. The baseflow value (5.1 pCi/L) at Kennedy Grove is slightly higher, suggesting only a small contribution (24%) of more recent precipitation. At Bell Park, the higher tritium value (8.3 pCi/L) suggests younger water ages are produced by the flatter terrain.

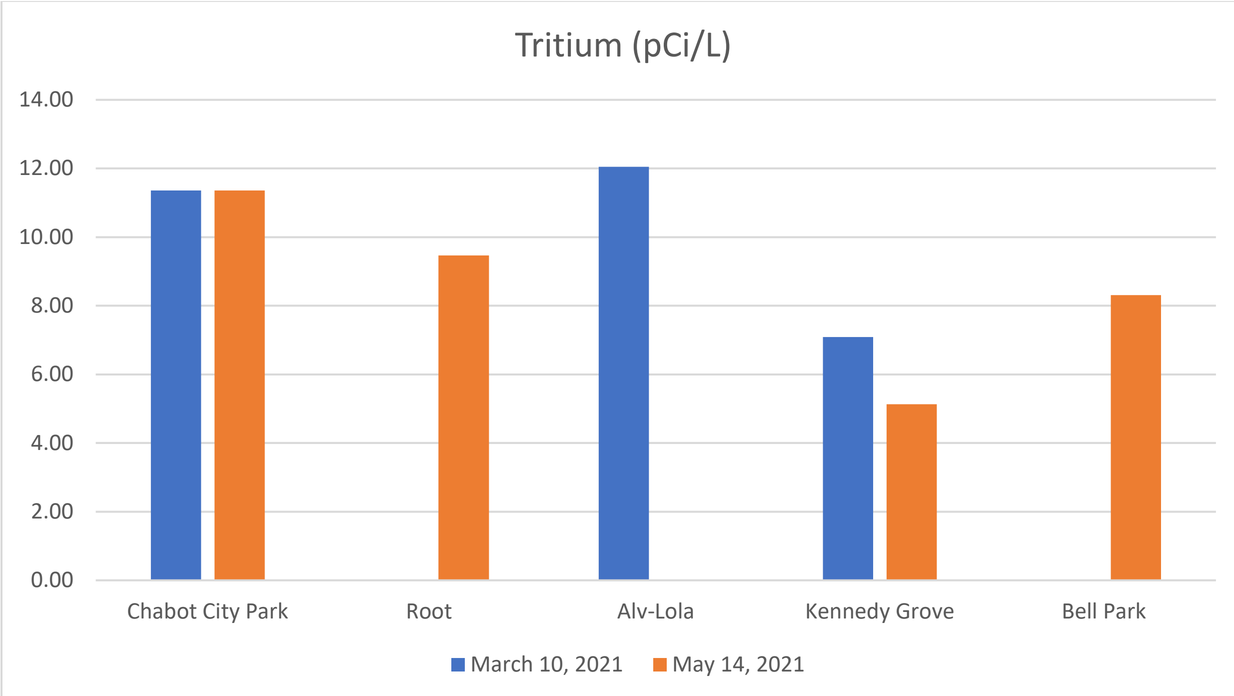
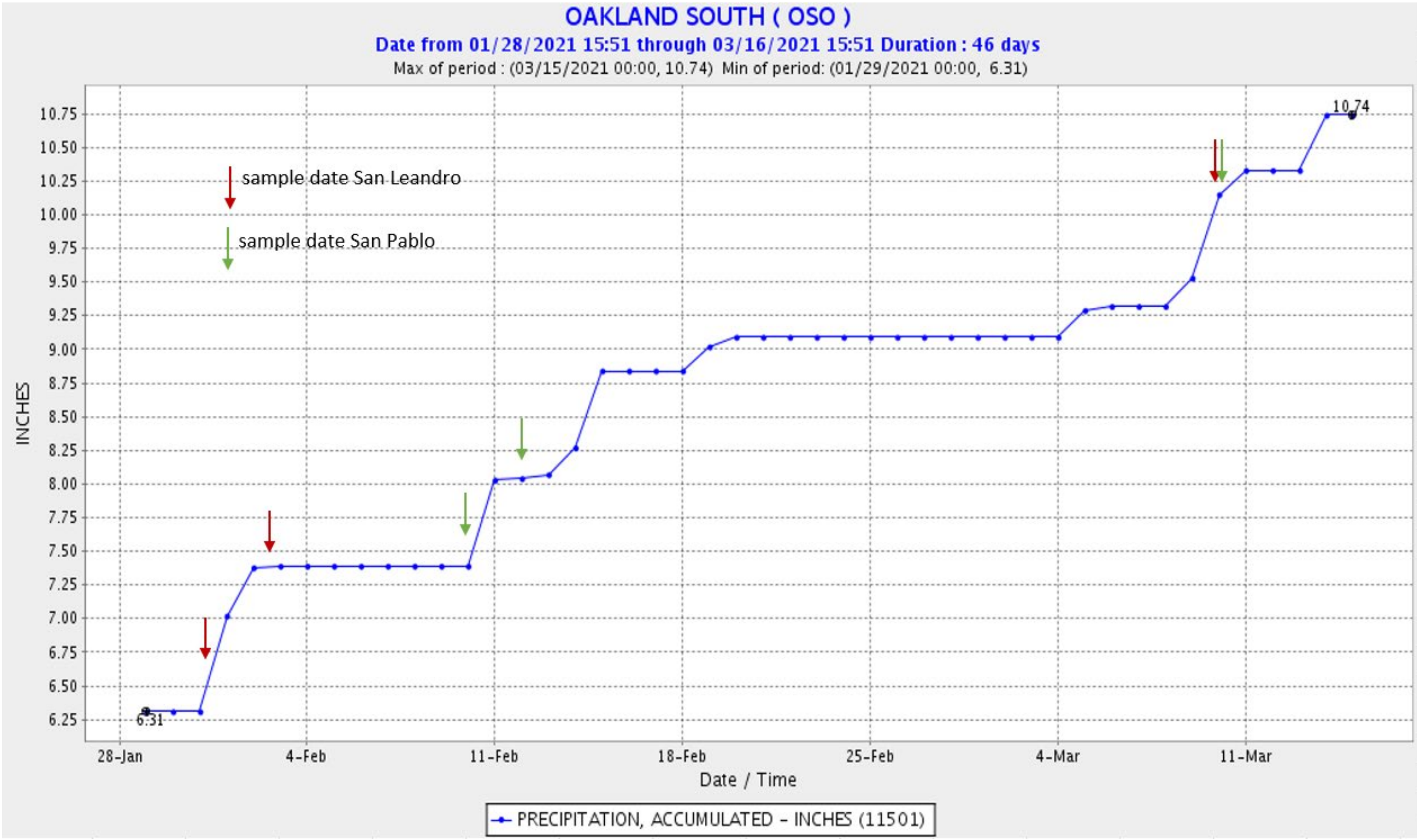



**Figure 17. Tritium Results at Selected Locations and Dates**

## 4.5. Stream Discharge

Stream discharge was measured at the sampling locations on San Pablo Creek and San Leandro Creek before and during runoff events and at baseflow. Dates of discharge measurement and sampling are shown on **Figure 18,** along with a record of cumulative precipitation at the OSO CDEC station in Oakland. Discharge was also measured on May 14, 2021 (not shown).




Note: Recorded at the Oakland South precipitation station, with arrows indicating the event and pre-event sampling dates in February and the event sampling date in March. Samples along both streams were also collected on May 14, 2021.

**Figure 18. Cumulative Precipitation**

Measured discharge on San Leandro Creek (**Table 8** and **Figure 19a**) is somewhat lower than on San Pablo Creek, and San Leandro Creek is intermittent, with the flow in the creek below Lake Chabot ceasing between the Cary St. site (6,512 ft) and the Root Park site (10,252 ft), as observed in October 2020 and May 2021. Before the February 1-2, 2021 event, water was present as isolated pools at the two downstream sites, providing further evidence for the intermittent nature of flow below the Cary St. site. Releases of 0.2-1 cfs from the reservoir generate flow at the two upstream sites, as noted above. During the runoff events on February 2 (flow measured at only the two upstream sites) and on March 10, the increase in discharge is the result of stormwater runoff via overland flow and/or the urban drainage system.

San Pablo Creek is perennial, although flow is <1 cfs during late summer and fall. Stream discharge measurement results from 2021 for San Pablo Creek are shown in **Table 8** and **Figure 19b**. Discharge significantly increases with distance downstream during runoff events on February 12, 2021 and March 10, 2021, with similar patterns of increase during the two events. Extremely low but measurable discharge was recorded on May 14, 2021, with an increase from 0.14 to 0.93 cfs between the two downstream locations. As noted above, tributaries enter the creek on the north and south sides and contribute to flow in the mainstem. The Kennedy Creek and Castro Creek northern tributaries enter between the Kennedy Grove (0 ft) and D'Avila (10,131 ft) sites, and Wilkie Creek and Appian Creek enter between the D'Avila and Via Verdi (22,681 ft) sites, while the eight smaller southern tributaries all enter upstream of Wilkie Creek and the Via Verdi site. Therefore, increases in discharge below Via Verdi (22,680 ft) cannot be attributed to tributary inflow and are likely due to groundwater inflow during both storm events and baseflow or to direct runoff during events. Mixing calculations indicate that local groundwater is an important component at baseflow when imported water makes up a small fraction of the water volume at downstream locations. As noted above, the lower variability in stable isotopes along San Pablo Creek suggests that the integrated groundwater signal dominates at baseflow and during runoff events. However, the small contrast between the baseflow signature and precipitation signature during the two runoff events examined on San Pablo Creek make the mixing calculations less robust.

| Sample Location | Date | Time | Total wet width (in) | Section No. | Depth at Markers (in) | Avg Velocity at Markers (ft/s) | Section Width (in) | Max Velocity (ft/s) | Flow (cfs) |
|---|---|---|---|---|---|---|---|---|---|
| **Table 8. Summary of Stream Discharge Measurements for East Bay Plain Subbasin** | | | | | | | | | |
| Cary | 2/2/2021 | 10:51 AM | 66 | | | | | | |
| | | | | 1 | 4.75 | 0.2 | 11.0 | 0.4 | 0.07 |
| | | | | 2 | 5 | 1.1 | 11.0 | 1.5 | 0.42 |
| | | | | 3 | 6 | 0.9 | 11.0 | 1.9 | 0.41 |
| | | | | 4 | 6 | 1.3 | 11.0 | 1.9 | 0.60 |
| | | | | 5 | 4 | 2.2 | 11.0 | 2.9 | 0.67 |
| | | | | 6 | 2 | 0.9 | 11.0 | 1.7 | 0.14 |
| | | | | | | | | **Total Streamflow =** | 2.31 |
| Chabot | 2/2/2021 | 11:53 AM | 86 | | | | | | |
| | | | | 1 | 2.5 | 0.1 | 12.3 | 0.2 | 0.02 |
| | | | | 2 | 5 | 0.1 | 12.3 | 0.2 | 0.04 |
| | | | | 3 | 7.75 | 0.2 | 12.3 | 0.4 | 0.13 |
| | | | | 4 | 5 | 0.4 | 12.3 | 0.4 | 0.17 |
| | | | | 5 | 9.25 | 0.2 | 12.3 | 0.4 | 0.16 |
| | | | | 6 | 7.25 | 0.1 | 12.3 | 0.2 | 0.06 |
| | | | | 7 | 3 | 0.1 | 12.3 | 0.2 | 0.03 |
| | | | | | | | | **Total Streamflow =** | 0.61 |
| D'Avila | 2/10/2021 | 11:30 AM | 38 | 1 | 3 | 0.6 | 9.5 | | 0.12 |
| | | | | 2 | 3 | 1.1 | 9.5 | | 0.22 |
| | | | | 3 | 2 | 0.2 | 9.5 | | 0.03 |
| | | | | 4 | 1 | 0.01 | 9.5 | | 0.00 |
| | | | | | | | | **Total Streamflow =** | 0.36 |
| Kennedy | 2/12/2021 | 8:00 AM | 108 | 1 | 4 | 0.075 | 15.4 | | 0.03 |
| | | | | 2 | 5 | 0.075 | 15.4 | | 0.04 |
| | | | | 3 | 5 | 0.075 | 15.4 | | 0.04 |
| | | | | 4 | 4 | 0.075 | 15.4 | | 0.03 |
| | | | | 5 | 2 | 0.075 | 15.4 | | 0.02 |
| | | | | 6 | 2 | 0.075 | 15.4 | | 0.02 |
| | | | | 7 | 2 | 0.075 | 15.4 | | 0.02 |
| | | | | | | | | **Total Streamflow =** | 0.19 |
| D'Avila | 2/12/2021 | 9:00 AM | 45 | 1 | 1 | 1.5 | 11.3 | | 0.12 |
| | | | | 2 | 2 | 1.7 | 11.3 | | 0.27 |
| | | | | 3 | 4 | 1.9 | 11.3 | | 0.59 |
| | | | | 4 | 3 | 0.4 | 11.3 | | 0.09 |
| | | | | | | | | **Total Streamflow =** | 1.07 |

**Table 8. Summary of Stream Discharge Measurements for East Bay Plain Subbasin**

| Sample Location | Date | Time | Total wet width (in) | Section No. | Depth at Markers (in) | Avg Velocity at Markers (ft/s) | Section Width (in) | Max Velocity (ft/s) | Flow (cfs) |
|---|---|---|---|---|---|---|---|---|---|
| St. Joe's | 2/12/2021 | 10:00 AM | 108 | 1 | 3.5 | 0.6 | 21.6 | | 0.32 |
| | | | | 2 | 5 | 1.1 | 21.6 | | 0.83 |
| | | | | 3 | 6.5 | 1.2 | 21.6 | | 1.17 |
| | | | | 4 | 6 | 0.6 | 21.6 | | 0.54 |
| | | | | 5 | 6 | 1.1 | 21.6 | | 0.99 |
| | | | | | | | | **Total Streamflow =** | 3.84 |
| Bell Park | 2/12/2021 | 10:30 AM | 108 | 1 | 4.5 | 0.8 | 21.6 | | 0.54 |
| | | | | 2 | 4.5 | 1.2 | 21.6 | | 0.81 |
| | | | | 3 | 4 | 1 | 21.6 | | 0.60 |
| | | | | 4 | 5 | 1.6 | 21.6 | | 1.20 |
| | | | | 5 | 8 | 1.5 | 21.6 | | 1.80 |
| | | | | | | | | **Total Streamflow =** | 4.95 |
| Alvarado & Lola | 3/10/2021 | 7:43 AM | 136 | 1 | 3 | 0.4 | 27.2 | | 0.23 |
| | | | | 2 | 6 | 0.6 | 27.2 | | 0.68 |
| | | | | 3 | 8 | 0.6 | 27.2 | | 0.91 |
| | | | | 4 | 6.5 | 0.8 | 27.2 | | 0.98 |
| | | | | 5 | 6 | 0.05 | 27.2 | | 0.06 |
| | | | | | | | | **Total Streamflow =** | 2.85 |
| Root | 3/10/2021 | 8:25 AM | 145 | 1 | 4 | 0.05 | 20.7 | | 0.03 |
| | | | | 2 | 4 | 0.5 | 20.7 | | 0.29 |
| | | | | 3 | 3.5 | 0.2 | 20.7 | | 0.10 |
| | | | | 4 | 4 | 0.5 | 20.7 | | 0.29 |
| | | | | 5 | 5 | 0.1 | 20.7 | | 0.07 |
| | | | | 6 | 4 | 1.1 | 20.7 | | 0.63 |
| | | | | 7 | 2.5 | 0.05 | 20.7 | | 0.02 |
| | | | | | | | | **Total Streamflow =** | 1.43 |
| Cary1 | 3/10/2021 | 9:04 AM | 74 | 1 | 5 | 0.4 | 12.3 | | 0.17 |
| | | | | 2 | 7.5 | 1 | 12.3 | | 0.64 |
| | | | | 3 | 7 | 0.7 | 12.3 | | 0.42 |
| | | | | 4 | 6 | 0.1 | 12.3 | | 0.05 |
| | | | | 5 | 6 | 1.1 | 12.3 | | 0.57 |
| | | | | 6 | 3.5 | 0.4 | 12.3 | | 0.12 |
| | | | | | | | | **Total Streamflow =** | 1.97 |
| Cary2 | 3/10/2021 | 9:09 AM | 77 | 1 | 5 | 0.5 | 12.8 | | 0.22 |
| | | | | 2 | 6 | 1.4 | 12.8 | 1.7 | 0.75 |
| | | | | 3 | 5 | 0.7 | 12.8 | 0.9 | 0.31 |
| | | | | 4 | 5 | 1 | 12.8 | 1.3 | 0.45 |

| Table 8. Summary of Stream Discharge Measurements for East Bay Plain Subbasin | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Date | Time | Total wet width (in) | Section No. | Depth at Markers (in) | Avg Velocity at Markers (ft/s) | Section Width (in) | Max Velocity (ft/s) | Flow (cfs) |
| | | | | 5 | 4.5 | 0.4 | 12.8 | 0.6 | 0.16 |
| | | | | 6 | 3 | 0.05 | 12.8 | | 0.01 |
| | | | | | | | | **Total Streamflow =** | 1.90 |
| Chabot | 3/10/2021 | 9:52 AM | 84 | 1 | 6 | 0.05 | 14.0 | | 0.03 |
| | | | | 2 | 6 | 0.2 | 14.0 | | 0.12 |
| | | | | 3 | 4 | 0.4 | 14.0 | | 0.16 |
| | | | | 4 | 8 | 0.3 | 14.0 | | 0.23 |
| | | | | 5 | 7 | 0.05 | 14.0 | | 0.03 |
| | | | | 6 | 5 | 0.1 | 14.0 | | 0.05 |
| | | | | | | | | **Total Streamflow =** | 0.62 |
| Bell Park | 3/10/2021 | 11:00 AM | 108 | 1 | 4 | 1 | 13.7 | 1.3 | 0.38 |
| | | | | 2 | 5.5 | 1.3 | 13.7 | 1.9 | 0.68 |
| | | | | 3 | 5 | 1.1 | 13.7 | 1.3 | 0.52 |
| | | | | 4 | 7.5 | 1.2 | 13.7 | 1.5 | 0.86 |
| | | | | 5 | 7.5 | 0.9 | 13.7 | 1.3 | 0.64 |
| | | | | 6 | 8 | 1.6 | 13.7 | 2.6 | 1.22 |
| | | | | 7 | 8 | 2.1 | 13.7 | 2.5 | 1.60 |
| | | | | 8 | 8 | 1.7 | 6.0 | 2.3 | 0.57 |
| | | | | 9 | 6.5 | 2.8 | 6.0 | 3.2 | 0.76 |
| | | | | | | | | **Total Streamflow =** | 7.23 |
| St. Joe's | 3/10/2021 | 11:43 AM | 139 | 1 | 6.5 | 1 | 13.9 | | 0.63 |
| | | | | 2 | 8 | 0.1 | 13.9 | | 0.08 |
| | | | | 3 | 6.5 | 0.05 | 13.9 | | 0.03 |
| | | | | 4 | 6.5 | 1.1 | 13.9 | | 0.69 |
| | | | | 5 | 8 | 0.7 | 13.9 | | 0.54 |
| | | | | 6 | 7 | 0.9 | 13.9 | | 0.61 |
| | | | | 7 | 8 | 1.4 | 13.9 | | 1.08 |
| | | | | 8 | 7 | 0.7 | 13.9 | | 0.47 |
| | | | | 9 | 5 | 0.7 | 13.9 | | 0.34 |
| | | | | 10 | 2.5 | 0.4 | 13.9 | | 0.10 |
| | | | | | | | | **Total Streamflow =** | 4.56 |
| Via Verdi | 3/10/2021 | 12:38 PM | 141 | 1 | 3 | 0 | 15.7 | 0.2 | 0.00 |
| | | | | 2 | 5.5 | 0.4 | 15.7 | 0.6 | 0.24 |
| | | | | 3 | 7.5 | 0.9 | 15.7 | 0.9 | 0.73 |
| | | | | 4 | 6.5 | 0.5 | 15.7 | 0.8 | 0.35 |

| Table 8. Summary of Stream Discharge Measurements for East Bay Plain Subbasin | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Date | Time | Total wet width (in) | Section No. | Depth at Markers (in) | Avg Velocity at Markers (ft/s) | Section Width (in) | Max Velocity (ft/s) | Flow (cfs) |
| | | | | 5 | 5.5 | 0.4 | 15.7 | 0.6 | 0.24 |
| | | | | 6 | 5.5 | 0.6 | 15.7 | 0.8 | 0.36 |
| | | | | 7 | 6 | 0.9 | 15.7 | 1.1 | 0.59 |
| | | | | 8 | 6.5 | 0.9 | 15.7 | 1.1 | 0.64 |
| | | | | 9 | 7.5 | 0.7 | 15.7 | 0.8 | 0.57 |
| | | | | | | | | **Total Streamflow =** | 3.72 |
| D'Avila | 3/10/2021 | 1:16 PM | 75 | 1 | 7.5 | 0.05 | 12.5 | | 0.03 |
| | | | | 2 | 7.5 | 0.5 | 12.5 | 0.8 | 0.33 |
| | | | | 3 | 6.5 | 0.4 | 12.5 | 0.6 | 0.23 |
| | | | | 4 | 6.5 | 0.05 | 12.5 | 0.2 | 0.03 |
| | | | | 5 | 5 | 0.05 | 12.5 | | 0.02 |
| | | | | 6 | 4 | 0.05 | 12.5 | | 0.02 |
| | | | | | | | | **Total Streamflow =** | 0.65 |
| D'Avila2 | 3/10/2021 | 1:20 PM | 46 | 1 | 5 | 0.1 | 7.7 | 0.4 | 0.03 |
| | | | | 2 | 4 | 0.9 | 7.7 | 1.1 | 0.19 |
| | | | | 3 | 4 | 1.1 | 7.7 | 1.5 | 0.23 |
| | | | | 4 | 4 | 1.6 | 7.7 | 1.9 | 0.34 |
| | | | | 5 | 3 | 1.4 | 7.7 | 1.5 | 0.22 |
| | | | | 6 | 2 | 0.7 | 7.7 | 0.8 | 0.07 |
| | | | | | | | | **Total Streamflow =** | 1.09 |
| Kennedy | 3/10/2021 | 1:57 PM | 105 | 1 | 2.5 | 0 | 11.7 | | 0.01 |
| | | | .046 ft/s leaf velocity | 2 | 4 | 0 | 11.7 | | 0.01 |
| | | | | 3 | 3 | 0 | 11.7 | | 0.01 |
| | | | | 4 | 4.5 | 0 | 11.7 | | 0.02 |
| | | | | 5 | 5.5 | 0 | 11.7 | | 0.02 |
| | | | | 6 | 5.5 | 0 | 11.7 | | 0.02 |
| | | | | 7 | 3.5 | 0 | 11.7 | | 0.01 |
| | | | | 8 | 3.75 | 0 | 11.7 | | 0.01 |
| | | | | 9 | 4 | 0 | 11.7 | | 0.01 |
| | | | | | | | | **Total Streamflow =** | 0.14 |

| Table 8. Summary of Stream Discharge Measurements for East Bay Plain Subbasin | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Date | Time | Total wet width (in) | Section No. | Depth at Markers (in) | Avg Velocity at Markers (ft/s) | Section Width (in) | Max Velocity (ft/s) | Flow (cfs) |
| Cary | 5/14/2021 | 9:09 AM | 63.5 | 1 | 4.25 | 0.05 | 12.7 | | 0.02 |
| | | | | 2 | 3.5 | 0.05 | 12.7 | | 0.02 |
| | | | | 3 | 3.25 | 0.05 | 12.7 | | 0.01 |
| | | | | 4 | 2.25 | 0.05 | 12.7 | | 0.01 |
| | | | | | | | | **Total Streamflow =** | 0.06 |
| Chabot | 5/14/2021 | 9:40 AM | 85.5 | 1 | 3.75 | 0.05 | 14.3 | | 0.02 |
| | | | | 2 | 5.25 | 0.1 | 14.3 | 0.2 | 0.05 |
| | | | | 3 | 7 | 0.1 | 14.3 | 0.2 | 0.07 |
| | | | | 4 | 6.25 | 0.05 | 14.3 | 0.2 | 0.03 |
| | | | | 5 | 3.5 | 0.05 | 14.3 | | 0.02 |
| | | | | | | | | **Total Streamflow =** | 0.19 |
| Kennedy | 5/14/2021 | 10:45 AM | 104 | 1 | 3.5 | 0.0625 | 13.0 | | 0.02 |
| | | | | 2 | 3.5 | 0.0625 | 13.0 | | 0.02 |
| | | | | 3 | 4 | 0.0625 | 13.0 | | 0.02 |
| | | | | 4 | 4.75 | 0.0625 | 13.0 | | 0.03 |
| | | | | 5 | 4 | 0 | 13.0 | | 0.00 |
| | | | | 6 | 2.5 | 0 | 13.0 | | 0.00 |
| | | | | 7 | 3.25 | 0 | 13.0 | | 0.00 |
| | | | | 8 | 1.5 | 0 | 13.0 | | 0.00 |
| | | | | | | | | **Total Streamflow =** | 0.09 |
| D'Avila | 5/14/2021 | 11:30 AM | 61 | 1 | 3.5 | 0.05 | 12.2 | | 0.01 |
| | | | | 2 | 3.25 | 0.05 | 12.2 | | 0.01 |
| | | | | 3 | 4.5 | 0.05 | 12.2 | | 0.02 |
| | | | | 4 | 5 | 0.05 | 12.2 | 0.2 | 0.02 |
| | | | | | | | | **Total Streamflow =** | 0.07 |
| Via Verdi | 5/14/2021 | 12:04 PM | 54.5 | 1 | 4.5 | 0.1 | 10.9 | 0.2 | 0.03 |
| | | | | 2 | 3.75 | 0.2 | 10.9 | 0.4 | 0.06 |
| | | | | 3 | 2.75 | 0.05 | 10.9 | 0.2 | 0.01 |
| | | | | 4 | 2 | 0.05 | 10.9 | 0 | 0.01 |
| | | | | | | | | **Total Streamflow =** | 0.11 |

| Table 8. Summary of Stream Discharge Measurements for East Bay Plain Subbasin | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Sample Location | Date | Time | Total wet width (in) | Section No. | Depth at Markers (in) | Avg Velocity at Markers (ft/s) | Section Width (in) | Max Velocity (ft/s) | Flow (cfs) |
| St. Joe's | 5/14/2021 | 12:40 PM | 58 | 1 | 3.75 | 0.1 | 11.6 | 0.2 | 0.03 |
| | | | | 2 | 5 | 0.2 | 11.6 | 0.4 | 0.08 |
| | | | | 3 | 5 | 0.05 | 11.6 | 0.2 | 0.02 |
| | | | | 4 | 2.25 | 0.05 | 11.6 | | 0.01 |
| | | | | | | | | **Total Streamflow =** | 0.14 |
| Bell Park | 5/14/2021 | 1:15 PM | 88 | 1 | 2 | 0.1 | 14.7 | | 0.02 |
| | | | | 2 | 3 | 0.3 | 14.7 | | 0.09 |
| | | | | 3 | 4 | 0.1 | 14.7 | | 0.04 |
| | | | | 4 | 2.5 | 0.7 | 14.7 | | 0.18 |
| | | | | 5 | 4.5 | 1.3 | 14.7 | | 0.60 |
| | | | | | | | | **Total Streamflow =** | 0.93 |

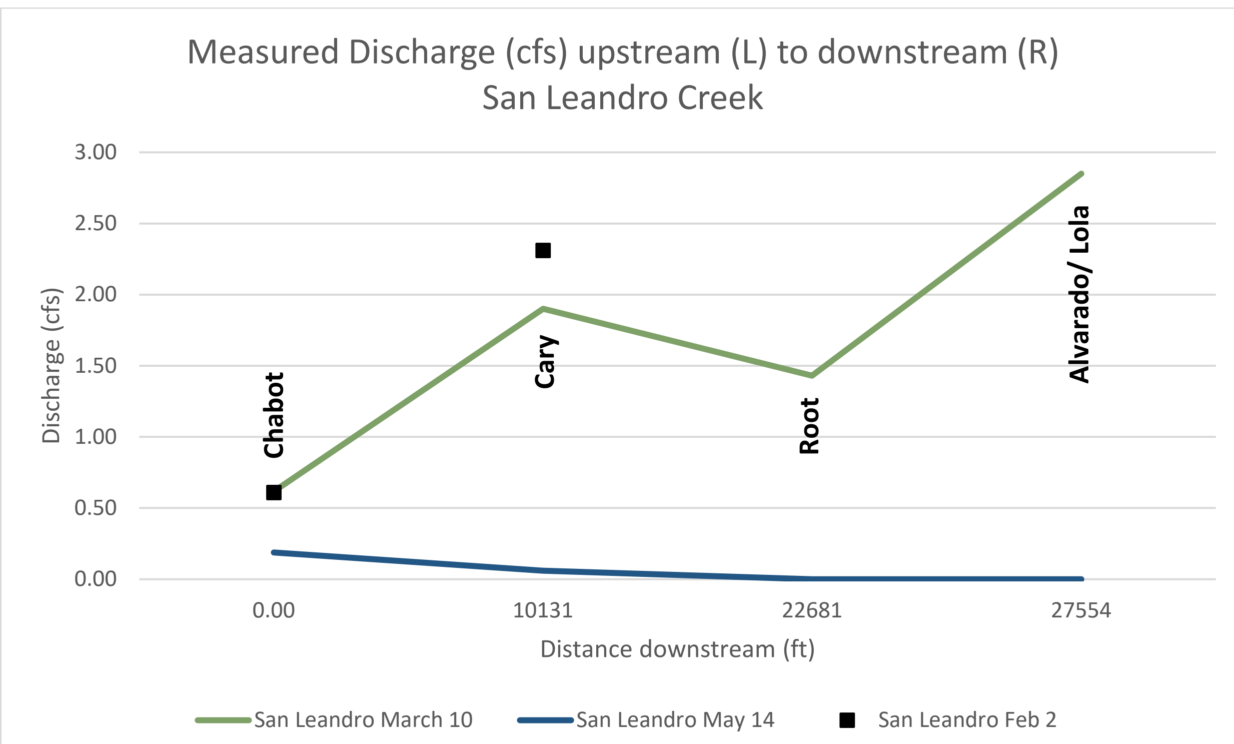



**Figure 19a. Measured Discharge on San Leandro Creek**

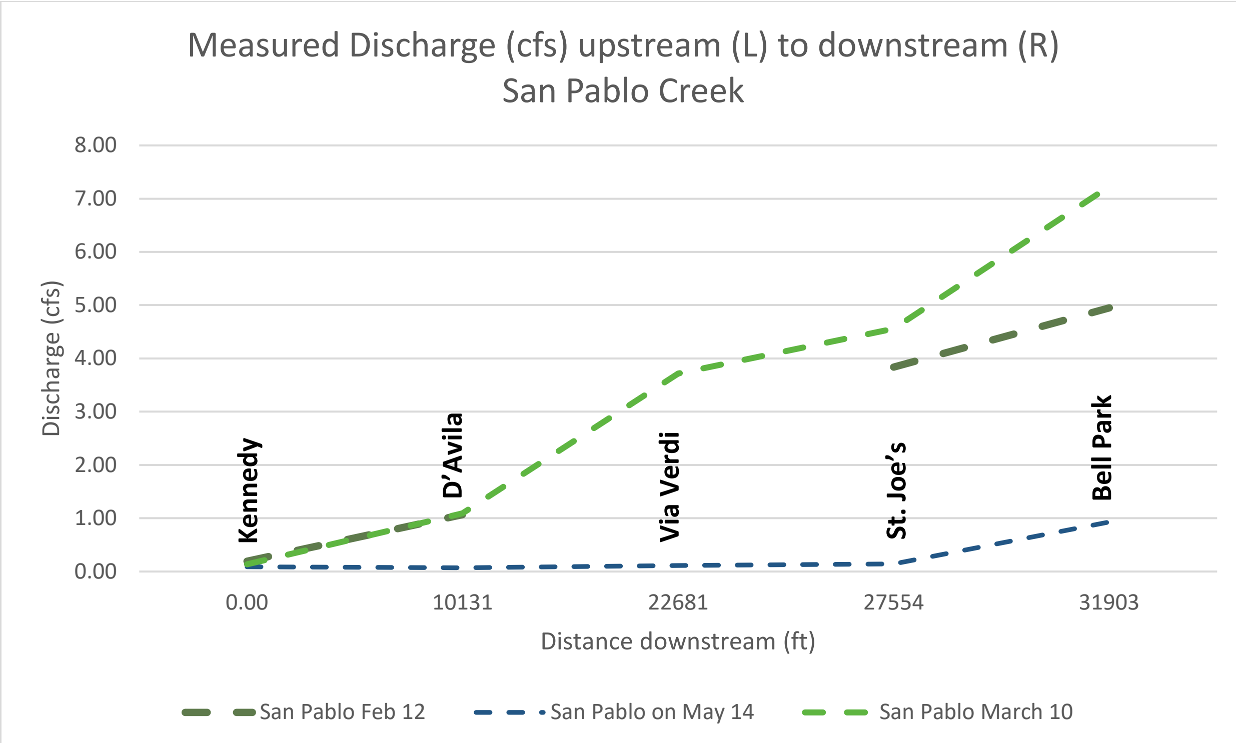
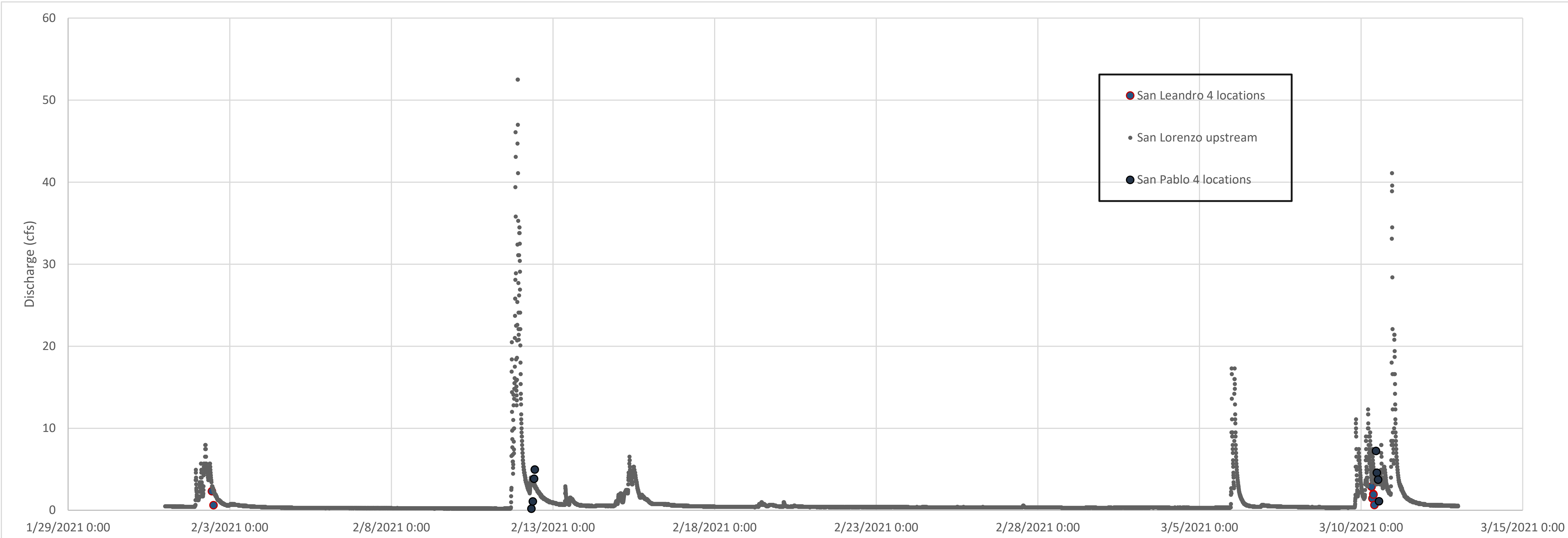



**Figure 19b. Measured Discharge on San Pablo Creek**

While neither San Pablo Creek nor San Leandro Creek is gaged, San Lorenzo Creek is gaged at three locations. The high-resolution discharge data from San Lorenzo Creek are compared with the synoptic discharge measurements in San Pablo Creek and San Leandro Creek in **Figure 20a**. The same flashy behavior, with rapid changes in discharge after rain events, that is observed on the San Lorenzo Creek hydrograph is expected on San Pablo Creek and San Leandro Creek, as the watersheds are similarly urbanized. During runoff events, the San Lorenzo Creek data show that discharge may change by 10's of cfs over 5-10 minutes near peak flows, so the synoptic measurements taken over a three-hour period at different locations may include temporal as well as spatial variation. **Figure 20b** shows that the rate of change in discharge is similar on the three creeks and that the discharge in San Leandro Creek at all locations is somewhat lower than that in San Lorenzo Creek (at the gage above Don Castro reservoir) and the discharge in San Pablo Creek is somewhat higher at downstream locations and somewhat lower at upstream locations than discharge in San Lorenzo Creek above Don Castro reservoir. All measured values are significantly lower than discharge values measured at the downstream gage on San Lorenzo Creek below Highway 880.




Note: Recorded over the Study Period, along with Individual Discharge Measurements on San Leandro Creek and San Pablo Creek.

**Figure 20a. Record of Discharge on San Lorenzo Creek above Don Castro Reservoir**

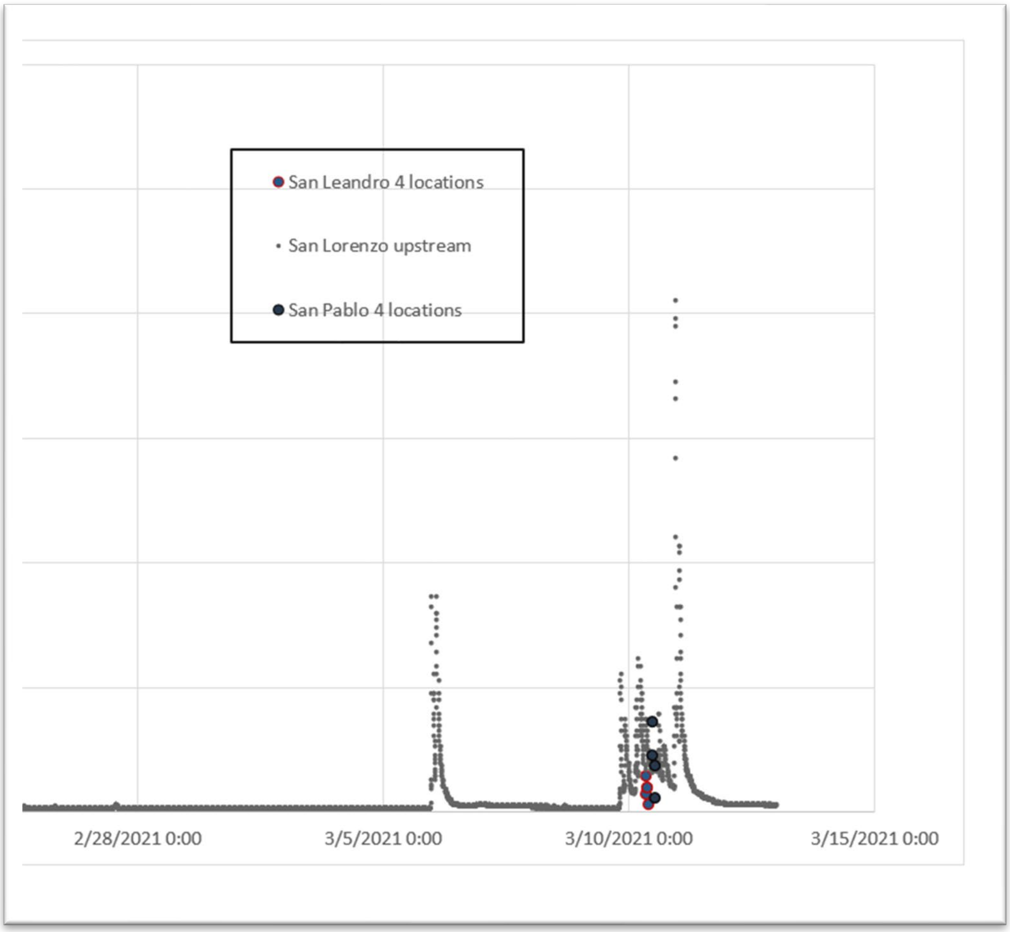



**Figure 20b. Expanded view of San Lorenzo Hydrograph and Synoptic Discharge Measurements During the March 10, 2021 Event**

The observed increasing flow with distance downstream, even in the absence of tributaries, highlights the significant contributions from the urban storm drain system. In addition, on San Pablo Creek, groundwater recharged by winter precipitation and stored in the near-stream aquifer system (Niswonger and Fogg, 2008; Banks et al., 2011) likely contributes significantly to increased discharge.

# 5. CONCLUSIONS

Results from isotopic tracers, water quality parameters, and flow measurements in San Pablo Creek and San Leandro Creek in the EBP Subbasin were combined to examine surface water-groundwater interaction. The tracers reveal that San Leandro Creek is losing along much of its course below Lake Chabot. Evaporated Lake Chabot water recharges shallow groundwater just below the dam for a distance of greater than 10,000 feet, but the stream becomes intermittent in lower reaches, with urban drainage providing limited flow between events and during baseflow. During precipitation events, quick flow (runoff) is the main source of water in the creek. Imported water contributes to flow at downstream locations, making up nearly all of the flow during dry periods and a small percentage of the flow during events. The sources of imported water are unknown but may include: irrigation return flows, pipe leaks, and/or urban drainage.

San Pablo Creek exhibits significant groundwater interaction with the stream along much of its course below San Pablo Reservoir. The stream is perennial and gaining at most locations and most times. Tritium results indicate that the groundwater entering the stream is up to 20 years old, suggesting long flow paths to the stream. An isotopically light (and low TDS) imported water component is evident at locations below the I-80 culvert. Groundwater pumping in the alluvium and stream alluvial terraces upstream of I-80 is likely to decrease groundwater inflow to San Pablo Creek, especially during periods of low streamflow.

# 6. STUDY LIMITATIONS AND FUTURE WORK

The analysis of water sources contributing to streamflow presented here was developed with minimal characterization of the contributing components. Stream-groundwater interaction may be quite variable in space and time, especially when available storage in the alluvium connected to the stream is limited. Such dynamic systems likely exhibit significant change between wet and dry years, for example. Additional data will be developed to build on the present study. In particular, neither San Leandro Creek nor San Pablo Creek is gaged, so water fluxes cannot be determined, including the flux of imported water that reaches the bay. New stream gages are planned for installation and monitoring as part of GSP implementation tasks, along with periodic synoptic stream surveys. Another future task to fill data gaps involves drilling shallow wells adjacent to the streams for monitoring of water levels. These shallow wells could also be sampled for the same tracers applied in this study, revealing flow direction and water sources over seasonal hydrographs. Automated sample collection during events for the same tracers would allow hydrograph separation, and additional water quality parameters such as nitrate, phosphate, and metals would reveal the scale of anthropogenic sources and overall suitability for beneficial uses. The results from all of these planned tasks will be evaluated together, and conclusions presented in the five-year Update Report.

# 7. REFERENCES

Banks, E.W., Simmons, C.T., Love, A.J. and Shand, P., 2011. Assessing spatial and temporal connectivity between surface water and groundwater in a regional catchment: Implications for regional scale water quantity and quality. Journal of Hydrology, p. 404(1-2): 30-49.

Beitz, P., 2014. A Multi-Tiered Catchment Analysis of Upper Redwood Creek, an Urban, Trout Bearing Stream in Oakland, CA, CSU East Bay M.S. Thesis, p. 111.

Cey, E.E., Rudolph, D.L., Parkin, G.W. and Aravena, R., 1998. Quantifying groundwater discharge to a small perennial stream in southern Ontario, Canada. Journal of Hydrology, p. 210(1-4): 21-37.

Craig, H., 1961. Standard for reporting concentrations of deuterium and oxygen-18 in natural waters. Science, v. 133, p. 1833-1834.

Epstein, S. and Mayeda, T. K., 1953. Variation of $^{18}O$ content of waters from natural sources. Geochimica et Cosmochimica Acta, v. 4, p. 213-224.

Gibson, J. J., Birks, S. J., and Edwards, T. W. D., 2008, Global prediction of δA and $\delta^2H$-$\delta^{18}O$ evaporation slopes for lakes and soil water accounting for seasonality, Global Biogeochem. Cycles, 22, GB2031, doi:10.1029/2007GB002997.

Grande, E.±, Visser, A., Moran, J.E. Catchment storage and residence time in a periodically irrigated watershed. Hydrological Processes 2020, 34 (14), 3028-3044; https://doi.org/10.1002/hyp.13798.

Harms, Patrick; Visser, Ate; Moran, Jean; Esser, Bradley 'Distribution of Tritium in Precipitation and Surface Water in California' Journal of Hydrology, DOI: 10.1016/j.jhydrol.2015.12.046, March, 2016

Lovelace, F., 2017 Sources of excess phosphate leading to cyanobacteria blooms at Lake Temescal, Oakland, CA, CSU East Bay M.S. thesis, p. 112.

Klausmeyer K., J. Howard, T. Keeler-Wolf, K. Davis-Fadtke, R. Hull, A. Lyons., 2018. Mapping Indicators of Groundwater Dependent Ecosystems in California: Methods Report. San Francisco, California.

Niswonger, R.G. and Fogg, G.E., 2008. Influence of perched groundwater on base flow. Water Resources Research, 44(3): W03405.

RWQCB SWAMP, 2007. Water Quality Monitoring and Bioassessment in Nine San Francisco Bay Region Watersheds in 2001-2003.

Thaw, M., Visser, A., Deinhart, A., Bibby, R., Oerter, E., Conklin, M., Rungee, J. Sierra Nevada isotope hydrology, tracking links between forest water sources, subsurface storage and major river runoff. LLNL-TH-800731.

The Watershed Project, Lower San Pablo Creek Report Card, August 2017-July 2018.