Evaluation of Approaches to Determine Mixing and Assimilation of Reuse Effluent

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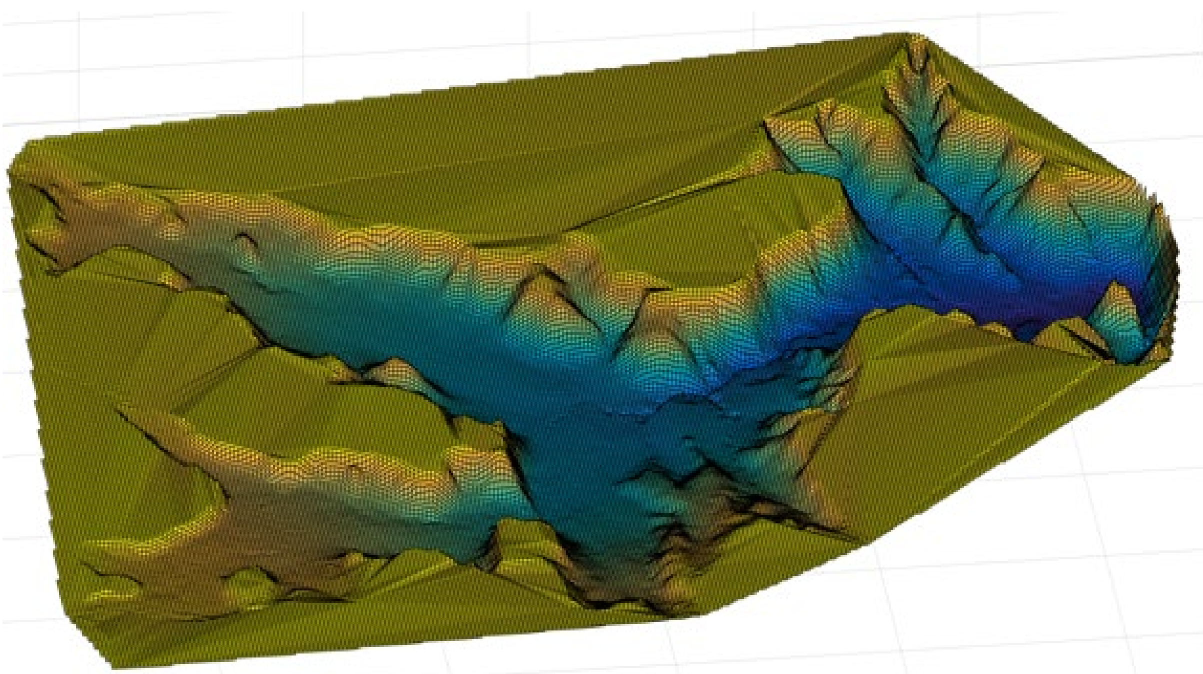

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Cover picture: Gridded elevations of Lake Arrowhead bottom, derived from 2008 Reclamation bathymetric survey, used in model.

14. ABSTRACT
As reuse water becomes an ever-larger component of water resource planning, issues associated with measuring and modeling the mixing and dispersion of reuse water will become more prominent. Hydrodynamic modeling and tracer studies are required to evaluate and assess risks for indirect potable reuse (IPR) by surface water augmentation (SWA) projects, but technical approaches vary based on locality, reservoir configuration and available information, models used, and local and state regulations. This project included a tracer case study and hydrodynamic modeling of Lake Arrowhead, which was used to develop a guidance manual. The guidance manual provides recommendations to help utilities plan and conduct hydrodynamic modeling and tracer studies for their reservoirs as part of the SWA-IPR evaluation process.

15. SUBJECT TERMS
Hydrodynamic modeling, tracer study, water reuse, surface water augmentation

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Mission Statements

The Department of the Interior (DOI) conserves and manages the Nation's natural resources and cultural heritage for the benefit and enjoyment of the American people, provides scientific and other information about natural resources and natural hazards to address societal challenges and create opportunities for the American people, and honors the Nation's trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities to help them prosper.

The mission of the Bureau of Reclamation is to manage, develop, and protect water and related resources in an environmentally and economically sound manner in the interest of the American public.

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Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research. The University of Nevada, Las Vegas, completed the research at Lake Arrowhead and developed the resulting guidance manual. Water Quality Solutions provided subject matter expertise. Lake Arrowhead Community Services District and Arrowhead Lake Association provided significant in-kind contributions and staff time for this research and the resulting guidance manual. Jeffery Pasek with the City of San Diego also provided significant expertise and contribution to this project.

Evaluation of Approaches to Determine Mixing and Assimilation of Reuse Effluent

Final Report No. ST-2021-7100-01

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Cover image: Bathymetry grid of Lake Arrowhead, used as an input file for the three-dimensional hydrodynamic model discussed in Section 2.3 of this report and in the Guidance Manual (Appendix 1)

Peer Review

Bureau of Reclamation
Research and Development Office
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Acronyms and Abbreviations

ADP	Acoustic Doppler Profiler
AEM3D	3-Dimensional coupled Hydrodynamic-Aquatic Ecosystem Model
ALA	Arrowhead Lake Association
CAEDYM	Computational Aquatic Ecosystem DYnamics Model
CIMIS	California Irrigation Management Information System
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DHI	Danish Hydraulic Institute, now known as DHI Group
EFDC	Environmental Fluid Dynamics Code – US EPA
EIR	Environmental Impact Report
ELCOM	Estuary, Lake and Coastal Ocean Model
EPA	US Environmental Protection Agency
FSI	Flow Science Incorporated
gpm	gallons per minute
GIS	Geographic Information Systems
IAP	Independent Advisory Panel
IPR	Indirect Potable Reuse
LACSD	Lake Arrowhead Community Services District
Lahontan	Lahontan Regional Water Quality Control Board
MIKE 21/3	DHI group three-dimensional hydrodynamic model
MRE	Mean Relative Error
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Reclamation	Bureau of Reclamation
REE/PAAS	Rare Earth Element/Post-Archean Australian Shale
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SBDDW	State Board Division of Drinking Water
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SWA	Surface Water Augmentation
SWSAP	Surface Water Source Augmentation Project; California term for SWA-IPR
thalweg	deepest longitudinal profile in reservoir corresponding to original stream bed
TSC	Technical Service Center
UNLV	University of Nevada, Las Vegas
USGS	U.S. Geological Survey
VOC	Volatile Organic Carbon
WASP	Water Quality Analysis Simulation Program – US EPA
WRA	Water Recycling Agency
WSEL	Water Surface Elevation
WQS	Water Quality Solutions
YSI	Yellow Springs Instruments

Contents

List of Appendices

Executive Summary

The purpose of this Reclamation Science and Technology (S&T) funded project (S&T 7100) is to present best practices for conducting data collection, tracer studies and hydrodynamic modeling that can provide guidance to water utilities as they implement surface water augmentation (SWA) by indirect potable reuse (IPR) studies in their reservoirs. This is increasingly important as drought continues in the western United States and more utilities pursue development of resilient local water supplies and augment their drinking water reservoirs with advanced treated recycled water.

Reclamation partnered with the University of Nevada, Las Vegas (UNLV), Water Quality Solutions (WQS), the Lake Arrowhead Community Services District (LACSD), and the Arrowhead Lake Association (ALA) to complete this research and produce a tracer study and hydrodynamic modeling guidance manual. In developing the guidance manual, Lake Arrowhead was used as a case study reservoir. Data were collected throughout the duration of the project, and a tracer study was completed at Lake Arrowhead in December 2019. A hydrodynamic model was developed and calibrated with environmental, meteorological, and hydrologic data, then validated with the tracer study measurements.

Results from the Lake Arrowhead case study combined with guidance from a Subject Matter Expert and experienced water agency managers provided the information used to develop the Tracer Study and Hydrodynamic Modeling Guidance Manual. The Manual was developed by UNLV, with input from project partners, and is included as Appendix 1. The Guidance Manual also includes information from other publicly available SWA-IPR tracer and hydrodynamic modeling studies, such as those completed for the City of San Diego's San Vicente and Miramar reservoirs.

1 Introduction

The purpose of this project was to develop best practices for conducting data collection, hydrodynamic modeling and tracer studies that can provide guidance to water utilities as they conduct SWA-IPR studies.

As drought continues in the western United States, an increasing number of utilities are looking to develop resilient local water supplies and augment their drinking water reservoirs with advanced treated recycled water. Recycled water is becoming an ever-larger component of water resource planning, and issues associated with measuring and modeling the mixing and dispersion of reuse water in reservoirs are becoming more prominent in the planning and implementation of sustainable and resilient solutions to water shortages.

Hydrodynamic modeling and tracer studies are required as part of the technical studies needed to assess water quality risks, evaluate feasibility of proposed SWA-IPR projects and obtain regulatory approval. Although SWA-IPR regulations may specify the minimum requirements for these studies, technical approaches currently vary based on locality and available information, reservoir configuration, water utility needs, and regulatory requirements.

This research project resulted in a Guidance Manual on how to conduct data collection, hydrodynamic modeling, and tracer studies for reservoirs to help utilities plan for SWA-IPR projects. It also includes discussion of regulatory requirements, and references SWA-IPR regulations and example SWA-IPR projects from six states. To develop recommendations for the Guidance Manual, results from SWA-IPR projects were evaluated and a tracer and hydrodynamic modeling demonstration project at Lake Arrowhead reservoir in California was used as a case study. Lake Arrowhead is owned and operated by ALA, and LACSD withdraws water from the reservoir for treatment as a potable water supply for local residents (ALA, 2021; LACSD, 2021).

Environmental and meteorological data were collected on Lake Arrowhead, and both a tracer study and hydrodynamic modeling were performed. Completed tracer and hydrodynamic modeling studies from other utilities are also included as examples throughout the Guidance Manual. This includes the City of San Diego's Miramar Reservoir tracer study, which will be used for the Pure Water San Diego SWA-IPR project (City of San Diego, 2019).

This research was funded under Reclamation's S&T program. Project partners include UNLV, WQS, LACSD, and ALA. UNLV led the data collection, tracer study, and hydrodynamic modeling efforts at Lake Arrowhead. LACSD and ALA provided significant in-kind and staff time contributions for these efforts. A subject matter expert was engaged through (WQS) to provide guidance on planning and implementation and to review results. The City of San Diego provided guidance based on their experiences completing tracer and hydrodynamic modeling studies at San Vicente and Miramar reservoirs.

Development of the Guidance Manual on tracer studies and hydrodynamic modeling was led by UNLV, with significant contributions from LACSD, WQS and Reclamation. The Guidance Manual is included, as a deliverable, in Appendix 1 of this final S&T report. The Guidance Manual provides advisory information about conducting tracer and hydrodynamic modeling studies. The intended audiences are agency managers, regulators and technical staff and consultants.

Readers are advised that appropriately skilled and sufficiently experienced professional teams are required to successfully complete the tracer and hydrodynamic modeling studies. The Guidance Manual provides overall guidance for technical components of the studies, but it does not substitute for the need to engage experienced professionals who are familiar with local conditions, regulations, engineering standards, and methods of data collection, modeling, and interpretation.

2 Methodology

The Lake Arrowhead demonstration project included data collection, a tracer study, and hydrodynamic modeling, that were used to develop the final Guidance Manual. These tasks were led by UNLV through a cooperative agreement with Reclamation. LACSD and ALA also provided significant contributions in lake access, data collection, operational support, and staff time for this project. WQS was contracted through UNLV to provide subject matter expertise. In addition, Reclamation's Technical Services Center (TSC) Hydraulic Investigations and Laboratory Services Group deployed two Acoustic Doppler Profilers (ADPs) with thermistor strings in 2019-2020.

Project data collected on behalf of Reclamation for this research will be uploaded to the Reclamation Information Sharing Environment (RISE), an open data system for viewing, accessing, and downloading Reclamation's water and water-related data (Reclamation, 2021). Data owned by other agencies/organizations (e.g., ALA, LACSD) or data that are already publicly available and were used for this project will not be published in RISE but are instead described in this Chapter.

2.1 Data Collection

Data were collected at Lake Arrowhead throughout the duration of the project to allow for development, calibration, and validation of the hydrodynamic model. These data included lake levels and inflows, water quality profiles, meteorological, water movement, and engineered infrastructure and operations data. Figure 2.1 shows a map of Lake Arrowhead with approximate locations of weather stations and ADP sites.

Data collected and/or used for this project included:

Lake Level, Inflows and Outflows

- LACSD provided:
  - historical operations data for water withdrawal rates at each drinking water intake and tertiary-treated wastewater generation rates, and
  - water withdrawal rate data at each drinking water intake for the period corresponding to the tracer study.
- ALA provided:
  - lake level data,

  - elevation data, rating curves and gate operations data for the Willow Creek spillway, and
  - gate operations data for the Grass Valley tunnel that provides inflow to Meadow Bay.
- Additional inflow, outflow, and rainfall data were obtained from U.S. Geological Survey (USGS) records that are publicly available on the USGS National Water information System website, https://waterdata.usgs.gov/nwis. Sites used included:
  - For currently operating gauges:
    - Grass Valley Lake tunnel outlet at Lake Arrowhead, CA
    - Bernina Drive Precipitation Gauge at Lake Arrowhead, CA
  - For historical records:
    - Little Bear Creek above Lake Arrowhead
    - Willow Creek below Lake Arrowhead
- Conductivity and temperature sensors were installed to monitor inflow properties to Lake Arrowhead from the Grass Valley channel and Little Bear Creek. Data collected for these sensors will be available in RISE.
- A water level logger was installed in Little Bear Creek and a barometric pressure compensation logger was installed nearby at LACSD headquarters in Blue Jay to estimate Little Bear Creek's inflows from a historical USGS rating curve, which was provided by USGS upon request. Data collected from the water level logger and barometric pressure gauge will be available in RISE.

Water Quality

- Two years of water quality monitoring data were collected by ALA using UNLV equipment for the purposes of this project, then processed and archived by UNLV. The data will be published in RISE. The data set includes:
  - Depth profile measurements of temperature, conductivity, dissolved oxygen, chlorophyll-a, photosynthetically active radiation (PAR), and pH.
- Raw water temperature, turbidity, and pH data at LACSD's two drinking water intakes were provided by LACSD.
- Background Rhodamine-like signal data were collected by UNLV in lake profiles and at LACSD's two drinking water intakes. This data will be published in RISE.
- Reclamation's TSC provided the final report from a prior two-dimensional hydrodynamic and water quality modeling study of Lake Arrowhead, titled "Hydrodynamic and Water Quality Modeling of Lake Arrowhead, California" (Bender, 2012).

Meteorological

- ALA provided historical data from its own weather station and pan evaporation data.
- Evaporation data were downloaded from the California Irrigation Management Information System (CIMIS) Lake Arrowhead Station 192 (https://cimis.water.ca.gov/WSNReportCriteria.aspx).
- UNLV installed four weather stations (see Figure 1) at Lake Arrowhead to collect 2 ½ years of wind and temperature data for use in calibrating the hydrodynamic model. Data from these weather stations will be available in RISE.
  - The UNLV weather stations were monitored through December 2020 to facilitate scenario analysis in the hydrodynamic model.

Water Movement

- Reclamation's TSC Hydraulic Investigations and Laboratory Services Group deployed two ADPs with thermistor strings (for temperature measurement) in Lake Arrowhead in April 2019. This effort provided information to develop an understanding of reservoir current patterns during mixing events caused by wind, inflows, and pumping station withdrawals.
    - A SonTek 500 kHz ADP was initially deployed mid-lake at a depth of 107 feet (see Figure 1). However, this ADP inadvertently tipped to its side during this first deployment. Although the initial data were not usable, the installation failure did provide lessons learned about deployment methods and temperature profile data from April to July 2019 were recovered. An improved installation method was developed, the mid-lake ADP was successfully re-deployed from September 2019 to January 2020 and usable data were collected.
    - A SonTek 1,500 kHz Pulse Coherent ADP (PC-ADP) was successfully deployed from a dock at the mouth of Meadow Bay (MB) at a depth of 35 feet between April 2019 and January 2020, and usable data were collected.
- Data collected from the ADP and thermistor string deployments will be available in RISE. Details on the ADP deployment can be found in Reclamation TSC's report (Vermeyen, 2020) in Appendix 2. The report recommends that vertical temperature profile data be collected in close proximity to ADP sites if ADP measurements are collected again in Lake Arrowhead.

Engineered Infrastructure and Operations Data

- Reclamation's TSC provided bathymetry data and the report from its 2008 bathymetry study of Lake Arrowhead (Ferrari, 2009). The bathymetry report and geographic information systems (GIS) data from that study are publicly available on TSC's Reservoir Surveys website (https://www.usbr.gov/tsc/techreferences/reservoir.html).
- LACSD provided:
    - GIS data of the entire lake shoreline
    - engineering drawings, location, and elevation data for its two drinking water intakes.

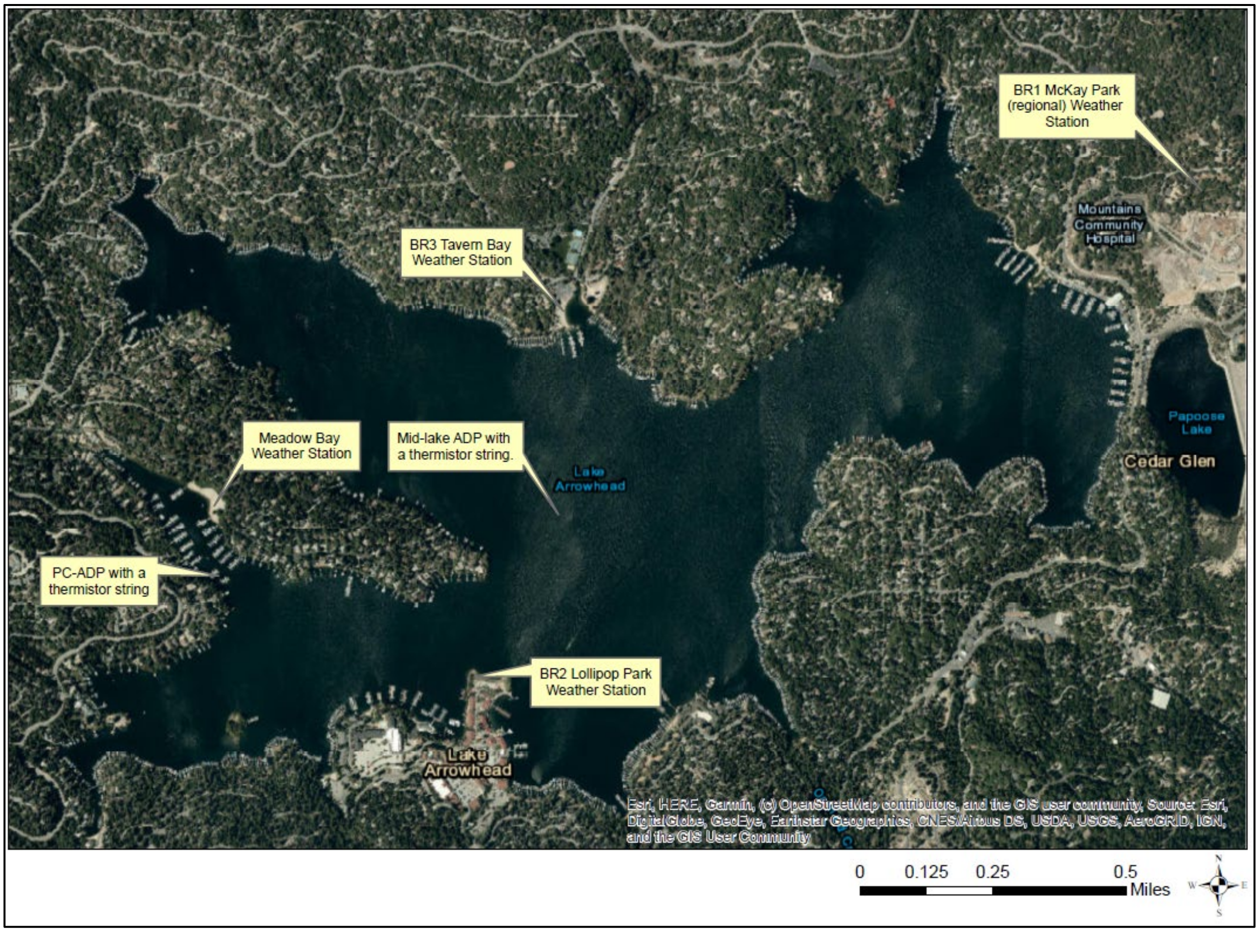

Figure 2.1. Map of Lake Arrowhead showing approximate weather station and ADP locations.

2.2 Tracer Study

A significant preparation effort was required before the tracer study could be conducted. This included operations planning and environmental compliance/approvals. Three state agency reviews (California Division of Fish and Wildlife, Division of Drinking Water, and Lahontan Regional Water Quality Control Board) were required due to Lake Arrowhead's large number of designated beneficial uses. As the lead Federal agency, Reclamation also completed a NEPA review.

A literature review and proposed tracer study methodology document was submitted in advance to the Lahontan Water Quality Control Board for their review. Additional steps taken to obtain environmental approvals for the tracer study included advance consultation with the California Fish and Wildlife Service and the State of California Division of Drinking Water. Two public meetings were held 90 days in advance of the tracer study, one with stakeholders at ALA and another at a LACSD board meeting to present the proposed methodology and obtain stakeholder and board feedback. Concerns raised at these meetings and also in meetings with ALA and LACSD operations and maintenance staff were summarized in a frequently asked questions document and then addressed in tracer study preparations. Operational steps included monitoring of tracer concentrations at each drinking water intake, and closure of the intakes during most of the tracer study. Tracer study planning and operational steps are described in the Guidance Manual (Appendix 1).

The Lake Arrowhead tracer study was completed between December 2 and December 7, 2019. It was led by UNLV in collaboration and close coordination with ALA and LACSD. Significant technical preparation steps were completed in advance of the tracer study. These included data collection, planning, design, fabrication, preparation and testing of injection and monitoring equipment, regulatory compliance, and public meetings. After preparation, UNLV arrived at the Lake on December 1, 2019, for set up and testing. The tracer injection site and sampling locations are shown in Figure 2.2.

Rhodamine WT (RWT) and sucralose were used as tracers and added to the lake on December 3, 2019. Masses of 3.9 kg each of RWT and sucralose (a value sufficient to provide a completely-mixed concentration of 0.1 ppb, the practical detection limit) were mixed with ambient lake water, diluted with additional lake water, and pumped into the lake through a diffuser at a depth of 10 meters. RWT concentrations were monitored *in situ* with depth-profiling fluorometric datalogging probes, and sucralose samples were collected with Van Dorn bottles at RWT peak concentration depths over the next 4 days. The RWT profiles and sucralose grab sample data will be available in RISE.

RWT tracer monitoring showed that the tracer mass descended to the depth of the thermocline after the first day and moved rapidly across the reservoir in two days. Due to vigorous mixing caused by two winter storms and a deep (22-23 meters) very weak (2^{o} C) thermocline, RWT concentrations had dissipated to background concentrations by mid-day on December 7, 2019, and tracer study measurements were terminated.

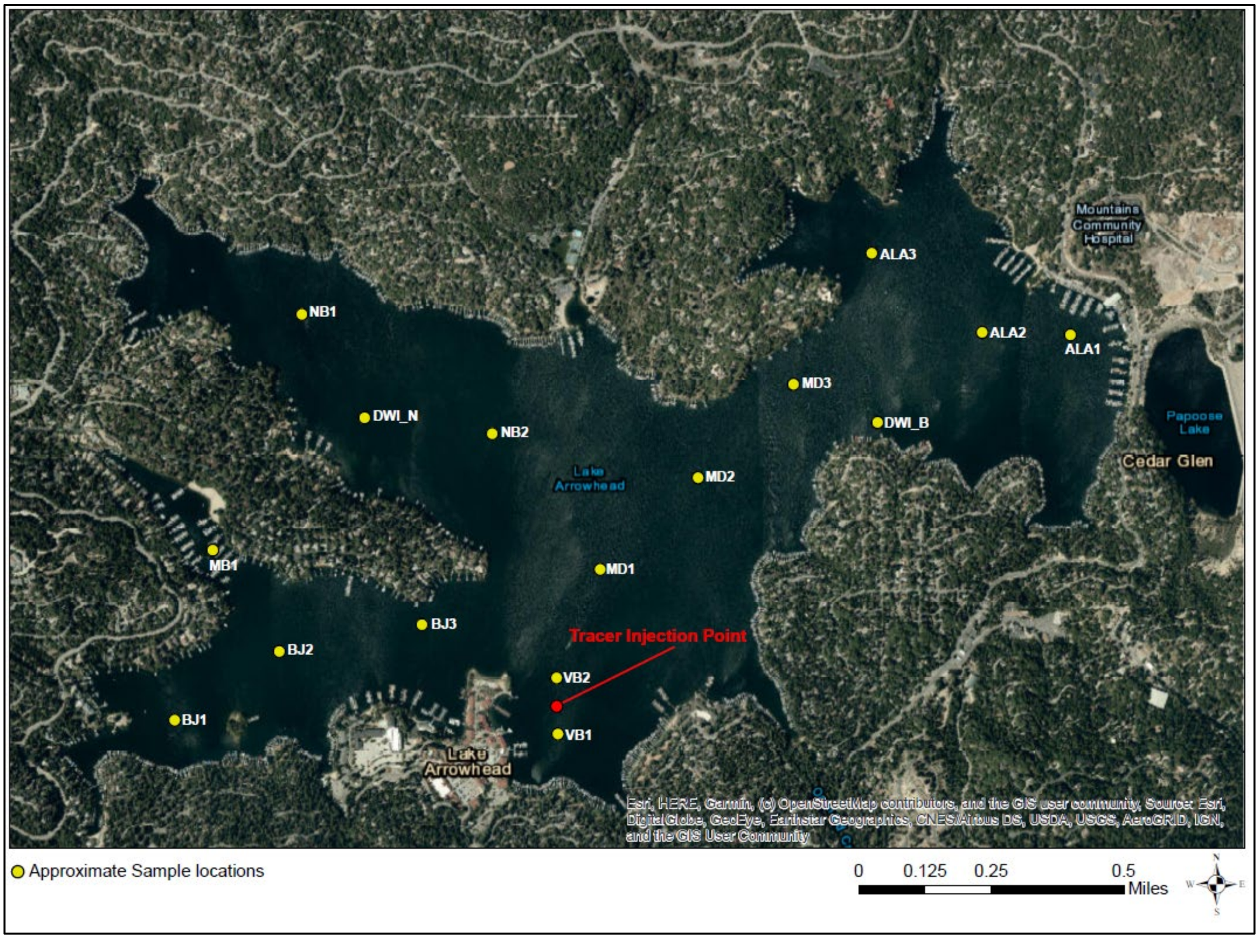

Figure 2.2 Map of Lake Arrowhead showing the approximate tracer injection point and fixed station sampling locations during the tracer study.

2.3 Hydrodynamic Model

The hydrodynamic model was developed by UNLV using the Three-dimensional coupled Hydrodynamic Aquatic Ecosystem Model AEM3D from Hydronumerics in Australia (https://www.hydronumerics.com.au/software/aquatic-ecosystem-model-3d). This model and its ELCOM-CAEDYM predecessor have been most commonly used in SWA-IPR studies.

UNLV developed the Lake Arrowhead model using gridded bathymetry derived from the 2008 Reclamation TSC study (see Section 2.1) and shoreline elevation data from LACSD. UNLV then calibrated the model with collected environmental, meteorological, and hydrologic data described in Section 2.1. The model was developed on a 30 meter x 30 meter horizontal x 0.5 meter vertical grid (about 133,000 grid cells for the entire lake) on a 3.5 GHz Intel Xeon(r) Dell Precision T3500 workstation. The gridded bottom contours of the Lake are shown on the cover photo of this report. After calibration, UNLV validated the model with the tracer study measurements (see Section 2.2 for the tracer study description).

UNLV used the validated model to compute dilutions and travel time scenarios for four representative combinations of reservoir stratification and elevation. Details on selection, set up, running the hydrodynamic model, and the four example scenarios are described in the Tracer Study and Hydrodynamic Modeling Guidance Manual in Appendix 1.

2.4 Guidance Manual

UNLV developed the Tracer Study and Hydrodynamic Modeling Guidance Manual with input from WQS, LACSD, ALA, and Reclamation. It is included as Appendix 1 in this report and is the primary deliverable for the S&T 7100 project. The manual was developed using publicly available information and literature, review of state regulations, publicly available studies from various utilities, guidance from WQS and the City of San Diego, and information and experience earned through the Lake Arrowhead case study.

3 Results

The project resulted in over two years of data collection at Lake Arrowhead, as described in section 2.1, as well as a calibrated and validated three-dimensional hydrodynamic model. Collected data, subject matter expert guidance, and thorough review of the literature and regulatory requirements allowed UNLV to develop the Tracer Study and Hydrodynamic Modeling Guidance Manual. Recommendations for water utilities based on the Lake Arrowhead case study are included throughout the guidance manual.

The primary deliverable for this project is the Guidance Manual, included as Appendix 1. The Guidance Manual covers major elements of a hydrodynamic model and tracer study, including:

- Regulatory requirements,
- Public outreach,
- Selection of a hydrodynamic model,
- Acquisition, evaluation, and formatting of model input data,
- Preparation for and completion of the tracer study,
- Calibration and validation of the hydrodynamic model, and
- Recommendations for maintenance and follow-on uses of the validated hydrodynamic model.

The Guidance Manual provides recommendations to help utilities plan and conduct hydrodynamic modeling and tracer studies for their reservoirs. Although SWA-IPR regulations may specify minimum requirements, the varying technical approaches for these studies created the need for the best management practices presented in the manual.

The intended audiences for the Guidance Manual are agency managers, regulators and technical staff and consultants. The manual does not substitute for the need to engage experienced professionals who are familiar with local conditions, regulations, engineering standards, and methods of data collection, modeling, and interpretation in these studies.

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Appendix 1 – Tracer Study and Hydrodynamic Modeling Guidance Manual

Tracer Study and Hydrodynamic Modeling Guidance Manual

U.S. Department of the Interior

June 2021

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The University of Nevada, Las Vegas's (UNLV) diverse faculty, students, staff, and alumni promote community well-being and individual achievement through education, research, scholarship, creative activities, and clinical services. UNLV stimulates economic development and diversification, fosters a climate of innovation, promotes health, and enriches the cultural vitality of the communities that they serve.

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Successful implementation of a surface water augmentation project requires collaborative services of skilled professionals. This manual provides overall guidance for technical components of a tracer and modeling study, but it does substitute for the need to engage experienced professionals who are familiar with local conditions, regulations, engineering standards, and methods of data collection, modeling, and interpretation.

Acknowledgements

The Science and Technology Program, Bureau of Reclamation, sponsored this research. UNLV completed the research and developed the resulting guidance manual. Water Quality Solutions provided subject matter expertise. The Lake Arrowhead Community Services District and Arrowhead Lake Association provided significant in-kind contributions and staff time for this research and the resulting guidance manual. We also thank the City of San Diego Pure Water project for the opportunity to participate in their summer 2019 Miramar Reservoir tracer study

Tracer Study and Hydrodynamic Modeling Guidance Manual

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Cover photo: Boat docks in Orchard Bay on the south shore of Lake Arrowhead; photo taken by David James of UNLV in August 2020

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WASP	Water Quality Analysis Simulation Program – US EPA
WRA	Water Recycling Agency
WSEL	Water Surface Elevation
WQS	Water Quality Solutions
YSI	Yellow Springs Instruments

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1 Summary and Purpose

Main points

1. This manual provides advisory information about conducting tracer and hydrodynamic modeling studies. The intended audiences for this guidance manual are:

    a. Water agency managers, where Chapters 1,2, 3 and 8 covering overview, regulatory considerations, public outreach, and recommendations would be of value, and

    b. Water agency technical staff and consultants, where Chapters 4, 5, 6, 7, and 8 covering model selection, model data requirements, tracers, and tracer studies, operating the model and conclusions and recommendations would be of value.

2. There is a need for this kind of guidance because national and international availability of potable surface water supplies is at risk from a combination of decreasing inflows and increasing population. Surface Water Augmentation by Indirect Potable Reuse (SWA-IPR) is one approach to improving water resource resiliency.

3. Agencies should employ appropriately skilled and sufficiently experienced professional teams to successfully complete the studies.

4. Planning meetings, tracer studies, model calibration and validation, uncertainty analyses and risk assessment scenarios are used to address applied research questions that water utilities must consider when conducting SWA-IPR studies.

5. Section 1.5 summarizes the technical steps described in this Guidance Manual to conduct tracer and hydrodynamic modeling studies.

6. Section 1.6 provides an overview of recommendations for successfully completing a tracer study and hydrodynamic modeling project.

1.1 Overview

The intended audiences for this manual are agency managers, regulators and technical staff and consultants.

This guidance manual is based on information from four sources:

1. A Reclamation-funded demonstration tracer study and hydrodynamic modeling project at Lake Arrowhead Reservoir, California,

2. Review of available published state regulations regarding SWA-IPR,

3. Recommendations from SWA-IPR stakeholders (ALA, City of San Diego Pure Water Project, LACSD) and from subject matter experts (Water Quality Solutions) with experience in conducting tracer studies and hydrodynamic modeling, and

4. Review of available published research literature about SWA-IPR, tracer studies and hydrodynamic modeling.

The Reclamation-funded demonstration tracer study and hydrodynamic modeling project, which took place from summer 2017 through spring 2021, included all the major project elements covered in this guidance manual, and information generated from that demonstration project is included in the following chapters. Agency managers might be most interested in Chapters 2, 3 and 8. Technical staff and consultants should consult Chapters 4, 5, 6, 7 and 8.

Chapter 2: Review of applicable regulatory requirements for SWA-IPR, and with lead participation from LACSD, submission of a request for permission to conduct the tracer study to the pertinent California regulatory body (the Lahontan Regional Water Quality Control Board).

Chapter 3: Public outreach, consisting of planning, preparation, and participation in three public meetings regarding conducting the tracer study.

Chapter 4: Selection of an appropriate hydrodynamic model for Lake Arrowhead Reservoir, in this case the AEM3D model from Hydronumerics Australia, Ltd.

Chapter 5: Acquisition, evaluation, and formatting of all needed input data to set up and run the hydrodynamic model for Lake Arrowhead Reservoir.

Chapter 6: Review of tracer candidates, development, and submission of a tracer study application to regulators, acquisition of all needed tracer measurement instrumentation, design and fabrication of all equipment needed to add tracer to Lake Arrowhead Reservoir and conducting the tracer study.

Chapter 7: Calibration of the hydrodynamic model with environmental, meteorological, and hydrologic data, validation of the model with tracer study measurements, and use of the validated model to compute dilution and travel time scenarios for different combinations of reservoir conditions.

Chapter 8: Summary, Conclusions and Recommendations.

Example data and findings from the Lake Arrowhead tracer study and modeling effort, along with results from published tracer and hydrodynamic modeling studies in other reservoirs, are referenced throughout this report.

1.2 Need for Guidance Manual and Applied Research

Given increasing populations and either fixed or decreasing water supplies, water agencies across the southern tier of the United States and across the world are seeking approaches to augment and protect surface drinking water supplies that include evaluation of options for direct or indirect potable reuse using purified water from advanced wastewater treatment plants. Hydrodynamic modeling and tracer studies are required to assess the risks associated with proposed indirect potable reuse (IPR) surface water augmentation (SWA) projects. Currently, hydrodynamic modeling and tracer studies are conducted by water utilities on a case-by-case basis. Although SWA-IPR regulations may specify the minimum requirements for these studies, technical approaches vary based on readily available information, reservoir configuration, water utility needs, regulatory requirements, and independent advisory panel requests. Reports describing these studies are delivered to a utility's stakeholders and their regulatory agencies. Although they are generally available to the public, the results are not always widely disseminated, and therefore, other water utilities seeking to implement similar projects may not be aware of them. The ability to refer to a guidance document that provides recommendations and case study information will help utilities plan and conduct hydrodynamic modeling and tracer studies of their own reservoirs.

The purpose of this document is to present recommendations for data collection, hydrodynamic modeling, and tracer studies that can guide water utilities as they conduct SWA-IPR studies in their own reservoirs. Results from a Bureau of Reclamation (Reclamation) funded case study of Lake Arrowhead Reservoir, managed by the Arrowhead Lake Association (ALA) utilized as a water supply by the Lake Arrowhead Community Services District (LACSD), as well as the City of San Diego's Miramar Reservoir study are included, in order to provide examples of implementation approaches, along with data and technical reports generated by hydrodynamic modeling and tracer studies.

1.3 Disclaimer

Utility managers are advised that successful implementation of a SWA-IPR project requires the collaborative services of many skilled professionals, including limnologists, engineers, hydrodynamic modelers, planners, water and wastewater treatment professionals, regulators and communications specialists who are familiar with local conditions and water supply needs. Therefore, this guide provides an "overall guidance" about the technical components of a SWA-IPR tracer and modeling study, but it does not serve as a substitute for the need to employ experienced professionals who are familiar with local conditions, regulations, and engineering standards.

1.4 Specific Applied Research Questions

Typical applied research questions that water utilities should consider as they look to implement hydrodynamic modeling and tracer studies, and how to address them, include:

1. What decisions, resource commitments, and timelines are required to set up, conduct, and evaluate results from environmental monitoring, hydrodynamic modeling, and tracer studies of a candidate reservoir?

   Planning meetings are held to decide upon the organizational framework, determine personnel and financial resource commitments, set goals, and establish timelines for environmental monitoring, conducting the tracer and hydrodynamic modeling studies, and reporting the results.

2. What are the overall levels of uncertainty over an annual cycle for a *calibrated* hydrodynamic model as it estimates the variations in a reservoir's energy balance, water level, and constituent concentrations?

   Calibrated model results are compared to measured environmental data, such as lake levels and water quality profiles, including temperature, light, conductivity, nutrients, and biological parameters.

3. What are the hydrodynamic model's uncertainty levels in estimating tracer travel time between injection point and the outlet, and tracer dilution after it is *validated* by a tracer study?

   Uncertainty evaluations are performed comparing the validated hydrodynamic model results to measured tracer data for environmental conditions corresponding to the tracer study.

4. What post-study steps are required to complete a risk assessment of a candidate reservoir?

   Risk assessment scenarios are computed covering long-term periods of hypothetical augmented reservoir operations per regulatory requirements and recommendations from a technical advisory panel. Summary narratives are prepared, reports, presentations and public communications are submitted to regulators, advisory panels, utility customers and all stakeholders who use the reservoir.

The above questions were considered for both the Lake Arrowhead and Miramar Reservoir case studies.

1.5 Summary

The following steps should be completed to conduct a hydrodynamic modeling and a tracer study for SWA-IPR.

1. Determine the locally applicable regulatory requirements for modeling, tracer studies, and data collection.

2. Select a hydrodynamic model appropriate for the reservoir's characteristics.

3. Collect historical inflow/outflow, water surface elevation and water quality data, along with any other information required by state/federal regulations. If water quality data are not available, establish a monitoring program and collect at least two years of water quality data.

4. Establish near-lake or on-lake meteorological stations and collect at least one year of data at high temporal resolution (e.g., 5-minute or 15-minute data). Also obtain historical information about reservoir climate (temperatures, relative humidities, wind speeds and directions)

5. Obtain reservoir surface area, volume, and bathymetry and shoreline configuration and elevation data, as well as the locations, elevations, and configurations of any inlet and/or outlet structures.

6. *Calibrate* the hydrodynamic model using the input data obtained from steps 1, 3, 4, 5, and 6 and determine calibration uncertainties in the modeled results for water levels, temperature, or conductivity profiles. For example: the normalized root mean square (RMSE) calibration errors were in the range of, 2-11% for temperature profiles, with an average of 6.1% and a 0.9-7.6% with an average of 4.2% for conductivity for Lake Arrowhead (Saber et al 2020).

7. Review candidate tracers, regulatory requirements, and associated environmental and toxicity literature; then select the appropriate tracer.

8. Develop and submit all required tracer study documentation to regulators for review.

9. Construct and test tracer addition equipment.

10. Acquire and calibrate tracer measurement instrumentation.

11. Conduct the tracer study.

12. *Validate* the calibrated model with tracer study data and determine levels of uncertainty. A successfully validated hydrodynamic model should be able to reproduce tracer travel times and attenuation rates for the studied reservoir with a low mean error. A particular reservoir's size, bathymetry, degree of stratification, and variations in weather conditions over all time scales, will significantly affect tracer travel times and attenuation rates. For example:

    a. The Rhodamine WT tracer, in a weakly-stratified Lake Arrowhead, dissipated to near background levels in four (4) days during a period of strong wind-driven mixing from a Pacific winter storm.

   b. In contrast, the same tracer, in a strongly stratified Miramar Reservoir, was detectable for nearly 90 days in generally calm, fair weather summer conditions before it dissipated (Pasek et al 2020).

13. After the hydrodynamic modeling and tracer study is completed, the next three steps include:

    a. Calculate and evaluate results of scenarios representing a wide range of weather, climate and operating conditions to compute residence times, travel times and dilutions.

    b. Generate reports and presentations intended for several target audiences, such as utility boards of directors, planning and operations, staff, utility customers and all reservoir users, and the news media. These reports should include:

       i. summaries of the results and recommended decisions, in the context of the larger community needs, for both the water utilities and reservoir users, and

       ii. the detailed methods used and the technical results, with an emphasis on estimated risks, as described in applicable federal and state regulations for utility management, technical staff, and regulators.

    c. Continue post-study meteorological and water quality monitoring of the reservoir, with updates to the hydrodynamic model input files as needed. Use the post-study data for additional scenarios as may be requested by regulators or independent advisory panels. These additional calculations may include updated risk assessments corresponding to proposed alternative configurations of recycled water inflow and water outlet structures, and worst-case combinations of weather and reservoir levels.

1.6 Recommendations

Based on the results of the Lake Arrowhead case study and review of other completed SWA-IPR tracer study and hydrodynamic modeling projects the lessons learned include:

- Required regulatory agency and regulator-requested levels of documentation can vary by jurisdiction. For example, communications for the proposed Lake Arrowhead tracer study were primarily with the State of California Lahontan Regional Water Quality Control Board, which requested a proposal to conduct the demonstration study and final report on the results. The following steps should be completed well in advance of the tracer study and documented in communications with regulators:

- Evaluate all research on prior use of models and select a hydrodynamic model that is appropriate for an agency's needs and water body.
- Obtain supporting research on the tracer's detection limits, prior use, and toxicity and select the candidate tracer and tracer measurement instrumentation.
- Design, construct, and test tracer addition equipment in advance of the tracer study, and thoroughly describe the system's design in reports to utility stakeholders and regulators.

- To *calibrate* the hydrodynamic model, establish meteorological stations as close to the reservoir as possible (ideally on the reservoir shoreline) in advance of the modeling and tracer study. Collect at least one year of records for wind, temperature, precipitation, relative humidity, and solar radiation. Combine this information with at least one year of simultaneous water quality monitoring data (Note: SWA-IPR regulations for a particular state may require a longer monitoring period). Calibrate the model by computing:
  - Reservoir water balances and comparing them to measured water levels,
  - Reservoir energy balances and comparing them to measured water temperature profiles, and
  - Conservative constituent profiles and comparing them to measured profiles.
- To *validate* the hydrodynamic model, conduct the tracer study in conditions that are representative of, at minimum, part of the reservoir's operating season. The tracer study should be of sufficient duration that allowances can be made for unanticipated meteorological or operational events. For example:
  - At Miramar Reservoir, the tracer study began in July 2019, with weather conditions representative of about half the calendar year. The reservoir was strongly stratified. The tracer study was conducted over a 90-day period in summer and early fall of 2019 and ended when the reservoir destratified and the tracer mixed up into a larger volume and was subject to photo-decay.
  - For the Lake Arrowhead study in December 2019, a prolonged winter storm that took place two-to-five days before the study, plus two more rainstorms that occurred during the study, greatly increased inflows and wind-driven lake mixing, compared to dry strongly stratified summer conditions.
  - Lake Arrowhead has a distinct rainy and snowy season, which typically occurs November through March. This is a period when Pacific frontal storms generate most of the reservoir's inflow, so tracer study conditions were representative for that

time of year. Additionally, the reservoir was weakly stratified, with the thermocline below the intake elevations.

  - The Lake Arrowhead tracer study was of sufficient duration such that, due to wind-induced vigorous vertical mixing and horizontal water movement, the tracer moved quickly towards the intakes and attenuated to background levels in a very deep epilimnion in 99 hours. Model validation runs and parameter adjustments using the tracer data generated a minimum overall root mean square error (RMSE) of 0.21 ppb and a mean absolute error of 0.10 ppb.

- Once the hydrodynamic model is calibrated and validated, perform *modeling scenarios* that cover a wide range of:

  - Combinations in the reservoir's level, stratification, and meteorological conditions, and

  - Variations in possible locations and depths, as well as inlet structures or diffuser designs and drawdown rates for water withdrawals and return rates for recycled water introduction.

  - The modeling scenarios should be statistically evaluated to assess risks to either actual, or hypothetical, drinking water intakes, using computed frequency distributions of travel time and dilution.

  - The occurrence probabilities of worst-case conditions for travel time (short) and dilution (low) should be estimated to evaluate the maximum risk to drinking water intakes.

  - In California, a second tracer study and a second model validation, required by regulations, must be conducted after project implementation to generate dilution values and residence times for all conditions for the designed recycled water treatment and inflow/mixing system.

  - Communicate results of all additional modeling efforts to regulators, public stakeholders and to agency and consultant technical staff to support decisions on recycled water system design and operations.

2 Regulatory requirements for tracer studies and hydrodynamic modeling associated with reuse

Main points

1. Conduct research about the current status on SWA-IPR project implementation, as the field is rapidly evolving. As of the mid-2021 date of this writing, SWA-IPR projects have been successfully implemented in six states: Arizona, California, Colorado, Georgia, Texas, and Virginia.

2. Evaluate the most recent state regulation revisions because SWA-IPR regulations vary considerably from state to state and are being constantly updated.

3. Prepare and present an extensive set of documentation and supporting information to address regulatory and public notification requirements.

2.1 Background – Surface Water Augmentation Indirect Potable Reuse Regulations

Drinking water supplies are protected by the federal Safe Drinking Water Act, state statutes and administrative codes that are designed to protect public and environmental health by designating water quality requirements to attain designated beneficial uses. The United States Environmental Protection Agency (US EPA) delegated designation of beneficial uses and regulations to attain and maintain those uses to the states. State agencies establish regulations and monitoring and reporting procedures to be followed by water utilities and water body managers.

Table 2.1 summarizes examples of Surface Water IPR regulations for six states and provides links to applicable codes and an example applicable SWA IPR project. Review of the six states' codes shows that California's regulations provide the most detail about:

- Processes of public notification and scientific advisory panel review,
- Required levels of pathogen removal,
- Minimum residence time for a surface water supply augmented with recycled water,
- Minimum recycled water dilutions to be attained at drinking water intakes, and
- Steps to be followed to demonstrate recycled water dilutions, specifically hydrodynamic modeling, and a tracer study.

Table 2.1 Six State Surface-Water Indirect Potable Reuse regulations and example projects

State	**Regulation Title**	**Document number, title and issue date**	**Web link**	**Example applicable project and web link**
Arizona	Title 18, Arizona Administrative Code, Chapter 9, Article 7	18 A.A.C 9 Supp 19-3, September 30, 2019	https://apps.azsos.gov/public_services/Title_18/18-09.pdf and https://azdeq.gov/recycled-water-rulemaking	Scottsdale Water. Direct and Indirect Potable Reuse https://www.scottsdaleaz.gov/water/recycled-water
California	Title 22, California Code of Regulations, Division 4, Chapter 3 and Chapter 17	SBDDW-16-02 Surface Water Augmentation Using Recycled Water October 31, 2017	https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf	City of San Diego Pure Water Project – Miramar Phase I- North City – Indirect Potable Reuse https://www.sandiego.gov/public-utilities/sustainability/pure-water-sd/northcity
Colorado	Regulation No. 84	5 CCR 1002-84 – Reclaimed Water Control Regulation	https://www.sos.state.co.us/CCR/GenerateRulePdf.do?ruleVersionId=9000	Aurora Water Prairie Waters Project - Indirect Potable Reuse https://www.auroragov.org/UserFiles/Servers/Server_1881137/File/Residents/Water/PDFs/Water%20Facts%20and%20Reports/PWP%20Fact%20Sheet.2018.pdf
Georgia	Georgia Safe Drinking Water Act O.C.G.A. §12-5-170 and Georgia Rules for Safe Drinking Water (Ga. Comp. R. &	Cited in Indirect Potable Reuse Guidance Document. March 2021, Version 1.0	https://epd.georgia.gov/media/download	Gwinnett F. Wayne Hill Water Resources Center, Chattahoochee River and Lake Lanier Discharge – Indirect Potable Reuse https://www.epa.gov/sites/production/files/2018-01/documents/potablereusecompendium_3.pdf

State	Regulation Title	Document number, title and issue date	Web link	Example applicable project and web link
	Reg. r. 391-3-5)			
Texas	Title 30, Texas Administrative Code, Part 1, Chapter 210, Chapter 290, and Chapter 321,	Chapter 210 – Use of Reclaimed Water Chapter 290 – Public Drinking water Chapter 321 – Control of Certain Activities by Rule	https://texreg.sos.state.tx.us/public/readtac$ext.ViewTAC?tac_view=4&ti=30&pt=1&ch=210 and https://www.tceq.texas.gov/assets/public/legal/rules/rules/pdflib/290d.pdf and https://texreg.sos.state.tx.us/public/readtac$ext.ViewTAC?tac_view=4&ti=30&pt=1&ch=321 and https://www.twdb.texas.gov/publications/shells/WaterReuse.pdf	Wichita Falls Resource Recovery Facility, Indirect Potable Reuse http://www.wichitafallstx.gov/691/Resource-Recovery?NID=691
Virginia	Water Reclamation and Reuse Regulations, 9VAC25-740-10 et seq,	Chapter 740	https://lis.virginia.gov/000/reg/TOC09025.HTM#C0740	Upper Occoquan Service Authority, Occoquan Reservoir – Indirect Potable Reuse https://www.uosa.org/DisplayContentUOSA.asp?ID=1021 and https://www.epa.gov/sites/production/files/2018-01/documents/potablereusecompendium_3.pdf

2.2 Become familiar with regulatory jurisdiction requirements to conduct a SWA IPR tracer study

2.2.1 Check the latest regulation revisions

Legislatures and regulatory agencies have recently been in the process of revising statutes and codes to protect public health while addressing water supply shortages. For example:

- In Arizona, the Arizona Department of Environmental Quality revised Title 18 of the Arizona Administrative Code to remove the ban on Direct Potable Reuse effective September 30, 2019 (Table 2.1).

- In California, the California State Water Resources Control Board promulgated Title 22 revisions dated October 31, 2017, in a document titled 'SBDDW-16-02 Surface Water Augmentation Regulations.docx' to establish "uniform water recycling criteria for surface water augmentation", effective October 1, 2018 (Table 2.1).

    - The final published text of Title 22, Division 4, Chapter 3, Article 1 amended existing sections and adopted new sections that include: Sections 60301.120, .851, .852, and .853 that respectively define augmented reservoirs, Surface Water Source Augmentation Projects (SWSAP, California's term for SWA-IPR projects), SWSAP public water systems, and SWSAP water recycling agencies.

    - The final published text of Title 22, Division 4, Chapter 17, Article 9, adopted sections 64668.10, .20, .30 that respectively require a water agency to apply to conduct surface water augmentation, conduct public hearings, and demonstrate minimum detention times and dilution requirements through tracer studies and hydrodynamic modeling. Specifically, the regulations state that at all times no more than 1% or 10% (depending on level of treatment) of the volume of water withdrawn for human consumption can be recycled municipal wastewater. A three-dimensional hydrodynamic model that is both calibrated to the reservoir's specific physical configuration environmental conditions and validated by a tracer study must be used to demonstrate attainment of the minimum dilution and residence time requirements that are defined in regulations.

- In Texas, Chapter 290, Public Drinking Water, Subchapter D, Sections 290.39(l) and 290.42(g) of the Texas Administrative Code, in effect since at least 2015, and incorporated in revisions effective January 3, 2019, are used by the Texas Commission on Environmental Quality to perform source water and treatability reviews of applications for "exceptions to the limited types of treatment technology approved in rule, and the use of what is considered innovate technology to treat water for potable consumption" (Texas Water Development Board, 2015).

2.2.2 Prepare supporting information

For a tracer and hydrodynamic modeling study, the organization of the owner (public or private), the permitted degree of public access, and number of overlapping government regulatory jurisdictions for the water body under consideration for SWA-IPR will all have a profound effect on the:

- Number of needed agency approvals,
- Process for approvals, and
- Timeline for approval.

For example, Lake Arrowhead Reservoir which has extensive public access and recreational beneficial uses and also provides some wildlife habitat, may require review by more agencies than a limited access reservoir and limited recreational beneficial uses that is managed primarily as a drinking water supply, such as Miramar Reservoir.

An extensive set of prior documentation is needed to obtain permission to conduct a tracer study. This may include:

- Memoranda of Understanding or other agency agreements that create the framework for conducting the tracer study,
- Communication records of regulator decisions,
- Properties of the intended tracer compound (Material Safety Data sheets) and descriptions of methods for application and detection of the tracer,
- Summary documents for public meetings,
- Memoranda regarding acceptance of liability, and
- Records of insurance policies and certificates of insurance.

The levels of needed documentation can be extensive, and the time to prepare them and obtain regulatory approvals should be included in project schedules. A tabular summary of documents associated with the 2017-2021 Reclamation-UNLV Lake Arrowhead Reservoir tracer study can be found in chronological order in Table 2.2. Selected example documents are located in Appendices 2.1, 2.2 and 2.3. Sixteen calendar months were required from the formal start of the process (Request for NPDES Pollutant Discharge Waiver) to the final step, issuance of a certificate of pollution insurance to cover the project. The tracer study was initiated on December 3, 2019, 12 days after receipt of the certificate of liability insurance.

Table 2.2 Example of timeline of steps undertaken to obtain approvals to conduct tracer study: 2017-2021 Reclamation-UNLV Tracer Study, Lake Arrowhead, California

Step description and (Document Location Appendix Number)	Requesting agency or agencies	Reviewing agency or agencies	Date
Notification of intent	LACSD	California – Lahontan Regional Water Quality Control Board	Sent: May 22, 2017
Request for NPDES Pollutant Discharge Waiver (Appendix 2.1)	LACSD	California – Lahontan Regional Water Quality Control Board	Sent: July 26, 2018
National Environmental Policy Act (NEPA) review (Appendix 2.2)[1]	UNLV (tracer study contractor) and Reclamation	Reclamation – Categorical Exclusion Study issued	Received: October 1, 2018
Memorandum of understanding to conduct and support tracer study	UNLV and Reclamation	ALA, LACSD, and Reclamation	Received: January 2, 2019
Internal review for Liability risk	UNLV	UNLV	Received: February 22 2019
California Environmental Quality Act (CEQA) determination	LACSD	LACSD - internal review	Received: February 25, 2019
Review for endangered or threatened species, scientific collecting permit	UNLV	California Fish and Wildlife Service	Received: March 7, 2019
Response to regulator questions about Pollutant Discharge waiver request	LACSD	California Lahontan Regional Water Quality Control Board	Sent: April 10, 2019
Public meeting for review of proposed study	UNLV and Reclamation	ALA and Lahontan	Conducted at ALA: August 24, 2019

[1] NEPA review may only be required if the project receives federal funding.

Step description and (Document Location Appendix Number)	Requesting agency or agencies	Reviewing agency or agencies	Date
Public workshop for review of proposed study (Appendices 2.2, 3.1, 3.2)	UNLV and Reclamation	LACSD and Lahontan	Conducted at LACSD: August 27, 2019
Request to proceed with tracer addition, NPDES permit waiver	LACSD	California – Lahontan Regional Water Quality Control Board – permit waiver not required Request for technical report	Received: October 17, 2019 Received: October 30, 2019
Insurance Policy and Certificate of Pollution Liability Insurance	UNLV	Willis Towers Watson (insurer)	Received: November 21, 2019

2.3 Prepare information to support the public decision process

This section summarizes the steps in Title 22 of the California Code of Regulations to be followed by a water agency considering implementation of SWA-IPR. In other states, interested water agencies should consult with their applicable regulators for initial tasks when initiating a surface water augmentation project.

In California, prior to permitting a reservoir as a source of supply by SWA-IPR Title 22 requires that:

- Three public hearings should be held in the area where recycled water use is proposed for the purpose of receiving public testimony,
- "...the State Water Board must ensure a project's treatment technology information is available to the public at least 10 days prior to a public hearing for a project," and
- Reports of the public meetings must be made publicly available and communicated to State Regulators.

Examples of public notification processes for three tracer study projects are shown below in Table 2.3.

Table 2.3 Public notification processes for recent tracer studies in the State of California

Agency / Agencies	Project	Notification and Hearing/Meeting process examples
ALA and LACSD	Reclamation Science and Technology Program: Evaluation of Approaches to Determine Mixing and Assimilation of Reuse Effluent	Community meeting held August 24, 2019, 99 days in advance of the December 2019 date of the proposed tracer study. Notice of public meeting held August 27, 2019, 96 days in advance of the December 2019 date of the proposed tracer study. See http://www.lakearrowheadcsd.com/special-meeting-of-the-board-lake-arrowhead-tracer-study-public-workshop-400-p-m/
Helix Water District and Padre Dam Municipal Water District	East County Advanced Water Purification Project	Fliers and social media posts to reservoir users, and October 10, 2017 San Diego Union Tribune article https://www.sandiegouniontribune.com/communities/east-county/sd-se-helix-lakejennings-20171016-story.html
City of San Diego	Pure Water Project Miramar Reservoir Tracer study	City of San Diego fact sheet, published June, 2019 https://www.sandiego.gov/sites/default/files/miramar_reservoir_tracer_study_fact_sheet_-_final.pdf

In preparing for regulator briefings, agency board members, risk managers, the public, the media, and insurers, proposing agencies and their contractors should:

- Prepare to answer a wide range of potential questions and implement operational and safety measures to minimize all possible risks, and

- Implement mitigation measures and operational solutions that minimize risks during the tracer study.

Examples of concerns raised by LACSD and ALA stakeholders at the August 26 and 29, 2019 review meetings for the Lake Arrowhead Rhodamine WT (RWT) tracer study included:

- Risks of spills and leaks during the study,

- Risks to human and aquatic organism health due to environmental exposure to the controlled application of the tracer, and
- Potential for discoloration of wildlife, boats, and docks,
- Risks of potential toxic chemical by-products from reaction with tracer and rates of destruction during water treatment, and
- Worker safety as a result of occupational exposure.

Appendix 2.4 shows a detailed summary of these topics as they were brought up in meetings and communications, along with mitigation measures and operational solutions implemented to address stakeholder concerns.

3 Public Outreach Considerations

This chapter of the Guidance Manual is limited to a discussion of the tracer study and hydrodynamic modeling portions of a SWA-IPR project. The tracer study and hydrodynamic modeling portions are parts of the larger project that include needs assessments; preliminary regulatory and public review; planning, financing, permitting and construction of advanced treatment capabilities; planning, permitting and construction of transmission and discharge/diffusion systems; and planning, permitting and construction of any modifications to drinking water intake and treatment/delivery systems.

Main points

When permitting tracer studies and conducting hydrodynamic modeling efforts, water agencies and their partners should:

1. Learn regulatory outreach requirements,
2. Limit the scope of planned communications to the tracer study,
3. Cooperate with responsible agencies to develop and implement a clear and accessible public outreach and feedback plan in compliance with requirements,
4. Prepare clear and accessible public communications materials, and
5. Conduct the outreach meetings and communicate the results to regulators and all stakeholders.

3.1 Develop and Implement a Clear and Accessible Public Outreach Plan

It is critical to the success of the project to engage the public at an early stage. Informing them about the purpose of the study and the facts of SWA-IPR will minimize misinformation in the community and give the citizens a chance to comment. Public comment will also inform the water supplier about the public’s perceptions and concerns regarding SWA-IPR in the beginning stages of the project. Elements of the outreach plan are described in Sections 3.2 through 3.7.

3.2 Learn applicable outreach requirements

When planning the tracer and hydrodynamic modeling study, a water agency and its partners should review published regulations to determine what public notification and agency review steps are required prior to conducting a tracer study. This includes requirements for:

- Number of public meetings or hearings,
- Content of the hearing information,
- State agency advance approval of the hearing information,
- Means of communication and posting of information to a repository,
- Advanced communications timing of the public meetings,
- Content of stakeholder notification, and
- Methods of communication with stakeholders.

For example, before augmentation of a reservoir, Title 22, Division 4, Chapter 17, Article 19, Section 64668.20 of the California Code of Regulations, titled "Public Hearings," released October 31, 2017, requires that a Public Water System (PWS) considering a Surface Water Source Augmentation Project (SWSAP)[2] (more universally known as SWA-IPR) perform the following:

- Conduct at least three public hearings.
  - Develop information that includes:
  - Descriptions of the proposed SWA-IPR project,
  - Identification of the municipal wastewater source for the SWA-IPR,
  - Descriptions of the treatment processes, monitoring, contingency plans, and
- Anticipated applicable California State Water Board and Regional Water Quality Control Board permit provisions.

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[2] California regulations use the term "Surface Water Source Augmentation Project (SWSAP)" to describe the generic term Surface Water Augmentation - Indirect Potable Reuse project (SWA-IPR). This manual will use "SWSAP" when referring specifically to California Title 22 regulations and "SWA-IPR" when generally discussing Surface Water Augmentation via Indirect Potable Reuse.

- Provide the information in advance to the appropriate California State Regional Water Quality Control Board (State Board).

- Place the information on an Internet Web site and in a repository such as a public library, upon approval of the information by the State Board in a manner that provides at least 30 days of public access to the information prior to the hearing,

- Notify its stakeholders and all public water systems that may receive drinking water impacted by the SWA-IPR project of:

    - The location and hours of operation of the repository,
    - The date, time, and location of the public hearing,
    - The Internet address where the information may be viewed,
    - The purpose of the public hearing and the repository, along with a brief description of the project, and
    - The manner in which the public can provide comments.

- Deliver the public hearing notification to reach all public water systems and persons whose source of drinking water may be impacted by the SWA-IPR by direct mail and by one or more of:

    - Local general circulation newspaper publication,
    - Local television or radio broadcast, and
    - Social media posts, including project web, Facebook, Instagram and Twitter pages, and other media posts as appropriate. For example:
    - The City of San Diego Pure Water project maintains an extensive and current social media presence that can be found at https://www.sandiego.gov/public-utilities/sustainability/pure-water-sd.
    - The LACSD maintains an archive of public meetings at its website, which can be searched at: http://www.lakearrowheadcsd.com/about-lacsd-2/board-of-directors/agenda-minutes/.

3.3 Limit scope of information to the tracer study and hydrodynamic modeling effort

The Public Hearings requirement in Title 22 of the California Code covers all phases of a complete SWA-IPR[3] project. The six phases are:

- Phase 1: Needs Assessment, consisting of review of historical and projected water demand, compared to available supply,
- Phase 2: Surface water body characterization, consisting of evaluation of monitoring data, tracer study and hydrodynamic modeling,
- Phase 3: Design and permitting,
- Phase 4: Construction,
- Phase 5: Commissioning, and
- Phase 6: Operations and Maintenance.

A water agency and its stakeholders can best advance a SWA-IPR project by maintaining a high level of outreach with regulators, customers, and all stakeholders during all project phases, starting with communicating the results of a Needs Assessment so that stakeholders are aware of the need to develop a resilient water supply system that can maintain water deliveries well into the future. A surface water body tracer study and modeling effort can be communicated to all stakeholders, planners, and regulators as part of the necessary process for evaluating options for developing resilient supplies.

After completing and communicating the results of the Phase 1 Needs Assessment, when a water agency is ready to advance to Phase 2 to evaluate a surface water reservoir to determine if it could be suitable for surface water augmentation, the agency and its partners should limit the scope of communications and initial permitting to the process of conducting the tracer study and developing a hydrodynamic model. This is recommended because, at the start of Phase 2, it is not yet known if the candidate water supply reservoir will achieve the state's mandated dilution targets for any augmentation water source.

All communications with regulators and stakeholders should emphasize the purpose of the tracer study and hydrodynamic modeling effort, which is to generate information that can be used to

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[3] California's Title 22 SWA-IPR terminology is Surface Water Source Augmentation Project (SWSAP)

determine if travel times from point of discharge to intakes and suitable dilutions, as may be required by applicable water regulations, can be attained in the water body.

A good additional step is to communicate that the collected tracer data and modeling efforts will be reviewed and published by an independent scientific advisory panel. In California, the Title 22 regulations[4] mandate the composition of the panel to be sure that appropriate expertise is applied to the data review. The panel should include "a toxicologist, a registered engineering geologist or hydrogeologist, an engineer licensed in California with at least three years' experience in wastewater treatment and public drinking water supply, a microbiologist, and a chemist."

3.4 Develop outreach plan, outreach materials and meeting schedule

Ahead of any advance notification window required by regulations, the organizations conducting the tracer study and hydrodynamic modeling studies should discuss the content, format and length of outreach materials with the public water system personnel with regard to the composition and interests of anticipated outreach audiences.

The water agency and its partners should work with responsible agencies to develop an outreach plan, outreach materials and a meeting schedule. As an example, early in planning for the tracer study, the California Title 22 Regulations require that public system water agency (and its partner organizations) should develop a public outreach plan that includes:

- Briefing materials,
- Public notifications of venues for public presentation and communication of the need for the proposed study,
- Description of the proposed study steps,
- Opportunities for public questions and answers, and
- Subsequent posting of written summaries of the meeting presentation and the questions and answers.

When preparing for the Lake Arrowhead tracer study, UNLV worked closely with the LACSD and the ALA as they issued advance notice and scheduled public meetings at least three months before

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[4] California Code of Regulations, Title 22. Division 4, Chapter 17 Article 9. Indirect Potable Reuse: Surface Water Augmentation, Section 60320.230 page 75

the tracer study. Meetings took place at both LACSD and ALA venues. The format and content of the briefing included:

- An information handout (Appendix 3.1),
- A public presentation by the UNLV Principal Investigator, and
- Question and answer sessions after the presentation, and
- Notices to the public providing the content, date, time, and location of the meetings were released more than 30 days in advance of the scheduled public meeting dates. After the meeting, a summary of questions raised and accompanying answers was provided to each partner agency and the Lahontan Regional Water Quality Control Board (Appendix 3.2).

3.5 Prepare information to support the public decision process

As an example of the process followed by one state, this section summarizes steps followed by California water agencies considering implementation of SWA-IPR. In other states, interested water agencies should consult with their applicable regulators when initiating a SWA-IPR project.

The following is required in California prior to permitting a reservoir for SWA-IPR. While these requirements are for the actual augmentation, they provide a useful guideline for other stages of the project, such as the proposed tracer study and hydrodynamic modeling effort.

- Three public hearings are required in the area where recycled water use is proposed for the purpose of receiving public testimony.
- The project's treatment technology information should be made available to the public at least 10 days prior to a public hearing.
- Reports of the public meetings must be made publicly available and communicated to State Regulators.

Examples of public notification and communication processes for three tracer study projects are shown in Table 2.3 of Chapter 2. Summarized here, the public notification and communication steps included:

- Press releases, social media postings and direct mailings to stakeholders and the media advising public meetings or hearings about the proposed project,
- Preparation of briefing materials and conducting the meetings per all open meeting and transparency requirements, and

- Publicly communicating to regulators, the public, and the media the questions and answers the occurred during the meetings.

3.6 Conduct outreach sessions and incorporate feedback into tracer study operations plan

Water agencies should establish a process for incorporating public concerns into the tracer study operations plan. The operations plan should include briefings for all stakeholders, including reservoir and treatment plant staff, regulators and the public that provide information about the timing and procedures of the tracer study, including boat and barge utilization, scheduling, and identities of personnel on the lake, during the study, and contact information for all participants, including mobile telephone numbers and radio call signs and channels.

To prepare for briefings before regulators, agency board members, risk managers, the public, media, and insurers, proposing agencies and their contractors should:

- Prepare to answer a wide range of potential questions, and

- Prepare a plan describing operations and safety measures to minimize risk of a spill or accidental occupational exposure that also includes spill mitigation measures and treatment plant operational solutions that minimize risks during the proposed tracer study.

For the proposed Lake Arrowhead tracer and hydrodynamic modeling study, outreach sessions were held on August 24, 2019 at an ALA membership meeting, and August 27, 2019 at a scheduled board meeting of LACSD after advance public notice was issued on each organization's web page and in the local newspapers. These two public meetings were scheduled more than three months in advance of the date of the proposed tracer study. The information handout provided at the meeting is shown in Appendix 3.1.

At each scheduled session, the responsible agency General Manager introduced the project's UNLV Principal Investigator, who demonstrated the instrumented method of tracer detection and presented information about the project. The LACSD General Manager and UNLV Principal Investigator then answered public and board questions about the proposed project. A summary of public questions and answers was prepared and distributed to the regulator (Lahontan Water Quality Control Board) per their request (Appendix 3.2).

Examples of concerns raised by stakeholders and organization staff at the August 24 and 27, 2019 review meetings for the Lake Arrowhead tracer study included:

- Risks of spills and leaks during the study,

- Risks to human and aquatic organism health due to environmental exposure to the controlled application of the tracer, and

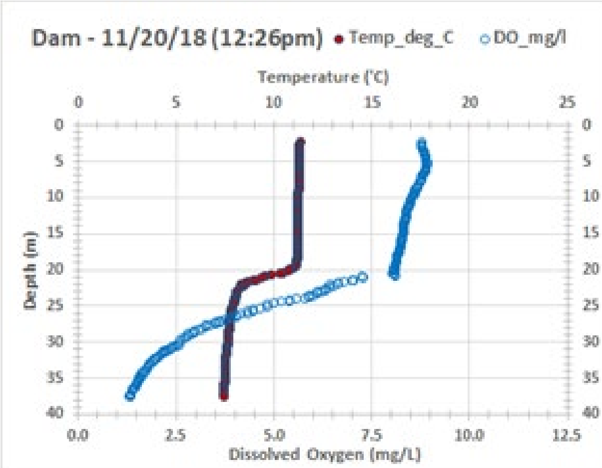
- Potential for discoloration of wildlife, boats, and docks,
- Risks of potential toxic chemical by-products from reaction with tracer and rates of destruction during water treatment, and
- Worker safety as a result of occupational exposure.

Appendix 3.2 provides details about the topics brought up in the Lake Arrowhead meetings and in other communications, along with mitigation measures and operational solutions implemented to address stakeholder concerns.

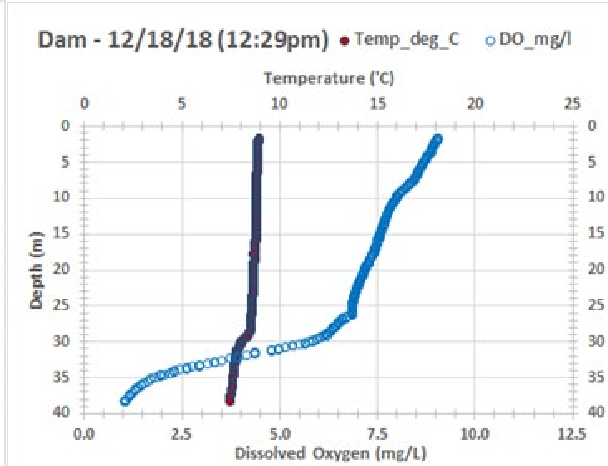
3.7 Present tracer study results to stakeholders

Technical data from a tracer study and hydrodynamic model can be complex, comprising thousands of numerical data points. Data complexity should be adjusted by the lead water agency and its project partners for different stakeholder audiences. For the Lake Arrowhead tracer study, UNLV prepared:

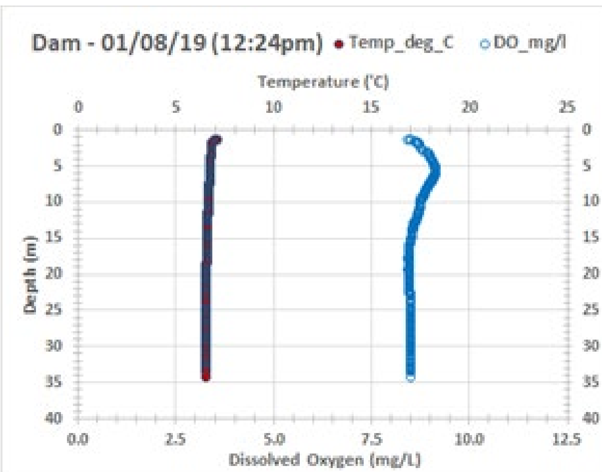
- Profile data showing evolution of limnological characteristics for technical and scientific audiences. (An example set of six depth profile plots for evolution of dissolved oxygen and temperature in Lake Arrowhead is shown Figure 3.1.
- Contour maps that color code tracer concentrations as a function of position within the boundaries of the water body. Contour maps generated for different dates and times can track tracer evolution through time as either a series of static images or as video animations. Video animations can successfully communicate movement in space and time for both general, and technical audiences. An example set of four contour plots showing modeled evolution of tracer concentrations depth and position for the December 2019 tracer study is shown in Figure 3.2.
- Tracer concentration vs depth profiles showing variations in with location at a particular point in time across a lake. These are of value for advisory panels and regulators. An example set of measured racer concentration profiles for the afternoon of December 6, 2019 is shown in Figure 3.3.



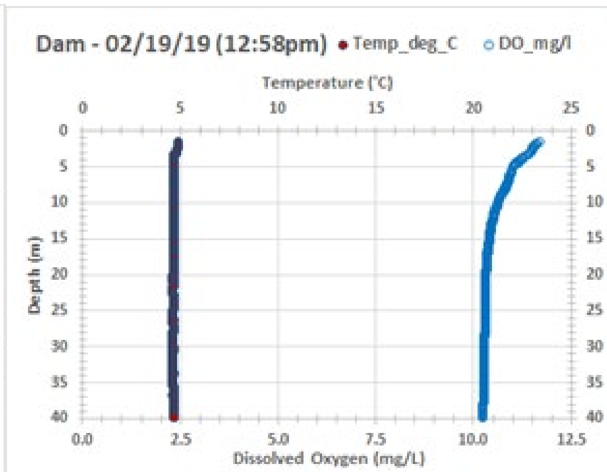
DO and Temperature vs depth profiles at Dam 11/20/2018



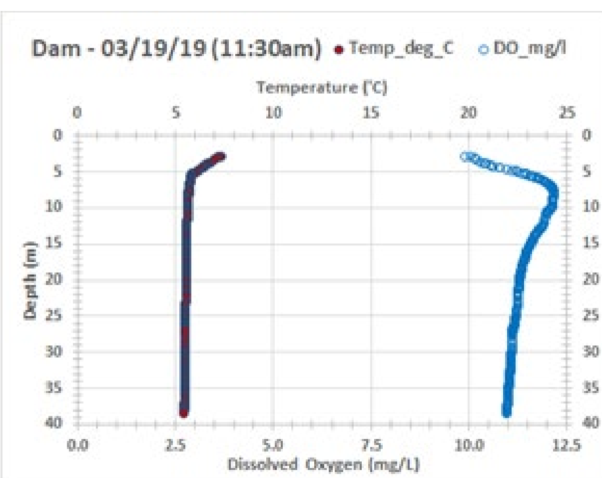
DO and Temperature vs depth profiles at Dam 12/18/2018



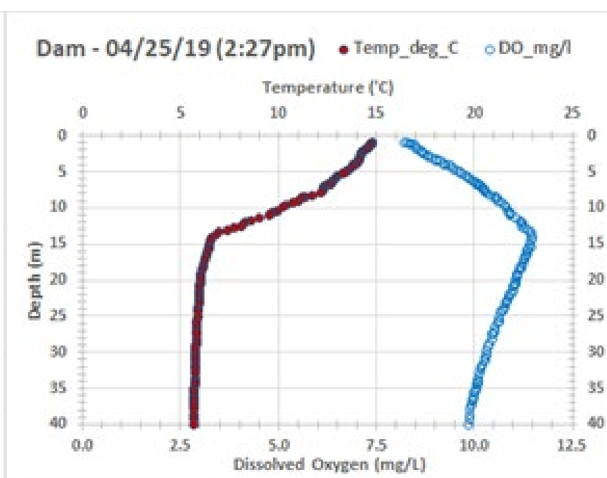
DO and Temperature vs depth profiles at Dam 01/08/2019



DO and Temperature vs depth profiles at Dam 02/19/2019



DO and Temperature vs depth profiles at Dam 03/19/2019



DO and Temperature vs depth profiles at Dam 04/24/2019

Figure 3-1 Example of Lake Arrowhead Reservoir monitoring profiles evolving from Nov 2018 to Apr 2019, near Dam showing loss of stratification in Fall and restratification in Spring. DO (blue open diamonds) is dissolved oxygen concentration. Temp_deg_C (purple) is Temperature (°C).

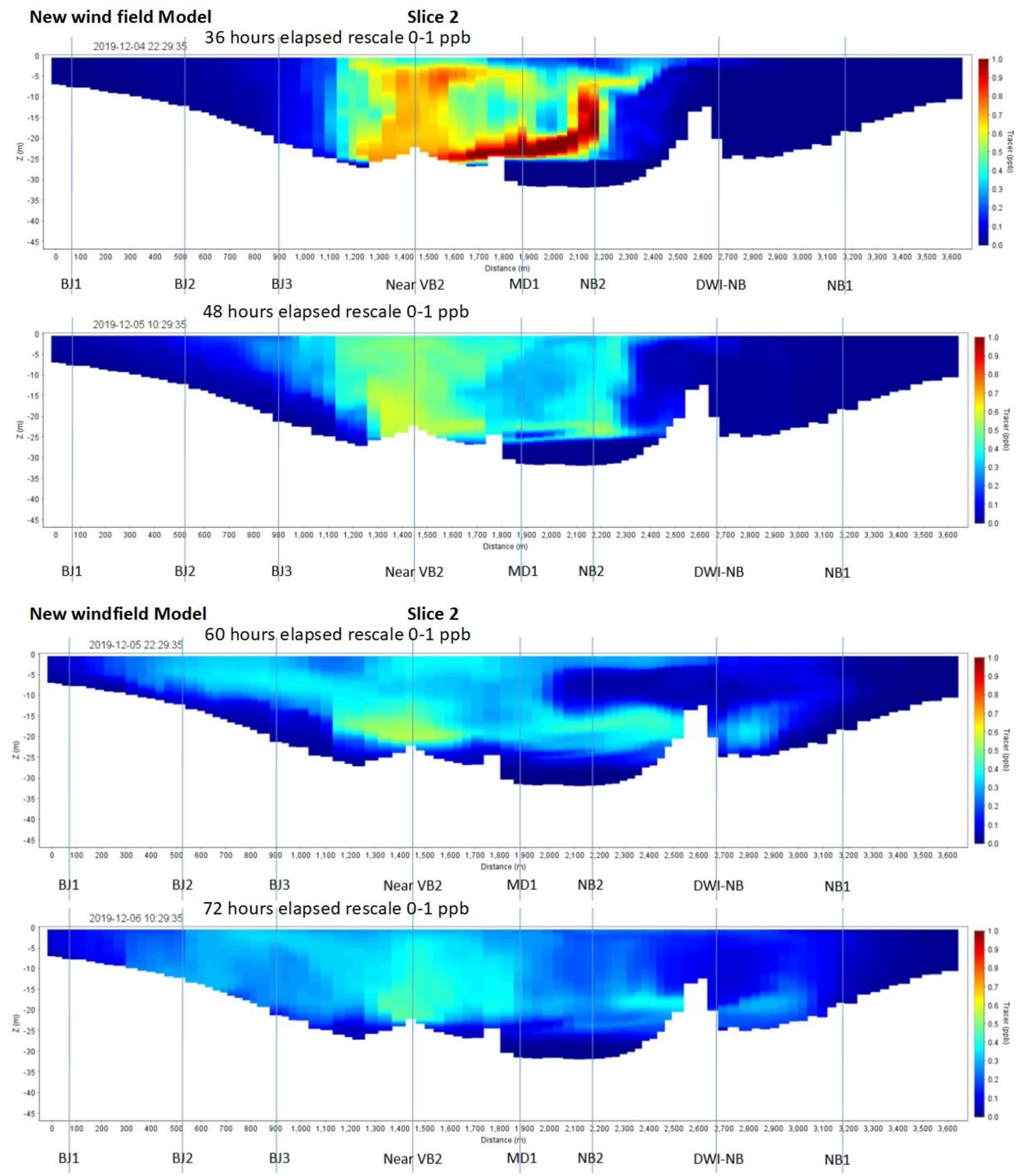


Figure 3-2 Example of modeled evolution of tracer mass concentration and movement through time along Little Bear Creek thalweg west side of lake (station BJ1) to east side of lake near Dam (station ALA2) from 1015pm Dec 4, '19 (36 hours elapsed) to 1015am Dec 6, '19 (72 hours elapsed).

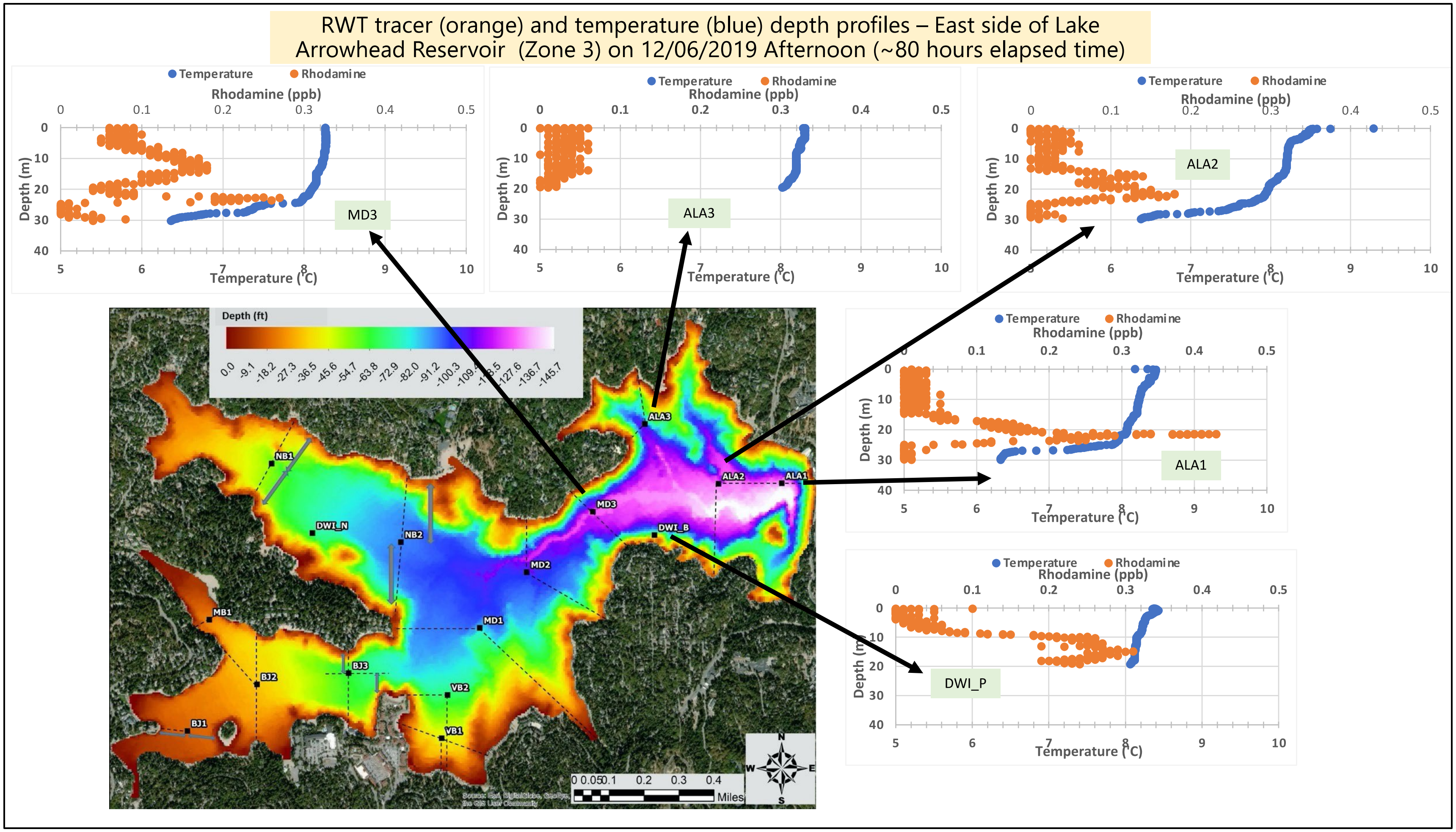


Figure 3-3 Example comparison plot of RWT tracer vs depth profiles – December 2019 Lake Arrowhead tracer study.

4 Select and set up model

Water agencies should select highly qualified teams for modeling efforts. Hydrodynamic models used in SWA-IPR studies are very complex, requiring selection, set up and operation by skilled practitioners who have solid backgrounds in fluid mechanics, limnology, numerical computational methods, water quality modeling and computational hardware. The selected modeling team must also have many years' experience in acquiring and evaluating the correct environmental data, preparing model input files, operating the models, and formatting, visualizing, and critically reviewing model results. A water agency may wish to consult with agencies that have previously completed SWA-IPR tracer and hydrodynamic modeling studies to determine how to establish criteria for review of proposing organizations' statements of qualifications and proposals.

Main points

1. Regulatory requirements to protect public health will determine nature and extent of modeling.

2. Review available models carefully. At least five well-referenced hydrodynamic/water quality models are maintained and available to model lakes and reservoirs. Of these, while all can be used successfully, AEM3D and its predecessor ELCOM-CAEDYM have been most often used for SWA-IPR studies.

3. Carefully investigate model system requirements and acquire fast, stable multicore processor workstations with error-correcting memory and back-up power supplies to conduct model calculations.

4. Model set-up requires preparation of a large number of complex input data files.

5. Perform modeling in three phases:

    a. Calibration with comparison to environmental data,

    b. Validation in comparison to a tracer study, and

    c. Once validated, run computational scenarios to simulate effects of weather, reservoir operations and seasonal changes. Use optional computational modules (for example for water quality) with caution in consultation with model developers.

4.1 Determine modeling requirements from regulations

When evaluating water agency applications to implement SWA-IPR, regulatory agencies, either by statute or letters of decision, will require a water agency to demonstrate by hydrodynamic modeling and tracer studies that specific minimum retention times and dilutions are met at all times to protect public health. For example, the State of California Regulations for Surface Water Augmentation Using Recycled Water (Title 22, Division 4, Chapter 17, Article 9) shown in Table 4.1, state that no more than 1% or 10% of the volume of water withdrawn for human consumption can be recycled municipal wastewater at all times. The percentage depends on level of removal of pathogens from the recycled water. A three-dimensional unsteady computational hydrodynamic model that is both *calibrated* to the reservoir's specific physical configuration environmental conditions and *validated* by a tracer study must be used to demonstrate attainment of the minimum dilution requirements that are defined in regulations.

A three-dimensional unsteady computational coupled hydrodynamic model and water quality model is needed because surface water reservoirs are constantly changing in response to seasonal variations and short-term meteorological conditions. Seasonal changes in reservoir stratification, operational and seasonal changes in reservoir elevation, and variations in wind speed and direction can all considerably affect the rates and directions of water movement and the extent of vertical mixing. These seasonal and short-term variations, coupled with temporal and spatial variations in the rates and locations of water and constituent inputs and water withdrawals, all combine to considerably affect the rates of transport and attenuation of potential contaminants from locations of entry to points of withdrawal. Steady-state well-mixed or two-dimensional models are not able to adequately describe these potential variations at a level of resolution sufficient to evaluate risks at drinking water intakes.

Table 4.1 California Title 22 dilution and retention time requirements for SWA-IPR

Code information	Web link	Paraphrased or "quoted" text
Title 22, Chapter 17, Article 9, Section 64668.30(b)	https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf	**Retention time** (p.28) ".. An initial approved minimum theoretical retention time may be no less than 180 days..." p.27 A water agency may apply for approval for an alternative minimum theoretical retention time of less than 180 days but no less than 60 days, provided that treatment objectives can be reliably met, provide data about maximum anticipated recycled municipal wastewater flow, and maximum percent by volume of recycled municipal wastewater that will be delivered during any 24 hour period, and for proposed alternative minimum theoretical retention times less than 120, days, no less than an

Code information	Web link	Paraphrased or "quoted" text
		additional one log_{10} reduction of pathogens beyond otherwise required in the regulations..."
Title 22, Chapter 17, Article 9, Section 64668.30(c)	https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf	**Tracer studies and hydrodynamic modeling** (pp. 28-29) The water agency shall demonstrate to the Calif. State Board that "at all times under all operating conditions, the volume of water withdrawn from the augmented reservoir to be ultimately supplied for human consumption contains no more than: (1) one percent, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-hour period, or (2) ten percent by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-hour period, with the recycled municipal wastewater delivered by the SWSAP WRA [Surface Water Source Augmentation Project Water Recycling Agency] having been subjected to additional treatment producing no less than a one log_{10} reduction of enteric virus, *Giardia* cysts and *Cryptosporidium* oocysts...."

4.2 Review available water quality models and data reduction/visualization software

At least five well-maintained computational codes are available to conduct unsteady three-dimensional hydrodynamic/water quality modeling of reservoirs for SWA-IPR (Table 4.2).

Surface water reservoirs that serve, or will serve, as potable water supplies, such as San Vicente Reservoir (San Diego, CA) (Ding, L., Hannoun, I.A., and List, E.J. (2012a, 2012b, 2012c)), Miramar Reservoir (Hannoun, 2017, Pasek et al, 2020), or Lake Mead (Preston et al, 2014a, 2014b) have been successfully simulated with coupled three-dimensional unsteady hydrodynamic-water quality models such as the Estuary, Lake and Coastal Ocean Model with Computational Aquatic Ecosystem DYnamic Model (ELCOM-CAEDYM), originally developed at the University of Western Australia, or its continued development, the Three-Dimensional coupled Hydrodynamic-Aquatic Ecosystem Model (AEM3D, Hydronumerics, Australia).

Other models that have been used to successfully model lake circulation include:

- DELFT-3D and DELWAQ, from the Netherlands, which have been used to model lakes in Italy and the Congo (Amadori et al 2021, Kranenburg et al 2020),
- US EPA's Environmental Fluid Dynamics Code (EFDC) model, which has been used to model a large urban reservoir, Lake Tianyinhu, in China (Gong et al, 2016),
- DHI's MIKE 21/3 model, which has been used to simulate Donghu Lake in China (Li et al, 2020), and
- US EPA's Water Quality Analysis Simulation Program (WASP) which has been used to model a water supply reservoir in Henan, China (Huang et al, 2010).

All of the above-described models can be configured to successfully model lakes and reservoirs. The selected modeling team should be highly experienced in the set-up and implementation of one of the models.

Table 4.2 Examples of currently maintained 3D unsteady hydrodynamic-water quality models

Model Acronym	Model description resources	Maintaining Organization and Web address:	Examples – surface water reservoirs simulated
Current AEM3D	Hodges & Dallimore, 2021 https://www.hydronumerics.com.au/software/aquatic-ecosystem-model-3d	Hydronumerics, Victoria, Australia https://www.hydronumerics.com.au/software/aquatic-ecosystem-model-3d	Miramar Reservoir, CA (Hannoun, 2017) https://www.sandiego.gov/sites/default/files/appendix_g_water_quality_modeling_of_miramar_reservoir.pdf (Pasek et al, 2020)
Predecessor ELCOM-CAEDYM[5]	Hodges and Dallimore (2013) https://doczz.net/doc/6541060/estuary--lake-and-coastal-ocean-model--elcom-v2.2-science...	(no longer available)	Lake Mead, AZ, NV (Preston 2014a, 2014b) San Vicente, CA (Ding et al, 2012a, 2012b, 2012c)
DELFT-3D and DELWAQ	https://oss.deltares.nl/web/delft3d/about	https://oss.deltares.nl/web/delft3d/	Lake Garda, Italy (Amadori et al 2021) Lake Kivu, Congo (Kranenburg, et al 2020)

[5] Note, ELCOM-CAEDYM, while used and described in published articles and reports covering SWA-IPR in reservoirs, is no longer available. Its successor is the currently available AEM3D model, that is maintained by the developers of ELCOM-CAEDYM (Hodges and Dallimore, 2021).

Model Acronym	Model description resources	Maintaining Organization and Web address:	Examples – surface water reservoirs simulated
EFDC	https://www.epa.gov/ceam/environmental-fluid-dynamics-code-efdc#Introduction	US Environmental Protection Agency https://www.epa.gov/ceam/environmental-fluid-dynamics-code-efdc#Audience	Lake Tianyinhu, Nanjing, China (Gong et al, 2016)
MIKE 21 3 Flow Model FM	Mike 21/3 Coupled Model FM User Guide (DHI, 2017) https://manuals.mikepoweredbydhi.help/2017/Coast_and_Sea/M21HD.pdf	DHI Worldwide https://www.mikepoweredbydhi.com/products/mike-21-3	Donghu Lake, Wuhan, China (Li et al, 2020)
WASP	https://www.epa.gov/ceam/water-quality-analysis-simulation-program-wasp	US Environmental Protection Agency https://www.epa.gov/ceam/water-quality-analysis-simulation-program-wasp#model.	Nanwan Reservoir, Henan, China (Huang, et al, 2010)

Per the cited published literature, each of the five above-described models has been used for unsteady three-dimensional water quality modeling in lakes and reservoirs. Of these models, agency reports and research literature published to date show that ELCOM-CAEDYM and AEM3D have been used to model SWA-IPR in water supply reservoirs. Two possible reasons for the use of these models for SWA-IPR are:

- Validation of model accuracy using tracer studies (Ding et al 2012a, 2012b, Hannoun 2017, Pasek et al, 2020), and
- Extensive published successful comparisons of results to measured data for complex stratified water bodies, including:
    - Boulder Basin, Lake Mead, AZ-NV, (Preston et al, 2014a, 2014b)
    - Lake Constance (Germany, Austria, Switzerland, Appt et al 2004),
    - Lake Kinneret (Israel, Laval et al 2003),
    - Miramar Reservoir (Pasek et al, 2020), and
    - San Vicente Reservoir, (CA, Ding et al 2012c).

4.3 Determine model system requirements and acquire workstation(s)

A water agency or its contractors should determine computing system requirements to successfully run the model before commencing a hydrodynamic/water quality modeling project.

In general, model computational requirements, such as time to complete the calculations, memory needed to hold code and data during calculations, and data storage, increase with:

- Size and complexity of the modeled water body,
- Number of constituents and processes to be modeled,
- Decreasing physical spatial grid cell sizes and time step durations, and
- Increasing duration of the desired modeling period.

Long computational runs at high spatial resolutions for medium-size water reservoirs can place heavy continuous workloads on workstations. For example, UNLV (Saber, personal communication (2020)) found that AEM3D run times for the 60 million cubic meter Lake Arrowhead Reservoir were 36 hours for three-month simulations using 30 m x 30 m x 0.5 m grid cells (about 133,000 grid cells for the entire lake) on a 3.5 GHz Intel Xeon(r) Dell Precision T3500 workstation. Model grid cell counts can be much higher and run times much longer for smaller grid sizes or larger reservoirs and can greatly burden computing resources. Use of ECC memory is strongly advised to minimize risk of data corruption during high resolution long duration simulations that can require many hours, days, or weeks of computational run time.

To minimize the risk of model computational errors, water agencies and their water quality modeling contractors should carefully examine model documentation for information about the model's physical approximations and numerical integration approaches as they consider combinations of grid cell size and time step duration when preparing both model input files and model run-time files to be sure that a feasible set of conditions has been established for the model. Modelers should also carefully review model outputs for errors. Agencies are strongly advised to select well-qualified, experienced, and well-resourced teams for modeling efforts.

Model instruction files that are input at the start of a model run can increase modeling speed and decrease required run times if a workstation's CPU and operating system allow for parallel computations. For example, for the AEM3D model, a user can establish up to eight parallel threads that can reduce computation time and thereby speed up the completion of multiple case modeling scenarios.

For medium-sized reservoirs such as Lake Arrowhead (Saber et al, 2020) or large reservoirs like Lake Mead (Preston et al 2014a, 2014b), fast dedicated workstations equipped with processors able to run parallel computational threads, along with sufficient Error Correction Code (ECC) memory, large fast hard drives, or solid-state drives and backup power supplies will be needed. For example, although the current compiled version of the AEM3D model will run on many 64-bit Intel or AMD processors, the User Guides for ELCOM-CAEDYM (Laval and Hodges, 2000, Hodges and Dallimore, 2013) and AEM3D (Hodges and Dallimore, 2021) are generally silent on computer system hardware requirements for rapid, stable, and repeatable numerical modeling. Well-qualified and experienced modelers should be consulted regarding computing requirements. For example, general guidance from Hannoun (personal communication, 2018) for using the AEM3D model is to use the most recent generation multicore processors with large internal caches that can address ECC memory, with at least 16 gigabytes of ECC RAM memory, and very large (at least one [1] terabyte) fast hard drives or solid-state drives. It is strongly recommended to specify professional-grade workstations with robust system cooling, redundant disk drives, and high-wattage power supplies with back-up power to avoid data loss in case of power failure.

Because of the models' complexities, agencies and contractors are strongly urged to engage the services of well-qualified, experienced modeling experts to select the computer hardware, prepare input data and run the models. Significant modeling errors can occur if incorrect inputs or incorrect run time files or inappropriate hardware are used.

4.4 Prepare input files for the model

Many input files, obtained from a variety of sources, are needed to prepare a coupled hydrodynamic-water quality model for successful operation. Needed data are summarized in broad categories in Table 4.3**.**

Table 4.3 Examples of inputs needed to develop a 3D unsteady hydrodynamic model

Data category	**Examples**	**Information needed for**
Positional data	Gridded bathymetry Shoreline geometry	Establishing lake hypsographic curves (volume and area vs elevation)
	Digital elevation data for watershed areas and slope	Quantity of point and nonpoint inflows
	Inflow locations and elevations, Outflow locations and elevations	Locations for inflowing and outflowing waters in model grid
	Locations of any other engineered appurtenant works (mixing systems, diffusers)	Identifying other sources of mixing and constituent addition
Environmental data	Meteorological data	Initializing model, computation of energy balance (solar energy, air temperature, relative humidity) and forcing inputs for water motion (wind speed and direction)

Data category	Examples	Information needed for
	Water quality profile data	Provide comparison data for calibrating model
	Tracer data	Provide basis for adjusting inputs and settings when validating model
	Inflow water quantity and quality data	Provide inputs for initializing model for calibration, validation and scenario runs
	Contaminant data from water quality grab samples	Provide comparison data for calibrating model
Engineering and operations data	Historical and anticipated schedules of operation and rates/amounts of inflow and outflow from reservoir.	Provide inputs for water motion (inflows and outflows) for model calibration
	Historical water level data	Provide comparison data for calibration of hydrodynamic model
	Historical and anticipated levels of contaminant removal and contaminant concentrations for candidate recycled water system	After validation to provide correct input conditions for model scenario runs
	Planned changes to water systems regarding surface water augmentation of reservoir	After validation to provide correct input conditions for model scenario runs
Regulatory data and reports	Designated Beneficial Use Standards and history of attainment/non-attainment of standards	After validation, to compare model outputs to water quality standards when conducting model scenario runs
	Agreements and Records of Decision regarding permitted water withdrawals and inflows and history of attainment	After validation, to provide correct input conditions when conducting model scenario runs

The first two categories in Table 4.3, positional data and environmental data, are essential to set up the model and conduct initial computational trials. User guides for hydrodynamic models provide tables of needed files that are required or optional for modeling purposes.

Modeling manuals also describe the types of control or run-time files needed to start a simulation. The control or run-time files can specify information such as start date, end date, parallelization, and time step size that all have considerable influence on both the time needed to run the model and accuracy of the results.

Agencies and qualified modeling contractors are urged to consult the most current edition of the model's manual or user guide to determine both input file and run-time file requirements and options.

4.5 Conduct modeling runs, reduce data, and generate visualizations and error analyses

Users should refer to the model's manual or user guide for the method of specifying run-time options that will determine how the calculations will be performed, and also turn on or off different water quality calculation modules, depending on the desired type of simulation.

Generic examples of modules that can be turned on or off are shown in Table 4.4. For more detailed descriptions of all module options, users should refer to the appropriate sections of their model's manual or user guide.

Table 4.4 Examples of hydrodynamic/water quality model modules that can be turned on or off at run-time

Simulation module	Information needed and example uses
Density stratification	Temperature and salinity specified in initial condition files and used to include or eliminate density terms from the calculations.
Tracers	Provide information about the timing, location, and inflow rates of tracers.
Wind	The user can either apply a uniform wind speed and direction on the reservoir surface or declare multiple fields on different sections.
Optional simulation module	**Information needed and example settings**
Chemical transformations and decay	The modeler can turn on or off water quality calculations regarding transformation and uptake of nutrients or settling and chemical or photochemical decay of constituents.
Microbial survival and decay	The user can specify decay rate coefficients for pathogenic microorganisms of concern, such as *Giardia*, *Cryptosporidium*, and enteric viruses.

Model users are strongly advised to work with the model's software developer to verify the performance of any additional simulation modules that they wish to incorporate into their model runs. Some optional modules may not yet have been extensively validated in reservoir modeling studies. Experienced modelers should critically review all module outputs to determine if model codes are functioning properly.

Model development for a particular reservoir under consideration for SWA-IPR occurs in three phases, as summarized in Table 4.5. The phases and steps below are intended as a general guide for water agencies to illustrate the modeling process and are not meant to serve as a book of recipes. Experienced modelers under contract to the water agency will carry out the phases and steps in a manner appropriate to their specific model and reservoir.

Table 4.5 Major Hydrodynamic modeling phases for SWA-IPR projects

Model phase	Description of steps
Calibration	1. Prepare input files with environmental, hydrological shoreline and bathymetric data. 2. Conduct initial runs to model lake energy balances and water levels. Model runs can be of long duration (three to six months) to evaluate the model's ability to successfully emulate seasonal changes in lake level, thermal structure, and conservative constituent distributions. 3. Compare model results to measured data and compute errors. 4. Evaluate errors and adjust model input files. Repeat modeling runs until errors are minimized.
Validation	1. Conduct tracer study and collect tracer profiles. 2. Initialize the calibrated model a few weeks ahead of the tracer study period and verify that modeled energy balance and reservoir level conditions at start of tracer addition match observed conditions. 3. Run calibrated model for specific conditions (to input and movement of tracer compound until measurements show tracer has dissipated). 4. Compare modeled to measured tracer concentration profiles and compute errors. 5. Evaluate errors, adjust model input file values, and repeat until computed tracer concentration errors are minimized.
Scenarios	After review and acceptance of the validated model, use the model to compute distributions of constituent travel times and dilutions at designated water withdrawal locations for modeling scenarios that represent combinations of different values of lake level, lake stratification, timing, locations, elevations and rates of proposed recycled water inflows; timing, rates, and elevations of outflows; wind speed, direction and insolation; and contaminant concentrations and decay rate constants if applicable.

Several approaches are commonly used to visualize model outputs. They are summarized in Table 4.6. Experienced modelers will use specific software tools to generate the appropriate visualizations for professional communications, regulatory review, and public presentations.

Table 4.6 Example model data visualization approaches

Type of representation	Reason for representation	Examples
Profiles with depth	Determine ability of model to accurately represent lake stratification conditions	Comparison of modeled tracer profile vs depth to measured profile vs depth (Figure 4.1)
Profiles with time	Determine accuracy of model predictions compared to measurements	Analysis of computed lake water level compared to measured water level (Figure 4.2)
Scatter plots	Overall analysis of modeled values vs measured data	Comparison of all lab-measured tracer concentrations (y-axis) to field measured tracer concentrations (x-axis) with computed correlation coefficient (Figure 4.3)
Contour map	Rapid visualization of modeled values in two spatial dimensions	Plan view tracer constituent concentration distribution across a lake at particular depth and particular point in time (Figure 4.4) Vertical cross section tracer constituent concentration as function of longitudinal position and depth along the reservoir thalweg at a particular point in time (Figure 4.5)

Water agencies are advised that generation of visualization displays such as high-resolution, contour maps or animations of tracer movement requires use of specialized scientific analysis and graphing software packages, such as Tecplot360®, MATLAB®, R, SigmaPlot®, or SURFER®. Because there are many options for visualization, and often there are specific forms of data presentation required by regulators to document modeled reservoir performance, experienced personnel should be engaged to visualize results for regulatory and scientific review.

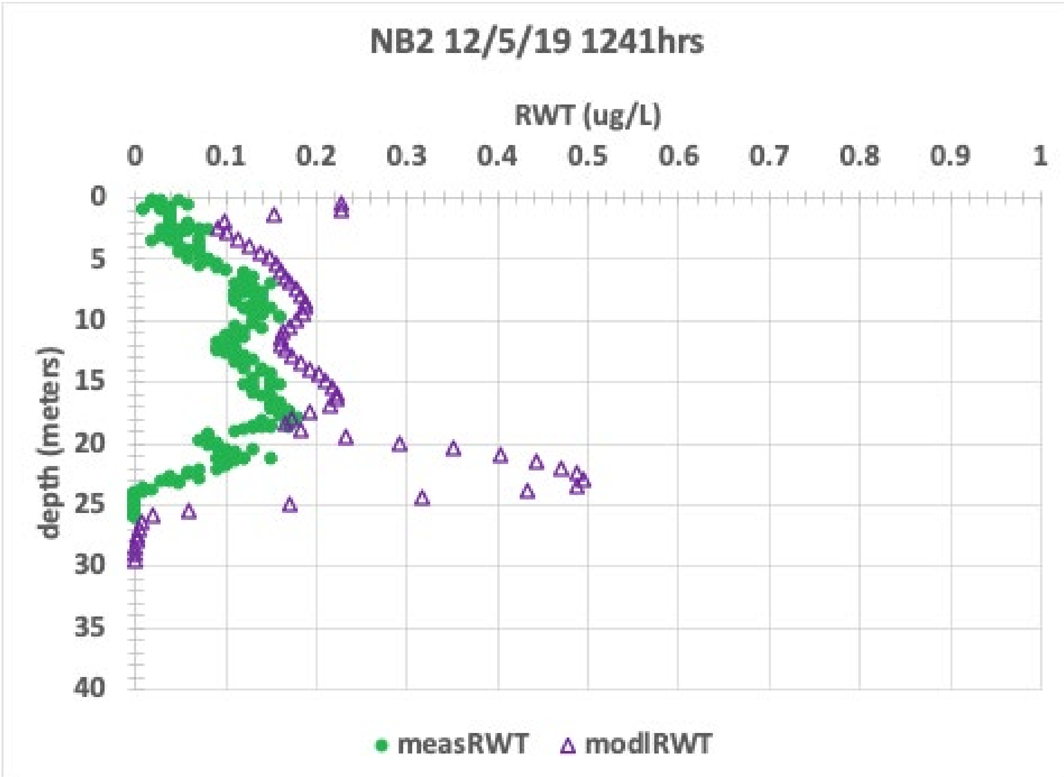


Figure 4-1 Example comparison plot of measured (green crosses) and AEM3D modeled (purple circles) tracer concentration profile with depth during the December 2019 Lake Arrowhead tracer study. Station North Bay 2 (NB2).

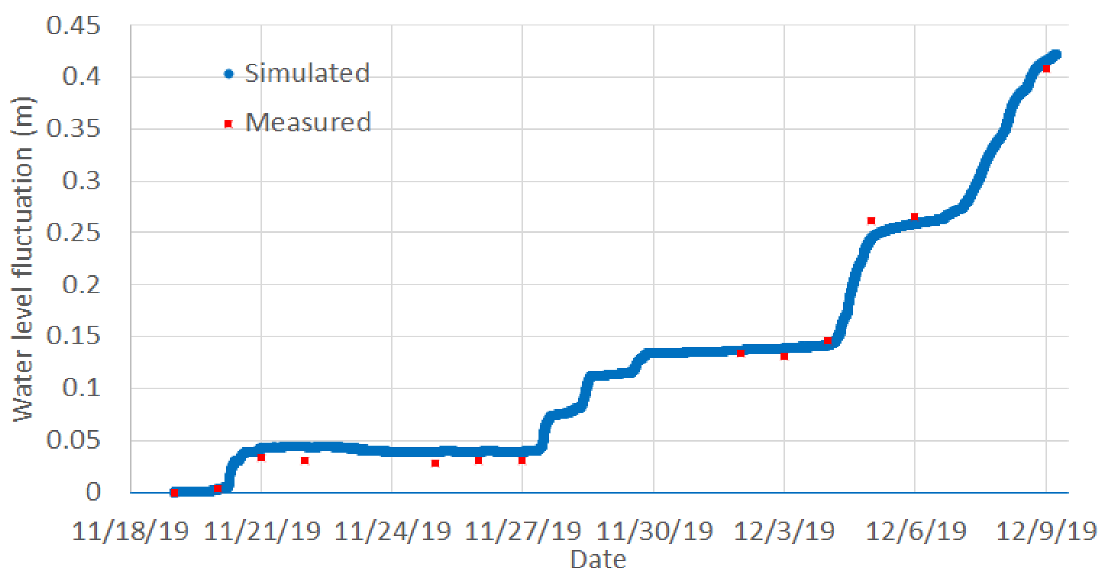


Figure 4-2 Example model calibration three-week time series plot comparing measured Lake Arrowhead Reservoir elevations to AEM3D simulated elevations using lake water and energy balance data covering the period of December 2019 Lake Arrowhead tracer study.

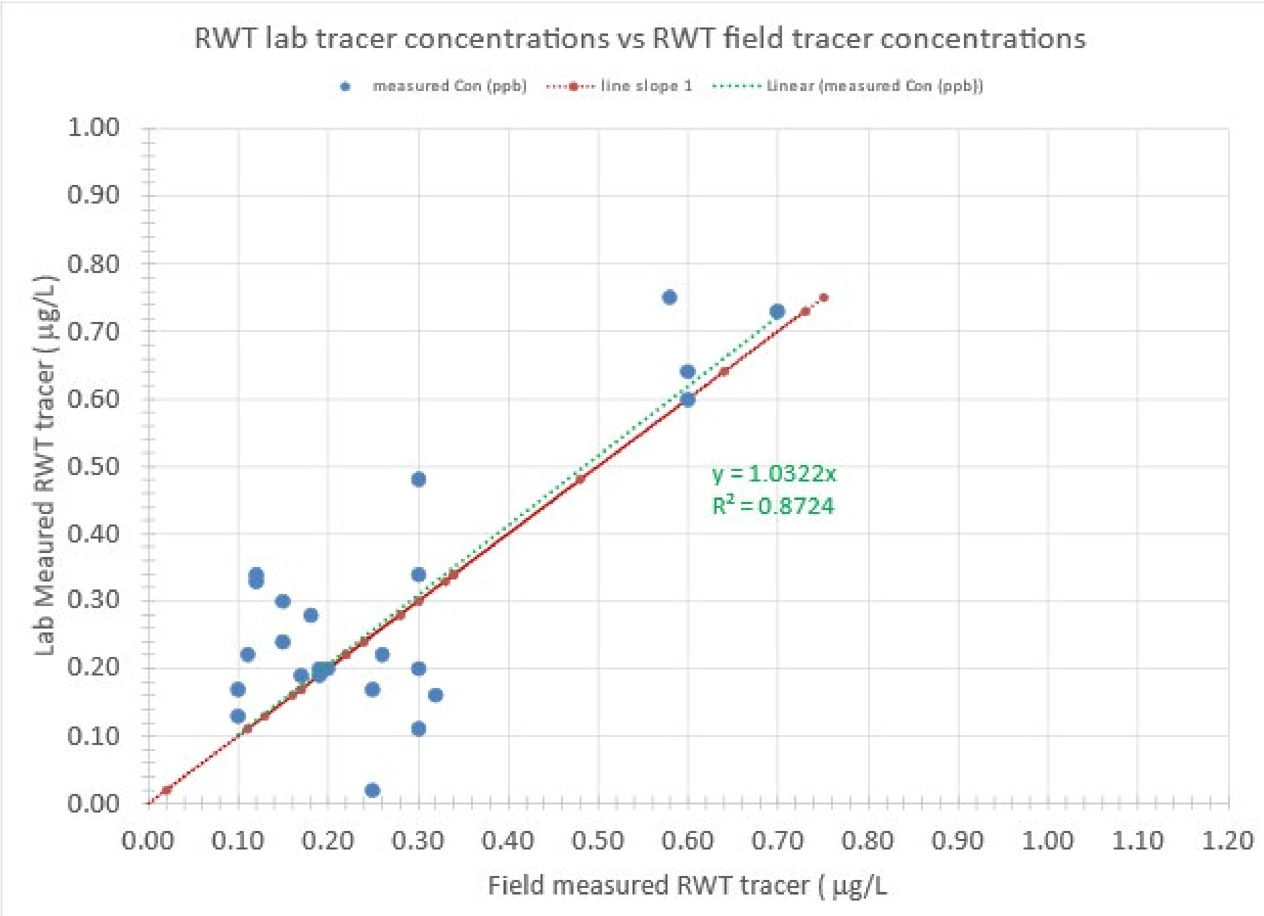


Figure 4-3 Example scatter plot comparing Van Dorn bottle lab-measured RWT samples (y-axis) collected at the depth of the in-situ field measured fluorometric RWT tracer peak concentrations (x-axis). December 2019 Lake Arrowhead tracer study.

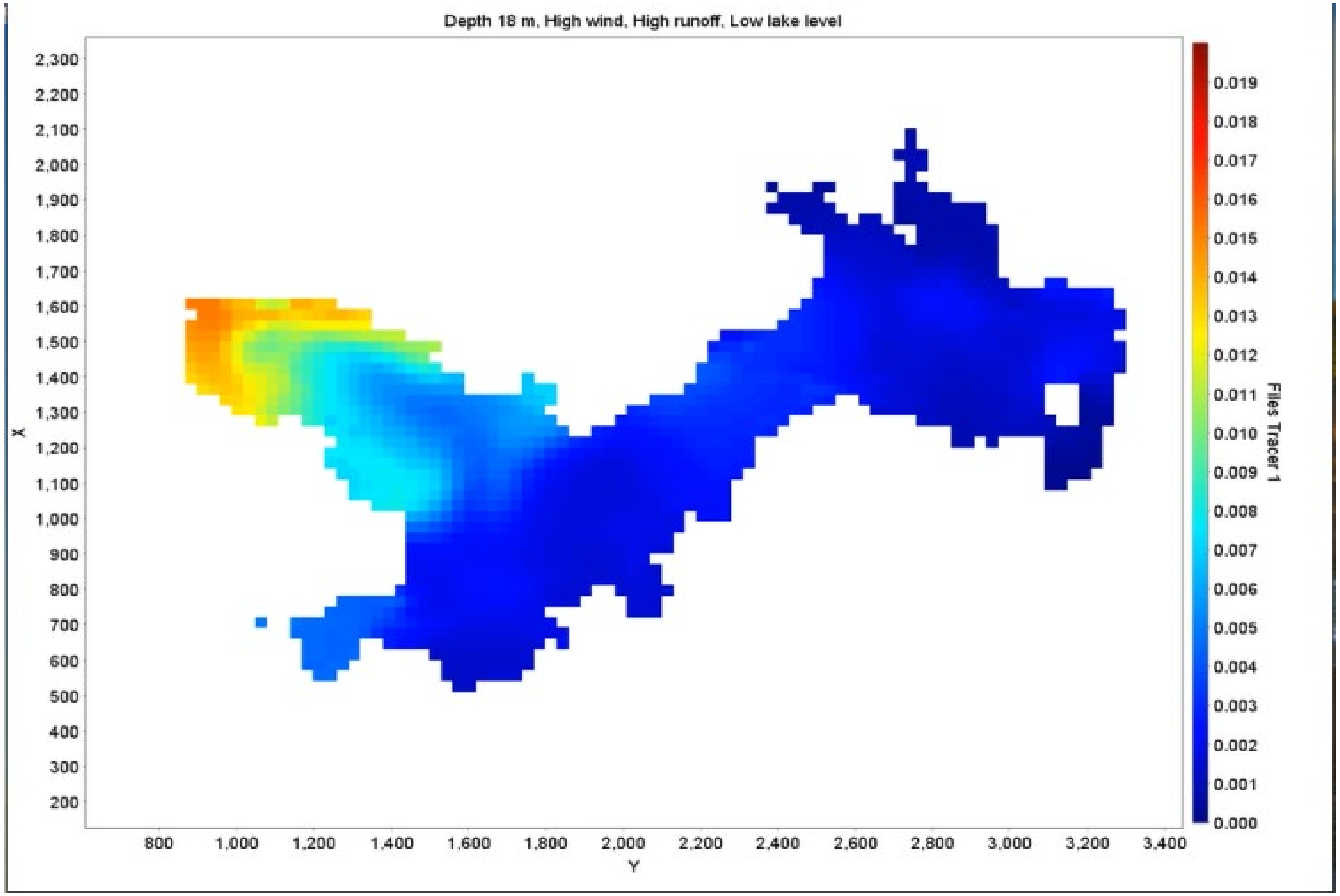


Figure 4-4 Example plan view of contour map showing two-dimensional AEM3D modeled tracer concentration across Lake Arrowhead at a depth of 18 meters for high-wind, high lake level model scenario using model validated from the December 2019 tracer study. Colors indicate f tracer concentrations (ppb) from low (blue) to high (red).

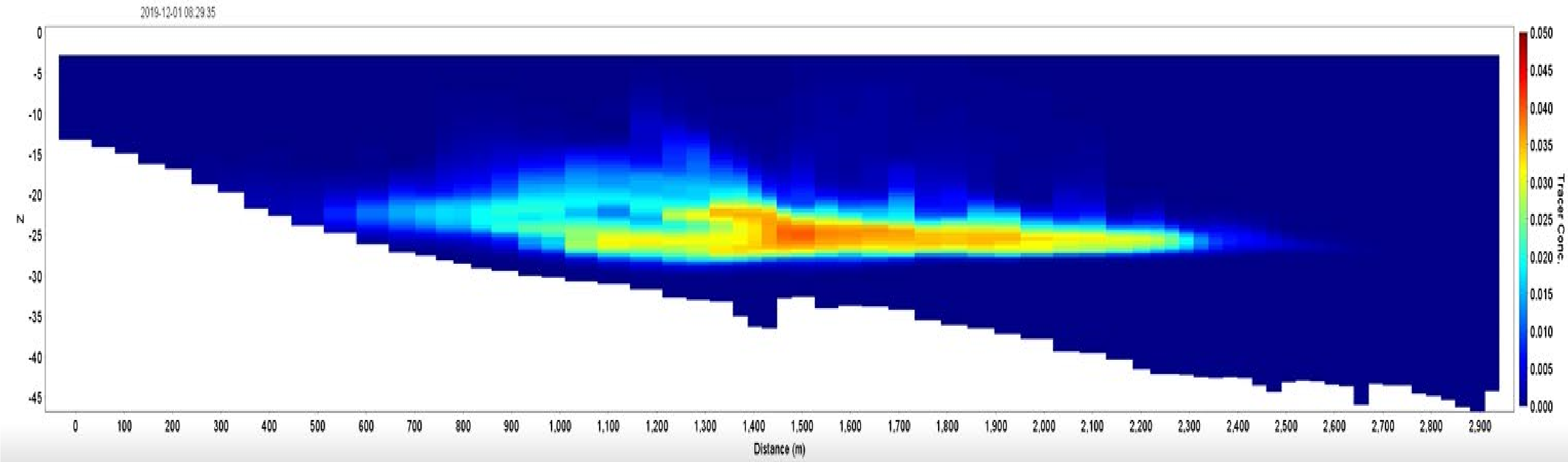


Figure 4-5 Example false color contour plot of tracer longitudinal and vertical concentrations along thalweg (deepest part) of Lake Arrowhead from west (on the left) to east (on the right) for high wind, high lake level model scenario using model validated by December 2019 tracer study.

5 Project Data Requirements

Main Points

1. Make a data collection plan and allow sufficient time to collect, organize and format input data needed for hydrodynamic/ water quality models.
2. Review regulations and regulatory communications for model thresholds for retention time and dilution.
3. Review model user guides and manuals for model input data requirements.
4. Evaluate available water quality data to determine what can be used for the model.
5. Develop and implement a plan to acquire any additional data needed for the model.
6. Review and format data for use in the model.

5.1 Plan data collection efforts

Organizations initiating a data collection effort to support a proposed tracer study and hydrodynamic modeling efforts are urged to:

- Allow adequate time to collect, organize and format the information,
- Designate a portion of the project schedule for expert review of the quality and completeness of the data sets, and
- Allocate time and expense in the project schedule and budget for the collection of additional information that will be needed to support the tracer study and modeling efforts.

At least one year of collected data, including meteorological data and reservoir water quality profile information, are needed to support model calibration. Measurements are needed of the seasonal variations in the lake's thermal structure, including development of a seasonal thermocline in spring and fall/winter destratification and turnover. Meteorological data are needed for the same time period, including insolation, air temperature and relative humidity, wind speed and direction, and rainfall so that the lake's energy and water balances can be correctly modeled.

Expert review of the data, for both quality and quantity, is needed before preparing model input files. An example of expert review is for meteorological data. Expert review may determine that if a candidate weather station is too far from the reservoir, then that station's data may not be representative of conditions at the reservoir, and installation of a station closer to the reservoir may be needed in order to generate representative information.

In some cases, monitoring data that are generated for regulatory compliance purposes will be useful for model inputs and tracer study planning. However, routine monitoring data might not be of sufficient spatial coverage or temporal frequency for model calibration and validation. For example, Clean Water Act required quarterly monitoring reports for nitrogen and phosphorus, while useful to help estimate a lake's trophic status, may not be sufficient to validate a model to permit estimation of reservoir nutrient cycling.

Monitoring data sets might not contain information about water quality constituents deemed critical for SWA-IPR, such as enteric virus counts or specified trace chemical contaminants. For example, routine monitoring of lake beaches for fecal coliforms can provide some useful human health risk information but might not be representative of contaminants introduced by wildlife or by non-point runoff at other locations in the water body.

It is strongly advised that water agencies secure the participation of well-qualified and experienced scientific advisors who can work collaboratively with the modeling team to assist with collecting, reviewing, visualizing, and formatting the data for the modeling effort. If expert review determines that existing data are not sufficient to permit model calibration or validation (see Chapter 6), then a data collection effort by appropriately experienced and trained personnel will need to be planned and implemented before model calibration or validation can be initiated.

5.2 Review published regulations and regulator communications for water quality modeling

Regulations promulgated by state environmental or water agencies and communications from staff will determine number and types of data collection and modeling effort to be conducted. As of the date of this writing (June 2021), California has promulgated the most specific regulations of any state regarding water quality modeling for SWA-IPR. Example excerpts from California's regulations are shown below:

- California's final published text of Title 22, Division 4, Chapter 17, Article 9, adopted Sections 64668.10 .20 and .30, respectively require a water agency to apply to conduct surface water augmentation, conduct public hearings, and demonstrate minimum detention times and dilution requirements through tracer studies and hydrodynamic modeling.

- Specifically, Section 64668.30, SWSAP Augmented Reservoir Requirements paragraph (c), states that "Prior to augmentation and whenever requested to do so by the State Board based on information that previous tracer studies or hydraulic modeling may not accurately reflect current conditions, the (water agency) shall demonstrate to the State Board, utilizing tracer studies and hydrodynamic modeling, that at all times under all operating conditions, the volume of water withdrawn from the augmented reservoir to be ultimately supplied for human consumption contains no more than:

- One percent, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-hour period, or

- Ten percent, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-hour period, with the recycled municipal wastewater delivered by the (water agency) having been subjected to additional treatment producing no less than a 1-$\log_{10}$ reduction of enteric virus, *Giardia* cysts and *Cryptosporidium* oocysts …"[6]

Regulations for three other states, Arizona, Colorado, and Texas, that have implemented surface water augmentation projects[7], are to date silent on modeling and tracer study dilution or residence time requirements for SWA-IPR. Regulators in those states may exercise discretion to request or require water quality studies that will provide appropriate information for demonstration of public health protection for SWA-IPR prior to system construction or operations.

5.3 Determine input data requirements for selected hydrodynamic/water quality model

Model input files will determine the types and frequency of data that must be collected to properly initialize and calibrate the model. Users should review the water quality model's manual to determine the input file requirements needed. For example, the AEM3D User Manual[8] describes:

- The conventions and definitions for model files,
- Organization and formatting of bathymetry and shoreline data,
- Establishment of grids for bathymetry and surface waters,
- How to "configure an AEM3D simulation with water quality, suspended solids or aquatic ecology" data, including generation and formatting of needed input files,
- How to set up files for biological, metals, biogeochemical and sediment data, and

[6] https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf

[7] See this document Chapter 2, Section 2.1, Table 2.1

[8] Hodges, B. R. and Dallimore, C. (2021). Aquatic Ecosystem Model: AEM3D v1.2 User Manual. Hydronumerics, Victoria, Australia. 183 pp. https://www.hydronumerics.com.au/software/aquatic-ecosystem-model-3d

- Methods for providing initial values in all files for the start of a modeling run.

5.4 Evaluate available water quality and environmental data to determine if any existing information can be used

As previously summarized in Section 5.1, a thorough review of existing sources of water quality data should take place prior to initiating any data collection effort. Information for input files for hydrodynamic/water quality models or for subsequent calibration of the models, can be obtained from a variety of sources. Examples are:

- Discharge monitoring reports and surface water quality monitoring reports, as required by regulations. For example:
    - Under Section 60320.312 of the Surface Water Augmentation rules[9], California requires quarterly sampling of recycled municipal wastewater discharges and analysis for secondary drinking water contaminants.
    - Under Section 60320.320[10], quarterly monitoring is required for Priority Toxic Pollutants, and chemicals specified by the State Board, including indicator compounds identified from an inventory of chemicals identified through chemical and contaminant source investigations.
- Discharge monitoring reports submitted to the US EPA or state environmental protection agencies under Clean Water Act rules. These reports can serve as sources of information regarding contaminant concentrations that may be discharged to an augmented reservoir. In relation to designated beneficial use standards, the wastewater discharge is a potential candidate for additional treatment to create recycled water that could be used as a source for surface water augmentation.
- Utility operational monitoring of water quality at drinking water intakes. For example, LACSD:
    - Monitors their intakes daily for pH, turbidity, and temperature,

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[9] https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/lawbook/RWregulations_20181001.pdf .p82

[10] Ibid, p.83

  - Monitors beaches weekly and bays monthly in the summer for fecal coliform bacteria, and
  - Generates annual analytical reports for reach intake's raw water for a wide array of water quality constituents including general physical analyses, general chemical analyses, trace metals, and Volatile Organic compounds (VOC's).

- Depending on reservoir ownership and operational agreements, lake and reservoir managers may also be monitoring lake water quality and operations separately from the water utility. For example, at Lake Arrowhead, the ALA maintains the following long-term data sets:
  - Lake level, measured daily,
  - Lake inflow (Grass Valley) and outflow (Willow Creek) gate position information (opening and closing dates and times),
  - Discharge gate elevations and dimensions and weir and gate discharge coefficient equations to estimate lake outflows,
  - Lake Secchi depth and surface water temperatures,
  - Lakeshore pan evaporation data, and
  - Lakeshore weather, including wind speed and direction, air temperature, relative humidity, insolation, and rainfall/snowfall.

- Federal, state, and other local agencies may also be collecting monitoring data or have commissioned research projects that may also provide additional useful information for model development. For example, at Lake Arrowhead Reservoir:
  - Reclamation had recently completed (2008) a bathymetric survey of Lake Arrowhead on a 100-foot grid. Data were available in digital format and used in the Lake Arrowhead AEM3D hydrodynamic model.
  - The US Geological Survey (USGS):
    - Currently maintains a gauging station that records a continuous record of inflows from Grass Valley Lake and a current rainfall station at the LACSD Bernina water treatment plant, and
    - Has datasets available online from discontinued gauging stations that provide information about inflows at Little Bear Creek and outflows from Willow Creek.

- The California Irrigation Management Information System (CIMIS) currently maintains a weather station at Grass Valley Lake, located 2.5 miles from Lake Arrowhead, that provides information about wind speed and direction, air temperature, relative humidity, insolation, and rainfall/snowfall.
- LACSD had recently:
  - Generated a complete Geographic Information Systems (GIS) digital elevation map (DEM) data set of the lake shoreline, and
  - Completed upgrades to each drinking water intake, with new positional and elevation information for the intake screens. Engineering drawings for each intake, with locations, dimensions and elevations were provided for the Lake Arrowhead modeling effort.

5.5 Develop and implement plan to acquire data for model

Existing data sets should first be obtained and evaluated to determine which data may be suitable for use in the hydrodynamic model and what additional data are needed. Input data 'gaps' can then be addressed through supplemental data collection efforts.

For example, at Lake Arrowhead Reservoir, data set inventory and review showed that:

- Existing lake level, pan evaporation and USGS Grass Valley inflow data were useful for hydrodynamic model calibration.
- There was a need to obtain additional information in four key areas:
  - At least a year of monthly reservoir monitoring data as depth profiles for temperature, pH, dissolved oxygen, conductivity, chlorophyll, and percent photosynthetically active radiation to evaluate both seasonal variations to support model energy balance and calibration, and also determine to what extent the lake's major bays exhibited differing characteristics. This effort was initiated at six stations in Lake Arrowhead in May 2018 and continued through April 2020.
  - Temperature and density of major inflows to improve estimation of the lake's water balance. Temperature/conductivity sensors were installed in the channels of two inflows, Grass Valley Tunnel and Little Bear Creek.
  - Watershed area and characteristic data to estimate inflows from ungauged water sheds using available rainfall data. Digital elevation maps and USGS rainfall records for the Bernina weather station near Lake Arrowhead were used to generate this information. A water level gauge and barometric pressure gauge were installed at

Little Bear Creek to obtain water level data and estimate inflows from a previously developed USGS rating curve.

- Additional weather stations were needed to measure wind speed, air temperature, relative humidity, insolation, and rainfall data at a time interval that matched the intended computational step size of the hydrodynamic model and to also ascertain differences in wind speeds and directions over different parts of the lake. Because of complex terrain, four additional weather stations were installed at Lake Arrowhead to generate these data.

5.6 Review and format data for use in the model

The water agency and its scientists should work with the water quality modeling team to:

- Review the data sets for both completeness and errors and monitor performance of installed environmental sensors. For example:
    - Monitoring instruments, including a relative humidity temperature sensor, a rain gauge, and a wind speed sensor, failed at two Lake Arrowhead weather stations. These data losses were identified, and instruments were repaired or replaced. Data losses were minimal; however, if not caught in time, data losses associated with these failures can create data 'gaps' in information critical to either initializing or calibrating the model.
- For manually entered monitoring data, errors in data entry can occasionally occur, including:
    - Incorrect dates and times for correct corresponding numerical data, and
    - Incorrect data values can be entered, either as typos, as inadvertently repeated data, or as a missing or misplaced decimal point that radically changes the order of magnitude of reported information compared to adjacent data points.
- In some cases, data entry errors in computer records can be caught by referring to original hard copy data entries, if the records are available. For example, for the Lake Arrowhead input data, several instances of inadvertently repeated manually entered lake level and turbidity data in Microsoft Excel® workbooks, covering time periods of a month were detected and subsequently corrected by comparison to hard copy bench data sheets.
- Once the data are reviewed, they then must be formatted for use in hydrodynamic model input files. The team should refer to model user guide to determine the correct:
    - Organization of the data fields,

- Numerical formats for time and date and measured data values,
- Stored format as a computer file (for example, *.txt, *.dat, or *.csv),
- Naming conventions for the files, and
- Folder organization for file locations.

The modeling team will be ready to conduct initial trial runs once all input files have been created and located in the correct scenarios.

Model trial runs, calibration, validation, and scenarios are covered in Chapter 7.

6 Tracer study

Main points

1. Usually, two tracer studies should be conducted. The first pre-project tracer study is to validate the hydrodynamic model for a candidate reservoir. The second tracer study, required by regulations, should be conducted utilizing the exact infrastructure that is in use or will be in use for SWA-IPR operations to provide a more accurate assessment of dilution and transport. Select an experienced, well-qualified, well-equipped tracer team that must work closely with the hydrodynamic modeling team.

2. Evaluate published literature and select a miscible, stable, low-toxicity, easy-to-rapidly detect tracer. Rhodamine WT is currently the tracer of choice for SWA-IPR studies.

3. Obtain water agency and stakeholder support for use of the tracer.

4. Apply for regulatory review and obtain regulatory approval for use of the tracer.

5. Determine water quality model input requirements for validation with tracer. Establish tracer release location and depth and tracer sampling frequency schedules to provide the best possible data for model validation.

6. Train personnel in safe handling and correct measurement of the tracer.

7. Develop tracer addition system that adds tracer at specified depth and rate, with redundant spill prevention and containment measures and spill clean-up equipment and procedures in place.

8. Prepare in advance and communicate a detailed operational plan for tracer addition, including communications protocols and notification procedures.

9. Conduct the tracer study per the plan. Where feasible analyze tracer data as collected to improve the targeting of subsequent tracer sampling locations and depths.

10. Archive, reduce, analyze, and visualize tracer data and communicate results to modeling team, the water agency, and all stakeholders.

6.1 Be prepared to conduct two tracer studies

Two tracer studies are needed to maximize the predicted accuracies of dilution, residence time and travel time in a reservoir under consideration for SWA-IPR.

The first tracer study, not typically required by regulations, is conducted to *validate* the hydrodynamic model. In the first non-regulatory tracer study, the tracer release location can be typically anywhere in the reservoir because the purpose of the first tracer study is through validation, to evaluate and demonstrate the accuracy of the hydrodynamic water quality model before a water agency expends considerable funds on engineering design and construction of the recycled water discharges, diffusers or other mixing systems and raw water intake structures in a reservoir. The actual location of tracer addition should be selected in consultation with the hydrodynamic modeling team. This first study can estimate mixing, transport and dilution for model validation and also be used to assist engineering design decisions regarding the SWA-IPR infrastructure to be constructed for the reservoir. Examples of these non-regulatory tracer studies include the 1995 tracer study in San Vicente Reservoir (Ding et al 2012b, Pasek, 2015) and the 2019 tracer study in Miramar Reservoir (Pasek et al 2020).

The second tracer study, required by regulations in California[11], is typically required after a project is constructed and utilizes the constructed project infrastructure. Tracer release location, depths, rates, and initial dilutions should match what has been constructed for SWA-IPR in the reservoir. Results of this second tracer study are used to verify that hydrodynamic modeling results regarding dilution, detention time and travel time are accurate.

In the case study for this guidance manual, only one tracer study was performed at Arrowhead Reservoir because it was performed in a reservoir that was willing to serve as a demonstration project for this manual. Lake Arrowhead's cooperating organizations are still considering alternative water supply options. A well-documented example of an agency that conducted two tracer studies is the City of San Diego's Pure Water project for Miramar Reservoir (Hannoun, 2017, Pasek et al 2020).

6.2 Employ a well-qualified, experienced tracer team

After completing a Needs Assessment and obtaining initial preliminary regulatory approvals, as a water agency initiates planning for a tracer study, it should recognize that a successful tracer study is a complex operation that requires extensive experience and knowledge in:

- Design and construction of a tracer addition system,
- Development and implementation of tracer monitoring protocols,

[11] SBDDW-16-02 Surface Water Augmentation Using Recycled Water October 31, 2017. https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf

- Laboratory techniques for calibration, operation, and maintenance of tracer monitoring instrumentation,
- Safe chemical handling, mixing, clean up and disposal,
- Boat, barge and platform operations and safety, and
- Tracer data reduction, visualization, and formatting for use in validating the hydrodynamic model.

As the agency prepares requests for statements of qualifications and bid proposals, it should develop procurement procedures to select well-qualified teams with long experience in conducting field science operations. This step is needed because high quality tracer data must be acquired at sufficient spatial and temporal intensity to properly *validate* the selected and already calibrated hydrodynamic model.

A water agency may wish to consult with agencies that have previously completed SWA-IPR tracer and hydrodynamic modeling studies to determine how to establish criteria for review of tracer team statements of qualifications and proposals.

The selected tracer team must work closely with the:

- Modeling consultant to develop and implement a reservoir sampling and data management plan that will provide the data needed for the model, and
- Water agency to establish tracer addition and sampling protocols that do not interfere with reservoir operations, water treatment plant operations, or reservoir recreational activities.

6.3 Review literature and prior studies to determine suitable candidate tracer

Tracers are used to both estimate dilution and travel time in reservoirs and to validate calibrated hydrodynamic model predictions of travel time and dilution. Evaluation of tracer performance has been an active area of research for more than 40 years. Following the comprehensive guidelines of Reid (1981), an ideal tracer for surface water studies would be:

- Rapidly and easily detected in the water body with available field or laboratory instrumentation,
- Nonreactive and rapidly and completely soluble in water, with
- Minimal sorption to suspended particulates or sediments,

- No density effects compared to the surrounding water,
- Stable over the anticipated duration of the proposed study, with minimal or predictable slow decay in the water body,
- Either absent from the water body or present in very low background concentrations to facilitate estimation of a wide range of dilutions,
- Very low in acute or chronic toxicity to aquatic biota and humans,
- Low in cost and readily available, and
- Convenient for application in the field.

An additional criterion is non-existent or low discoloration of surface waters, aquatic organisms, and lakeside infrastructure.

UNLV reviewed available literature in 2018 when preparing an application for a discharge permit waiver for the Lake Arrowhead tracer study. UNLV's evaluation of published literature reports against the above criteria showed that two classes of compounds, stable fluorescent dyes, and artificial sweeteners, were possible candidates for reservoir tracer studies. Table 6.1 summarizes the properties of the three tracers, Lanthanum chloride, Rhodamine WT, and sucralose per Reid's (1981) criteria.

Table 6.1 Evaluation of three candidate tracers for suitability for SWA-IPR tracer studies using Reid's 1981 criteria

Criterion	Lanthanum chloride	Rhodamine WT	Sucralose	Operational Recommendations
Rapidly and easily detected in water body	Detected in laboratory from field collected samples to 0.01 ppb using Atomic Absorption Spectrophotometry	Detected in the field with Eureka and Yellow Springs Instruments (YSI) fluorometers to 0.01 ppb. Rapid feedback is possible to provide direction to sampling teams	Detected in laboratory by Solid Phase Extraction and High-Pressure Liquid Chromatography to 0.01 ppb	Use calibrated RWT fluorometers for sampling at high temporal frequencies to quickly build picture of tracer mass distribution during study
Minimal sorption	Can react with ambient phosphorus to form flocs and settle.	Non-sorbing	Non-sorbing	Spike collected surface water samples in lab, allow for sorption, filter, and measure any attenuation
No density effects	5.3% weight/weight solution has specific gravity of 1.10. Diluted solutions at typical initial mixed concentrations have density identical to surrounding water	20% weight/weight solution has specific gravity of 1.16. Diluted solutions at typical initial mixed concentrations have density identical to surrounding water	Diluted solutions at typical initial mixed concentrations have density identical to surrounding water	Evaluate mixed density at target solution in pumped tank. Compare to densities estimated from ambient conductivity and temperature profile and apply at depth for constant density. Set diffuser for horizontal injection
Stable over anticipated duration of tracer study	Very stable in water absence of phosphate. However, can bind to phosphate, coagulate, flocculate and settle. Loss ranged from 50%	Photolytic decay in surface waters at rates of up to 3%-5% per day in sunlit waters (Tai and Rathbun, 1988). Decay rate depends on	Very slow decay by microbial co-metabolism in range 0.6%-1.7% per month (Labare and	For RWT, conduct parallel decay measurements in bottle strings at similar depth ranges to apply decay rate correction if needed

Criterion	Lanthanum chloride	Rhodamine WT	Sucralose	Operational Recommendations
	to 85% over 35 days (1.4 to 2.4% per day) in high phosphate waters (Ding et al , 2012a).	intensity of solar radiation at range of water depths in which tracer is located.	Alexander, 1993 1994)	No decay rate adjustments needed for sucralose
Absent or low background	Present in concentration range 0.003-0.03 ppb (3-30 parts per trillion) based on data reported by Kulaksız, S., & Bau, M. (2011) as ratios to REE/PAAS (Rare Earth Element/Post-Archean Australian Shale) values in (McLennan, 2001)	Typical background RWT-like signal in range of 0.01-0.1 ppb (10-100 parts per trillion) from Lake Arrowhead background monitoring prior to study. Background data for other reservoirs are not yet available.	Detected in many North American surface waters in range from <2 to 1,900 parts per trillion (Tollefsen et al 2012). May 2018 detection in Lake Arrowhead at 30-84 parts per trillion	Sample surface water body prior to study and during study to measure background concentrations. Subtract background values from ambient water tracer measurements as necessary
Low acute and chronic toxicity	Lowest Aquatic Predicted No Effect Concentration (PNEC) is 4 ppb (Hermann et al 2016), applying a safety factor of 10 from published aquatic toxicity studies. EPA regulatory or advisory limit not yet established	EPA (1988) advisory limit 100 ppb in surface waters and 10 ppb around drinking water intakes. Recommended max short-term concentration 1,000-2,000 ppb (Field et al 1995) and chronic maximum 100 ppb, Rowinski and Chrzanowksi (2010).	Lowest No Observation Effect Concentration (NOEC) for 28-day exposure 93,000 ppb (Tollefsen et al 2012) EPA regulatory or advisory limits not yet established	Obtain Safety Data Sheets for each compound and submit with literature toxicity data and method and duration of tracer addition to contractor, agency, and regulatory staff for review

Criterion	Lanthanum chloride	Rhodamine WT	Sucralose	Operational Recommendations
Low cost and readily available	Available as 4 L and 20L 5.3% solution containers from Cole Parmer	Available as 20% concentrate in 5-gallon (19 Liter) buckets from Sensient Colors.	Available in bulk 2.5 kg packages from commercial vendors	Use Rhodamine WT concentrate solutions before expiration date.
Convenient for application in field	Can be completely mixed into ambient water and pumped through diffuser at designated depth	Can be completely mixed into ambient water and pumped through diffuser at designated depth	Can be completely mixed into ambient water and pumped through diffuser at designated depth	Design for spill prevention, containment and clean up

Table 6.2 summarizes information about tracers used in three recent published California reservoir tracer studies. Two of the published studies (Lake Jennings, Miramar Reservoir) utilized Rhodamine WT tracer, and one (San Vicente Reservoir) used lanthanum chloride salt solution.

Table 6.2 Summary of four reservoir tracer studies for IPR-SWA

Reservoir- and agency	Date(s)	Tracer used and method of detection	Study duration	Primary loss (other than mixing or dilution)	Source
Lake Arrowhead Reservoir	Dec 2019	Rhodamine WT – field fluorometry	5 days	None detected over 5-day study period. Very slow loss detected after 44 days	Lake Arrowhead tracer study (this document)
Lake Jennings Reservoir	Oct-Nov 2017	Rhodamine WT – field fluorometry	20 days	Not covered	Rogowski et al, (2019)
Miramar Reservoir – City of San Diego	July- Sept 2019	Rhodamine WT – field fluorometry	90 days	Photolytic decay (slow, depended on movement of tracer into surface waters)	Pasek et al (2020)
San Vicente Reservoir – City of San Diego	Jan-Feb & Jul-Sept 1995	Lanthanum chloride field sample collection; lab analyses	32 days (Jan-Feb) 37 days (July – Sept)	Coagulation, flocculation and particulate settling (slow, depended on stratification and ambient phosphorus concentrations)	Ding et al (2012a, 2012b)

Chemical technology and instrumental detection techniques continue to evolve and improve over time. For example, stable field-portable RWT depth logging probes became commercially available in the 2nd decade of the 21st century, greatly simplifying the process of measuring tracer concentrations throughout a reservoir in near real-time. When working with consultants and contractors to select a tracer for a SWA-IPR study, water agencies should continue to evaluate available product literature and research publications to determine if new tracers and detection techniques are available, and to see new ecotoxicity information has been reported in the research literature.

6.4 Obtain utility and stakeholder support for proposed use of the tracer

Water agencies should prepare literature summaries, provide complete documentation in applications to regulators, and schedule stakeholder meetings to address public and regulator concerns about addition of tracer compounds to surface water bodies used for drinking water supplies, fisheries, and recreation.

A technical summary of available literature regarding tracer properties of greatest interest to stakeholders, such as toxicity, color, and persistence, should be prepared in advance for regulatory review and also made available for public review at the scheduled meeting. An example of this information for the Lake Arrowhead Reservoir tracer study, consisting of the technical document prepared for review by the California's Lahontan Regional Water Quality Control Board, is provided in Appendix 2.1. The public outreach document that summarized tracer properties can be found in Appendix 3.1.

An example timeline and brief descriptions of regulator communications and public notification processes for the Lake Arrowhead Reservoir tracer study is summarized below.

Table 6.3 Summary of communications prepared regulatory review and public tracer study discussion

Document	Date	Process
Application to Regulator	July 2018	Formal request for Waiver of Discharge Report was prepared by UNLV and reviewed and submitted by LACSD to the Lahontan Regional Water Quality Control Board (Lahontan). The waiver request included a statement of Needs, Benefits, Public Interest and Risk, descriptions of proposed tracer properties, and proposed methods of tracer addition, measurement and clean up. A complete copy of this formal request, with a cover memo prepared by LACSD's General Manager Catherine Cerri, and a technical report prepared by UNLV (Saber, James, Stutzman, 2018) is shown in Appendix 2.1.
Public Meetings	August 2019	Two public meetings were held more than 90 days before the proposed tracer study date. An informational hand out was provided as shown in Appendix 3.1. The Lead scientific investigator demonstrated the methods of detection and answered public questions. A synopsis of questions and answers was prepared and submitted by LACSD to Lahontan. Appendix 3.2 contains the public meeting Q&A summary, prepared by Catherine Cerri, that was transmitted to Lahontan.

Table 2.2 provides additional details about the communications processes followed for Lake Arrowhead Reservoir.

6.5 Obtain regulatory review and approval for tracer

When applying for regulatory approval of tracer addition to a surface water body, water agencies should:

- Determine which local agency, entity or association will be the lead for communications,
- Review designated beneficial uses, applicable regulations, and letters of decision,
- Contact the appropriate regulatory office for guidance on how to apply, and
- Request what documentation is needed to support the request to conduct the proposed study.

Communications and the extent of required documentation will vary depending on governing regulations, level of public access and designated beneficial uses of the reservoir.

For example, for the proposed Lake Arrowhead Reservoir tracer study, the Reservoir's Beneficial Uses under the Lahontan Basin Plan (Lahontan, 2020) include irrigation, drinking water supply, non-contact and body contact recreation, groundwater recharge, commercial and sport fishery and cold water and wildlife habitat.

Three state agency reviews (California Division of Fish and Wildlife, Division of Drinking Water, and Lahontan Regional Water Quality Control Board) and one federal agency NEPA review (Reclamation) were required because of federal funding by Reclamation for the project and Arrowhead Reservoir's large number of designated beneficial uses. Complete details of the July 2018 request to Lahontan Regional Water Quality Control Board can be found in Appendix 6.1.

In their reply to the request, Lahontan, to protect the reservoir and as a condition of providing permission to conduct the tracer study, required that UNLV accept liability assignment in the event of a tracer spill or leak, obtain liability insurance to cover the cost of clean-up of a spill or leak, and prepare emergency notification procedures, spill containment and mitigation plans.

From initiation to receipt of a go-ahead to perform the tracer study, the entire timeline for preparing the request and meeting all requested conditions, took 18 months (June 2018 to November 2019). A detailed summary of the steps and documents required to obtain tracer study permission can be found in Table 2.2.

6.6 Determine water quality model input requirements for tracer study

Pre-project tracer studies are conducted for *validation* of a calibrated computational hydrodynamic water quality model. The purpose of the validation is to estimate the accuracy of the water quality model's computed tracer concentrations compared to measured concentrations. An overall mean error expressed as a numerical value (typically ppb) and a relative error expressed as fraction or percentage are usually computed from model predictions that correspond to the conditions and time period of the tracer release. The mean error and relative error are estimates of the ability of the model to correctly calculate tracer concentration profiles under identical weather conditions. A low mean error implies that overall, the model is doing a good job of estimating tracer concentrations.

The following steps should be followed when planning a tracer study that can well serve to validate a hydrodynamic model.

Decide upon time of year and conditions of lake stratification needed for model validation. Rates of tracer movement and mixing will depend on stratification and weather and will affect the needed tracer sampling frequencies and locations.

Determine tracer release location and depth that is representative of the proposed reservoir SWA-IPR addition. A representative location and depth typically selected so that tracer travel times and attenuations can be both measured and modeled from point of addition to intakes or points of discharge.

Work with hydrodynamic modelers to determine sampling frequencies and locations for tracer measurements to provide information. Measurements must be made more often and in a smaller region in the vicinity of the tracer release early in the study (first 24-48 hours), since relative rates of tracer volume expansion and associated tracer concentration changes are greatest early in a tracer study.

Identify candidate tracer, monitor lake for natural tracer background concentration, and determine tracer mass needed to provide adequate range of dilution while not exceeding toxicity or discoloration limits. A sufficient mass must be added to provide at least a four order-of-magnitude dilution range above background. Background tracer-like concentrations can occur when there are water quality constituents that provide a signal similar to the added tracer.

- An example for Lake Arrowhead is a small fraction of natural chlorophyll in phytoplankton fluoresces in the same light wavelength as Rhodamine WT tracer and that fluorescence is picked up by the RWT profiling loggers, during monitoring in the five months leading up to the tracer study. Measured background RWT-like signal ranged from 0.01 to 0.28 ppb, well above the 0.01 ppb clean water detection limit of the RWT fluorometric probes. An example plot is shown in Figure 6.1.

- Background RWT-like values in Lake Arrowhead varied with depth, location and time, and values in the 0.01-0.10 ppb range were detected immediately prior to the start of the tracer study, with highest values below the thermocline near the lake bottom. Upper and mid-water column background values seldom exceeded 0.1 ppb. Example plots showing a 0.10 ppb peak well below the thermocline in the deepest part of the lake (Emerald Bay) and much lower concentrations in the upper water column on the morning of tracer addition is shown in Figure 6.2. After December 3, 2019, deep background RWT-like signals were no longer detected during profiling. RWT-like background concentrations were very low (< 0.02 ppb) in the upper and mid water column during the December 2019 tracer study.

- If a background Rhodamine WT tracer-like concentration is not measured, phytoplankton chlorophyll-a, small portion of which fluoresces in the same waveband as RWT, could be mistaken for tracer during the study. Tracer-like background concentrations must be subtracted from Rhodamine WT measurements to provide correct estimate of tracer concentration and dilution. For Lake Arrowhead, to compensate for background, the tracer team had to set the practical added tracer detection limit at 0.02 ppb.

Determine tracer mass needed to provide sufficient signal above background when completely mixed in the reservoir, but not too much mass that the reservoir would be discolored or that aquatic toxicity levels would be exceeded. For Lake Arrowhead, with a nominal full volume of 46,855 acre-feet (USBR, 2009) or (57,795,000 cubic meters) and a desired well-mixed detection limit of 0.067 parts per billion (0.067 milligrams/cubic meter) above background, the tracer mass needed was (57,795,000 cubic meters) x (0.067 milligram/cubic meter) or 3,870,000 milligrams (or 3.87 kilograms). The team elected to prepare a slight excess of tracer at 3.91 kg for addition to the lake, to allow for minor possible losses during addition.

Establish a procedure for measuring representative rate attenuation of tracer due solely to chemical or biological processes. For Lake Arrowhead, two strings of static 1-liter glass bottles, one with clear glass, the other with amber glass (to attenuate sunlight) containing 20 ppb Rhodamine WT tracer solution were suspended off a deep water dock with bottles at water depths from 0.5 to 12 meters and measured daily to estimate rates of tracer decay (Figure 6.3).

Obtain water quality profile data to be used for model energy balance calibration and to provide measured data if water quality calculations will be generated. For Lake Arrowhead Reservoir, water quality profile data were generated on an approximately biweekly basis at five lake locations from May 2018 through November 2019, then monthly from January through April 2020. Profile measurements were made with a seven-parameter logging sonde that measured depth, dissolved oxygen, chlorophyll-a, conductivity, pH, photosynthetically active radiation (PAR) and temperature. Example 2-year plots of these parameters for dissolved oxygen (HDO in mg/L), and chlorophyll-a are shown at monthly intervals in Appendix 6.1. These data were used to support calibration of the hydrodynamic model.

Water quality parameter profiles were also collected on December 2, 2019, the day before start of the tracer study, to establish the depth and strength of the reservoir's thermocline, as well as levels of oxygenation and any locations of any other anomalies in the measured parameters. Examples of these profiles are shown in Appendix 6.1.

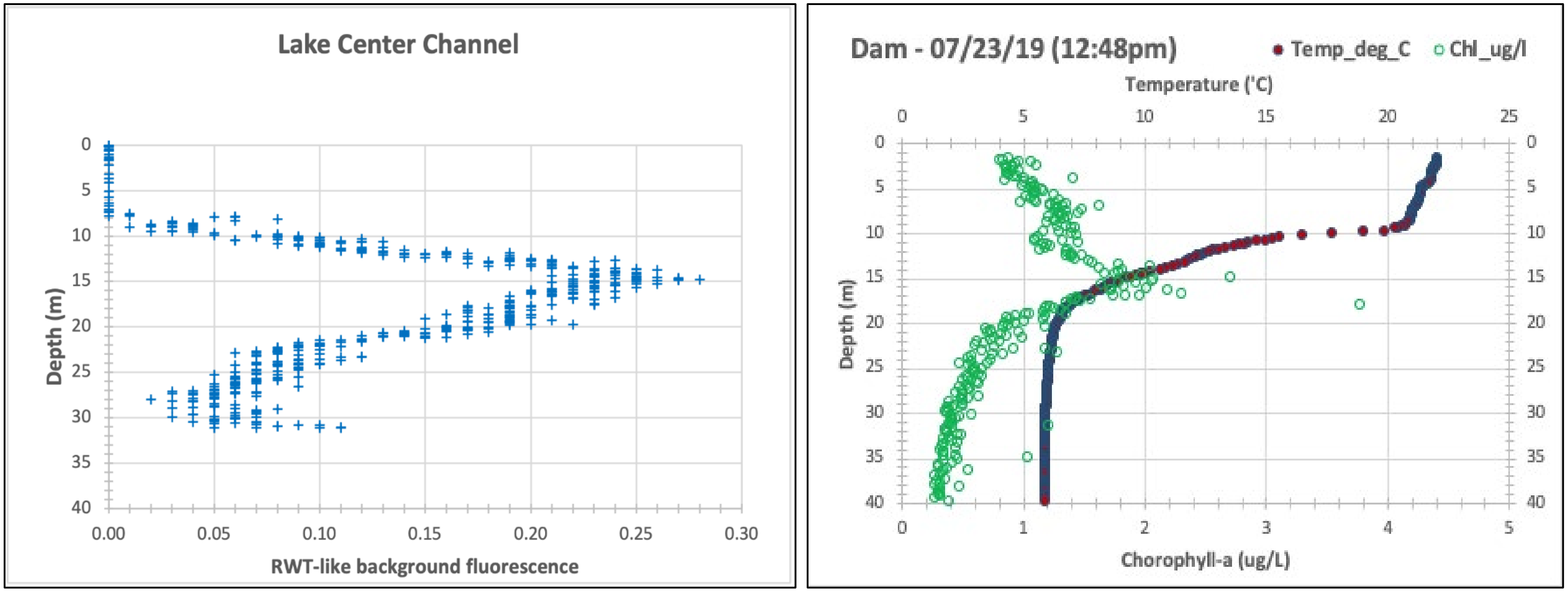


Figure 6-1 Left: Example plot of RWT-like background signal (µg/L) measured at the lake Center channel, indicating 0.28 ppb peak at 15-meter depth – July 23, 2019. Right: Chl-a concentration (µg/L) measured by fluorometry, measured near the Dam, showing peak value at 14-16 meters, in lower part of thermocline, – July 23, 2019.

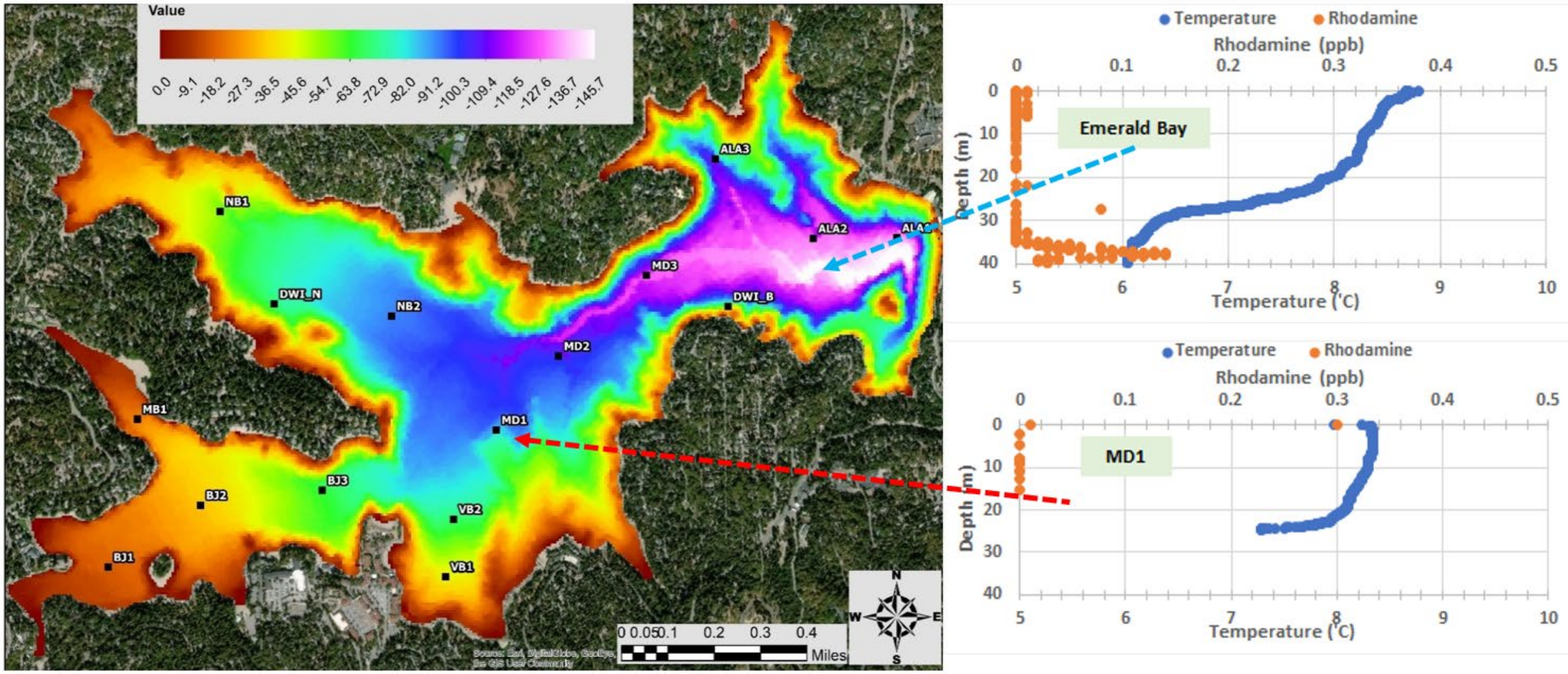


Figure 6-2 Example RWT-like background signal profiles 12/3/19. Left: bathymetric color contour map with fixed tracer monitoring locations shown. Right: RWT-like background profiles at two of the fixed locations. Top: Deep (39 meter) peak of 0.14 ppb at Emerald Bay did not appear again in subsequent monitoring 12/4/19 – 12/7/19; Bottom: mid like profile showing no RWT-like signal. Deep lake origin hypothesis: possibly from plunging inflow of snow melt runoff during the Nov 29 – Dec 1, 2019 winter storm.

Figure 6-3 Left - Amber bottle string used for RWT static decay tests during December 2019 tracer study. Right - Placing clear bottle static decay string in Lake Arrowhead off the end of a deep-water dock.

6.7 Prepare personnel and equipment and conduct operational planning for tracer study

A water agency can conduct the tracer study in-house with existing staff or engage an outside consultant to perform the study. Considerable advance planning and preparation is needed in three primary areas to conduct the tracer study.

- Train personnel,
- Prepare equipment, and
- Plan tracer study operations.

A summary of the needed steps in each area is provided below. The detailed personnel briefing used in the Arrowhead tracer study is attached as Appendix 6.2.

6.7.1 Train Personnel

The key areas for training are as follows:

a) Sample collection methods and monitoring equipment operation.

If water samples are to be collected for subsequent analysis, personnel will need to be trained in operation of the depth samplers (often Van Dorn Bottles) and recording correct information for each sample collected, which can include sample number, sampling station ID, GPS coordinates, sample depth, environmental conditions, and time of collection. Sample preservation techniques and storage, if any, should also be part of the training.

If direct readings are to be made with water quality probes, then personnel should be trained in advance regarding calibration, operation with data collection terminals or software, and appropriate file naming conventions and archiving procedures. At Lake Arrowhead, all four sampling personnel were trained in probe calibration and maintenance, software operation and data file naming conventions.

b) Equipment

Sampling and monitoring equipment should be deployed to each boat in at least duplicate form to permit continued operations in case of equipment failure or loss. Weather-proof containers and the ability to dry out electronics are strongly advised. For example, at Lake Arrowhead, where the teams operated in mostly open boats during three intense winter rainstorms.

Water-proof storage boxes were used to transport a minimum of three laptop computers on each boat. Each laptop was deployed with fully charged batteries and an identical suite of data collection software. In the event of battery failure or water-exposure failure, the sampling team could switch to a second or third laptop to keep sampling on schedule.

At least three RWT sampling probes and two probe batteries, carried in umbrella or tent pole shoulder cases, calibrated to at least two order-of- magnitude RWT ranges (typically 0-1 ppb, 0-20ppb and 0-100 ppb in the early parts of the study, or 0-1 ppb, 0-10 ppb and a duplicate of either of those ranges later in the study), were deployed on each boat.

In the event that an unanticipated high out-of-range RWT concentration was detected by a probe, the team could switch to a probe calibrated to the correct range and continue measurement without having to return to base camp.

In the event of probe or probe connection or battery failure, a redundant probe or battery could be switched into the connection, and profiling could continue without having to return to base to pick up an additional probe.

Spare laptop computers and probes were also maintained at base camp in case the redundant deployed equipment on the boats failed.

c) Scheduling

As the first one to three days of sampling could require 24-hour on-lake presence with frequent sampling, scheduling and communications procedures should be established well in advance. Although hazards may be perceived as minimal, a minimum crew size of two on each boat is essential in the event of an accident, injury, or person overboard.

At Lake Arrowhead Reservoir, teams worked 18-hour shifts from two boats from December 3 through December 6, and in one boat on December 7 to monitor the movement of the tracer. After limited horizontal movement and some vertical mixing the first day, the tracer was observed to mix and move rapidly to the north across the lake and also eastwards towards the dam on the 2nd through 4th days of the study. Westward tracer movement into two of the lake's bays (Blue Jay and North Bay) was detected but was much more limited. Detectable tracer concentrations in the water column above the intakes were observed on the fourth day of the tracer study (December 6) and had attenuated to background concentrations at the intakes on the fifth day (December 7).

d) Sampling Locations

The locations of fixed tracer sampling stations were determined in advance with GPS coordinates to correspond to the thalweg of each bay (Appendix 6.2). Boat crews were assigned sampling stations in portions of the lake that they should visit on each deployment.

Logs of sampling station locations and dates/times visited were maintained and used in the naming conventions for the saved data logging files.

e) Safety

Personnel should be familiarized with tracer safety data sheets, tracer addition equipment operations, and use of appropriate flotation personal protective equipment (PPE) if any. Boat operations, use of flotation equipment and lifesaving and emergency communications procedure, including who to call regarding a spill, accident or person overboard should be covered in all personnel briefings.

For example, at Lake Arrowhead, each team was provided with:

- Laminated water-proof sheets containing GPS coordinate sampling locations,
- A floatation-capable toolbox that contained first aid equipment. Gloves, flashlights, illuminated headbands, extra batteries, and GPS receivers. Illuminated headbands were extensively used to provide hands-free lighting for night-time sampling.
- At least two two-way radios were provided in each boat, each radio set to communicate on the standard lake safety channel for Arrowhead. Each sampling team member also carried a charged mobile phone for redundant communications and mapping capabilities.
- Buoyancy vests to be worn outside the foul weather gear. It was mandatory that the vests be worn during field sampling when personnel were leaning over the sides of the boats to deploy logging probes or Van Dorn bottles.

Additionally, given the cold (0-8 ºC air and 5-8 ºC lake water temperatures), wet (persistent rainfall, wind, and wave splash) conditions of the winter-time tracer study each boat team was assigned a duffel bag with additional cold weather and rain gear, a change of dry clothes and towels to permit rapid drying and re-warming of any individual showing hypothermia from either rain exposure or in case of falling overboard. Overboard procedures were rehearsed, and a personnel rescue float and rope were maintained on each boat. Each boat was also equipped with search lights to facilitate night-time equipment or personnel recovery.

Appendix 6.3 shows the Crew Overboard Procedure used for the Lake Arrowhead Tracer Study, derived from a similar document developed for the San Diego's Miramar Reservoir tracer study (Pasek, personal communication 2019).

Readers should note that in summertime conditions in the southwest, the risks of exposure for tracer study personnel are significant but very different from the winter-time Arrowhead tracer study. In summer conditions, such as occurred at Miramar Reservoir in July through September 2019, personnel and equipment should be prepared to operate in conditions of strong sunlight, including sunshades for equipment and people, sunblock, water or electrolyte fluids for rehydration, and wide brimmed hats, light colored and breathable clothing and sunglasses.

In any case, tracer study teams must be able to maintain a healthy completely alert status during field operations. Personnel who are excessively tired, cold, and wet or excessively hot and dehydrated will not be able to operate with full awareness of their own safety, nor will they be able to follow correct sampling procedures. Scheduling, preparation, and training should always be planned and implemented to mitigate these risks to the maximum extent possible.

6.7.2 Prepare equipment

The key areas for equipment preparation are as follows:

a) Tracer addition system.

The tracer addition system (Figures 6.4 and 6.5) should be designed to allow for measurement and control of the rates of mixing and addition to the reservoir. Control of flow rates is achieved through use of pressure regulators, needed valves and ball valves. For the UNLV Lake Arrowhead system, flow measurement of added dye concentrate was accomplished with an inline spring-loaded sight gauge, and flow rate measurement of the entire mixed system was made with a strap-on digital ultrasonic gauge.

It is strongly advised that the tracer be added at a specified depth through a diffuser designed to only inject the tracer horizontally in the water body. This is necessary so that the reservoir's inherent rate of vertical mixing, as determined by vertical expansion and dilution of the tracer 'cloud' with time after addition, can be correctly estimated.

A recommended diffuser design is cross-shaped, consisting of four arms, to allow for tracer addition in a wide "pancake" at a specified water depth in the reservoir. To best estimate rates of vertical mixing dye outlet holes in the arms should be horizontal to eject tracer in a thin "pancake" layer (Hannoun, personal communication, 2019). For Lake Arrowhead, the UNLV diffuser arms were 2 meters long (Figure 6.4). The diffuser for the July 2019 Miramar Reservoir tracer study used 3-meter arms.

The tracer system should be designed to dilute the tracer solution and make sure that it is at the same temperature (isothermal) with the lake water so that the injected solution is at the same density of the lake water at the specified level of addition. This mixing is accomplished with a main pump that draws water up from the lake at that level where it is mixed in the piping with a second pump that injects tracer concentrate solution.

For Lake Arrowhead the UNLV system achieved this as follows:

- The 3.91 kilograms of Rhodamine WT tracer as a 20% concentrate solution (total volume of 25.5 liters (6.7 gallons) of solution at a specific gravity of 1.16) was first mixed with 60 gallons of lake water, pumped from the desired level of addition in a 100-gallon holding tank. Figure 6.5 shows the holding tank system in the lab and on the barge. The initial dilution was 6.7 gallons concentrate)/(60 gallons lake water) for a total of 66.7 gallons of solution = or 6.7/66.7 = 1:10.

- Pumped lake water solution was drawn from 10 meters depth at 106-107 gallons per minute (gpm) and used a second electric pump that mixed the diluted tracer concentrate at 6 gpm into the 100-101 gallon per minute (gpm) lake water stream. The mixture was then pumped into the lake and out the diffuser at a depth of 10 meters, providing another factor of 6/106 =1:17.6 dilution of the tracer solution, or total dilution of (1:10).x(1:17.6) $\simeq$ 1/176.

- The diffuser was estimated to provide another factor of 1:5 to 1:10 initial dilution for the tracer solution after addition (Hannoun, personal communication, 2019), providing a total initial dilution of the concentrate of 1:880 to 1:1,760. At this total dilution, the tracer solution, when mixed with lake water from the desired depth, will be sufficiently diluted to be at the same density as surrounding lake water.

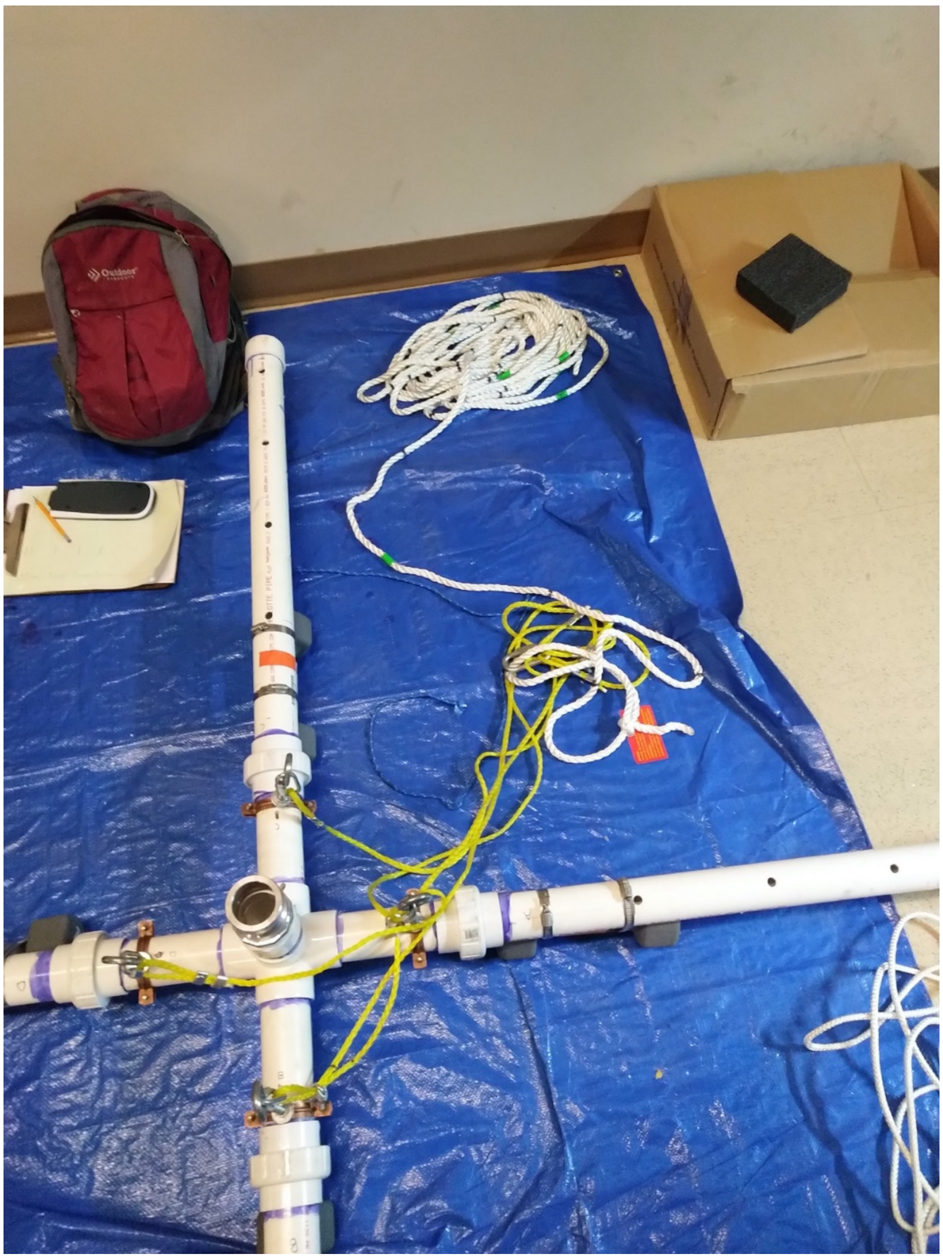


Figure 6-4 UNLV Lake Arrowhead diffuser system – 2 meter arms, with lifting harness and arm weights

The following tracer addition system design characteristics are highly desirable to ensure safe and accurate functioning of the system.

- All pumps, hoses, valves, flow gauges, lift harnesses, diffusers and fittings should be tested for proper operation and minimization of leaks. Spiral-wound pressure hoses, ball valves with long lever actuators and rapid connection systems that were used in the July 2019 Miramar Reservoir and December 2019 Lake Arrowhead tracer studies, are strongly recommended to insure reliable and safe operations. Three-inch fire hoses and associated fittings were found to work well for the Lake Arrowhead and Miramar tracer systems. The green three-inch hoses can be seen deployed on the Lake Arrowhead tracer addition barge in Figure 6.5.

- Proper flow rates should be ensured at the lab or on the shoreline prior to the addition day to make sure that initial tracer dilutions in the water column will take place as anticipated. For the Lake Arrowhead study, flow meters were used to measure both dye solution injection rate and total flow addition rate.

- Availability of redundant tracer addition approaches is strongly advised in the event of a pump or motor failure. For example, UNLV's Lake Arrowhead system could still function with adequate dilution due solely to positive head from the tracer mixing tank and low pressure at the main pump intake if the tracer concentrate pump were to fail.

- Redundant spill clean-up equipment should be available to capture any tracer that may escape containment.

- The tracer addition system should be field tested at the lab or on the shoreline prior to deployment on the lake for tracer addition. For example: UNLV's Lake Arrowhead tracer addition system was first tested with clean water in the UNLV natatorium pool, then twice tested with clean water at Lake Arrowhead to evaluate sources of possible malfunction prior to the date of the tracer study. Modifications made as a result of testing included adoption of spiral wound pressure hoses to prevent hose movement, and collapse and quick disconnects with positive latching to minimize connection leaks.

Figure 6-5 Left: Lake Arrowhead dual tank tracer addition system set up in laboratory. Right: Lake Arrowhead dual tank system with diffuser as deployed on ALA barge on day of tracer study, after tracer addition (small volume diluted dye solution remaining in tank on right.

Figure 6.5's left-side photo shows: White tracer mixing tank on left in overflow trough. White dump tank on right in overflow trough. Pipe on front right connects to intake hose deployed at depth. Right-angle pipe on back right connects to discharge hose with diffuser attached. Black electric pump in center meters dye solution at fixed rate into low pressure entrace of main lake water pump. Green three inch fire pressure hose with pink labels in background (also visible in background for the right-side photo).

b) Tracer monitoring instrumentation and sampling equipment

It is vital that all field instrumentation and sampling equipment be acquired with spares to permit measurement and sampling to continue in the event of equipment failure or loss. For example:

- UNLV calibrated and deployed 12 Eureka Trimeter® Rhodamine WT sondes for its 2019 Lake Arrowhead tracer study (example in Figure 6.6). Two boats on the lake each carried three sondes. The three sondes were calibrated to cover three different tracer concentration ranges early in the study. Later in the study they were calibrated to two ranges with the third sonde calibrated to duplicate the most likely expected range. Additional calibrated sondes were ready at base camp in case a probe or connection failed. On two occasions, failed probes had to be switched out for functioning units from available spares.

- Two of the sondes were deployed at the drinking water intakes to monitor background concentrations and two sondes were kept at base camp for static bottle test measurements.

- Each boat carried three laptops in weather-tight storage containers in the event of system crashes or premature battery failures.

- The water sampling boat carried redundant Van Dorn bottles in the event of a bottle malfunction or loss.

- Sonde-to-laptop cables and Bluetooth® batteries were acquired in duplicate in order to continue measurement in case a cable was crushed or cut. At Lake Arrowhead, one sonde cable was cut by a boat prop during tracer measurements, a sonde was lost, and a spare cable and sonde were deployed.

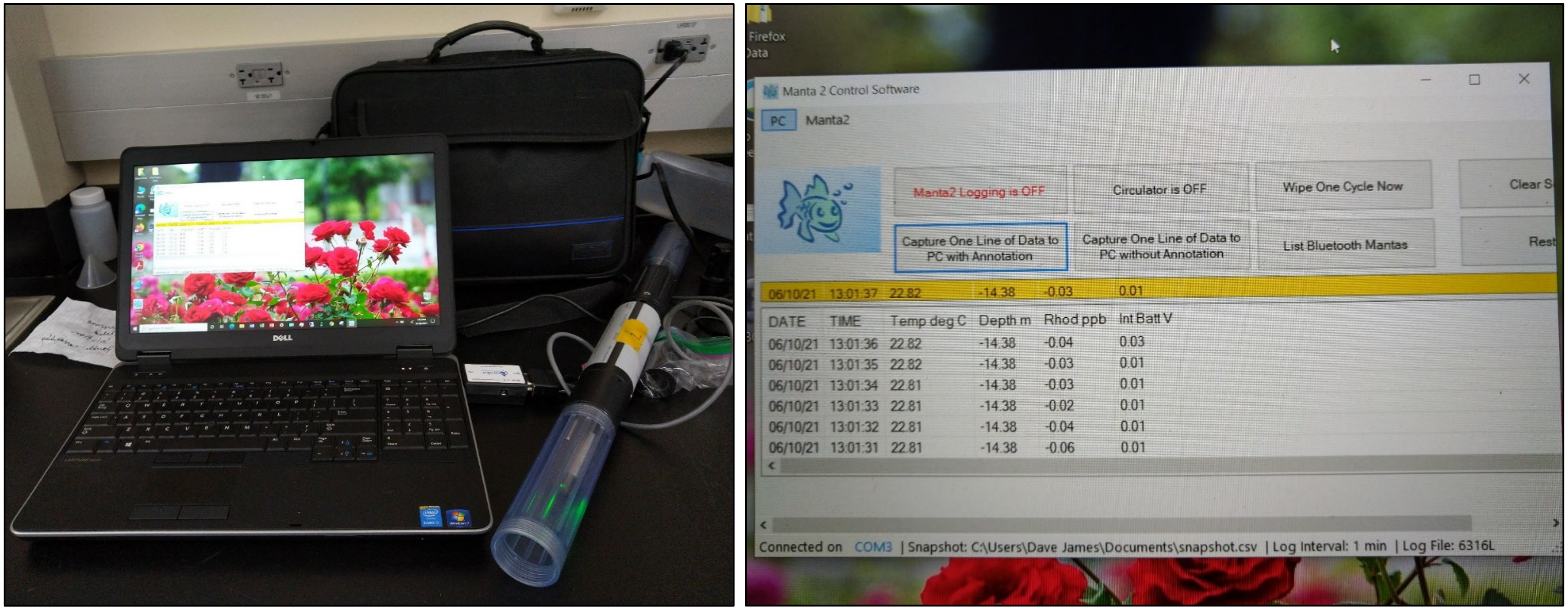


Figure 6-6. Left: RWT Sonde and Laptop System. Right: example software readout on laptop.

Figure 6.6's left-side photo shows the RWT sonde and laptop system used for in-situ measurement and profiling of added tracer. The green light visible at end of sonde is emission LED for RWT fluorescence. RWT fluorescence is in the yellow waveband. A RWT fluorescence detector (not visible) is located next to emission LED picking up backscattered fluorescence from the RWT. The sonde in the photo is a Eureka Water probes Trimeter® with a fluorescence sensor provided by Turner Designs. Equivalent sondes from other equipment vendors, such as Yellow Springs Instruments (YSI) are also available.

Figure 6.6 right-side photo shows an example of *in situ* data acquisition Eureka Water Probes Manta® software readout on a field sampling laptop showing acquisition of depth, RWT signal, temperature, and internal battery voltage as a function of time. Data were recorded at 1-second intervals. Equivalent software programs are available from other vendors, such as Yellow Springs Instruments (YSI).

c) Communications and positioning equipment

Redundant charged two-way radios should be kept on each boat. Two-way radios are recommended over mobile phones because they are robust enough to withstand rough use, such as being dropped and water exposure, and have long standby battery life.

Especially on large lakes, redundant global positioning equipment on each boat, with at least one-map-enabled system, is strongly recommended to permit both logging of sample location and avoidance of navigational hazards, especially in conditions of limited visibility that may occur during foggy weather, storms or at night. During the Lake Arrowhead tracer study, one boat was completely fogged in at night, with complete black out conditions, no landmarks were visible. The sampling team stopped boat movement and deployed real-time GPS with mapping visualization to establish boat position relative to the lake shore until visibility was restored and then resumed navigation to the next sampling position.

6.7.3 Plan operations and coordination in advance

Once the tracer study is approved, the water agency and its contractors should start planning to carefully coordinate field operations during the tracer study. Recommended steps are summarized below.

The key areas for advance operational planning and coordination are:

a) Coordination with water utility operations. The tracer study team should coordinate with the water utility to:

- Understand drinking water intake locations, elevations, operating schedules, and flow rates. If there is a possibility that the tracer may impinge on the intakes during operations, a decision must be made to determine if intake operation should continue which may be representative of typical reservoir operations, or if the utility should close the intakes for the duration of some part of the tracer study.

- Communications procedures and telephone numbers should be established in the event that lake monitoring indicates a risk of the tracer reaching an operating intake.

- Water treatment plant processes should be understood, along with their ability to remove tracer during treatment in the event that tracer reaches the intakes. For the Lake Arrowhead tracer study, tests in Lake Arrowhead's water showed that a 10 ppb starting concentration of Rhodamine WT (the maximum concentration recommended by US EPA in 1988) was reduced to 0.1 ppb (the EPA allowed concentration in drinking water) in 8 minutes at the standard applied 4.0 mg/L chlorine residual (Figure 6.7) obtained from Saber et al, 2018).

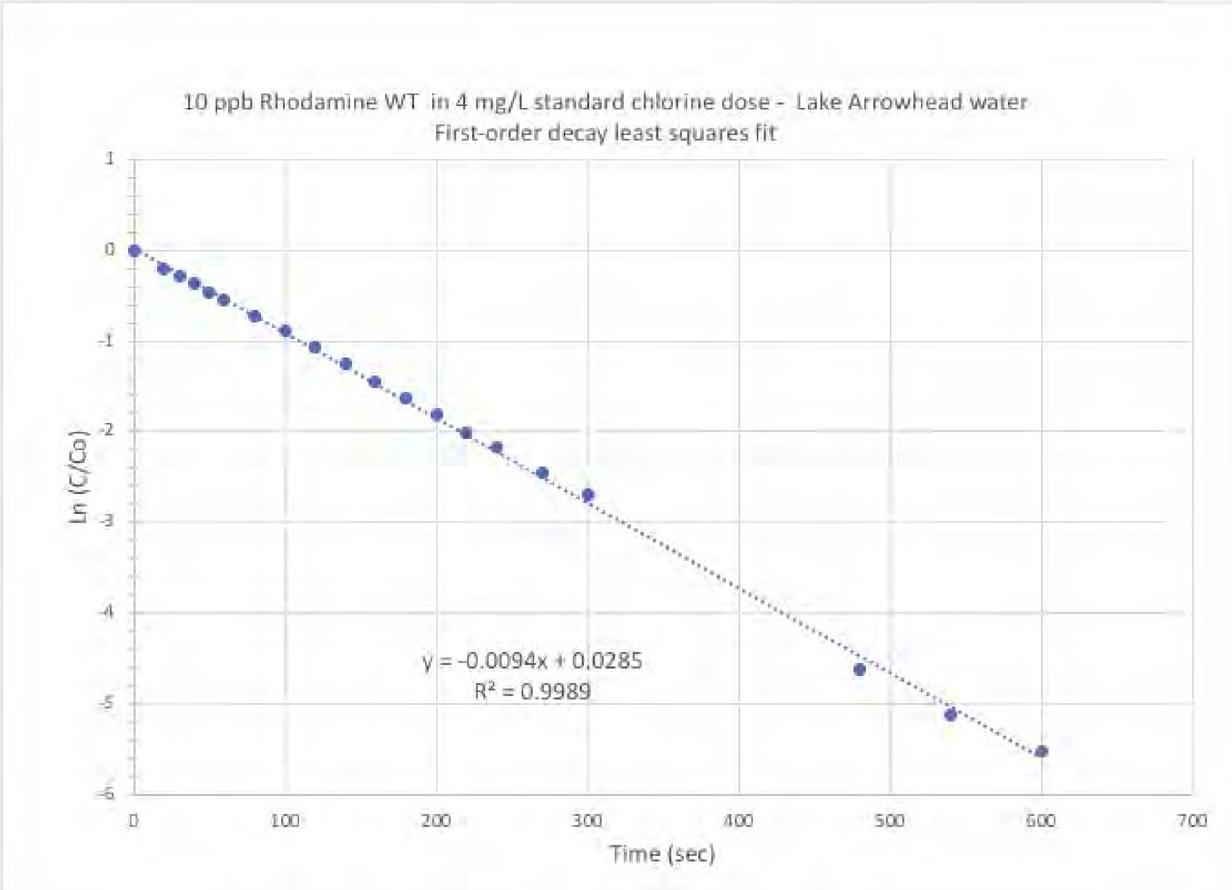


Figure 6-7 Example RWT dye decay data in Lake Arrowhead water at 22°C with 4 milligram per liter applied chlorine dose. Red dashed horizontal line indicates 0.1 ppb, 1988 US EPA advisory limit for drinking water. Corresponding elapsed time on x-axis is 8.2 minutes (8 minutes, 12 seconds**)**

b) Coordination with reservoir management

- For multi-use reservoirs, especially those with significant recreational activities, such as fishing tournaments, and water ski or boat races, the tracer team should work with reservoir management to determine if a reservoir can be closed or if tracer addition and monitoring should be scheduled to not conflict with recreational activities or events. Timing should generally avoid peak summer activities and major holiday weekends.

- Determine if logistical support can be provided by reservoir managers such as access to maintenance barges for tracer addition or patrol craft for tracer sampling and to maintain a safety perimeter during tracer addition. Reservoir staff scheduling should be discussed along with any need to provide compensation for over-time pay or extended work weeks.

6.8 Conduct tracer study

The field portion of the tracer study occurs in six phases as summarized below.

Phase 1 – Arrive, set up and weather check. The team should arrive on site at least two days before the scheduled tracer study to unpack, set up base camp, and field test the tracer addition system either at shoreline or on the barge (without tracer) to make sure that everything is working properly.

Phase 2 – Schedule check, team deployment plan and baseline water quality profiles. One day before tracer addition, final team meetings should be held to brief all personnel on equipment operations, communications protocols, field safety procedures, and one last time, on all addition, sampling, and monitoring equipment operations. Team deployment schedules for the critical first two to three days of the study must be established and well understood by all participants. A baseline set of water quality profiles should be collected on this day to determine lake conditions and identify the location of the thermocline, or in wintertime, ascertain that the lake is well-mixed.

Phase 3 – Tracer addition and initial monitoring. Early on the day of the study, if not already deployed, all equipment should be embarked and set up on boats prior to departure. A temperature-depth profile should be taken to establish the location of the thermocline. The tracer addition barge, monitoring boat(s) and safety boats should arrive and set up at the injection point. Tracer should be mixed, equalized to target lake temperature, and then injected into the lake at the target depth. The tracer addition system should then be shut down and the barge should leave the area (if powered) or remain anchored with no further activity, if not powered.

Phase 4 – Initial tracer concentration profiling should begin immediately to determine the initial horizontal and vertical extent of the tracer mass. Researchers are strongly advised that the tracer may exist in a layer only 10 to 20 centimeters thick after initial addition, so careful, very slow depth profiling with the sampling probes is needed to identify the tracer mass location and concentration. Subsequent monitoring at fixed stations, corresponding to known hydrodynamic model grid cells, should occur on a predetermined schedule. Initial monitoring at nearby stations should occur on a frequent schedule to capture the initial rapid relative spread and decline in concentration of the added tracer mass. More frequent monitoring should occur in the first two days at all stations to adequately capture initial tracer spread. All stations should be monitored because the tracer can move at depth in unexpected directions.

Phase 5 – Long-term tracer concentration profiling should continue after day 2 on a schedule that reflects anticipated rates of tracer movement and decay. Significant lateral displacements can occur. For example, an added tracer mass can move laterally 864 meters in a day (about 0.5 mile) at average current velocities of 1 centimeter per second. This schedule duration can vary considerably depending on ambient conditions and reservoir stratification, surface area and depth. In conditions of strong stratification and light winds, the tracer mass can persist at depth for many weeks, only slowly mixing, with limited rates of movement and decay. If current speeds are very low, it may take weeks for the tracer to move across a large reservoir (Ding et al 2012b). For example, at Miramar reservoir in summer 2019, the tracer was monitored for more than 90 days until stratification.

weakened in the fall and the tracer mixed up into the water column and became subject to photo decay (Dorman et al, 2019; Pasek et al, 2020).

In contrast at Lake Arrowhead Reservoir in late fall 2019, in conditions of strong winds, rain and weak stratification, the tracer mixed up into a substantial portion of the water column and dissipated to background levels in approximately four days.

Phase 6 – Tracer Data reduction and visualization – should commence immediately upon data acquisition so that mapped profiles can be communicated with all team members to both permit advance planning of priority stations for measurement or sample collection and advance calibration of monitoring probes, if used, to the correct concentration ranges.

6.9 Reduce tracer study and other data for use in model

It is important to carefully estimate the amount of time needed for reduction, analysis, and storage of tracer field data. A general rule of thumb is that up to 10 hours of effort will be needed for each field data collection hour. Seven recommended data analysis and reduction steps needed for use in the hydrodynamic/water quality model are summarized below and presented in detail in Appendix 6.7.

The seven steps are:

Step 1 – Raw Tracer profile visualization. Plot tracer concentration profiles for each station along with temperature profiles to determine magnitude of tracer concentration changes over time at each station and also to see if tracer establishes a peak value at some location in the thermocline. Example tracer concentration profiles at one station, showing evolution of tracer concentration with time are shown in Figure 6.8.

Step 2 – Average tracer concentrations in each grid cell and format tracer and all water quality constituent profiles into data file format used by hydrodynamic model to facilitate direct comparison of measured depth-averaged tracer concentrations to modeled grid cell tracer concentrations.

Step 3 – Compute grid cell averaged measured tracer dilutions using the same equations to compute modeled tracer concentrations to facilitate dilution comparisons with hydrodynamic model predictions. Example grid-cell averaged tracer dilution plots are shown in Figure 6.9.

Step 4 – Evaluate tracer concentrations at intake depths over time to estimate travel time of tracer from point of addition to drinking water intake at specific elevations, to facilitate comparison of measured reservoir detention time and travel time to modeled detention time and travel time.

Step 5 – Analyze tracer static bottle decay data to generate estimates of tracer decay rates, and if possible, derive kinetic coefficients that can be used in the hydrodynamic model.

Step 6 – Obtain meteorological data corresponding to time of tracer study and format it for input into the hydrodynamic model. It is best to collect raw frequently sampled meteorological data and then average the data to correspond to model time steps. High frequency raw data permits the team to adjust the averaging interval to correspond to different time steps that might be selected for hydrodynamic modeling purposes.

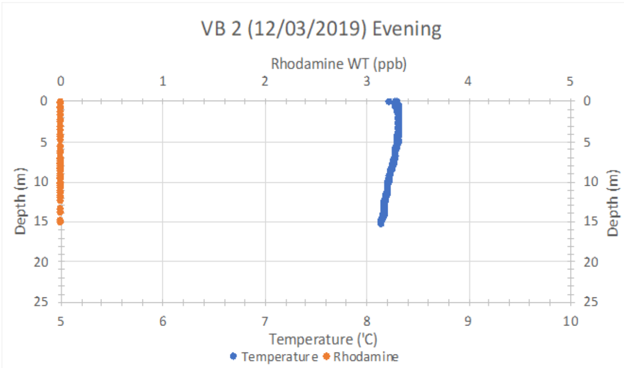
Step 7 – Obtain reservoir water levels, inflows and outflows corresponding to time of tracer study and format for input into the hydrodynamic model. This is necessary to determine:

- If a reservoir volume change could dilute or concentrate the tracer (if no tracer left the reservoir) or

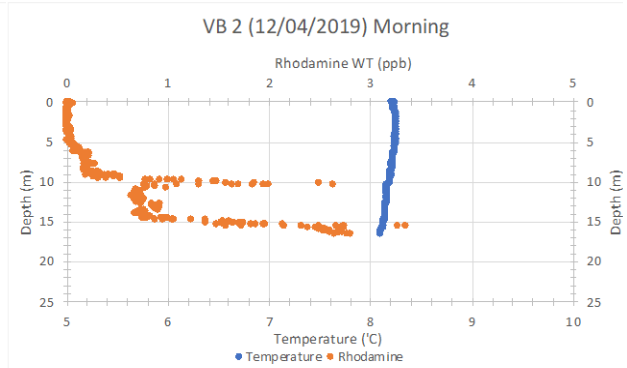
- If any tracer could have been removed by outflows during the study period.

Both calculations are necessary to determine if tracer mass was conserved during the period of the tracer study.

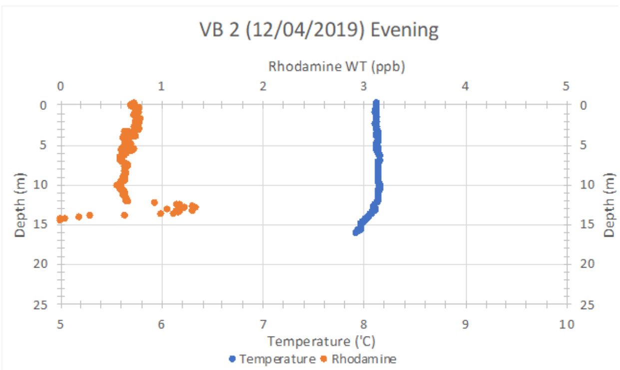
Charts below show Village Bay Station 2 RWT tracer (orange) and temperature (blue) vs depth



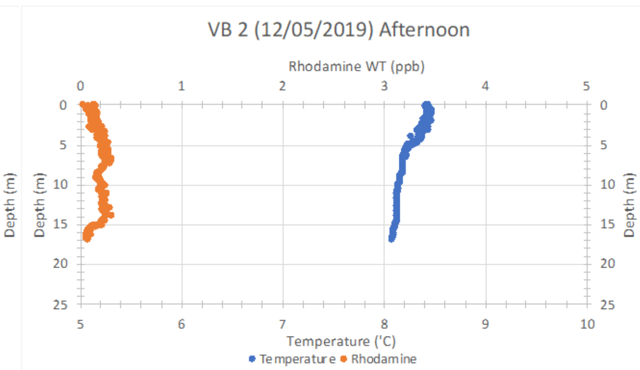
10.5 hours after tracer addition



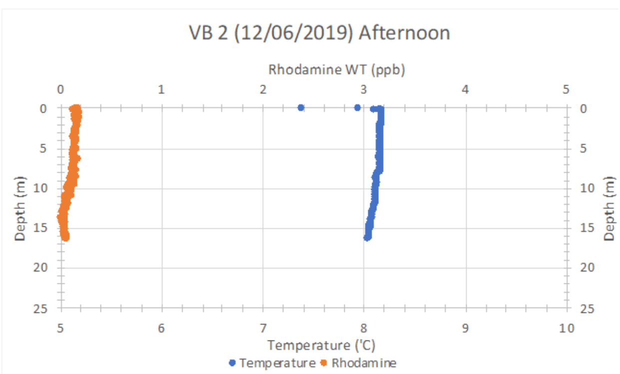
23 hours after tracer addition



35 hours after tracer addition



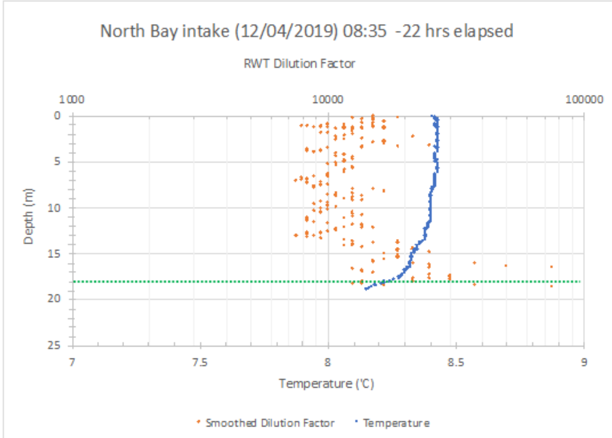
53 hours after tracer addition



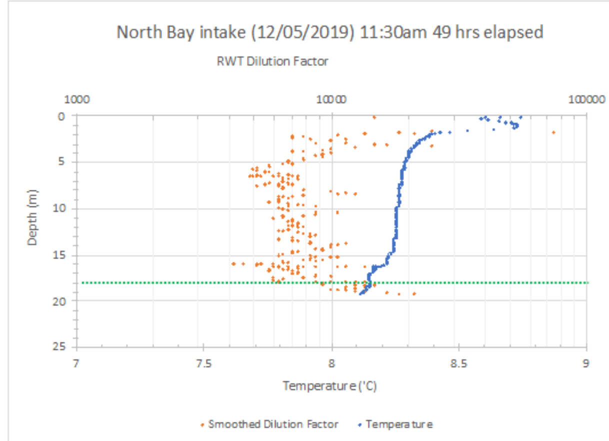
78 hours after tracer addition

Figure 6-8 Example plots for evolution of RWT tracer concentration vs depth, Station Village Bay 2 (VB2) Lake Arrowhead, Ca showing maximum concentrations of 2.8 and 3.4 ppb at 10 and 15 meters, respectively at 23 hours elapsed time.

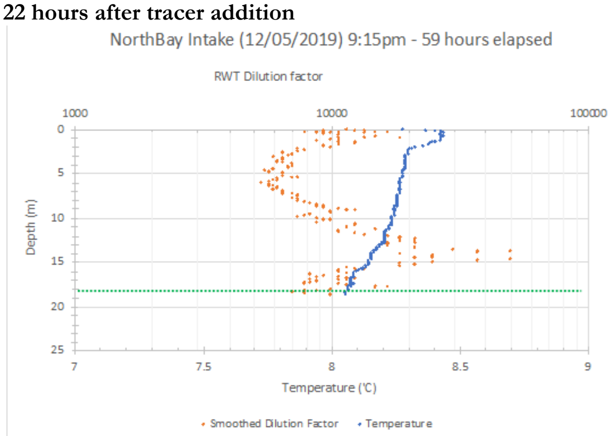
In the charts below, tracer estimated dilution from field measurements assuming 300 ppb starting concentrations (orange) and temperature (blue) vs depth. Green line is North Bay intake elevation.



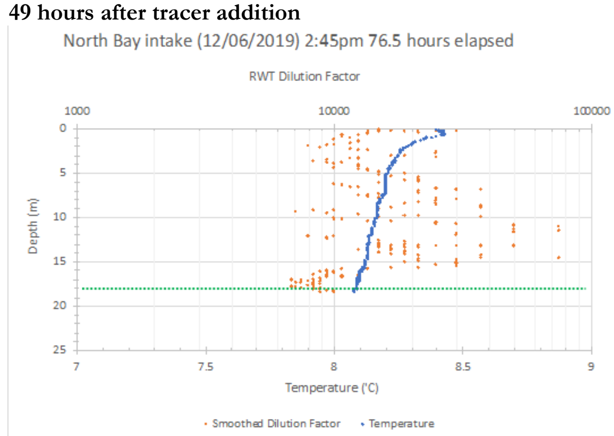
22 hours after tracer addition



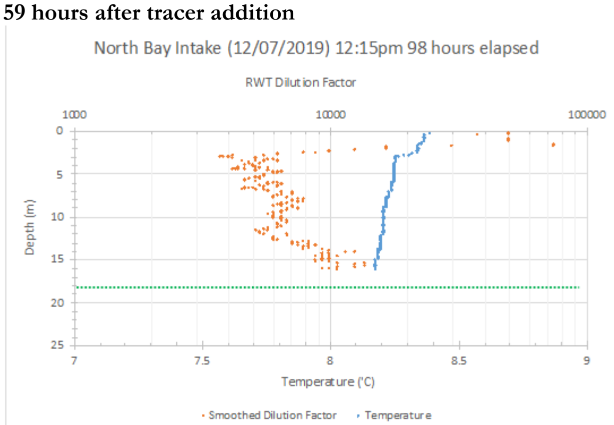
49 hours after tracer addition



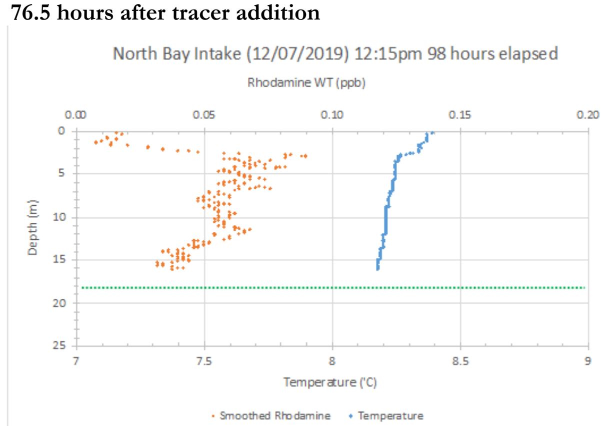
59 hours after tracer addition



76.5 hours after tracer addition



98 hours after tracer addition



North Bay 98-hour field measured tracer concentration Water column <0.10 ppb EPA advisory drinking water limit

Figure 6-9 Example estimated RWT dilutions from tracer field measurements at North Bay Intakes Lake Arrowhead, Ca. Green line is North Bay intake elevation. Thermocline starts at 16-17 meters on 12/4/19 and morning 12/5/19 then moves below 18-meter intake elevation during the study as the lake continued to cool.

7 Running the model

Main points

1. Install the model on your workstation and then test the model with known input files for a simple standard water body. Correct errors until model trial runs complete without errors and the results match the known outputs.

2. Use meteorological, hydrological, water quality and digital elevation data (bathymetry and shoreline) as inputs to *calibrate* the model for the candidate reservoir. Compare simulated results to measured lake water surface elevations, temperature-depth profiles (for energy balance) and to measured constituent vs depth profiles, estimate errors, and adjust until errors are minimized.

3. Conduct a *first validation* of the calibrated model using the data from the first tracer study performed before project implementation. This first set of validation runs will simulate vertical mixing and horizontal movement of tracer across the reservoir. Adjust model inputs (such as wind velocity distributions and wind to water surface drag coefficient until the error of modeled tracer vertical profiles is minimized relative to measured tracer vertical profiles.

4. After the first validation, use the model with combinations of representative climactic and operational conditions for the reservoir to compute alternative operational scenarios, using a hypothetical starting tracer concentration, depth, and location to estimate the ranges of hypothetical tracer concentrations and detention times that may occur at the drinking water intake locations. From the estimated tracer concentrations at the intakes, generate dilution estimates of the tracer from the starting concentration at the point of discharge to drinking water intakes. Compare estimated dilutions to regulatory requirements for specified water quality contaminants.

5. After recycled water project engineering design and implementation, conduct a *second validation* by comparing measured results of a second tracer study that represents the actual location, depth, and method of planned recycled water addition to the modeled dilutions and rates of movement of the tracer. In this second validation, model input parameters are not usually adjusted. Instead, modeled results at the intakes are compared to second tracer study measurements and errors are calculated. Subsequently, additional modeling scenarios using the actual proposed location and configuration of recycled water input may be conducted to estimate dilutions at the intakes for a wide range of environmental conditions, including 'black swan' worst case combinations of conditions to determine if required regulatory minimum dilutions and residence times are attained.

6. Write technical memoranda for review by stakeholders, independent advisory panels, and regulators.

7.1 Conduct initial trials and correct until the model can complete runs without errors

After acquiring suitable workstations and preparing model input data and files as described in Section 5.6, it is recommended that the modeling team initiate a two-phase set of initial trial runs with sample input files to see if the model can complete runs without errors.

The two phases are:

Phase 1) Test the model with a simple known set of input files to assure that the model configuration on the workstation is correct.

- "Configuration" means establishing directory structures, file folder names, and instructions in a model run file regarding which files to use and in which folders to locate them.

- Most hydrodynamic models include a set of trial input files that permit the modeler to perform initial calculations on a simple hypothetical water body. In general, these initial trials also employ only a limited set of computations (for example, only mixing and advection without simulating any chemistry or biology) to simplify the comparisons to known outputs.

- Once the model is installed, the modeling team can perform trial calculations with these input files and compare results to the known outputs to determine if they match. If there is a match, then the model is set up correctly.

- Subsequently, the modeling team may 'turn on' additional chemical and biological computations and compare results again to see if there is a match to previous results.

Phase 2) Apply, in the known file directory structure, new model input files that represent the conditions of the proposed SWA-IPR reservoir, including bathymetry, shoreline geometry, water level, winds, and conduct initial trial calculations to determine if:

- The model completes calculations without errors, and

- The results of the initial calculations agree with observations (for example a known set of water levels or temperature-depth profiles.

If the model returns error codes that allow tracing of possible problems, or fails to complete a run, or if it generates results that are significantly different from measured values, then the team must troubleshoot the model to identify and correct the problems before proceeding to model calibration.

Once the model can complete the Phase 2 runs without errors, then the model trial run output data files should be evaluated and visualized to determine if model outputs make sense compared to measurements.

For example, lake levels calculated from an energy and water balance should be compared to measured lake levels, and the magnitudes of errors should be estimated and reported. An example comparison of modeled lake level to measured lake level is shown for Lake Arrowhead Reservoir in Figure 4.2. Good agreement was obtained.

If model results do not satisfactorily match measurements, revisions to input files should then be undertaken to address errors before modeling computations begin for calibration, validation, or scenario calculations.

Once the model successfully completes the Phase 2 runs without either performance errors (failing to complete the calculations) or substantial numerical errors in comparison to known values, then the model is ready for calibration efforts.

7.2 Use bathymetric, water quality profile and meteorological data to calibrate the model

Model *calibration* consists of

- Creating model input files from long duration meteorological, hydrological, and environmental monitoring of the reservoir,
- Running the hydrodynamic model with those input files and generating model-estimates of reservoir elevation, temperature, and other water quality profiles, and comparing them to measurements to determine if the model can accurately reproduce a reservoir's energy and water balances, and
- Adjusting model input parameters and repeating the runs until the differences are minimized. Typical parameter adjustments include:
- Estimated magnitudes of wind speed and direction over the reservoir water surface,
- Degree of coupling of turbulent kinetic energy input from winds to the reservoir water surface,
- Coefficient for absorption of solar energy into surface waters,
- Estimated coefficients of vertical diffusion of momentum and mass into deeper water layers,
- Rates of evaporation from the lake surface, and
- Estimated coefficients of light extinction with depth into the reservoir.

Results of model computations are compared both graphically and numerically to determine the level of error. As examples,

- Figure 7.1 shows a lake water balance and level simulation conducted as part of AEM3D model calibration for Lake Arrowhead Reservoir, showing good agreement between measured and modeled values.

- Figure 7.2 shows results of one year of a Lake Arrowhead simulation comparing evolution of monthly measured and modeled lake vertical temperature profiles as part of model calibration, again showing good agreement among measured and modeled temperatures.

Model calibration runs are repeated until errors are minimized. For SWA-IPR studies, the first of several independent scientific reviews may take place at this stage.

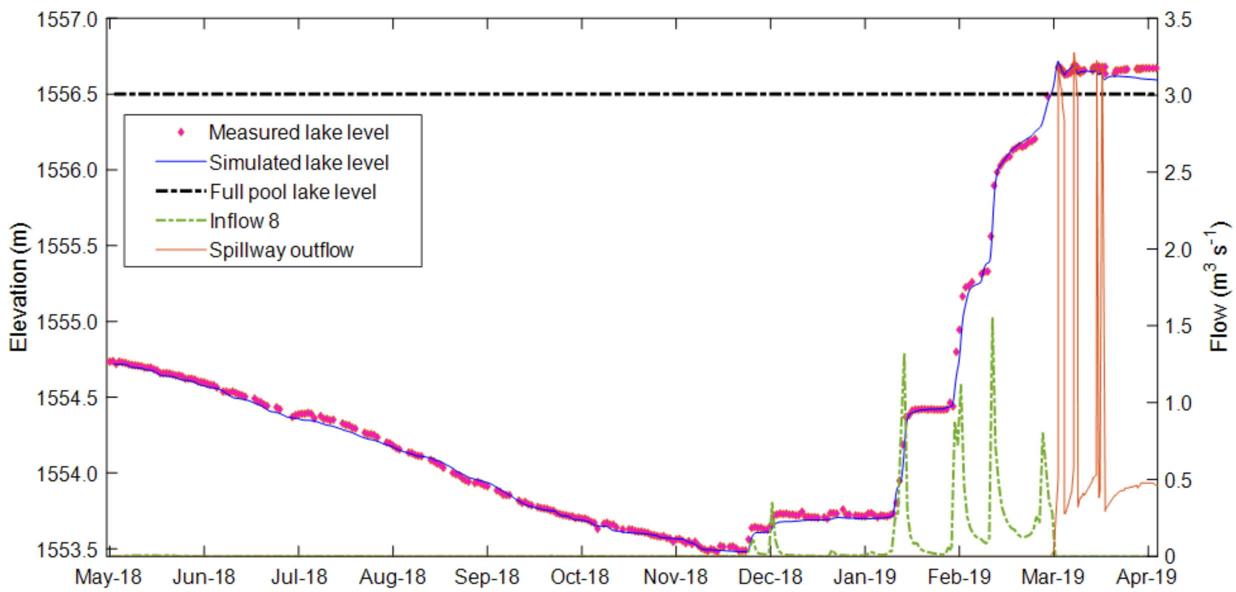


Figure 7-1 Reservoir water surface elevation (shown as "lake level" in legend) simulated by AEM3D model compared to measured level, inflow, and spillway outflow patterns. Magenta dots: Measured lake level (elevation). Blue line: Simulated lake level. Green dotted line: Little Bear Creek inflow (Inflow 8). Red solid line: Willow Creek Spillway outflow.

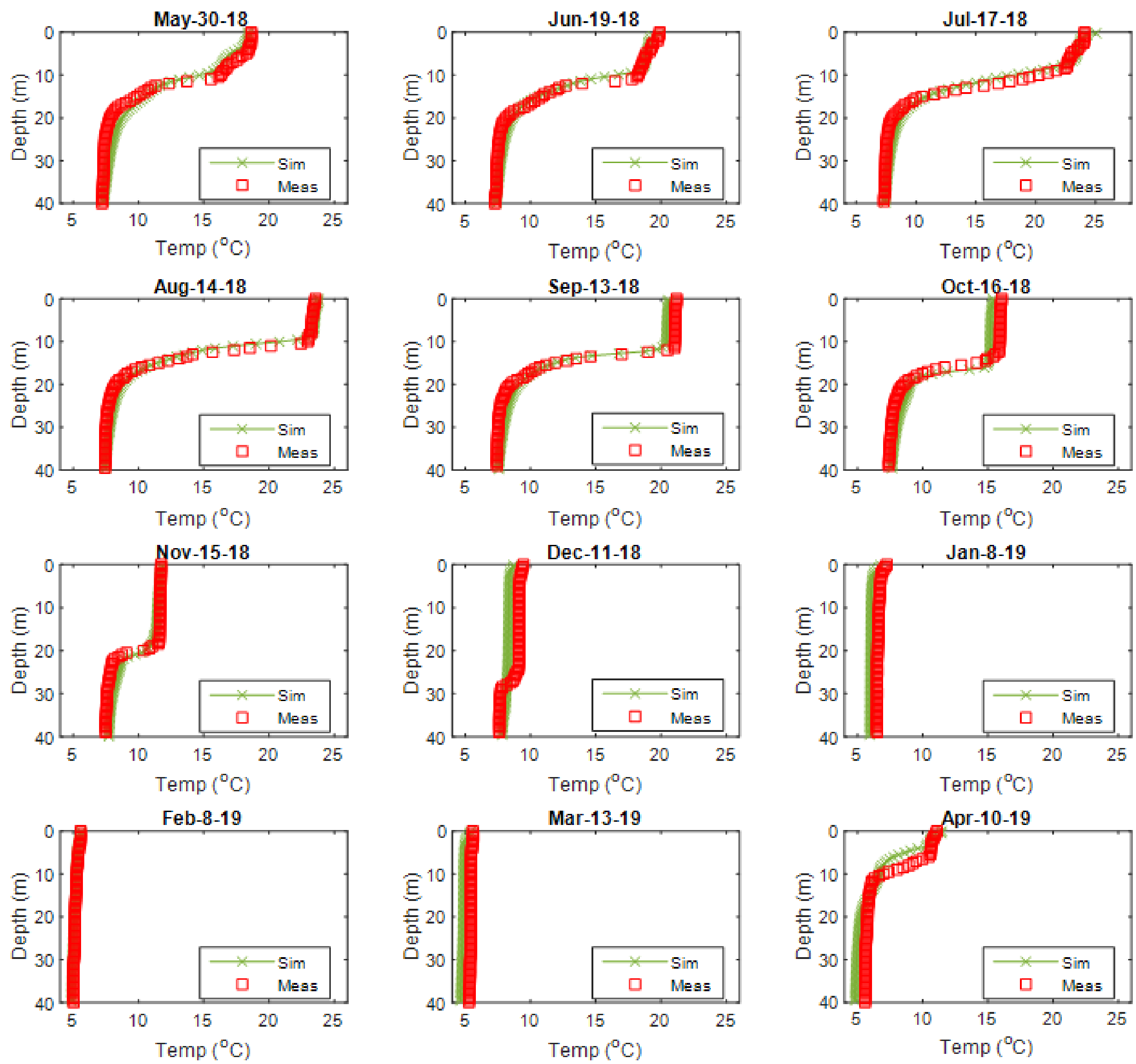


Figure 7-2 Lake Arrowhead hydrodynamic model. Example calibration plots showing evolution of AEM3D simulated (green - Sim) and measured (red - Meas) temperature profiles from May 2018 through April 2019.

Use first tracer study data to initially validate the model

The first, or initial model *validation* consists of:

- Creating new model input files for the now-calibrated model from available meteorological, hydrological, and environmental data sets that were collected before, during and after the period of the tracer study. The model will typically require at least a month of input data and computations before the start of the tracer period so that its calculations can stabilize and be representative of reservoir conditions at the time of the tracer addition.

- Organizing tracer profile measurements into a format that permits comparison with model output. Tracer sampling location, date, time, and profile data with depth are needed for validation. Temperature profile data must be collected simultaneously with tracer concentration data so that measured and modeled tracer data can be compared to the depth and 'strength' (defined as the rate of change of temperature with depth) of the thermocline.

- Knowledge of the depth and strength of the thermocline is vital because typically a tracer, after mixing with ambient water, descends to a level at which its density is neutral with regard to the surrounding water and then spreads laterally at that depth. This neutral density level is typically in the thermocline.

- Typically, model vertical grid cell size (in the range of 0.10 meter to 0.50 meters) is larger than the depth intervals used for tracer measurements, so tracer concentrations must be averaged over depth ranges corresponding to the elevations and vertical dimensions of the grid cells. Averaged tracer concentrations usually 'smooth out' small amplitude fluctuations in tracer concentrations before comparing measured tracer concentrations to modeled concentrations. For example,

    - Figure 7.3 shows the location of station MD2, in the center of Lake Arrowhead Reservoir relative to the tracer injection location in Village Bay.

    - Figures 7.4 and 7.5 compare raw and smoothed tracer concentration profiles with depth at station MD2 over time during the tracer study.

Model numerical *validation* follows these steps:

- Compare modeled tracer concentration profiles with the measured smoothed tracer profiles at the different fixed reservoir sampling stations for the duration of the tracer study and compute model *validation errors*.

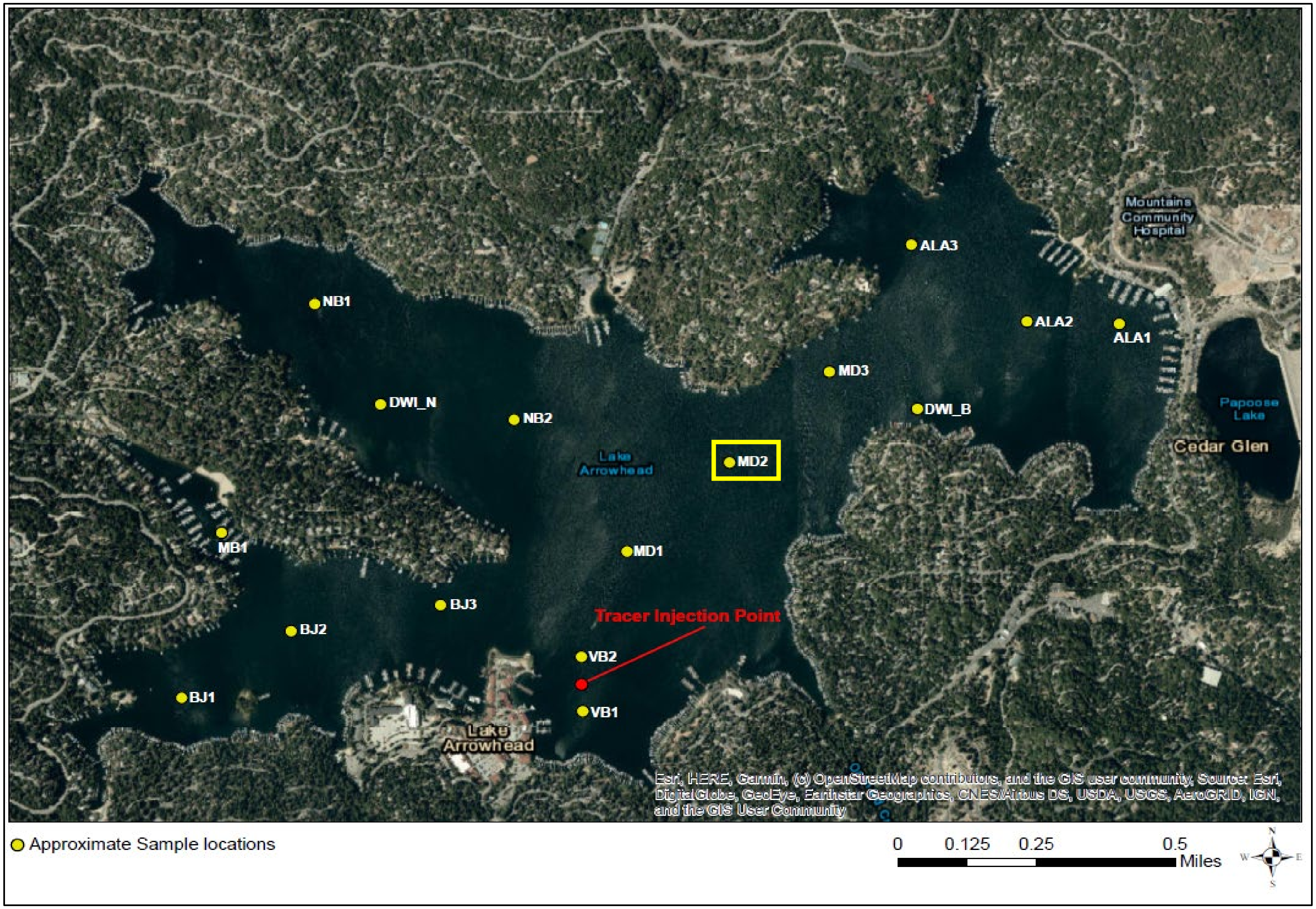


Figure 7-3 Lake chart showing location of station MD2 compared to tracer injection point.

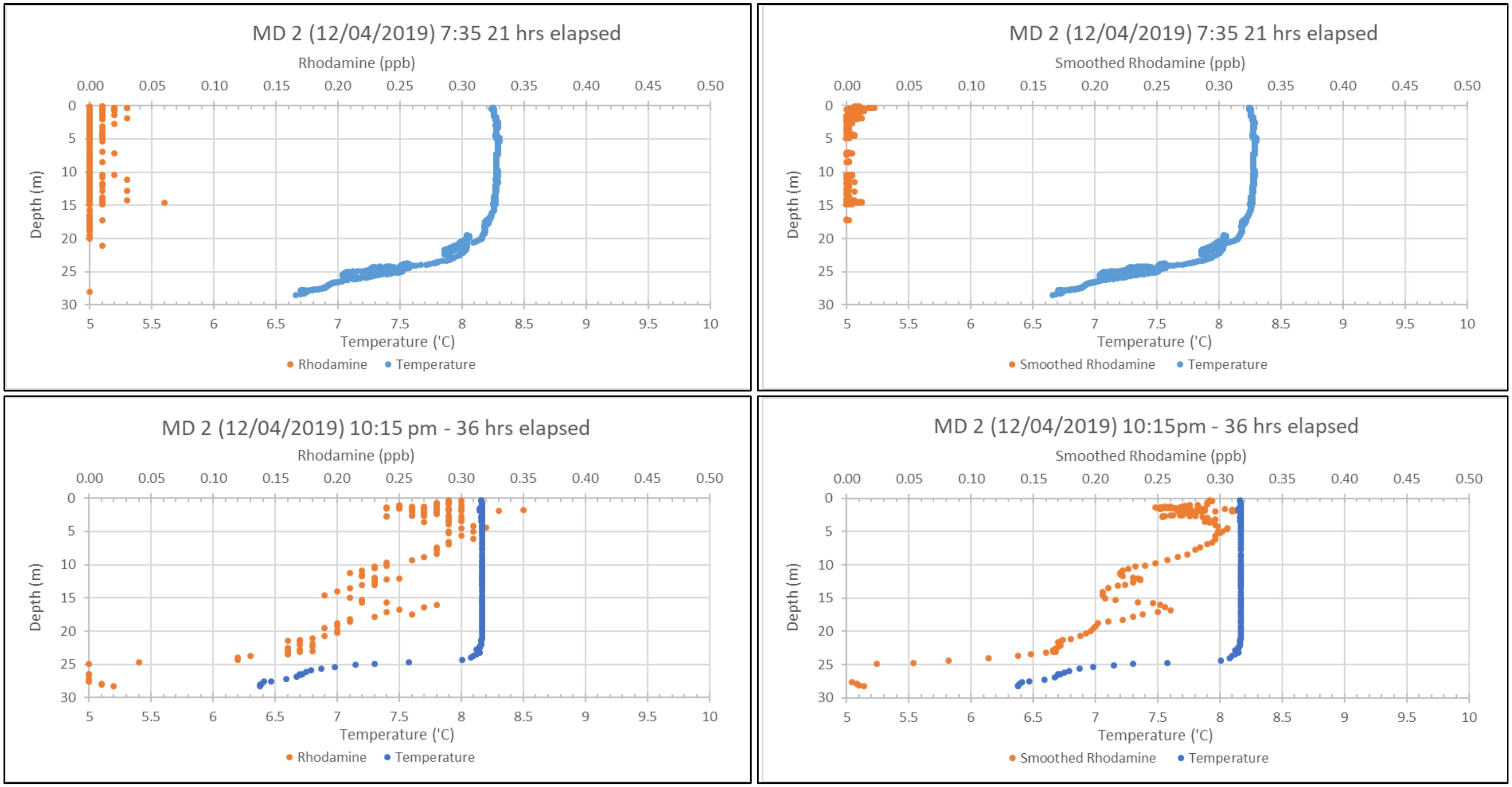


Figure 7-4 Comparison of tracer concentration profiles for 21 and 36 hours elapsed since tracer addition. Left: raw tracer concentrations. Right: smoothed concentrations. 5-point running smoother, averaging over approximately 0.10 meter rolling intervals. Smoothing reduces RWT fluctuations from approximately +/- 0.03 ppb (raw) to +/- 0.01 ppb (smoothed)

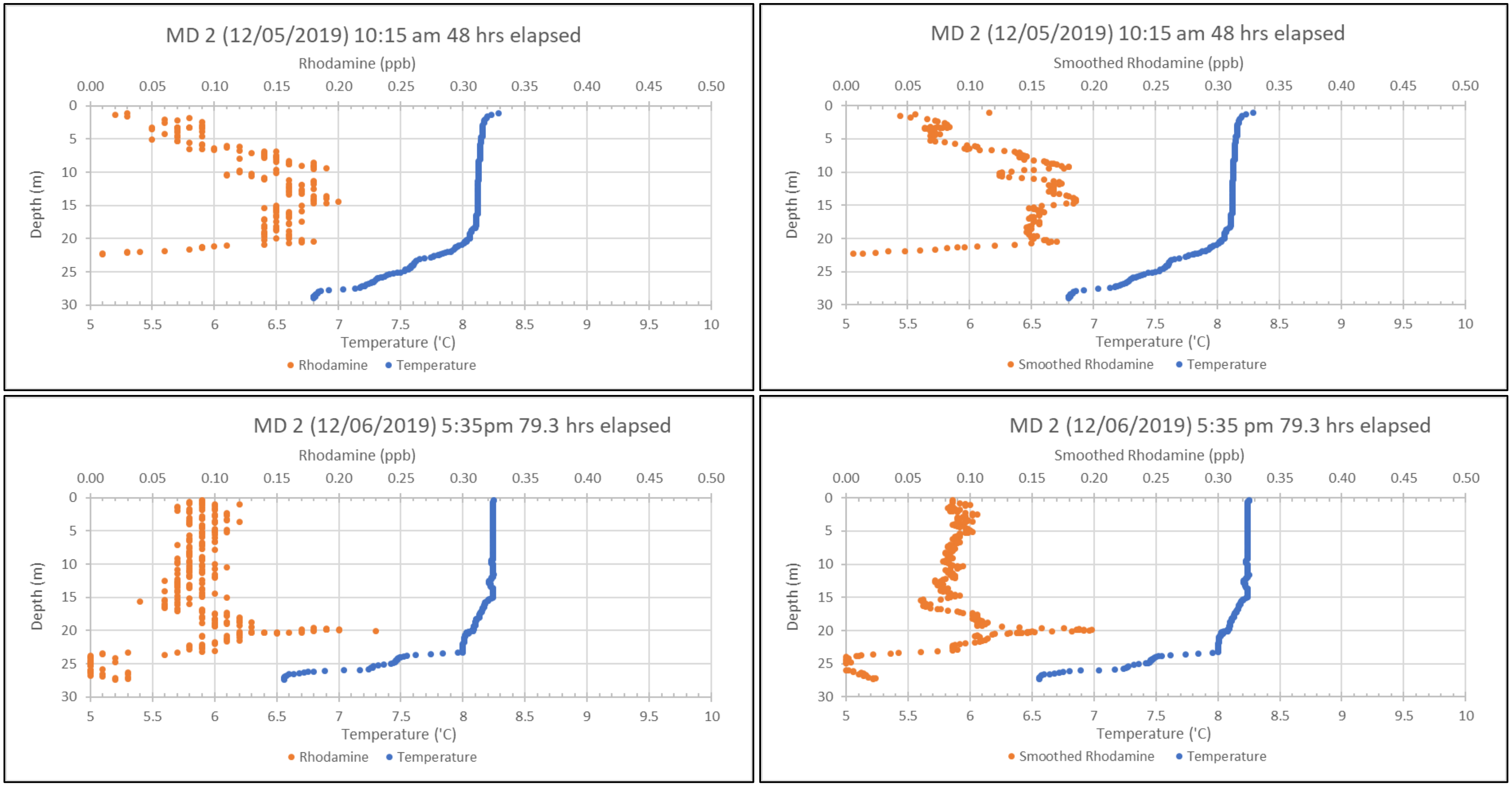


Figure 7-5 Comparison of tracer concentration profiles for 48 and 79.4 hours elapsed since tracer addition. Left: raw tracer concentrations. Right: smoothed concentrations. 5-point running smoother, averaging over approximately 0.10 meter rolling intervals. Smoothing reduces RWT fluctuations from approximately+/- 0.02 ppb (raw) to +/- 0.01 ppb (smoothed)

- *Validation errors* are computed as averages of all differences among measured and modeled tracer concentrations. The errors may be presented in absolute concentration units, such as Mean Error (ppb), Mean Absolute Error (ppb), or Root Mean Square Error (RMSE) (ppb) or as relative Root Mean Square Error, which is RMSE divided by the measured tracer concentration range.

- Adjust the model input parameters, as discussed in Section 7.2, and compare again to tracer measurements, and repeat the process until errors are minimized.

- As an example, Table 7.1 compares three cases for the December 2019 Lake Arrowhead model validation error calculations for three different vertical grid cell sizes. The 0.10meter grid cell size produced the lowest overall error for three of four measures, and the 0.50 meter grid cell height produced the lowest error in one measure (RMSE).

- Generate plots of evolution of computed tracer concentration with time for different combinations of model input parameters. For example,

- Figure 7.6 illustrates some comparisons of measured vs modeled tracer profiles with depth at different points in time at a fixed lake measurement station in Lake Arrowhead.

- Figure 7.7 depicts a false color vertical section of the Lake Arrowhead modeled tracer movement along a curved transect from point of tracer addition in Village Bay northeastwards towards the Cedar Glen drinking water intakes and then eastwards to the dam. Sets of these plots are generated at different points in time and then compared for different model input parameters to determine if tracer vertical distribution and longitudinal movement match observations.

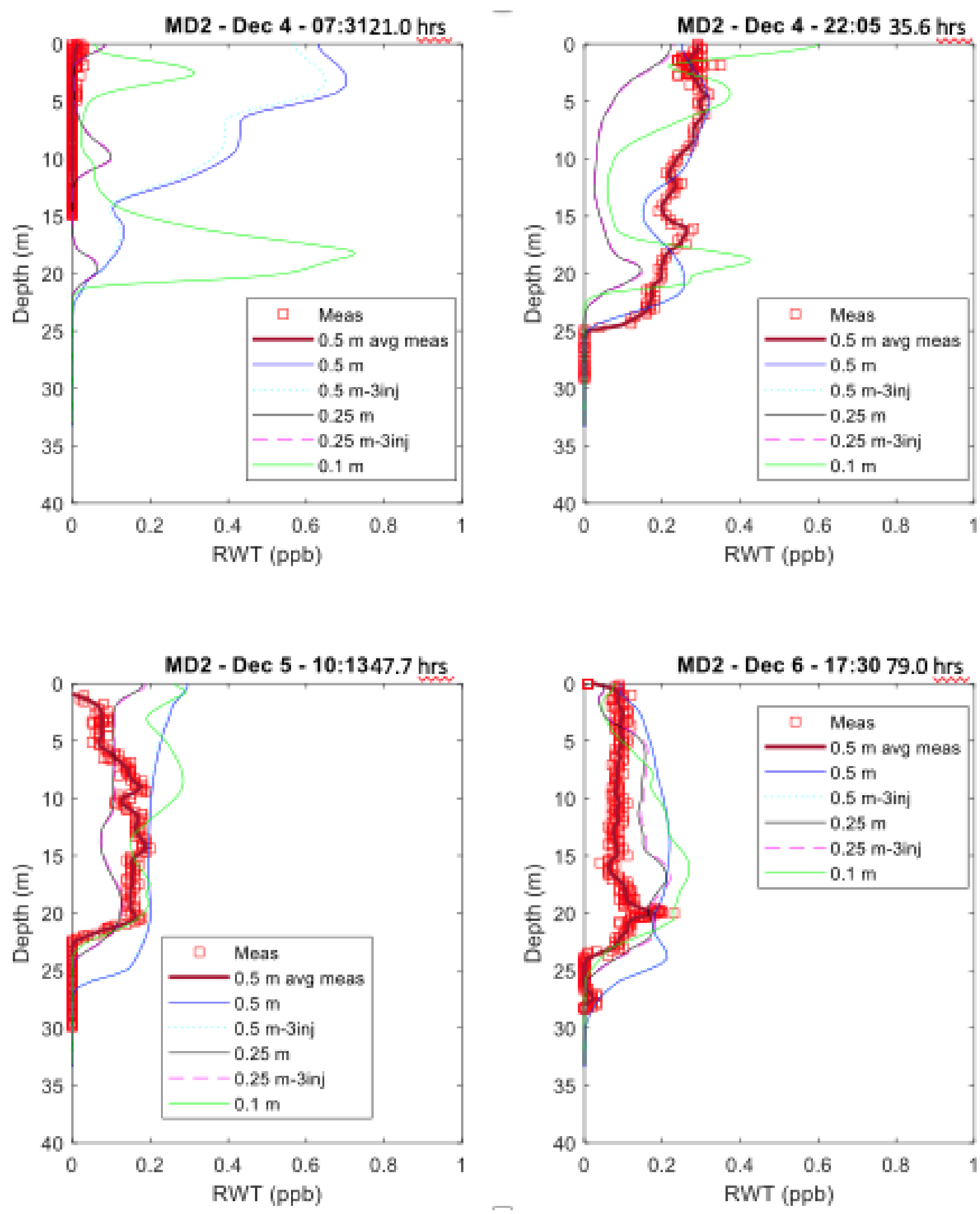


Figure 7-6. Example comparisons of measured vs modeled tracer profiles with depth at different points in time station MD2 in Lake Arrowhead for different vertical grid cell sizes at four time-steps corresponding to in situ tracer measurements. Top four panels: 21.0 and 36.0 hour estimates. Bottom four panels: 47.7 hour and 79.0 hour estimates. Red squares: tracer measurements. Heavy red line: 0.5-meter averaged tracer measurements. Blue line: 0.5-meter grid cell model results; Black line: 0.25-meter grid cell. Light green line: 0.1-meter grid cell model results.

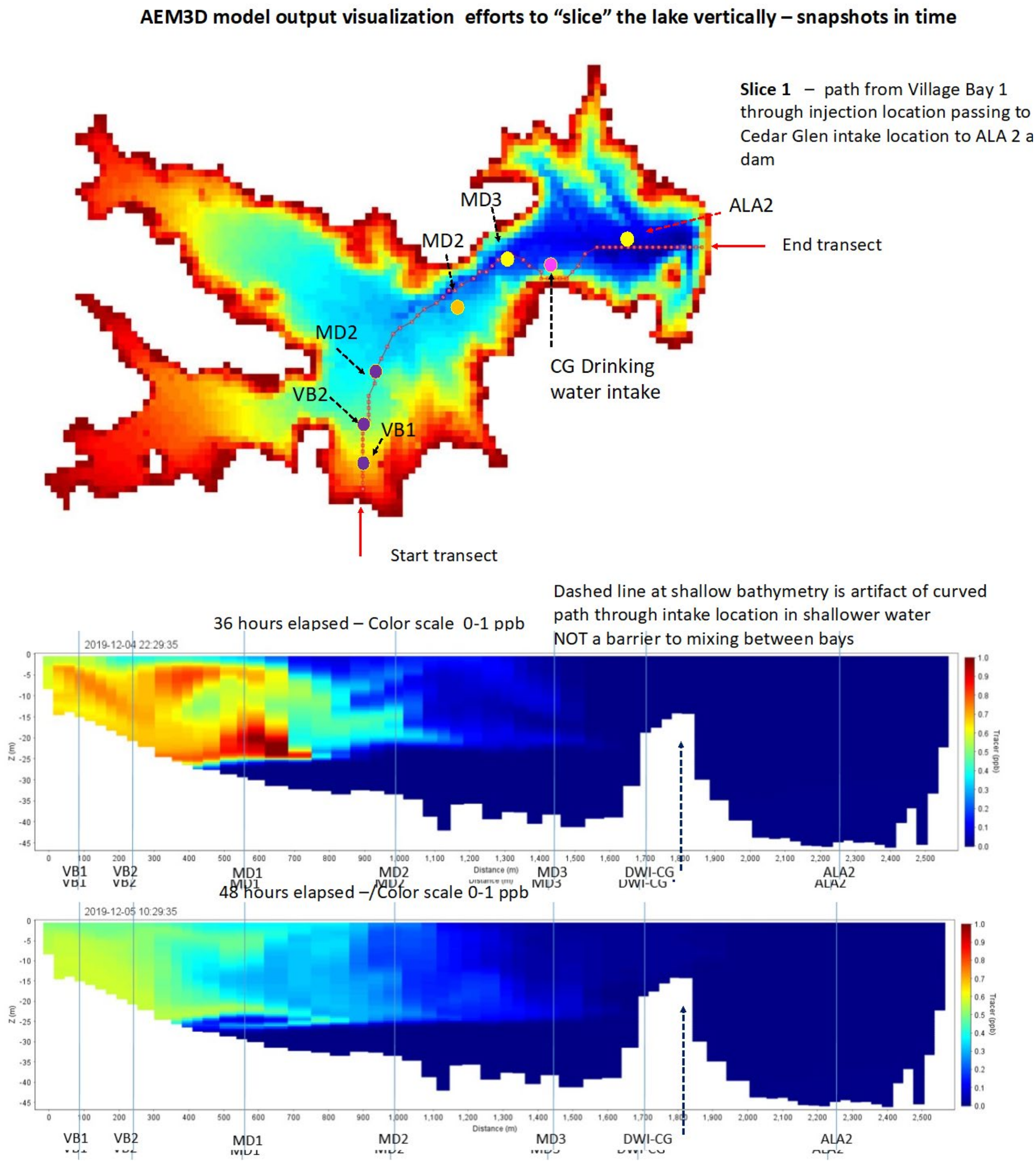


Figure 7-7. Top: curved transect from point of 12/3/19 tracer addition in Village Bay northeastwards towards the Cedar Glen drinking water intakes and then eastwards to the dam. Bottom: False color vertical sections of the Lake Arrowhead modeled tracer movement along curved transect at 36 hours and 48 hours elapsed time.

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- Estimate total tracer mass in the reservoir at several time steps during the tracer study and compare these estimated mass values to the known added tracer mass. If tracer loss due to outflow or tracer decay are known to take place, then calculations must be made to allow for these losses.

- In San Vicente Reservoir, Ding et al (2012a, 2012b) were able to account for settling and outflow losses of lanthanum phosphate precipitates and show that the validated San Vicente reservoir hydrodynamic model was accurately estimating tracer mass throughout the computations.

- In Miramar Reservoir, Pasek et al (2020) showed that Rhodamine WT tracer mass decay was negligible throughout the summer until, in the fall, the tracer mixed up into surface waters and began to photo decay. The validated Miramar hydrodynamic model was able to successfully account for all of the tracer mass throughout the computations.

- In Lake Arrowhead Reservoir, UNLV was able to evaluate Rhodamine WT tracer concentrations in static bottles and show that tracer decay was minimal over a 44-day duration, with detectable decay only in the 0.5 meter to 6-meter zone of the water column (Figure 7.8). Estimated decay rates were -0.14 +/- 0.02 ppb per day at 0.5 meters (100% PAR), -0.07 +/- 0.02 ppb per day at 2 meters (70% PAR), and -0.03 +/- 0.02 ppb per day at 4 meters (35% PAR). Decay was not detected at depths 6 meters (15%PAR), 8 meters (10% PAR), 10 meters (5% PAR) and 12 meters (3% PAR).

- Depths of the bulk of the tracer mass were generally in the range of 5 to 20 meters (examples Figure 7.6), or where light ranged from 25% PAR to 0% PAR, (Figure 7.8). Therefore, tracer was assumed to not decay significantly during the December 2019 Lake Arrowhead tracer study. The validated Lake Arrowhead model was able to successfully account for the tracer mass throughout the computations.

- Finalize adjustments of model input parameters and report results of validation runs to stakeholders and scientific advisory panels. Examples of these reports are cited in this report's references in Ding et al (2012a, 2012b), Dorman et al 2019 Pasek et al (2020).

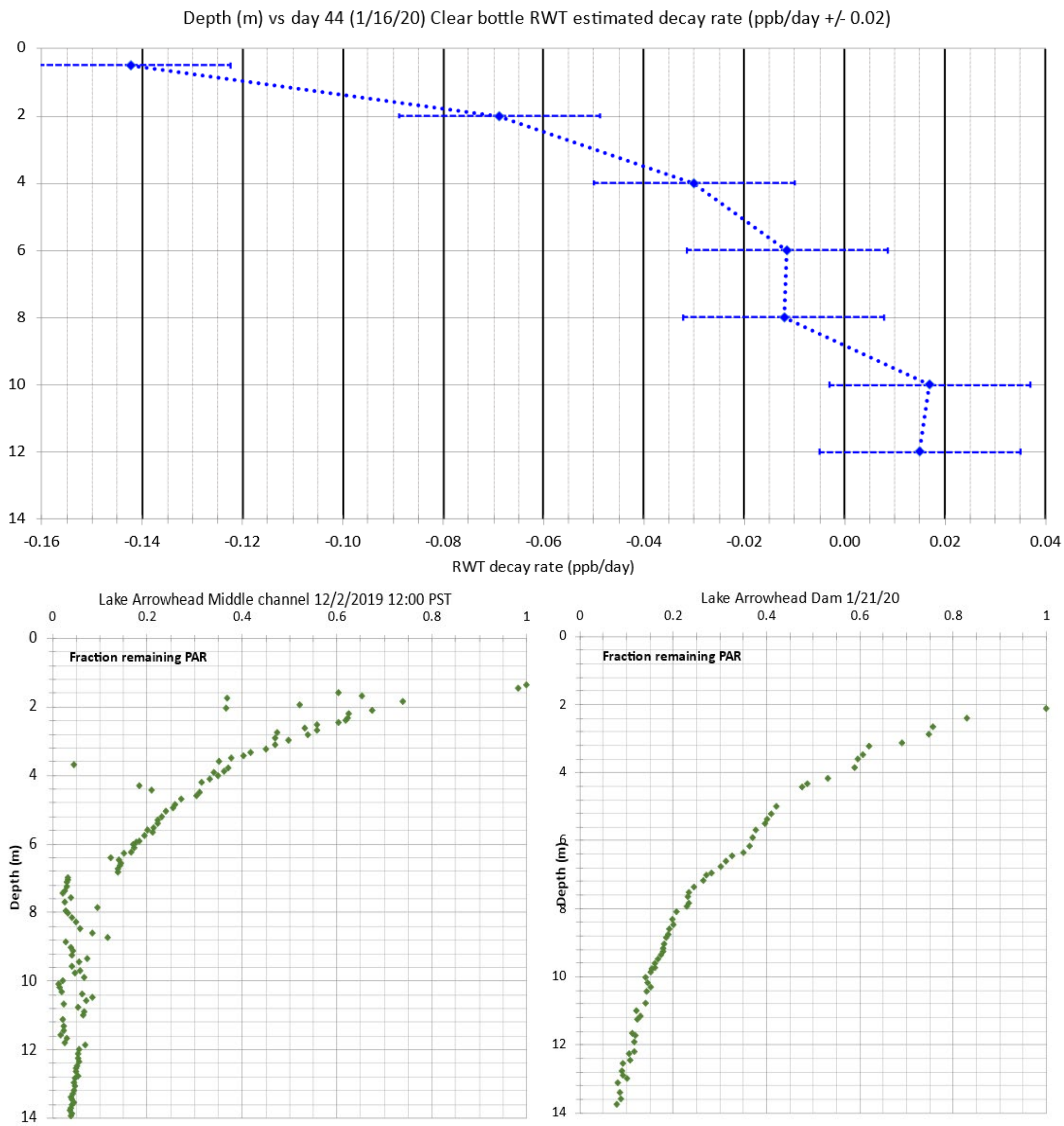


Figure 7-8. Example: Lake Arrowhead RWT dye decay rates estimated from 12/2/19 to 1/16/20 measured RWT data, assuming zero-order straight line decay.

Top: 44-day zero-order decay rate. Detectable rates only in 0.5m, 2.0m and 4.0m bottles.

Bottom: Percent PAR at start and end of dye decay study. % PAR at 6.0 m ranged from 15% on 12/2/19 (middle) to 35% on 1/16/20 (right).

7.3 Use the initially validated model to conduct scenario calculations to estimate tracer dilutions and retention/travel times

Scenario model calculations cover a range of combinations of. weather and reservoir operations that correspond to both typical conditions and to 'worst-case' (sometimes identified as 'black swan') events. Three typical types of scenario calculations are discussed below:

1. Run the hydrodynamic model for short (two weeks to three month) periods with a pulsed or constant hypothetical tracer release rate and location in different representative combinations of stratification, water level, and weather (wind direction, wind speed) to estimate spread of tracer along thalweg and dilutions at the drinking water intakes.

    - An example of three scenario calculations for longitudinal spread of a hypothetical tracer added at the mouth of Meadow Bay in Lake Arrowhead is shown in Figures 7.9 and 7.10

    - Figure 7.9 shows two maps of the reservoir's thalweg from Little Bear Creek (southwest end the lake at the head of Blue Jay Bay) to the Dam (east side of lake) as both an aerial photo (top) and with reference to a color-coded depiction of the lake's bathymetric contours (bottom)

    - Figure 7.10 shows modeled cross-sections of concentration contours for three different elapsed times. The three plots show progressively eastward spread of the hypothetical added tracer along the lower part of the thermocline as time increases after initial injection.

Transect along Lake Arrowhead Little Bear Creek thalweg from head of Blue Jay Bay to Dam

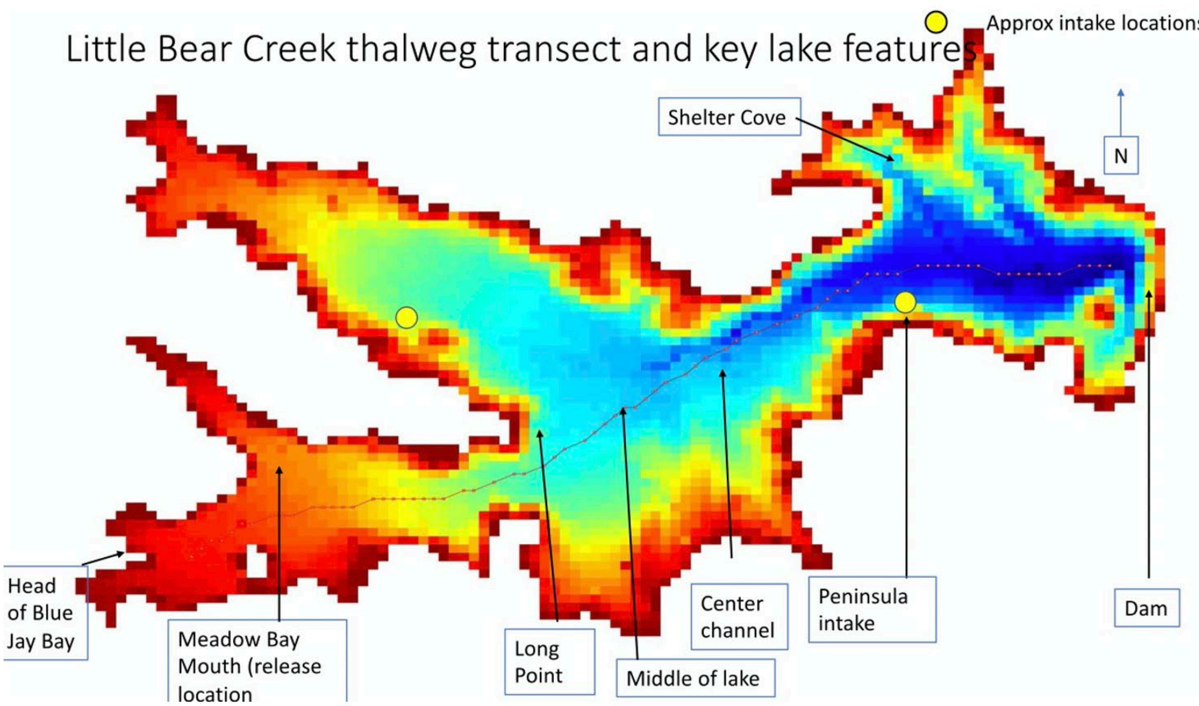
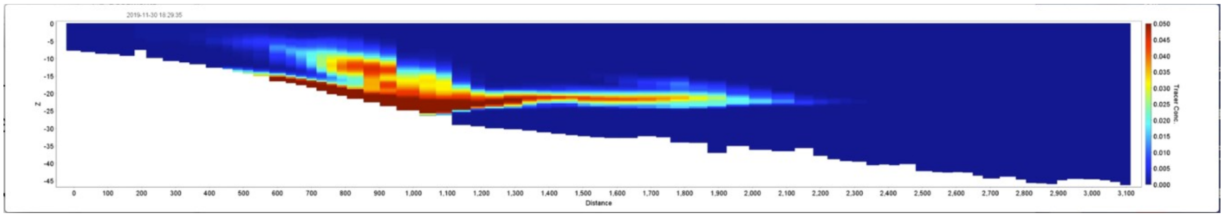
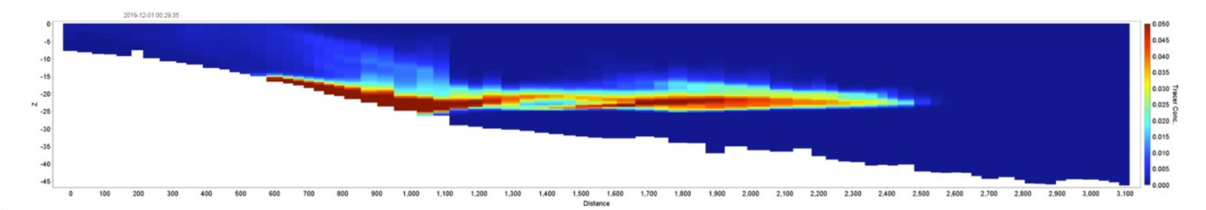


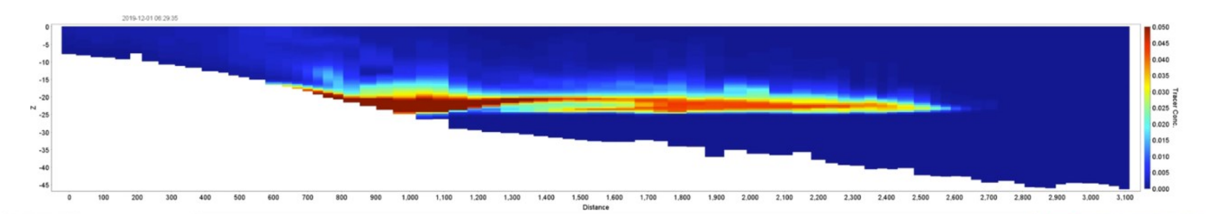
Figure 7-9 Top: Satellite photo of Lake Arrowhead Reservoir showing Little Bear Creek thalweg transect (white dashed line) from the head of Blue Jay Bay (lower left) to the Dam (upper right). Bottom: Little Bear Creek transect superimposed on lake bathymetry. Red = Shallow. Blue = Deep



Simulation 18.5 hours elapsed at low lake WSEL (5,097.5' ALA datum)



Simulation 24.5 hours elapsed at low lake WSEL (5,097.5' ALA datum)



Simulation 30.5 hours elapsed at low lake WSEL (5,097.5' ALA datum)

Figure 7-10 Example scenario simulation. False-color contours of concentration evolution of 100 ppb hypothetical tracer injected at 0000 hours 11/30/19 at Meadow Bay along axis from head of Blue Jay Bay (southwest end of lake) to Dam (east side of lake).

Examples of four different scenarios for hypothetical tracer release under different measured combinations of water level and stratification are shown for Lake Arrowhead in Figures 7.11 and 7.12

- Figure 7.11 (left side: late fall, right side: mid-winter) shows that hypothetical tracer travel times (for arrival of the maximum value) were shorter at 42 hours to North Bay intakes and dilutions were lower for lake conditions corresponding to weak stratification in late fall compared to winter conditions (194 hours to North Bay intakes) in a cold vertically well mixed lake For this example, in Lake Arrowhead, in conditions of southerly winds, travel times were shorter and dilutions lower for the North Bay intakes on the west side of the lake than they were for the Cedar Glen intakes on the east side of the lake.

- Figure 7.12 (left side: early summer and right side: late summer) shows that, compared to weak deep stratification or well-mixed conditions, hypothetical tracer travel times (for arrival of maximum values) were much longer, and dilutions were higher for lake conditions corresponding to strong stratification when tracer was released into the metalimnion or the epilimnion and the reservoir's two drinking water intakes were generally in the metalimnion.

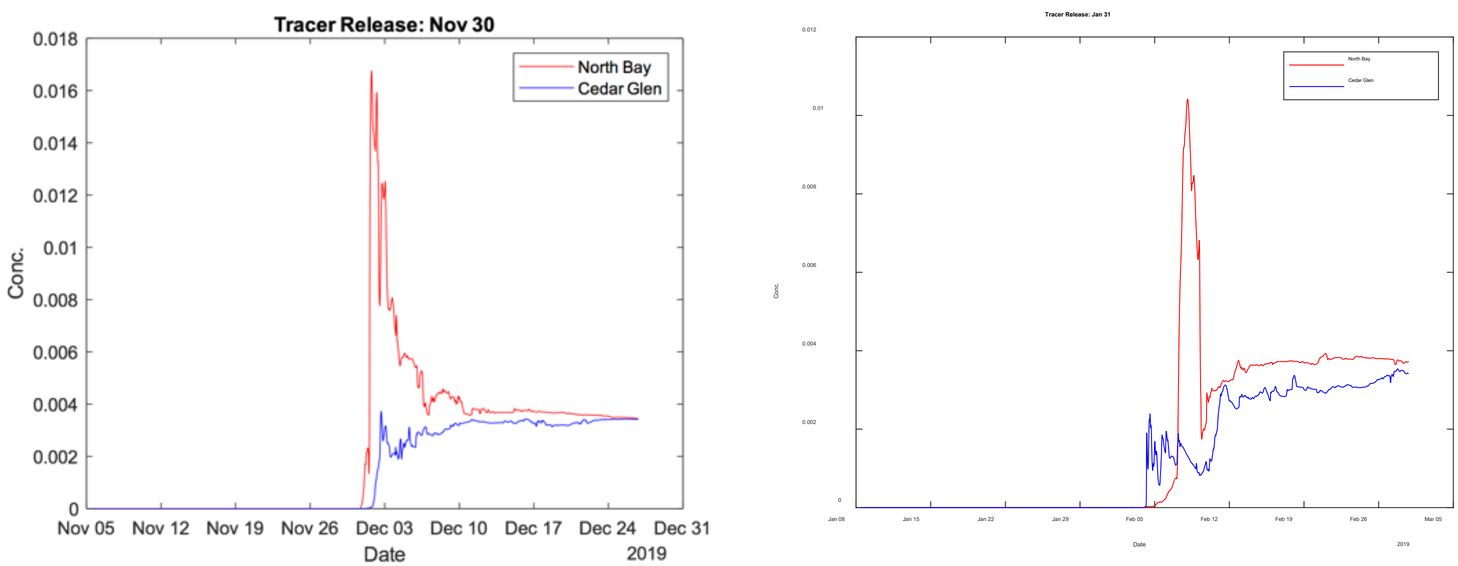
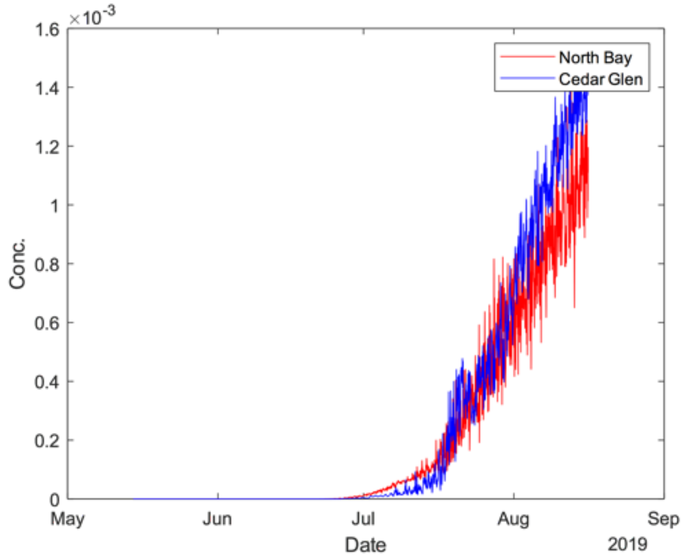


Figure 7-11 Example scenario calculation for evolution of hypothetical 100 ppb one-day tracer release at 0.7 MGD using validated model, Left: late fall. Right: mid-winter.

Figure 7.11 Details (left graph): Simulated late fall (11/30/19 0000 hrs) release (green arrow) of tracer at lake level 5,097.5 feet (1917 ALA datum). Numerical simulation starts 11/9/19.. Tracer Release elevation 5,073 feet ((24.5 feet, 7.5 meters deep) in epilimnion, above thermocline). Thermocline elevation 5,026-5,020 feet, 71.5-77.5 feet deep 21.8-23.6 m. North Bay intake at 5,044 feet elevation is 53.5 feet, 16.3 meters deep. Cedar Glen intake at 5,049 feet elevation is 48.5 feet, 14.8 meters deep. Both intakes in epilimnion. Low southerly winds, low inflows. Peak North Bay concentration (red): 0.0168 ppb at *42.15 hrs* elapsed time (12/1/19 – 18:09 hrs) corresponding dilution: 1/5,900. Peak Cedar Glen concentration (blue): 0.0037 ppb at *63.9 hrs* elapsed time (12/2/19 – 15:54 hrs) corresponding dilution: 1/27,000.

Figure 7.11 Details (right graph): Simulated mid-winter (1/31/19 0000 hrs) release (green arrow) of tracer at lake level 5,097.5 feet (1917 ALA datum). Numerical simulation starts 1/10/19. Tracer Release elevation 5,073 feet (24.5 feet, 7.5 meters deep) in unstratified lake. Thermocline absent, lake is well-mixed, unstratified. North Bay intake at 5,044 feet elevation is 54.5 feet, 16.6 meters deep. Cedar Glen intake at 5,049 feet elevation is 48.5 feet, 14.8 meters deep. Both intakes in unstratified lake. Low southerly winds, low inflows. Peak North Bay concentration (red): 0.0104 ppb at *194 hrs elapsed time* (2/8/19 – 2:14 hrs) corresponding dilution: 1/9,600. Maximum Cedar Glen concentration (blue): 0.0036 ppb at *801 hrs elapsed time* (3/6/19 – 8:59 hrs) corresponding dilution: 1/27,800.



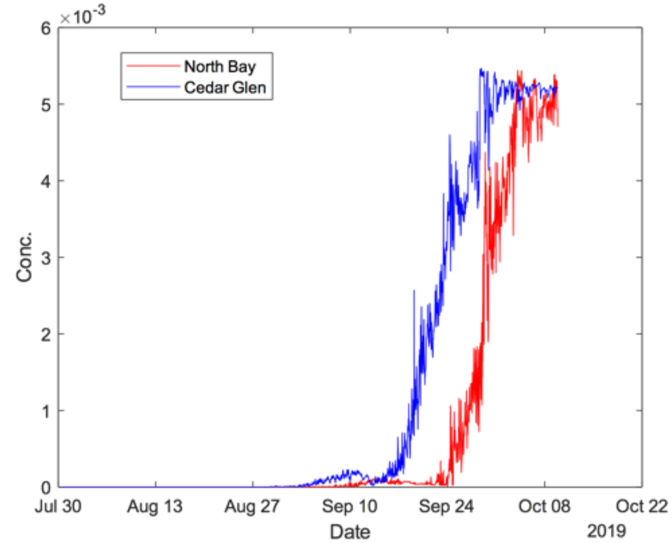


Figure 7-12 Example scenario calculation for evolution of hypothetical 100 ppb one-day tracer release at 0.7 MGD using validated model. Left: early summer. Right: late summer.

Figure 7.12 Details (left graph): Simulated early summer (6/15/2019 0000 hrs) release (green arrow) of tracer at lake level 5,097.5 feet. Numerical simulation starts 5/25/2019. Thermocline elevation: 5,080-5,047 feet 17.5-50.5 feet (5.3-15.4 m) deep. Tracer Release elevation 5,073' (24.5 feet, 7.5 meters deep) in metalimnion, within thermocline). North Bay intake at 5,044 feet elevation is 53.5 feet, 16.3 meters deep. Cedar Glen intake at 5,049 feet elevation is 48.5 feet, 14.8 meters deep). North Bay in hypolimnion. Cedar Glen in metalimnion. Low southerly winds, low inflows. At end of computation, North Bay concentration (red): 0.0013 ppb at *62 days (1,488 hrs)* elapsed time (8/17/19) corresponding dilution: 1/76,900. At end of computation Cedar Glen concentration (blue): 0.0015 ppb at *62 days* elapsed time (12/2/19 – 15:54 hrs) corresponding dilution: 1/66,900.

Figure 7.12 Details (right graph): Simulated late summer (8/17/2019 0000 hrs) release (green arrow) of tracer at lake level 5,097.5 feet. Numerical simulation starts 7/27/19. Thermocline elevation: 5,070-5,030 feet 27.5-67.5 feet (8.4-20.6 m). Tracer Release elevation 5,073' (24.5 feet, 7.5 meters deep) in epilimnion. North Bay intake at 5,044 feet elevation is 54.5 feet, 16.6 meters deep. Cedar Glen intake 5,049 feet elevation is 48.5 feet, 14.8 meters deep). North Bay and Cedar Glen intakes both in metalimnion (within thermocline). Low southerly winds, low inflows. Peak North Bay concentration (red): 0.0054 ppb at *46 days (1,104 hrs) elapsed time* (10/2/19) corresponding dilution: 1/18,500. Peak Cedar Glen concentration (blue): 0.0055 ppb at *42 days (1,008 hrs) elapsed time* (9/28/19) corresponding dilution: 1/18,200

2. Run the hydrodynamic model over long periods of time until the tracer concentration becomes either uniform in the reservoir or until the maximum computed tracer concentration is well below the regulatory limit (for example in California, either a 10:1 dilution for 9-log pathogen removals or 100:1 dilution for 8-log pathogen removals). with constant updates for changes in reservoir operations, weather (wind speed, direction, air temperature), water withdrawal rates, locations and elevations, and reservoir levels. An example of these kinds of computations can be found in Ding et al 2012a for San Vicente Reservoir.

3. Run the model with 'worst-case' combinations of wind speed, direction, stratification, reservoir level and water inflow and outflow rates that might be anticipated to occur over the system life cycle.

   - These worst-case combinations are sometimes identified as rare "black swan" events, that might reasonably be expected to occur and pose a risk to public health (Pasek, 2015). If modeled dilutions and retention/travel times are still sufficient during these "black swan" events, then regulatory authorities and stakeholders are more likely to be assured that public health risks are minimized.

   - Results of hydrodynamic modeling of a "black swan" event scenario for San Vicente Reservoir, corresponding to a combination of the reservoir at low water level, unstratified in winter, and a high wind event blowing directly from recycled water inlet towards reservoir outlet, are presented in Pasek, 2015. In these conditions, hydrodynamic modeling of San Vicente showed that "purified water will be diluted at least 100:1 under all anticipated reservoir operations, at the selected purified water inlet locations" (Pasek, 2015, slide 28).

In response to water agency inputs, the modeling team can also use the validated model to conduct additional studies such as evaluating:

- Potential water quality effects of future changes in dam elevations, lake levels, water input or outflow rates and reservoir intake tower elevation operations (see Ding et al, 2012c) to generate predicted values of durations of low-oxygen conditions (anoxia) in the reservoir hypolimnion and estimated chlorophyll-a concentrations and Secchi depths.

- Possible changes in reservoir chlorophyll-a levels as a result of updated nutrient loading scenarios when operating with purified water inputs, as was conducted for Miramar Reservoir (Hannoun, 2017).

7.4 Perform a second model validation after the post-project implementation second tracer study

The purpose of the second set of model validation runs is to compare the previously validated model predicted performance to the results of the second tracer study (Section 6.7). The second tracer study injects tracer into the reservoir at the intended or actual inflow location of recycled water and tracks tracer dilution and travel time at the reservoir outlet (drinking water intakes). In the second model validation, model parameters usually cannot be adjusted, as the goal is to determine how well the initially validated model predicts tracer dilution and rates of movement towards the drinking water intakes compared to measurements from the second tracer study.

In the second validation, a hypothetical tracer is introduced to the reservoir at the same rate, location and depth as for the second tracer study. Hypothetical tracer concentrations and dilutions are constantly updated with changing reservoir levels, inflow rates, outflow rates and weather conditions. Results are typically presented as a tabular summary time series or scatter plot. Modeled dilutions are compared to regulatory dilution requirements to see if sufficient dilutions are obtained throughout the entire modeled period of reservoir operation.

It is important to comprehensively model all possible combinations of a particular reservoir's Water Surface Elevations (WSEL), water outlet operations (flow rates, operating outlet port elevations and operating port combinations), degrees of reservoir stratification, weather, recycled water inflow rates and inlet location to determine which combinations of conditions would meet required regulatory minimum dilutions or residence times.

- Under some circumstances for some reservoirs, operations of a particular outlet port may need to be prescribed in order to attain regulatory minimum dilutions. For example, for Miramar Reservoir, Dorman et al (2019) cites modeling results in Water Quality Solutions (2016) that indicate under some circumstances that dilutions at Port #2 may be of concern.

- However, modeling results described in Dorman et al 2019, (pages 11-13) also showed that use of individual outlet Port #3, for WSELs between 696.6 and 701 feet, under any conditions would achieve the required 10:1 dilution with greater than 99.9% confidence, and Port #4 will also show greater than 10:1 dilution with 99.9% confidence at the nominal WSEL of 706 feet. Dorman et al 2019 also states that additional results regarding combinations of outlet ports can also attain the minimum 10:1 dilution with a "high confidence level."

- As another example, for the much larger San Vicente Reservoir, hydrodynamic modeling for worst-case conditions, corresponding to strong east-to-northeast Santa Ana winds driving hypothetical purified water inflows directly towards the outlet in conditions of minimum reservoir volume and almost or complete vertical mixing, successfully showed that dilutions always exceeded the 100:1 regulatory minimum at outlet Port #2 for any of the four proposed recycled water inlet locations (Ding et al, 2012b, pages 24-27).

7.5 Write technical memoranda and obtain regulatory and independent scientific review of modeling results

Extensive documentation must be prepared to address regulatory requirements and inform all stakeholders of the results of the modeling effort. Documentation is generated in the form of Technical Memoranda that describe reservoir characteristics, anticipated loads of recycled or purified water, model input data, and model calibration, validation scenario results.

One example of the needed documentation is the Independent Advisory Panel review of the San Vicente Reservoir tracer study and modeling efforts that were documented in a technical memorandum submitted by the modeling consultant Flow Science Incorporated (FSI) to the City of San Diego (Ding et al 2012a, originally referenced as FSI, 2010) The FSI report was then peer-reviewed by the National Water Research Institute Independent Advisory Panel (NWRI IAP, 2010, as cited in Ding et al 2012a). The Independent Advisory Panel (IAP) determined that the model, "with some fine-tuning", was "an effective and robust tool for:

- Simulating thermoclines and hydrodynamics of the San Vicente Reservoir,
- Assessing biological water quality for nutrients, and
- Assessing options for the purified water inlet location (NWRI IAP, 2010)."

After the IAP review, FSI fine-tuned the San Vicente model per the IAP's recommendations and conducted additional modeling runs.

As another example of documentation, for Miramar Reservoir, Appendix G of the Environmental Impact Report (EIR) for Miramar Reservoir, describes how the water quality and nutrient analyses were performed for that water body (Hannoun, 2017).

- It is important to include water quality modeling for nutrients and productivity because water quality of the augmented reservoir as withdrawn at the drinking water intakes can be a significant issue with regard to levels of dissolved and particulate matter that must be removed at the drinking water treatment plant.
- Therefore, a National Pollutant Discharge Elimination System (NPDES) permit and an EIR may be required before a SWA-IPR project can be implemented. Water quality is typically modeled after completion of tracer studies and hydrodynamic model validation using additional biology and chemistry modules available in water quality models such as ELCOM-CAEDYM (Ding et al 2012c) or AEM3D (Hannoun, 2017).

As an example of regulatory review, the City of San Diego received conditional acceptance on July 12, 2019[12] from the San Diego Regional Water Quality Control Board of their April 2019 Title 22 Engineering Report – North City Pure Water Project (Dorman et al 2019). That report included a hydrodynamic modeling study, with results in Section 11, regarding the City's application to augment Miramar Reservoir with up to 30 million gallons per day of advanced treated recycled water.

The Section 11 Miramar Reservoir modeling studies in the Title 22 North City Pure Water Project Engineering report (Dorman et al, 2019) were submitted as part of a much larger SWA-IPR project report for Miramar Reservoir that included detailed information about the source wastewater, project facilities, purified water treatment processes, operations, notifications, and contingency plans and, monitoring and reporting.

[12] October 16, 2019 Agenda for Metro Technical Advisory Committee to the Metro Joint Powers Authority, Exhibit C, see https://www.metrojpa.org/Home/ShowDocument?id=3219

8 Summary, Conclusions and Recommendations

8.1 Summary

The Reclamation-funded tracer study and hydrodynamic modeling demonstration project, conducted by UNLV, that took place from summer 2017 through summer 2020, included the following project elements that are covered in this guidance manual, including:

- Review of applicable regulatory requirements for SWA-IPR, and lead participation from LACSD, submission of a request for permission to conduct the tracer study to the pertinent California regulatory body (the Lahontan Regional Water Quality Control Board).

- Public outreach, consisting of planning, preparation, and participation in three public meetings regarding conducting the tracer study.

- Selection of an appropriate hydrodynamic model for Lake Arrowhead Reservoir, in this case the AEM3D model from Hydronumerics Australia, Ltd.

- Acquisition, evaluation, and formatting of all needed input data to set up and run the hydrodynamic model for Lake Arrowhead Reservoir.

- Review of tracer candidates, development, and submission of a tracer study application to regulators, acquisition of all needed tracer measurement instrumentation, and design and fabrication of all equipment needed to add tracer to Lake Arrowhead Reservoir.

- Calibration of the hydrodynamic model with environmental, meteorological, and hydrologic data, validation of the model with tracer study measurements, and use of the validated model to compute dilution and travel time scenarios for different combinations of reservoir conditions.

Findings from the Reclamation-funded demonstration study are included throughout this manual. UNLV's 'lessons learned' throughout the project are aligned with and reinforce the prior experiences and results of the project's WQS Subject Matter Expert and from San Diego's prior tracer and hydrodynamic modeling projects in San Vicente and Miramar Reservoirs.

8.2 Conclusions

- Well-qualified and experienced surface water field science, chemical laboratory, hydrodynamic modeling, and regulatory teams should be engaged to conduct tracer and hydrodynamic modeling studies.

- Calibrated hydrodynamic models that have been validated with tracer studies can successfully simulate reservoir water movements with low errors, and can be used as part of the planning, design and operation of systems that implement surface water augmentation by indirect potable reuse.

- Assembling and preparing all input data for a hydrodynamic model will require at least a year of data collection effort prior to model calibration.

- Tracer selection should be made with consideration for stability, ease of rapid field detection and low toxicity. Currently Rhodamine WT (RWT), a fluorescent tracer, meets all three criteria and has recently been successfully used to validate hydrodynamic models in a number of reservoirs. Background monitoring of fluorescence signals that emulate RWT should be measured in advance of the tracer study so that corrections for background can be made when determining the mass of tracer to add to the candidate reservoir, measuring tracer concentrations during the tracer study, and computing tracer dilutions.

- Two tracer studies are typically needed for a SWA-IPR project. The first tracer study is intended to support an initial validation of the calibrated hydrodynamic model. Model inputs and coefficients may be adjusted to minimize error compared to all tracer measurements during the study.

- Once initial validation is completed, initial modeling scenarios consisting of combinations of climactic conditions, reservoir levels, and inflow and outflow locations and rates to determine if planned infrastructure improvements will work to attain regulatory required minimum dilutions and residence times from point of discharge to drinking water intakes.

- After project implementation, a second tracer study is recommended, where tracer release is representative of the location, depth, and method of planned recycled water addition. A second model validation is then performed, and errors are calculated without model adjustment. Subsequently, additional modeling scenarios may be conducted to estimate dilutions at the intakes for a wide range of environmental conditions, including 'black swan' worst case combinations of conditions to determine if required regulatory minimum dilutions and residence times are attained.

- The validated hydrodynamic model can be maintained by the agency or its consultants, updated with new information and then operated to support engineering design studies, such as incorporating effects of diffusers, aerators or new intake structures, and risk assessments associated with climate change, new water use scenarios and updated nutrient loadings.

8.3 Recommendations

It is strongly recommended that water agencies:

- Maintain a technical archive of project documentation, including all input data sets, input data files, model specifications and settings and technical memoranda, to be able to respond to regulator and stakeholder information requests and to also support future modeling studies.

- Maintain a public archive of technical memoranda and public communications regarding tracer and modeling studies. An example of such an archive is provided by the City of San Diego Pure Water Project. The web link for the entire project can be found at https://www.sandiego.gov/public-utilities/sustainability/pure-water-sd

- Examples of hydrodynamic modeling studies that can be found in this archive include:

    - "Appendix G. Water Quality Modeling of Miramar Reservoir in Support of Assessment of Nutrients and Productivity" found at: https://www.sandiego.gov/sites/default/files/appendix_g_water_quality_modeling_of_miramar_reservoir.pdf

    - "Limnology and Reservoir Detention Study Of San Vicente Reservoir" a 481 page document that comprises tracer studies and hydrodynamic modeling of the effects of raising the height of the dam at San Vicente Reservoir to increase storage and incorporate SWA-IPR found at: https://www.sandiego.gov/sites/default/files/legacy/water/purewater/pdf/projectreports/limnologyreport.pdf

    - "Appendix F. Independent Advisory Panel Findings" regarding SWA-IPR, including hydrodynamic modeling at San Vicente Reservoir, found at: https://www.sandiego.gov/sites/default/files/legacy/water/purewater/pdf/projectreports/publicoutreachappendixf.pdf

- Maintain an active "up" version of the hydrodynamic model, either in-house or with consultants on retainer, on continually updated high-end[13] workstations to permit rapid implementation of new modeling studies as needed in response to the recommendations of engineering studies, new scientific findings, independent advisory panel recommendations, or regulator or public requests.

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[13] High-end professional-grade workstations have fast multicore processors that address substantial amounts of ECC memory, large fast and redundant solid-state drives, large power supplies with back-up power and robust cooling systems with multiple fans.

  - Examples of a need for rapid response may be in the form of requests to evaluate dilutions and retention times associated with "black swan" worst-case scenarios that might be raised by a regulator or as part of the independent advisory panel review (Pasek, 2015) to determine if regulatory minimum dilution and residence time requirements can still be met.

  - Examples of worst-case "black swan" scenarios could include combinations of low reservoir level, stratification conditions that direct discharges to intake elevations, and unfavorable winds that accelerate the movement of weakly-diluted tracer towards the drinking water intakes. This type of scenario was modeled by FSI for the City of San Diego's San Vicente Reservoir. Modeling showed that regulatory minimum dilutions and residence times were still attained under worst-case conditions (Pasek, 2015).

- The hydrodynamic model will also need to be reconfigured and run again if SWA-IPR engineering studies indicate that there must be changes to the location and design of the reservoir's recycled water discharge structures. An example is incorporation of a conveyance pipeline and a diffuser at Miramar Reservoir (Pasek et al, 2020) to increase dilutions of recycled water. to further increase dilutions at the intakes for certain combinations of weather and reservoir stratification.

- Water agencies are urged to comprehensively model all possible combinations of reservoir Water Surface Elevation (WSEL), drinking water intake operations (flow rates and operating port elevations), degrees of stratification and weather and recycled water inflow rates to determine if there are any combinations that may not attain required regulatory minimum dilutions or residence times. For example, there are possible combinations that may occur for Miramar Reservoir for one particular drinking water intake, Port #2 where there is a small risk that mandated dilutions may not be always met. To address this, there are two options:

  - Option 1: Design and install a pipeline and diffuser system that will distribute recycled water throughout the reservoir and increase dilutions.

  - Option 2: Adjust system operations, such as varying combinations of operating port elevations to withdraw water from zones where dilution targets are always met. Hydrodynamic modeling can be used to establish the boundaries of acceptable operation. For example, there may be some circumstances under which a minimum WSEL has to be maintained or when some drinking water intake ports cannot be used (Dorman et al, 2019).

- In addition to regulatory requirements for public meetings and posting documents and reports in public archives, maintaining information in social media about the hydrodynamic modeling and tracer studies is strongly recommended. For example, the City of San Diego maintains an extensive social media presence about the Miramar reservoir tracer study and hydrodynamic modeling efforts. Available documents include:

- A web posting of a Miramar Reservoir tracer study 2-page fact sheet. See: https://www.sandiego.gov/sites/default/files/miramar_reservoir_tracer_study_fact_sheet_-_final.pdf and

- A continually updated social media page about the tracer study. See https://m.facebook.com/PureWaterSD/photos/?tab=album&album_id=2870423876351895

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Appendix 2.1 – Request for NPDES Pollutant Discharge Waiver

Appendix 2.1 - LACSD Request to Lahontan Water Quality Control Board for waiver of discharge report - with UNLV research summary and technical documentation of properties of Rhodamine WT and sucralose tracers.

Catherine Cerri, General Manager

July 26, 2018

Jehiel Cass
Lahontan Water Board

Dear Mr. Cass,

The Lake Arrowhead Community Services District (LACSD) is pleased to be working with researchers from the University of Nevada, Las Vegas, supported by the United States Bureau of Reclamation (USBR) in cooperation with the Arrowhead Lake Association to prepare a USBR guidance manual for water purveyors to determine the feasibility of surface water augmentation with recycled water. As you are aware, many water agencies are exploring expanded uses of recycled water for drought resiliency. This guidance manual will provide a consistent approach to surface water augmentation studies which may also assist regulators in their consideration of related permit s.

Attached is a waiver request to allow the use of two tracers in Lake Arrowhead to calibrate a three-dimensional hydrodynamic computer model that will simulate dilution and assimilation of a hypothetical recycled water influent under different weather conditions. The two tracers are Rhodamine WT and Sucralose. The sampling, monitoring and contingency plans are included in the attached. Please let me know if you have any questions. We would be happy to meet with you in person to fully discuss the details.

Thank you,

Catherine Cerri
General Manager

cc: David E. James, Ph.D., Associate Professor, University of Nevada, Las Vegas
Wayne Austin, General Manager, Arrowhead Lake Association
Doug Blatchford, United States Bureau of Reclamation

Requests for waiver of Report of Waste Discharge - Proposed Lake Arrowhead Tracer Study

Background - Needs and Benefits, Public Interest and Risk

1.1 Executive summary

The attached proposal describes the use of US-EPA approved Rhodamine WT (RWT), a fluorescent dye tracer, and sucralose, an artificial sweetener, as two environmentally safe tracers (co-tracers) to investigate the pattern and intensity of mixing in Lake Arrowhead. If use of tracers is approved, tracer study results will be used to calibrate a three-dimensional hydrodynamic computer model that will be used to simulate dilution and assimilation of a hypothetical recycled water influent into Lake Arrowhead under different weather conditions. Findings obtained from the combined tracer study and computer simulations will be used as a basis for preparation of a guidance manual for water purveyors to support future studies of potential use of recycled water for surface water supply augmentation that can improve communities' drought resilience.

As this study proposes the use of two different tracers, this waiver of discharge reporting requirements application contains two distinct parts that can be reviewed separately:

- Sections 1, 2 and 3: Request for Waiver of Report of Waste Discharge for a proposed Rhodamine WT (RWT) tracer study, and
- Sections 4 and 5: Request for Waiver of Report of Waste Discharge for a proposed sucralose tracer study.

The proposed RWT tracer study can be conducted if the proposed sucralose tracer study is not approved. However, if approved, implementation of sucralose as the second tracer (or co-tracer) depends on approval of the RWT tracer study, because RWT fluorescence will be used to determine where to sample for sucralose. Use of the two co-tracers will significantly increase the validity of findings, as each tracer result can compared to the other. In addition, since RWT tracer will slowly photodegrade in well-illuminated surface waters, and sucralose is very stable, cross-validation with sucralose as a non-fluorescent tracer can be used to determine the overall rate of RWT decay in Lake Arrowhead, improving the accuracy of dilution estimates.

After RWT tracer injection, Eureka fluorometric sondes with a resolution of 0.01 parts per billion (ppb) for RWT and a feasible detection limit of 0.01 ppb for RWT, and a combined analysis method of Solid Phase Extraction (SPE) followed by High Pressure Liquid Chromatography-Tandem Mass Spectrometry (HPLC-MS) with a Method Detection Limit (MDL) of 0.005 ppb for sucralose will be used to measure tracer concentrations. Due to the low detection limits of both the RWT sondes and the HPLC-MS methods, very small masses (3.91 kilograms or 8.62 pounds) of each tracer could be released and tracked in the lake. Assuming a full lake level, the final concentration of each tracer when completely mixed with lake water would be 0.067 ppb. These mixed concentrations are factors of several thousand to several million below the tracers' recorded toxicities for aquatic life. The completely mixed RWT concentration is well below the US EPA advisory opinion stating a 10 ppb limit for use as a tracer in the vicinity of drinking water intakes (Turner Designs website, document 998-5104). No adverse effects are expected on either human health or Lake Arrowhead's aquatic life at the proposed concentrations.

In this proposed study, if approved, both tracers would be released simultaneously. The primary tracer in this proposed study is the Rhodamine WT (RWT) dye. If approved, movement and dilution of RWT would be measured in real-time after injection by repeatedly conducting vertical profiles Manta TDX fluorometric sondes at different locations on the lake. For the proposed second tracer, sucralose, 1-liter water samples would be withdrawn from the lake at designated target depths using Van Dorn bottles, and transported to UNLV's environmental engineering laboratory for chemical analysis. Since neither tracer will be visible, identification of sampling locations for the sucralose tracer will rely on the real-time fluorometric readings of the RWT tracer.

If the tracer study is approved, results of these two proposed tracer studies will be used to calibrate a three-dimensional hydrodynamic model that will be used to simulate dilution and assimilation of a hypothetical recycled water influent into Lake Arrowhead under different weather conditions. Findings obtained from the combined tracer studies and computer simulations will be used as a basis for preparation of a guidance manual to support future studies of potential use of recycled water for surface water supply augmentation that can improve communities' drought resilience.

1.2 Needs and Benefits

Many communities currently use surface water sources of varying quality to supply their drinking water, including sources that are subject to upstream discharges of treated wastewater. In an era of sustained drought, the need to develop additional sustainable water supplies to address growing populations and declining supplies, combined with recent advances in water reclamation technologies, has motivated study of recycled water (highly-treated wastewater treatment plant effluent) as a potential resource to augment drinking water supplies (Asano et al., 2007). Currently, in the United States, direct use of recycled water for human consumption is not permitted. However, a growing number of communities are studying potential indirect potable reuse through surface water augmentation, with two-fold protection provided by advanced water reclamation technologies and blending recycled water in a lake or reservoir (Asano et al., 2007). In this context, the lake or reservoir acts as an environmental buffer, allowing the recycled water to undergo additional processes of degradation, dilution, and assimilation (Hawker et al., 2011). Hence, the degree of dilution of the recycled water discharge with the lake or reservoir and travel time to intakes are the two key components of a multiple barrier approach to reduce public health risks (Preston et al., 2014).

The University of Nevada, Las Vegas (UNLV) is conducting an applied research project, funded by the U.S. Bureau of Reclamation, on development of a guidance manual for communities to evaluate and use best-practice approaches to estimate the dilution and travel time of recycled water in lakes and reservoirs. In partnership with the Lake Arrowhead Community Services District (LACSD) and the Arrowhead Lake Association (ALA), this project is using Lake Arrowhead as a case study site to develop the best practice guidelines. The manual includes sections on environmental data collection, lake water quality monitoring, three-dimensional hydrodynamic modeling to simulate mixing and assimilation of recycled water, and the potential use of tracers to validate the hydrodynamic model. An ongoing water quality monitoring program has been initiated in May 2018 to generate input data for the hydrodynamic model by measuring recording and analyzing various properties of the lake. Measured water quality parameters include temperature, conductivity, chlorophyll-a, pH, dissolved oxygen (DO), and photosynthetically active radiation (PAR) versus depth at six locations to determine the intensity of horizontal and vertical mixing that exists in Lake Arrowhead.

This project proposes to use Rhodamine WT (RWT) fluorescent dye and sucralose, an artificial sweetener, as co-tracers to estimate dilution, travel time and mixing intensity in different parts of Lake Arrowhead. Results of this proposed dye tracer study will be used to estimate the magnitudes of both wind-driven mixing and coefficients of eddy diffusion that will serve as inputs to the three-dimensional hydrodynamic model. Subsequently, the calibrated model will be used to accurately determine travel time and simulate dilution of hypothetical recycled water discharges to Lake Arrowhead under representative variations in meteorological conditions.

1.3 Public Interest

This proposed tracer study has the support of the Lake Arrowhead Community Service District (LACSD) and the Arrowhead Lake Association (ALA). The proposed discharge of tracer, and associated waiver of discharge reporting is in the public interest because, if approved, results of the proposed tracer study and associated numerical modeling would be used to prepare a best practice “how to” guidance manual for communities throughout California and the western United States that are interested in conducting water quality studies that would support decisions about augmenting their water supplies and improve their drought resilience. Results of the proposed tracer study could also serve as preparatory material for a future specific indirect potable reuse surface water augmentation study to support improvement of drought resilience for the Lake Arrowhead community.

1.4 Risk

The proposed RWT discharge will use calibrated high resolution (0.01 ppb) fluorometric sondes to assess the movement of low concentrations of Rhodamine WT tracer dye. US EPA’s August 2, 1988 letter stated that they did “not anticipate any adverse health effects resulting from the use of Rhodamine WT as a fluorescent tracer in water flow studies when used within the following guidelines:

- A maximum concentration of 100 micrograms/liter Rhodamine WT is recommended for addition to raw water in hydrological studies involving surface and ground waters.
- Dye concentration should be limited to 10 micrograms/liter in raw water when used as a tracer in or around drinking water intakes.
- Concentration in drinking water should not exceed 0.1 micrograms/liter. Studies which result in actual human exposure to the dye via drinking water must be brief and infrequent. This level is not acceptable for chronic human exposure.”

There are two water intakes in Lake Arrowhead, one 2,950 feet and another 4,235 feet from the proposed injection site. The intakes are at a summer 2018 depth of about 71 feet, approximately 21-38 feet deeper into denser waters in the thermocline than the proposed 33-50 foot injection depth in warmer less dense waters. Preliminary estimates of travel time, dilution and movement of the dye tracer indicate that, since the plume will continue to be diluted as it travels across the lake, expected estimated concentrations of tracer will be will be in the range of 1.7 to 2.6 ppb at the level of the intakes if, in a worst-case scenario the tracer plume were to approach the drinking water intakes in the first 1.2 to 1.6 days of the study. Tracer concentrations would be 0.067 ppb when fully mixed with lake water, if, assuming conservatively, no degradation were to occur. These predicted results shows that it is very unlikely that RWT concentrations approaching the 10 ppb limit will occur at the drinking water intakes. In place will be monitoring and notification procedures, along with a plan by LACSD to divert to alternative supplies in the event that the 10 ppb limit is approached.

Sucralose is approved by the Food and Drug Administration (FDA) as a safe general-purpose sweetener. Sucralose has been studied extensively, and the FDA reviewed more than 110 safety studies in support of its approval of the use of sucralose as a general-purpose sweetener for food (US FDA, 2018).

Aquatic toxicity of sucralose is much lower than for RWT dye. Ecotoxicological assessments of sucralose using U.S. EPA's Ecological Structure Activity Relationship Model, ECOSAR (USEPA, 2010) suggests that sucralose may cause toxicity to aquatic organisms only at concentrations ≥ 1,123 mg/L (1,123,000 ppb) (Tollefsen et al., 2012). Comparing the toxicity threshold of 1,123,000 ppb to either starting concentrations of 70-100 ppb or to the final mixed concentration of 0.067 ppb that will be used in this tracer study, no adverse effects on aquatic environment in Lake Arrowhead are expected.

Detailed descriptions of the proposed tracer addition, monitoring, notification and if needed, spill clean-up procedures are described in the attached requests for permit waivers that can be reviewed separately:

- Sections 1, 2 and 3: Request for Waiver of Report of Waste Discharge for a proposed Rhodamine WT (RWT) tracer study, and
- Sections 4 and 5: Request for Waiver of Report of Waste Discharge for a proposed sucralose tracer study.

1.5 References

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Sections 1, 2 and 3

Request for Waiver of Report of Waste Discharge for a proposed Rhodamine WT tracer study

Request for Waiver of Report of Waste Discharge for a proposed Rhodamine WT (RWT) tracer study to Investigate Mixing and Assimilation Patterns in Lake Arrowhead

Prepared by: Ali Saber, David E. James, Sadie Stutzman
Department of Civil and Environmental Engineering and Construction, University of Nevada, Las Vegas

Executive summary

The following request for waiver describes, in Sections 1,2 and 3 the proposed use of US EPA-allowed Rhodamine WT (RWT), a fluorescent dye tracer, and, in Sections 4 and 5, the proposed sucralose, an artificial sweetener, as two environmentally safe tracers (co-tracers) to investigate the pattern and intensity of mixing in Lake Arrowhead. Proposed injection and monitoring sites, estimates of tracer use and nominal target concentrations are provided herein, along with information regarding the method of Rhodamine WT and sucralose tracer release, tracer monitoring, notification plans, and instrument calibration.

This proposed study is intended to determine the rate of movement and the dilution and dispersion of RWT and optionally, sucralose, as co-tracers. If use of tracers is approved, tracer study results will be used to calibrate a three-dimensional hydrodynamic computer model that will be used to simulate dilution and assimilation of a hypothetical recycled water influent into Lake Arrowhead under different weather conditions. Findings obtained from the combined tracer study and computer simulations will be used as a basis for preparation of a guidance manual for water purveyors to support future studies of potential use of recycled water for surface water supply augmentation that can improve communities' drought resilience.

Section 1: Introduction - RWT and/or sucralose

For this proposed study, the proposed tracer release site is in Village Bay on the southern side of Lake Arrowhead. The movement and dispersion of the RWT tracer would be monitored in real-time by continuous fluorometric measurements using depth-profiling sensors as it spreads across the lake. For measurement of sucralose movement and dispersion, water samples would be withdrawn from the lake simultaneously with RWT measurement and transported to UNLV's laboratory for analysis.

Results of the proposed study would provide the following useful information:

1) travel time for tracers as they track water movement across Lake Arrowhead and spread laterally into Lake Arrowhead's several bays;
2) dilution of tracers as they travel across the lake;
3) estimates of numerical values of horizontal and vertical dispersion coefficients needed for the hydrodynamic model;
4) validation of dilution and dispersion by using two different tracers; and
5) estimation of RWT photodegradation rate in the lake by comparing the concentration of the RWT fluorescent tracer to the stable non-fluorescent tracer (sucralose).

Section 2: About Rhodamine WT in the aquatic environment

Rhodamine WT (RWT), a fluorescent red dye, was formulated as a less toxic replacement for the Rhodamine B dye that had been previously used for tracer studies. When excited with green light of wavelength 558 nm, it fluoresces predominantly in the yellow (peak 582 nm) and red (up to 600 nm) (USGS 1986). While it can be used as a visual tracer, RWT is not visually detectable over long path lengths at concentrations of 10 ppb or less. It can be detected by fluorometric methods at concentrations down to 0.01 ppb. It is most commonly detected using either bench top fluorometers (such as Turner Designs model 10AU) or fluorometric sensors installed on multiparameter water quality sondes or probes such as the Eureka TDX or Eureka Trimeter. The sensitivity of Eureka TDX/Trimeter probes (0.01 ppb RWT) is documented in **Appendix 1.**

RWT's aquatic toxicity has been extensively studied **(Appendix 2)**. It has been found to have very low aquatic toxicity. It is non-toxic to aquatic life at the 1988 US EPA advisory level of 100 parts per billion (ppb) in surface waters. RWT decays when exposed to sunlight at rates on the order of 1-2% per day (Tai and Rathbun, 1988), with estimated half-lives on the order of 15-22 days at 30 ºN, and a time to degrade to 1% of added RWT estimated to be 3 to 5 months[6] (**Appendix 2**).

RWT can potentially react with nitrite ion (NO_2^-) to form the carcinogen N-nitroso-diethylamine (NDEA) also known as diethylnitrosoamine (DENA) (Abidi, 1982, Steinheimer and Johnson, 1986) (**Appendix 3)**. However, Steinheimer and Johnson (1986) found that NDEA was unlikely to form in surface waters at typical RWT tracer concentrations and nitrite concentrations of 2 - 46 *u*g/L (ppb). A more detailed literature summary can be found in **Appendix 3**.

Nitrite sampling of Lake Arrowhead by UNLV on July 17, 2018 found a maximum value of 0.008 mg/L (0.8 ppb) in the lake's metalimnion, with values below the 0.005 mg/L (0.5 ppb) detection limit[1] in the hypolimnion and values of < 0.2 to 0.8 ppb in the epilimnion and in the metalimnion. Details of UNLV's July 17 nitrite sampling results can be found in **Appendix 3**.

Estimated worst-case (low) RWT travel times from the proposed point of release to the Lake Arrowhead Community Services District (LACSD) drinking water intakes are on the order of 1.15 to 1.60 days **(Appendix 4).** A finite difference numerical dispersion model indicates that, at these expected travel times, RWT concentrations approaching the LACSD drinking water intakes would be in the range of 1.7-2.7 ppb, below the US EPA 10 ppb advisory limit for drinking water intakes.

This document includes a plan for monitoring of Lake Arrowhead's waters near each intake, closing the intakes in the event that RWT concentrations near the intakes approach the 10 ppb advisory limit, and monitoring LACSD drinking water treatment plant water. Standard chlorination doses in LACSD's drinking water treatment plants are sufficient to eliminate 10 ppb RWT from drinking water in a time interval far less than the treatment plant's typical storage time (**Appendix 5,** and see paragraph below).

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[1] Hach method 8507, https://www.hach.com/asset-get.download.jsa?id=7639983623 Accessed July 21, 2018

At the 10 ppb 1988 US EPA advisory opinion limit for use as a tracer near drinking water treatment plant intakes, RWT concentrations were reduced in 8 minutes to the US EPA Advisory 0.1 ppb limit for drinking water distribution systems in Lake Arrowhead water in the presence of the typical 4 mg/L standard added chlorine dose(1.5 mg/L residual) used by LACSD (**Appendix 5**). RWT was reduced to below the 0.01 ppb TDX probe instrument detection limit in 11 minutes. Detention times at the 4 mg/L standard applied chlorine dose (1.5 mg/L chlorine residual) in the LACSD storage tanks are 10-20 hours. We conclude that there is more than sufficient detention time to completely destroy any RWT that might enter the treatment plant despite monitoring effort and action plan efforts.

Section 3: Proposed Tracer Release, Monitoring and Notification Plan - RWT

1. **Tracer release site location and size**
   The white circle in Figures 1-A and 1-B shows the proposed tracer release site in Village Bay. The yellow pins show the locations of Lake Arrowhead's drinking water intakes. **Table 1** shows the coordinates of the proposed tracer release site and the two drinking water intakes using the World Geodetic System, 1984 datum (WGS 84). By nearest line of sight, the proposed tracer release location is 2,950 feet from the North Bay (Bernina) intakes and 4,235 feet from the Emerald Bay (Cedar Glen) intakes.

Table 1. GPS coordinates* of tracer release site and distances to the two LACSD drinking water intakes . *World Geodetic Survey, 1984 and California State Plane coordinates

Location	Site Name	North Latitude	West Longitude	Shortest distance to proposed tracer release site (feet)	Site elevation (1929 NGVD) (feet)**	Water depth at summer 2018 lake level (feet)***
Proposed	Village Bay	34° 15' 13"	117° 11' 10"	N/A	5,022	85.7
tracer	East of					
release	Village					
location	Point					
Bernina	North Bay	34° 15' 37"	117° 11' 34"	2,950	5,040#	67.7
Intake						
Cedar	Emerald	34° 15' 35"	117° 11' 34"	4,235	5,040#	67.7
Glen	Bay					
Intake						

**Using the 1929 National Geodetic Vertical Datum (NGVD), which is 8.0 feet higher than the ALA datum[2], the full lake level is 5,114.7 feet. Mean bottom elevation at chosen site is 5,022 feet. As of June 27, 2018, the summer 2018 lake level was 7 feet below full = 5,107.7 feet. #elevation of lake bottom at intake. Intake screens up 7 ft from bottom

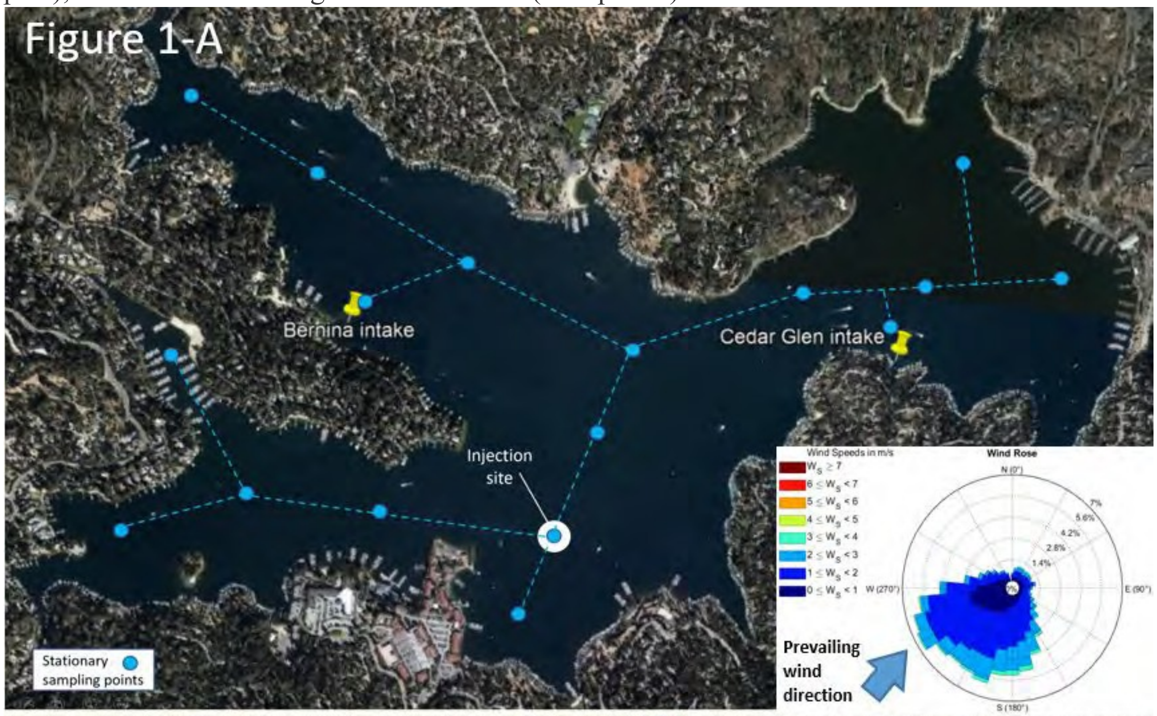
***tracer release site water depth = June 27, 2018 lake level – mean bottom elevation = 5,107.7-5022 = 85.7 feet

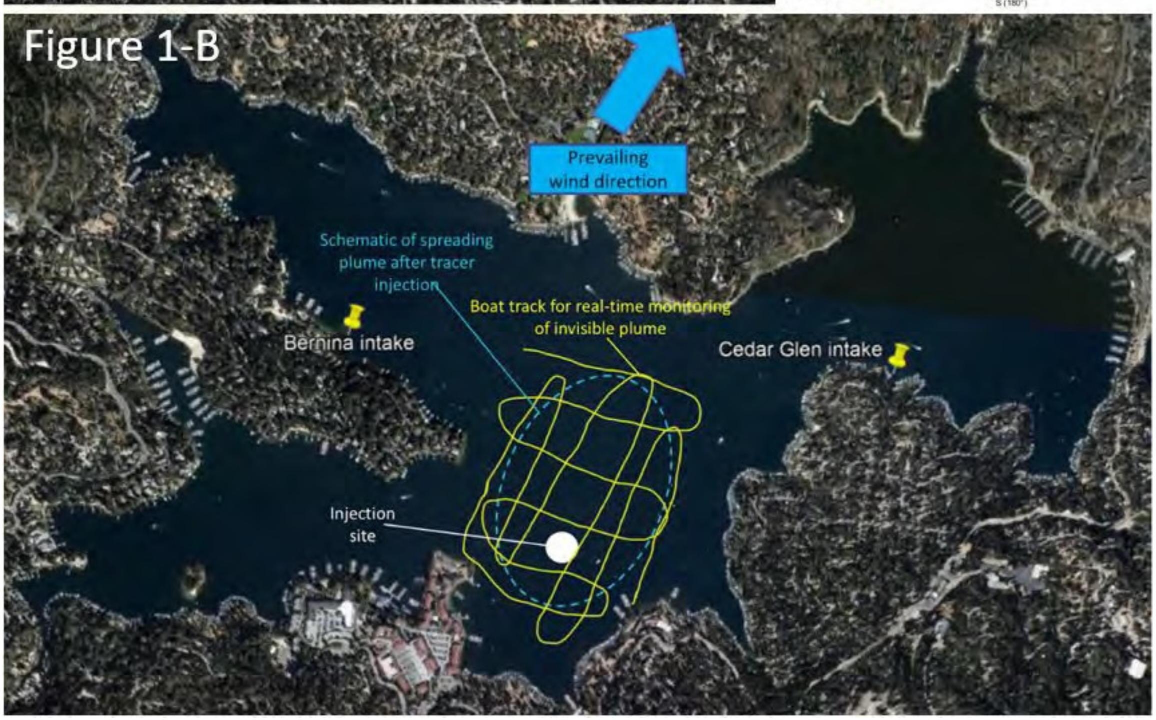
***Intake water depth = June 27, 2018 lake level – site elevation = 5,107.7 feet – 5,040 feet = 67.7 feet

[2] USBR, 2009. *Lake Arrowhead 2008 Reservoir Survey. Technical Report No. SRH-2009-9.* URL: https://doi.org/https://www.usbr.gov/tsc/techreferences/reservoir/Lake Arrowhead 2009 Report.pdf

Figure 1.

a. Proposed tracer release site (white circle), locations of drinking water intakes (yellow pins), and fixed monitoring station locations (blue points).





b. Proposed tracer release site, and boat track (yellow line) for real-time tracer monitoring.

The proposed Village Bay tracer release site will be a circular area with a diameter of 230 ft = 41,548 sq. ft (ca. 0.95 acre) located on the top portion of the lake's seasonal thermocline at a depth ranging from 33 to 50 feet. This depth range is proposed to both provide sufficient dilution before the injected RWT reaches the water surface, and also to reduce the rate at which the tracer could spread vertically downwards into denser water at the depth level of the LACSD drinking water intakes, located at a depth of approximately 68 feet at the current summer 2018 lake level (**Table 1**).

If approved, RWT tracer would be injected using a weighted 2-meter long diffuser attached to a pumping system that mixes 1,300 gallons of pumped lake water with 80 gallons water containing 8.62 pounds of RWT concentrate contained in a 100-gallon high density polyethylene mixing tank. The mixed diluted RWT tracer would be injected over a 20-minute time period.

To develop an initial lake concentration that is at or below the EPA's 1988 advisory recommendation maximum RWT dye concentration of 100 ppb in surface waters[3], the diluted RWT dye solution will be discharged through a diffuser to mix within a 230-foot diameter circle (41,548 sq.ft. surface area, 0.95 acres) at the designated tracer release site. Based on depth from the water surface to the depth of dye release above the thermocline (33 to 50 feet), the tracer release rate through the diffuser within the 41,548 sq.ft. zone, and estimated wind-driven diffusivities in the lake's upper layers, the well-mixed dye concentration within the tracer release zone would be in the 70 to 100 ppb range (**Table 2),** less than the EPA's 1988 advisory opinion of 100 ppb concentration for surface waters.

2. Estimated RWT concentrations

There are two potable water intakes (Figure 1) in Lake Arrowhead:

1. The Bernina intake is located at North Bay, at a distance of 2,950 feet northwest from the proposed tracer release site.
2. The Cedar Glen intake is located at Emerald Bay approximately 4,235 feet northeast from the proposed tracer release site.

Both intakes are at elevations that position them in either the hypolimnion or the lower part of the seasonal metalimnion (depending on time of year) at an expected summer 2018 depth of 68 feet, at current lake levels. The current 68-foot summer 2018 intake water depth is approximately 18-35 feet below the proposed 33-50 foot depth range for tracer release. The intakes are also in colder denser water than at the level of tracer release. The denser more quiescent deep water should limit downward spreading of the dye tracer.

With prevailing summer southerly to southwesterly winds expected to occur during the tracer release, if authorized during late summer, neither drinking water intake is expected to be directly downwind of the proposed tracer release site. In the absence of a perennial stream inflow to the reservoir (Little Bear Creek and Grass Valley tunnel inflows are seasonal in winter time), water circulation is expected to be driven by predominant south to southwesterly winds, with estimated shoreline-following or depth contour-following wind-driven circulation travel distances of 1.5 to 1.6

[3] Turner Designs, https://www.turnerdesigns.com/t2/doc/appnotes/998-5104.pdf)

miles for the Bernina intakes in North Bay, and 1.9 to 2.2 miles for the Cedar Glen intakes in Emerald Bay **(Appendix 4).** These estimated circulation distances are much longer than the direct line distances listed in **Table 1.**

At these estimated circulation distances, for a worst-case wind-driven all-day average current velocity[4] of 0.025 meter/second at plume depth, (Bender 2012), travel times are estimated to be on the order of 1.15 to 1.2 days for Bernina and 1.4 to 1.6 days for Cedar Glen **(Appendix 4)**.

At these estimated travel times, preliminary finite-difference numerical modeling, with vertical diffusion coefficients in the range of k = 0.0015-0.0075 m^2/s and horizontal diffusion coefficients in the range of k = 0.09-0.20 m^2/s for the top 8.4 meters (28 feet) of the water column (the approximate peak depth of the warm well-mixed epilimnion in summer), and k = $8x10^{-5}$ to $4.0x10^{-4}$ m^2/s and k = 0.007-0.050 m^2/s for depths of 8.4 meters (28 feet) to the bottom of the lake, simulating spread of the tracer in Lake Arrowhead, assuming distances for tracer release that take into account prevailing summer southerly to southwesterly winds ,with advection and spreading that follows the lake shoreline or bathymetry back towards the drinking water intakes at a conservatively estimated (worst-case) maximum constant wind-driven current velocity of 0.025 meter/second, based on values modeled by Bender, (2012), and also assuming zero degradation[5], indicate that estimated worst-case mixed RWT concentrations would reduce from the initial 70-100 ppb tracer concentrations to 2.4 to 2.7 ppb for Bernina and to 1.7 to 2.1 ppb for Cedar Glen before the tracer would reach either intake, below the 1988 US EPA advisory opinion level for RWT. Details of the assumptions and data used to generate these estimates can be found in **Appendix 4**.

Conservatively assuming no photodegradation, the 8.62 pound added RWT mass, if mixed completely into the entire 46,855 acre-foot lake volume, would result in an added concentration of 0.067 ppb. This added concentration would likely decay away to zero in 3 to 5 months[5,6].

3. Measurement Instrumentation and calibration

Two boats, as well as the tracer-dispensing barge, will monitor tracer concentrations after addition to the lake. On-board fluorometric RWT concentration monitoring will be performed using Eureka TDX fluorometric sondes with RWT-specific sensors. The TDX sondes have a resolution of 0.01 parts per billion for RWT and a quantification limit of 0.01 ppb **(Appendix 1)**. The fluorescence signatures from microalgal chlorophyll-a and other background fluorescent constituents in the water tend to resemble Rhodamine WT dye, and therefore can be detected as a background RWT-like worst-case 0.025 meter/second (1.34 mile/day) current velocity is assumed to persist throughout the day and concentration. Weekly water quality monitoring in Lake Arrowhead in summer 2018 has

[4] Note, summertime Lake Arrowhead winds vary diurnally in speed, with low wind speeds at night and in the early morning hours, and with winds building from the southwest throughout the day. A worst-case 0.025 meter/second (1.34 mile/day) current velocity is assumed to persist throughout the day and evening hours. Instead, it is more likely that this velocity magnitude would exist for a few hours in the afternoon when surface winds are strongest.

[5] Note: Tai and Rathbun, 1988, measured surface water RWT degradation rates corresponding to 3-5% loss in one day and 6-9% loss in 2 days, so degradation is expected to be minimal in one day, but substantial over a period ranging from two weeks (36%-49% loss) to one month (61-76% loss).

found background fluorescent RWT-like concentrations of up to 0.05 ppb.

To be able to detect and track the added RWT tracer, its concentration must be sufficiently above the lake's RWT-like background to be distinguished as added tracer. Considering that the volume of Lake Arrowhead, when full is 57,795,000 cubic meters (46,855 acre-feet) (USBR, 2009), the proposed added 3.91 kg RWT dye mass would result in a final concentration of 0.067 ppb when fully mixed within the lake if no photodegradation were to occur. This value provides a 1.3x elevation over the 0.00 to 0.05 natural fluorescence background. At currently-published sunlight photodecay rates in surface waters (Tai and Rathbun, 1988), photodecay would result in 99% removal of all added RWT from the lake over a period of about 3 to 5 months[6].

The Eureka TDX RWT sondes will be calibrated according to manufacturer's protocols using laboratory-prepared RWT standard solutions. Calibrated RWT sondes will be able to measure RWT concentrations ranging from 0.01 ppb to 1,000 ppb. The sondes will be deployed on cables from monitoring boats. At each predetermined monitoring location, sondes will be vertically moved through the dye tracer mass at a rate of 10 centimeters per second (4 inches per second, or 1 foot every 3 seconds) to capture the RWT tracer's changing concentration with depth. To track the position and concentrations in the released tracer mass, the sondes' fluorescence, temperature and depth readings will be automatically combined with a GPS signal and recorded in at 1-second intervals and displayed in real-time laptop computers.

4. Sampling locations and method of measurement

Two RWT sonde-equipped boats and the tracer-dispensing barge will be deployed in the first few hours after tracer release. Two sampling boats will monitor RWT concentration profiles on an hourly schedule at a fixed grid of 16 sampling points that follow the thalweg of the reservoir (Figure 1-A). They will also sample at the LACSD drinking water intakes (Figure 1) on an hourly basis. The barge will track the plume by moving on a North-South East-West curving path (Figure 1-B) from one edge of the plume to the other edge to track RWT fluorescence in real time. Sampling locations will be adjusted over time as the tracer mass expands and dilutes in concentration. Based on prevailing summer south to southwesterly winds (Figure 1-A) the tracer plume is expected to gradually move to the north-east. Sampling will be timed to track the plume as it moves through the lake over a period of 14-28 days.

Depending on wind intensity and rate of advection, RWT sampling will be continuous for the first 24-48 hours after tracer release as the dye mass spreads. Afterwards, sampling will occur every 4 to 6 hours at the Dam and at each major bay in the lake (Blue Jay Bay, North Bay, Tavern Bay, Village Bay, Emerald Bay) for the next 2 to 3 days, and after that, the concentration profiles will be measured daily at the intended locations until concentration profile changes are no longer detected. Complete mixing is expected to occur in 14 to 28 days.

[6] For RWT half-lives derived from Tai and Rathbun (1988) data of 15-22 days at 30 ^{o}N, time to degrade to 1% of added RWT is estimated to be 3 to 5 months.

5. Measurement of Ambient Environmental Conditions

1) A Eureka Manta+30 7-parameter multiprobe will be used to measure and record profiles versus depth of conductivity, temperature, pH, photosynthetically active radiation, chlorophyll-a and dissolved oxygen at six predetermined sampling locations, one at the proposed tracer release location in Village Bay, and one in each of the other major bays of the lake (Blue Jay Bay, North Bay, Tavern Bay, Emerald Bay), as well as near the dam. Manta+30 profiles will traverse the entire water column from surface to bottom. The Manta+30 probe will be calibrated against laboratory standards before each deployment. Manta+30 profiles will be taken:
   1. On the day before the tracer release;
   2. On the day of tracer release, before the start of release, and every 3 hours during the first day of measurement; and
   3. Once daily on subsequent days, until tracer concentrations measured with the RWT TDX probes drop below 1 ppb, assumed to be about 10 days.
2) During the Manta+30 measurements, wind speed and direction will be recorded approximately five feet above the water surface by a hand-held monitor and compass.
3) Five-minute interval wind speed, direction, air temperature and total radiation will be obtained from two lakeshore meteorological stations operated by UNLV. One station is located on Lollipop Point near Village Bay on the south shore of the lake, and the other is located at Tavern Bay on the north shore of the lake.

6. Contingency Spill Plans

1) **Spill prevention**. To capture any spillage of tracer solution, the 100-gallon tracer mixing tank will be tied down inside a 18-inch high 200-gallon spill-containment pan. The 200-gallon containment pan will have sufficient capacity to capture the entire volume of dye should a leak occur in the 100-gallon mixing tank. The mixing tank pump line, with a valved shutoff, will be routed over the top of the containment pan using a vertical U-bend to prevent accidental gravity drainage from the tank. In the event of a pump failure, a check valve in the main discharge line will automatically prevent the blended lake water plus dye from flowing backwards into the lake through the surface intake.

2) **Spill pick up.** Absorbent material and two 55-gallon drums, sufficient to capture the entire 80 gallons of tracer solution, will be on board the injection barge in case tracer solution escapes the spill-containment pan. The absorbent will be pre-positioned at the ALA docks prior to transfer of the tracer from shoreside to the barge. Since RWT is water soluble, water-absorbent materials will be used.

3) **Spill reporting**. Any spillage escaping the containment tank, other than small drops that can be wiped/washed clean, will be reported to the Lahontan Regional Water Quality Control Board (LRWQCB) within 15 minutes of occurrence, and actions to clean up spills will be documented and reported to LRWQCB within 24 hours of occurrence.

4) **Unexpected movement monitoring and reporting**.
A TDX sonde-equipped monitoring boat will measure RWT fluorescence hourly by vertical profiling at the location of each drinking water intake over the first 2 days of the study. Measured RWT concentrations will be compared to movement of the main body of the tracer by radio or cell phone communications between the monitoring boats. If a RWT tracer concentration near the EPA 10 ppb advisory limit appears to be approaching either water intake, the water purveyor, the Lake Arrowhead Community Services District, will be notified within 5 minutes and the LRWQCB will be notified within 15 minutes. Results indicating direction of movement and concentration of the RWT tracer will be provided to both LACSD and LRWQCB within one hour.

Please see also below: **7. Dye Preparation, Transport and Mixing,** for additional steps to be taken to minimize magnitude of potential spills. Please see also below **10. Notification and Action Plan,** for steps to be taken should a tracer concentration near 10 ppb approach either LACSD drinking water intake.

7. RWT Preparation, Transport and Mixing to minimize magnitude of potential spills

Liquid RWT dye concentrate, commercially available as a 20% by mass solution, will be transported to the vicinity of Lake Arrowhead in a double-walled cooler chest capable of retaining the entire contents of the stock dye solution.

The needed amount (volume) of dye concentrate required for the intended tracer addition will be placed in sealed five-gallon bucket and stored at a location away from the Lake Arrowhead waterfront in a room at the Arrowhead Lake Association (ALA) administrative offices.

Only the mass of Rhodamine WT needed for the proposed tracer (8.62 pounds, or 3.91 kilograms, delivered as as 4.4 gallons of 20% solution) will be transported in the sealed 5-gallon bucket positioned in a wheeled 32-gallon cooler chest to serve as the secondary containment from the ALA offices to the docks and loaded on the tracer injection barge. The liquid spill pick-up materials will be pre-positioned at dockside near the barge before transport. The RWT tracer concentrate will be kept in the sealed bucket and cooler until the barge is anchored at the proposed tracer release point. This approach limits the risk of a spill before mixing, and minimizes the potential for a spill to the amount that would be injected in the site as planned.

The predetermined 4.4 gallon Rhodamine WT concentrate volume (8.62 pound mass of dye) will be mixed with 75.6 gallons of water in the 100-gallon on board mixing tank while the injection barge is anchored at the intended site of tracer release. In addition to on board adsorbents, the 100-gallon tank will be surrounded by the 200-gallon containment pan to capture any tank leaks. An on-board gasoline powered pump will be able to withdraw lake water and have a T-fitting connecting to a spray nozzle and hose with sufficient length to cover the entire barge mixing area to wash off any spilled RWT solution if the on board adsorbents are not able to capture all of a spill. This method ensures that only the intended amount of dye could be spilled in the same area where it is planned to be released.

8. RWT tracer quantity, tracer release surface area and measurement procedures

a. Surface Area and volume of water needed for discharge

1) The white circle in Figures 1-A and 1-B shows the proposed tracer release site location and tracer release site surface area within Village Bay, comprising a circular diameter of 230 feet and a surface area of 0.95 acres (**Table 2**). At a minimum depth of 33 feet, this corresponds to a water volume of 31.2 acre-feet. These dimensions were chosen to obtain an acceptable initial RWT tracer concentration.

2) **Table 2** shows the proposed tracer release site location and, surface area, water depth, tracer release site water volume (acre-feet) and mass of Rhodamine WT to be released at the proposed site.
   Note. Some modifications to the proposed tracer release depth could be needed as result of potential variation in the depth of thermocline due to changes in weather or seasonal cooling depending on the actual tracer release date. LWRQCB and LACSD will be notified of any proposed change in the tracer release depth 3 days prior to tracer release (**Table 3**).

b. Proposed quantity of added RWT tracer

The projected maximum amount of RWT, 8.62 pounds, or 3.91 kilograms, is sufficient to generate a detectable 0.067 ppb increase in RWT fluorescence above the 0.00-0.05 ppb fluorescence background if the RWT were to not degrade and completely mix into the entire lake volume. This mass of dye will be mixed as 4.4 gallons of 20% by mass dye concentrate solution into a volume of 75.6 gallons of lake water contained in the 100-gallon mixing tank, for a total volume of 80 gallons. The 80 gallons of mixed tracer solution will then be discharged from the mixing tank at a flow rate of 4.0 gallons/minute (gpm) and simultaneously blended with a 65 gpm stream of pumped clean lake water, for a total flow rate of 69 gallons/minute, and then injected into the lake at 33-50 meters depth via a 2-meter long diffuser. Mixing of the dye over the intended area in the water column will result in a dilution to a starting concentration of 70-100 ppb.

Note: The three-step formula sequence for calculating the volume of water needed to achieve a well-mixed target dye concentration in *u*g/L (ppb) is:

1. Volume of water in liters = $\dfrac{\text{[(dye mass, lbm) x 0.453kg/lbm x } 1\text{x}10^{9}\text{ ug/kg]}}{\text{(target concentration in ug/Liter)}}$

then

2. Volume of water in acre-feet = $\dfrac{\text{Volume of water in Liters}}{(28.3\text{ liters/ft}^3) \text{ x } (43{,}560\text{ ft}^3\text{/acre foot})}$.

then

3. Area required = volume of water in acre-feet / maximum vertical mixed depth

Needed water surface areas are summarized in **Table 2**. Step by step calculations are shown below:

For an initial RWT concentration of 70 ppb in a maximum depth of 50 feet, the calculations are:

$$\textit{Volume of water in liters} = \frac{[(8.62\ lbm) \times 0.453 kg/lbm \times 1\times10^{9}\ ug/kg]}{(70\ ug/L)}$$

$= 5.58 \times 10^7$ liters

then

$$\textit{Volume of water in acre-feet} = \frac{5.58\times10^7 \text{ liters}}{(28.3 \text{ liters/ft}^3) \times (43{,}560 \text{ ft}^3\text{/acre foot})}$$

= 45.2 acre-feet

Water area required = 45.2 acre-feet / 50 foot depth = 0.90 acres
0.90 acres x 43,560 ft^2/acre = 39,423 ft^2 or a circular diameter of 224 feet.

For an initial RWT concentration of 100 ppb at the minimum depth of 33 feet, the calculations are:

$$\textit{Volume of water in liters} = \frac{[(8.62\ lbm) \times 0.453 kg/lbm \times 1\times10^{9}\ ug/kg]}{(100\ ug/L)}$$

$= 3.91 \times 10^7$ liters

then

$$\textit{Volume of water in acre-feet} = \frac{3.91\times10^7 \text{ liters}}{(28.3 \text{ liters/ft}^3) \times (43{,}560 \text{ ft}^3\text{/acre foot})}$$

= 31.2 acre-feet

Water area required = 31.2 acre-feet / 33 feet depth = 0.95 acres
0.95 acres x 43,560 ft^2/acre = 41,548 ft^2 or a circular diameter of 230 feet.

Results of the calculations are summarized in **Table 2**. Based on these calculations, for the higher RWT tracer concentration (100 ppb) in the shallower mixed depth (33 feet) we selected the larger diameter, 230 feet, as conservative in estimating the volume of water needed to assimilate the tracer to keep it below the US 1988 EPA advisory opinion level of 100 ppb for surface waters.

c. Depth of tracer release

The tracer release depth at the proposed site in Village Bay will be on the top layer of the seasonal thermocline, which, if the study is conducted in the summer, will likely be in the 33-50 foot depth range. The exact depth range will be determined by conductivity-temperature-depth profiles measured by the Manta+30 multiprobe at the tracer release site on both the day before and the day of the tracer release. The goal is to release the tracer in the top half of the thermocline to limit downward spread to the level of the drinking water intakes. LRWQCB and LACSD will be notified of any changes in the proposed release depth range.

Table 2. Summary of calculations to estimate needed initial receiving water volume and surface area to be within the 100 ppb EPA-recommended RWT limit for surface waters.

Tracer release condition (assumes tracer mixes completely from surface to water designated release depth	Concentration (ppb)	Depth (feet)	Volume of water (liters) for 3.91 kg (8.62 pounds)	Volume of water in acre-feet	Water surface area needed = Area (acre-feet) / Depth (feet)	Water surface area (square feet)	Circular diameter (feet)
Maximum concentration at minimum mixed depth of tracer release	100	33	3.91×10^7	31.2	0.95	41,812	230
Minimum concentration at maximum mixed depth of tracer release	70	50	5.58×10^7	45.2	0.90	39,423	224

d. Aquatic vegetation

The depth of the water at the proposed site in Village Bay, approximately 85 feet on June 27, at lake water levels current for that date, 7 feet below the spillway, is below the 1% limit for the photic zone (at approximately 60 feet as measured in June profiling) for freshwater aquatic plants. We expect that submersed vegetation is neither expected to be found nor affected by the proposed RWT tracer release.

e. Tracer mixing tank and spill containment

The on-board 100-gallon mixing tank containing 80 gallons of mixed RWT tracer solution is translucent to enable monitoring of the mixed concentrate liquid level. The tank will be placed in a 200-gallon containment pan to capture any spills or leaks. An in-line flow meter will be placed in the discharge line from the mixing tank to monitor its evacuation flow rate (4.0 gallons/minute (gpm)). The 4.0 gpm flow rate from the mixing tank will be blended into a 65 gpm flow rate of lake surface water that is supplied by a gasoline-engine powered pump. The discharge side of the gasoline pump will inject the blended and diluted RWT tracer solution at a rate of 69 gpm through a diffuser at the 33-50 foot depth range. Pump pressures and flow rates in both the mixing tank and lake water lines will be continuously monitored to ensure the correct mixing ratio and constant output rate of the blended flow through the diffuser.

f. Pump flow rate settings

The objective is to distribute the diluted tracer solution evenly throughout the midwater zone at the proposed tracer release site. Total flow rate will be adjusted so that the mixing tank solution blended with lake water can be injected into the lake over a 20-minute period at a total rate of 69 gallons/minute. Flow rates will be controlled by valves on the discharge side of each pump. Valve settings for both the mixing tank line and the lake water line will be determined beforehand using plain water and verified with flow meters installed in each line to show an output of 4.0 gpm for the mixing tank pump and 65 gpm for the main lake water pump. Output will be measured at least three times during the plain water verification phase to determine the correct settings. Depending on the length of the discharge line and fitting losses, the pressure drop in the blended lake water discharge line is expected to be no more than 10 pounds per square inch (psi). Discharge pressure will be monitored with a pressure gauge.

g. Solar radiation intensity in the water column and monitoring for RWT photodegradation

A LiCor™ Spherical Quantum detector for photosynthetically active radiation (PAR) attached to the Eureka Manta+30 probe will be used to monitor light levels at the tracer release site from the water surface and in 10-centimeter increments to the lake bottom at the tracer release site. This information will be used to estimate the potential rate of sunlight decay of RWT at varying depths. PAR measurements will commence one hour before the tracer release begins, and continue during the tracer release, and every one-hour after the tracer release and used in combination with RWT samples suspended in a string of bottles to monitor the RWT dye's photodegradation rate at ambient conditions. Measured photodegradation rates will be used to correct estimated dilutions of the tracer. Additional PAR measurements will be made at the other lake monitoring sites as described in **Section 5. Measurement of Ambient Environmental Conditions.**

9. Implementation Schedule

Table 3 shows a proposed implementation schedule, notification plans and reporting dates for a late summer 2018 release. If permission is obtained after LRWQCB's review, a discharge date will be determined immediately after notification by LRWCQB, a tracer release date will be selected that corresponds to minimum activity on the lake, probably a weekday early in the week. Any subsequent change in selected discharge date or notification plans will be communicated to both LACSD and LRWQCB within 24 hours of a decision to change and at least 24 hours prior to implementation. If the study can be conducted during late summer, the interim report will be provided on March 31, 2019 and the final report will be provided on April 30, 2019.

10. Notification and Action plan

a. Village Bay tracer release site notification

Notification timing is summarized in **Table 3. Implementation Schedule**. If the study is approved, LRWQCB will be notified at least 7 days before the proposed tracer release is to take place. At least 7 days before the proposed tracer release, Lake Arrowhead property owners and community members will be notified by email and by posters located at LACSD and ALA offices. Public notices will be posted in the two Lake Arrowhead area newspapers, the Alpenhorn and the Mountain News. The location of the site will be provided in a map in the email and on the posters at the LACSD and ALA offices.

A buoy will be installed at the center of the tracer release site two (2) days before the proposed injection. Four buoys delineating the boundaries of the tracer release area will be positioned the afternoon before the day of tracer release. The buoys will remain in place for the day of the tracer release. If summertime south-southwesterly (Figure 1-A) winds were prevail throughout a 1-2 day period and influence lake water movement at the tracer release depth at maximum rates modeled by the US Bureau of Reclamation (Bender, 2012), estimated to be, on average, about 0.025 meters/second, or 1.34 miles per day, advection of the tracer plume to the northeast is expected to move the mass of released tracer away from the tracer release site within one day.

b. Lake Arrowhead Community Services District (water purveyor) notification

One potable water purveyor, the Lake Arrowhead Community Services District (LACSD) draws potable water directly from Lake Arrowhead using intakes located in North Bay, at approximately 2,950 feet from the proposed tracer release location, and in Emerald Bay at approximately 4,235 feet from the proposed tracer release location (**Figure 1-B, Table 1**).

For prevailing summertime southerly to southwesterly winds, neither intake is directly downwind of the proposed release location; expected tracer travel distances are greater than the direct line distance. LACSD will be notified by email and telephone three days before dye application. LACSD has the option to use alternative sources of supply, including both groundwater wells, and the State Water Project, if diversion is needed. The conditions for notification of LACSD were described in **Section 6.4 Contingency Spill Plans - Unexpected movement monitoring** and reporting, above.

c. Lake Arrowhead Community Services District (water purveyor) proposed action plan

Upon notification of the potential approach to either intake of a RWT tracer concentration near 10 ppb, LACSD would take the following actions:

1. The potentially affected intake would be shut down.

2. Alternative water supplies would be obtained from the Crestline Lake Arrowhead Water Agency (CLAWA);

3. Samples would be taken from the raw water line inside the plant at the potential affected intake at the location where operators perform daily process control testing. RWT fluorescence would be measured with a RWT fluorometric probe to determine if any tracer reached the intake;

4. Lake water at the intake will be monitored if the closed intake does become impacted by a RWT concentration exceeding the 10 ppb US EPA advisory limit. The intake would remain shut down until the RWT concentration drops below the 10 ppb advisory level.

5. In the unlikely event that any RWT were to be drawn into the intakes, it would be rapidly consumed by the 4 mg/L standard applied chlorine dose in the treatment plant's finished water storage tanks before entering the distribution system. Please see below, **d. Destruction of Rhodamine WT by chlorine dose - experimental results**

6. Upon notification that the above-intake RWT concentrations had dropped below 10 ppb, once the intake is re-opened, RWT sampling would continue with measurement by the fluorometric sonde in raw water and in the finished water to make sure that RWT concentrations are below EPA advisory levels for both drinking water intakes (10 ppb) and in finished drinking water (0.1 ppb).

d. Destruction of Rhodamine WT by standard chlorine dose - experimental results

LACSD reports (Brooks, personal communication, July 17, 2018) that their drinking water treatment plant storage tanks hold 1.8 million gallons of finished water, with maximum daily customer demand varying from 90,000 to 180,000 gallons per hour, giving typical storage tank residence times varying from 10 to 20 hours. On being sent to the storage tanks from the treatment plant, finished water is treated with sodium hypochlorite bleach solution at a standard applied chlorine dose of 4 mg/L, with a target chlorine residual upon withdrawal to the distribution system of 1.5 mg/L.

UNLV performed RWT decay experiments on a hypothetical 10 ppb RWT tracer concentration in Lake Arrowhead raw water on July 19, 2018 using a 4 mg/L chlorine dose added as bleach solution (identical to the approach used by LACSD). RWT decayed to 0.1 ppb (the US EPA advisory limit level for drinking water) in 8 minutes and decayed to the RWT sonde's 0.01 ppb detection limit in 11 minutes. When this result is compared to the 10-20 hour residence time of chlorinated finished water before delivery to LACSD customers, in the unlikely event that a 10 ppb RWT concentration were to reach the drinking water intakes before an intake could be shut down, it is concluded that LACSD's standard procedures for water disinfection chlorine dose and detention time would be sufficient to oxidize the RWT to below the 1988 US EPA 0.1 ppb advisory limit for drinking water. Additional details can be found in **Appendix 5**.

Regular RWT monitoring above the intakes during the initial stages of tracer release, combined with:

1) the July 17, 2018 finding that Lake Arrowhead nitrite concentrations were 0.0008 mg/L (0.8 ppb) or less (**Section 2**),

2) intensive monitoring and rapid notification of LACSD in the event that a tracer concentrations approach 10 ppb moves near the intake,

3) a plan to shut the intakes and shift to alternative water sources, if needed,

4) in-plant raw water RWT monitoring immediately after the intakes, and

5) the ability of standard added 4 mg/L chlorine dose to destroy 10 ppb RWT to the 0.1 ppb advisory limit, in 8 minutes compared to a 10-20 hour detention time in water storage tanks,

the available evidence and response measures described in 1) through 5) above should be sufficient to make sure that:

a) it is very unlikely that formation of NDEA (DENA) will occur in Lake Arrowhead

b) the 1988 US EPA advisory limit of 0.10 ppb RWT in drinking water will not be exceeded in the unlikely event that a tracer concentration approaching 10 ppb moves near the LACSD intakes.

Table 3. Proposed Late Summer 2018 implementation schedule

Action	Notification to LRWQCB	Emails and public notices at LACSD and ALA offices Media notices Signage placement	LACSD	Center Buoy placement	Boundary Buoy placement	Monitoring for RWT	Interim Report	Final Report
	7 days prior	7 days prior	3 days prior	2 days prior	1 day prior	Day of tracer release until RWT concentration s drop to background levels, assumed to be 114 days.[a]	3/31/19	4/30/19

[a]RWT can be rapidly measured by TDX probe *in situ* to determine status of tracer concentration elevation above background.

11. References

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Appendix 1 - Eureka TDX fluorometric sonde/probe specifications.

Data for Rhodamine WT dye are located on the next to the last row in **Table A1**

Table A1 - Eureka Fluorometer Specifications.

Source: https://www.waterprobes.com/fluorometers

Fluorometer Specs

Application	Minimum Detection Limit	Dynamic Range
CDOM/FDOM	0.15 ppb**	0-1250 ppb**
Chlorophyll in vivo - Blue Excitation	0.025 µg/L	0-500 µg/L
Chlorophyll in vivo - Red Excitation	0.5 µg/L	>500 µg/L
Fluorescein Dye	0.01 ppb	0-500 ppb
Oil - Crude	0.2 ppb***	0-2700 ppb***
Oil - Fine	10 ppb*	6,000 ppb*
Optical Brighteners	0.6 ppb***	0-15,000 ppb***
Phycocyanin (Freshwater Cyanobacteria)	2 ppbPC	0-3500 ppbPC
Phycoerythrin (Marine Cyanobacteria)	0.15 ppbPE	0-750 ppbPE
Rhodamine Dye	0.01 ppb	0-1000 ppb
Tryptophan	3 ppb	1000 ppb

Appendix 2: Ecotoxicity of Rhodamine WT

1. Summary of Reviewed Literature and Recommendation

A review of available articles on ecotoxicity of Rhodamine WT (RWT) published before and after the August 1988 US EPA (Turner Designs, Document 998-5104.pdf) letter indicates that the majority of cited works find very low ecotoxicity of RWT. Smart (1984) after an extensive review of the then-extant literature, recommended that it should not be a problem to keep persistent dye concentrations below 100 *u*g/L. The lowest limits available in the literature appear to be 1.0-2.0 mg/L (1,000 to 2,000 ppb) for accidental human ingestion and 20 mg/L (20,000 ppb) for a predicted growth effect on green algae (Field et al 1995). Behrens et al's 2001 finding of RWT mutagenic effects in bacteria has not subsequently been replicated in tests with standard bioassay organisms, and RWT continues to be used worldwide as a tracer. Rowinski and Chrzanowski (2011) observed some behavioral effects of RWT in two small aquatic organisms at 100 ppb, and some red dye uptake at 100 ppb. They concluded that concentrations used for hydrological purposes are low enough to exert almost no toxic impact on the studied water fauna. Combining these reports with the 1988 US EPA advisory letter recommending a maximum value of 100 *u*g/L (100 ppb) in surface waters and 10 *u*g/L (10 ppb) around drinking water intakes, it would appear to be prudent to continue to limit the initial well-mixed injected RWT concentration in the target initial water volume at Lake Arrowhead to 100 *u*g/L (100 ppb). Lake Mixing should be sufficient to reduce the RWT dye concentration to below 10 *u*g/L before it reaches the intakes (**Appendix 4),** and the proposed response and chlorination measures should be sufficient to eliminate any RWT from LACSD's drinking water.

2. Objective

Determine if there is a risk toxicity to aquatic life at concentrations resulting from proposed released mass of RWT into Lake Arrowhead

3. Annotated Bibliography of discovered articles about Rhodamine WT aquatic toxicity.

Parker, 1973 tested 8 each of silver salmon and rainbow trout as 4-6 inch long smolt in seawater and reported "neither mortalities nor respiratory problems in concentrations of rhodamine WT of 10 mg/L (10,000 ppb) for 17.5 hours at 22ºC or an additional 3.2 hours at 375 mg/L (375,000 ppb). The fish remained healthy in dye free water a month after the test. Parker, 1973 also stated that for RWT, "development continued normally in Pacific oyster (*Crassostrea gigas*) eggs and no abnormalities occurred in 12-day old larvae exposed in concentrations ranging from 1 *u*g/L (1 ppb) to 10 mg/L (10,000 ppb) for 48 hours at 24ºC.

Smart and Laidlaw, 1977, evaluated eight fluorescent dyes, including RWT, comparing them in laboratory and field experiments, and also reviewed available early literature about RWT toxicity. They reported that according to a personal communication from J.S. Worttley and T.C. Atkinson (1975), "Toxicity experiments conducted at 10 ºC with a number of fresh and brackish water invertebrates including water flea (*Daphnia magna*), shrimp (*Gammarus zaddachi*), log louse (*Asellus aquaticis*), mayfly (*Cloeon dipterum*) and pea mussel (species *pisidium*) at a maximum concentration of Rhodamine

WT of 2,000 mg/L (2,000,000 ppb) showed no mortality of any species over periods of 48 hours and 1 week compared to control animals."

Smart, 1984, extensively reviewed available published toxicity data for 12 dyes used as tracers, including Rhodamine WT. Smart advised that results of testing can vary with purity of dye solutions and presence/absence of additives. With this qualification in mind, Smart's literature review found:

- for RWT mammal dosages, an oral dosage greater than 25.0 gram/kg body weight was needed for a LD_{50} (dose that was lethal to 50% of tested individuals) in rats, (meaning low toxicity). The acute intravenous dose LD_{50} was 430 mg/kg. The no effect acute intraperitoneal dose was > 167 mg/kg. Smart concluded that "there is no evidence of either a short term or long term toxic hazard to dye users or those drinking water containing tracer dyes. Even those employing tracers routinely in their work would not be likely to ingest sufficient dye to cause concern."
- For mutagenicity tests on microbes, Smart cited a study by Douglas et al (1983), where Douglas et al. found very weak in vitro mutagenicity in the Ames test on *Salmonella typhum* bacteria using very high dye concentrations and concluded that "Rhodamine WT appears not to represent a major genotoxic hazard."
- For aquatic toxicity, Smart's literature review found that the RWT concentration needed for a 30-day median lethal time (TL_{50}) was 1,360 mg/L (1,360,000 ppb) for the guppy fish *Lebistes reticulatus*. This mean lethal time concentration was three orders of magnitude greater than the visible dye concentration and "five orders of magnitude in excess of those (concentrations) expected in long-term tracer experiments." The 48-hour and 96-hour LC_{50} toxicities for rainbow trout (*Salmo gairdneri*) were greater than 320 mg/L (> 320,000 ppb). The 96-hour LC_{50} for the water hog louse *Asellus aquaticus* was cited to be > 2,000 mg/L (> 2,000,000 ppb). The 72-hour LC_{50} for the water flea Daphnia magna was cited to be 170 mg/L (170,000 ppb). No effect on Pacific oyster (*Crassostrea gigas*) egg development was observed in a 48-hour exposure at 10 mg/L (10,000 ppb). Smart concluded that concentrations of 1 to 10 mg/L of Rhodamine WT and two other dyes (depending on test organism) do not affect development or cause mortality after 48-hours' exposure.

Field et al., 1995, reviewed available toxicity testing data for 12 fluorescent dyes, including Rhodamine WT with the objective of addressing toxicity issues and explaining how the dyes could be used in a safe manner. In their Table IV, they summarized RWT's Ecological toxicity Structure Activity Relationships (SAR) for RWT as > 320 mg/L measured (> 320,000 ppb) as a 96-hour 50% lethal concentration (LC_{50}) for fish, 170 mg/L measured (170,000 ppb) as 48-hour LC_{50} for Cladocera (*Daphnia magna*), and as 20 mg/L (20,000 ppb) as an estimated 96-hour 50% reduction in growth (EC_{50}) for green algae and stated that the algae No Effect Concentration for Acid Dyes as a class is 20.0 mg/L (20,000 ppb).
Field et al 1995 recommended that: "(1) individuals doing the tracer work be experienced or well-trained in their use and (2) tracer concentrations not to exceed 1 to 2 mg/L (1,000-2,000 ppb) persisting for a period in excess of 24 hours in groundwater at the point of groundwater withdrawal or discharge." They stated that this limit for human ingestion was far below known aquatic toxicity results.

Behrens et al, 2001, assessed 17 water tracers including RWT on the basis of results of toxicological tests, available literature and expert knowledge. Tests of genotoxicity were conducted using salmonella bacteria for microsome gene mutation and mammalian cell culture (for chromosome aberration). Ecotoxicity assessment were based on acute toxicity to daphniae and zebrafish. They found that RWT did not exhibit any ecotoxicity (no mortality, LC_0) at 10 mg/L (10,000 ppb) in the daphniae and zebrafish tests. RWT exhibited genotoxicity in the salmonella microsome test and in the cytogenetic analysis. On the basis of the genotoxicity results, they recommended against using RWT as a water tracer.

Rowinski and Chrzanowski (2011), evaluated Rhodamine B and Rhodamine WT toxicity in standardized ecotoxicological tests against fairy shrimp larvae (*Thamnocephalus platyurus*), and observed effects on water flea (*Daphnia magna*), horned planorbis snail *(Planorbis corneus*), guppy fish (*Poecilla reticulata*), and the protozoan *Paramecium caudatum*. In the standardized fairy shrimp larvae test, a RWT concentration of 1,698 mg/L (1,698,000 ppb) was needed to obtain 24-hour 50% mortality of the larvae. *Daphnia magna* and *T platyurus* larvae exhibited some red dye uptake in RWT concentrations of 0.1 mg/L (100 ppb) and 5 mg/L (5,000 ppb). *P. caudatum* and *D. magna* exhibited escape reactions at 0.1 mg/L (100 ppb). *P corneus* embryos experienced size reduction in 100 mg/L (100,000 ppb) and dye uptake at 5 mg/L (5,000 ppb). *P corneus* mature forms did not react to 100 mg/L (100,000 ppb) after 14 days' exposure. Guppy fish (*P reticulata*) survived for 14 days in 100 mg/L (100,000 ppb) RWT, exhibited increased mobility after exposure to dye concentrations of 5 mg/L (5,000 ppb) and 100 mg/L (100,000 ppb) and showed dye staining in their gill covers at 100 mg/L (100,000 ppb). They concluded that the concentrations of RWT in which bioindicative tests were performed do not occur in rivers during tracer studies, that RWT should not cause a strong negative influence on the natural environment and that "recommended concentrations should not be exceeded within long time intervals." They concluded that concentrations used for hydrological purposes are low enough to exert almost no toxic impact on the studied water fauna.

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Appendix 3. Nitrite concentrations in Lake Arrowhead in relation to risk of formation of diethylnitrosamine in Lake Arrowhead waters

Executive Summary

Steinheimer and Johnson's 1986 USGS paper indicates that Diethylnitrosamine (DENA) could not be detected (detection limit 0.03 ppb) in four streams at typical Rhodamine WT tracer concentrations and ambient nitrite concentrations ranging from 2 to 46 *u*g/L. UNLV measured nitrite in 13 Lake Arrowhead water samples and found a maximum concentration of 0.8 *u*g/L. We conclude that, based on data available to date, DENA formation is unlikely to occur at the planned tracer concentrations and observed nitrite concentrations in Lake Arrowhead.

Objective

Determine background nitrite concentrations in Lake Arrowhead to assess potential risk of NDEA formation if Rhodamine WT dye tracer were to be released into Lake Arrowhead.

Literature Background

Abidi (1982) in laboratory experiments, detected DENA in the range of 0.25-7.02 *u*g/L (ppb) in river water samples with pHs ranging from 7.3 to 8.2, at RWT dye in the concentration range of 1- 20 *u*g/L (ppb) containing 10-27 *u*g/L (ppb) nitrite after the water samples had been spiked with additional nitrite in the range of 10-100 *u*g/L, creating a large stoichiometric excess of nitrite. She found that NDEA photodegradation rates were slow in the first 24 hours of simulated sunlight exposure. It is important to note that Abidi's total experimental nitrite concentrations in the range of 20 to over 100 ug/L are far above any values observed in well oxygenated streams (see Steinheimer and Johnson, 1986, below) and far above what has, to date, been measured in Lake Arrowhead.

Steinheimer and Johnson could not detect NDEA (detection limit 0.03 *u*g/L) in four different river samples under field dye injection conditions with river water nitrite concentrations ranging from 2 to 46 *u*g/L (ppb). Their RWT concentrations were not reported, but the USGS advisory limit at the date of their experiments was 10 *u*g/L near drinking water intakes, Wilson et al. (1986). In laboratory experiments, they found that the half-life of 2 *u*g/L NDEA from a river water sample spiked with 20 ug/L RWT and 43 *u*g/L total nitrite ion was less than 3 hours at pH 8 under simulated sunlight intensities, a rate of decay much faster than measured by Abidi (1982).
They concluded that their findings differed from those of Abidi (1982) because Abidi's experiments used a much larger stoichiometric excess of added nitrite, generating nitrite concentrations above values observed in surface streams. Steinheimer and Johnson concluded that "Our findings indicate that, under these conditions of recommended usage, rhodamine WT as an agent for surface-water-tracing studies does not constitute an environmental hazard associated with man-made nitrosamines in the environment."

Laboratory measurement of nitrite in Lake Arrowhead water

To assess potential risk of NDEA formation during a proposed dye tracer experiment, UNLV collected 13 samples of lake water from the epilimnion, metalimnion and hypolimnion of Lake Arrowhead on July 17, 2018 and, within 15 seconds of bringing the water sample to the surface, initiated the colorimetric reaction that measures nitrite in the field using Hach method 8507, Low Range for nitrite detection, with an uncertainty of +/- 0.1 ppb, a detection limit of 0.5 ppb and a maximum limit of 350 ppb.

Epilimnetic and metalimnetic nitrite concentrations ranged from < 0.3 ppb to 0.8 ppb. **(Table A2)**. The maximum measured nitrite concentration was 0.8 *u*g/L (0.8 ppb) from the metalimnion of the lake. Hypolimnetic nitrite concentrations were less than the 0.1 ppb detection limit

Conclusions
Pending additional sampling of Lake Arrowhead for nitrite, since the 0.8 *u*g/L maximum observed nitrite concentrations to date are a factor of 2/0.8 = 2.5 below the lowest value (2 *u*g/L) recorded by Steinheimer and Johnson in four river samples, a factor of 10/0.8 = 12.5 below the lowest ambient value (10 *u*g/L) recorded by Abidi (1982), and a factor of 20/0.8 = 25 below the lowest experimental value used by Abidi in spiked samples, and, drawing upon Steinheimer and Johnson's report of non-detectable (< 0.03 *u*g/L) NDEA formation in the four river water samples at ambient nitrite levels ranging from 2 to 46 *u*g/L, it is concluded that, based on nitrite data available to date, that there is minimal risk of NDEA formation in Lake Arrowhead waters during the proposed tracer release experiment.

Table A2 – July 17, 2018 UNLV findings of nitrite concentrations as NO_2-N with a method reporting limit of 0.001 mg/L in Lake Arrowhead waters

Location	Depth (ft)	NO_2-N (mg/L)
North Bay	12	0.007
North Bay	48	0.005
North Bay	75	0.003
Blue Jay	12	0.003
Blue Jay	25	0.005
Village Bay	12	0.007
Village Bay	45	0.005
Near the dam	12	0.003
Near the dam	60	0.008
Near the dam	100	Zero
Lake's middle	12	0.003
Lake's middle	48	0.003
Lake's middle	75	0.003

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Appendix 4. Preliminary estimated wind-driven circulation distances and worst-case travel times to LACSD drinking water intakes for notification and response-planning purposes

Executive Summary

Assuming released tracer mass trajectories from the proposed release location influenced by prevailing southerly to southwesterly winds to the north shore of the lake, that then either follow the shoreline or bathymetry to the east or west, taking curved paths to the LACSD drinking water intakes, it is estimated that travel distances would be 1.55 to 1.63 miles to the Bernina intakes in North Bay and 1.86 to 2.15 miles to the Cedar Glen intakes in Emerald Bay. Assuming, as a worst-case steady winds blowing for more than two days[7], tracer mass travel times at estimated water current velocities of 0.025 meter/second (1.34 mile/day) would be in the range of 1.15 to 1.60 days. For the given range of travel times, estimated peak tracer concentrations at the level of the intakes would be 1.7 to 2.7 ppb, below the 1988 US EPA advisory opinion 10 ppb limit for use of RWT around drinking water intakes.

Objective

For planning purposes for a proposed tracer release in Lake Arrowhead, generate preliminary estimate travel distances and worst-case travel times for tracer mass to circulate from intended point of release to Lake Arrowhead drinking water intakes.

Input data and resulting assumptions

1) **Inflow data:** Recent USGS gauging station data for Little Bear Creek and the Grass Valley Tunnel **(Figures A1 and A2)** and Willow Creek outflow **(Figure A3)** show that channel inflows to Lake Arrowhead are episodic, driven primarily by winter storm events, with zero flow rates during the summer. **Assumption 1:** Because of this it is assumed, that there isn't a perennial flow through Lake Arrowhead that might follow the thalweg (original stream channel) of the reservoir or direct flow to the outlet during a summer tracer release.

2) **Wind direction and speed data**: Summer weather station monitoring from a station at Lollipop Park on the south shore of the lake show that predominant summer wind directions are southwesterly to southerly, with most wind speeds on the south shore of 3 meters/second (6 mph) or less (**Figure 1-A**). **Assumption 2:** Although wind speeds typically vary diurnally, with maximum intensities in the afternoon, and low intensities in the late evening and early morning hours, it is assumed, for worst-case preliminary modeling purposes, that surface winds on the lake would blow steadily at 3 meter/second from the south or southwest for more than 2 days, influencing, in the absence of defined inflow or outflow current, the released tracer mass to gradually move in a northerly to north-easterly direction towards the north shore of Lake Arrowhead.

[7] Note, Figure A4 from Lollipop Park on the south shore of the lake shows that summer wind speeds vary diurnally from an evening minimum of about 1 meter/second to an afternoon maximum of 2-3 meter/second.

3) **Water current speed data:** Bender (2012), conducted a QUAL2E water quality modeling study of Lake Arrowhead. Bender's model generated maximum wind-driven current speeds of 0.025 meter/second in the midwater of the lake (Bender's Figures 13, 14, and 15). These estimated values are slightly less than 1% of the maximum recorded 3-3.5 meter/second afternoon surface wind velocities at Lollipop Park **(Figure A4)** on the south shore of Lake Arrowhead. Lawrence et al 1995 found current velocities of 0.01 m/sec to occur in Twin West Lake, British Columbia in response to a wind speed of 1 meter/second, also about a 1% ratio of wind speed to water current speed, and indicated that this 1% ratio was consistent with two other cited sources for reservoirs. **Assumption 3:** As a worst-case, it is assumed that 0.025 meter/second current speeds would persist for more than 2 days in the case of persistent 3 meter/second winds, even though it is more likely that water current speeds would vary as wind speeds vary diurnally. **Figure A4** data show that wind speeds drop at a steady rate after sunset, until late evening and early morning when wind velocities are down to 0.5-1.5 meter/second. From a preliminary calculation of the Burger number, it is further assumed that internal waves, if they exist, would not influence rate of travel or vertical mixing of a tracer mass in a lake the size of Lake Arrowhead.

4) **Tracer release depth assumption:** It is assumed that a 3.91 kg (8.62 pound) mass of tracer would be released as a cylinder of water occupying a depth of 33-50 feet and a diameter of 230 feet.

5) **Bathymetry data:** The US Bureau of Reclamation conducted a bathymetric survey of Lake Arrowhead that shows steep gradients long the north shore of the lake **(Figure A5). Assumption 4:** It is assumed that a released tracer would, if encountering a shoreline barrier with near-shore depths greater than its released depth, would turn in response to the prevailing wind direction upon contact with the shoreline and follow the shoreline. This assumption applies to the shoreline directly north of the release site and eastward into Emerald Bay. **Assumption 5:** It is assumed that a tracer, if encountering the bottom at its approximate release depth before reaching the shoreline, would turn and follow the bottom contour. This assumption applies to bathymetric data available for the middle of North Bay, where North Bay's bottom shoals from 100 feet depth at its mouth to depths of 20 feet or less at the head of the bay.

6) **Turbulent diffusivities. Assumption 6:** It is assumed that vertical and horizontal diffusivities would vary with depth, with highest values in the epilimnion and lower values in the metalimnion and hypolimnion **(Table A4).** We chose representative values for lakes with length scales (100 meters to 1,000 meters) similar to Lake Arrowhead that were estimated to change with depth, based on calculations in Saber et al (2018). Diffusivity ranges were:

    a) for the top 8.4 meters of the water column (epilimnion) horizontal turbulent diffusion coefficients in the range of $k_h = 0.09\text{-}0.20\ m^2/s$ and vertical diffusion coefficients in the range of $k_v = 0.0015\text{-}0.0075\ m^2/s$.

    b) For the meta and hypolimnion below 8.4 meters, horizontal turbulent diffusion coefficients in the range of $k_h = 0.007\text{-}0.050\ m^2/s$ and and vertical diffusion coefficients in the range of $k_v = 8x10^{-5} - 4.0x10^{-4}\ m^2/s$.

Assumed horizontal turbulent diffusion coefficients are consistent with prior published work for similar length scales of 100 to 1,000 meters. Lawrence et al (1995) computed a surface horizontal diffusivities of 0.05 m^2/sec at a length scale of 100 meters in a small lake, Twin West Lake, in British Columbia, Canada. Peeters et al 1996 computed horizontal diffusivities in the upper hypolimnion of 0.02 to 0.18 m^2/sec after accounting for velocity shear. Peters and Hoffman (2015) estimated horizontal diffusivities to be 0.01 to 0.03 m^2/sec at length scales of 100 meters and 0.1 to 0.7 m^2/sec at length scales of 1,000 meters in Lake Constance. Little experimental data is available in the literature for vertical diffusivities, so we used estimated vertical diffusivity values based on the computational modeling of Saber et al (2018).

After tracer release, vertically varying turbulent diffusion will cause the tracer mass to expand non-uniformly over time, with higher diffusivities in the epilimnion causing more rapid lateral expansion and vertical expansion and lower diffusivities in the metalimnion and hypolimnion limiting rate of horizontal and vertical expansion towards the depth at which the drinking water treatment plant intakes are located.

Preliminary estimates of travel distance to drinking water intakes for response planning purposes

While actual trajectories will be determined during the tracer release study, if approved, and subsequently estimated with the hydrodynamic model, preliminary curved trajectories to each intake were estimated based on a range of wind directions and response to shoreline geometry and lake bathymetry.

Southerly to southwesterly winds were assumed for preliminary estimated tracer trajectories to the Cedar Glen intake **(Figure 1-A)** on the south shore of Emerald Bay (**Figures A6, A7 and A8)**. It was assumed that a released tracer mass would migrate across the lake, contact the north shore in deep water, then turn east and migrate along the shoreline, eventually turning back towards the Cedar Glen intake. Upon reaching the south or southeasterly shore of Emerald Bay, it was assumed as a worse-case estimate that the tracer mass would be sheltered by nearshore terrain from winds that might push it back out into the center of Emerald Bay. Depending on initial wind direction, the estimated travel distances from point of tracer release to the Cedar Glen intake on the south shore of Emerald Bay would be 1.86 to 2.15 miles. Preliminary trajectory distances were estimated using Google Maps(r) Estimate Distance function.

Southerly to southeasterly winds were assumed for preliminary estimated tracer trajectories to the Bernina Intake (**Figure 1-A**) on the south shore of North Bay (**Figures A9, A10, A11**). It was assumed that a released tracer mass would migrate across the lake, contact the north shore in deep water, then turn west and migrate along the shoreline until encountering shoal water due to decreasing water depth, that would influence the tracer mass to continue turning before reaching the head of North Bay. Upon reaching the south shore of Emerald Bay, it was assumed as a worse-case estimate that nearshore terrain on the peninsula that separates North Bay from Blue Jay would shelter the tracer mass from winds that might push it back out into the center of North Bay. Depending on initial wind direction, the estimated travel distances from point of tracer release to the Bernina intake on the south shore of North Bay would be 1.55 to 1.63 miles. Preliminary trajectory distances were estimated using Google Maps(r) Estimate Distance function.

Preliminary estimate of travel times to drinking water intakes for response planning purposes

Worst-case (lowest) travel time estimates were made by dividing the estimated trajectory distances by the 0.25 meter/second (0.056 mile/hour, 1.34 mile/day) water current speed data at depth shown in Bender's (2012) Figures 13, 14 and 15. For the 1.55 to 1.63 mile estimated trajectory distances to the Bernina intakes, estimated travel times range from 1.15 to 1.21 days. For the 1.86 to 2.15 mile estimated trajectory distances to the Cedar Glen intakes, estimated travel times range from 1.39 to 1.60 days.

Degree of dispersion of released RWT tracer mass

A finite-difference numerical model employing the turbulent diffusivities shown in **Table A4** was used to estimate the change in concentration distribution of the released tracer mass as a function of time. The model was operated in a series of time steps up to the maximum estimated travel time to a maximum time of 2.2 days. Although RWT is known to photodegrade slowly in sunlight, it was assumed that RWT did not degrade for modeling purposes. Travel distances were computed from the travel times using the estimated 1.34 mile/day travel velocity. Using a depth of 22 meters (corresponding to 73 feet) the maximum value of the estimated concentration profile vs horizontal position was selected as a worst-case estimate of a tracer concentration that might reach the drinking water intakes. The 22-meter maximum concentrations were plotted as a function of time. Results are shown in **Figure A12**.

Discussion

Figure A12 shows that, for response planning purposes, using the above-described assumptions, RWT concentrations in the range of 1.7 to 2.7 ppb might reach the LACSD intakes in the event that southeasterly to southwesterly winds blow constantly over the duration of the proposed tracer release experiment. These estimated values are below the 1988 US EPA advisory opinion limit of 10 ppb RWT near drinking water intakes.

Actions to be taken as a consequence of Appendix 4 modeling and Appendix 5 RWT decay

A monitoring and notification plan has been established (Section 10 above) to monitor RWT concentrations over the LACSD drinking water intakes and notify LACSD if plume concentrations near 10 ppb approach the LACSD intakes. The monitoring and notification plan states that LACSD intakes would be closed if this should occur, and that alternative sources of water supply would be used until RWT concentrations decline in the vicinity of the intakes. In-plant monitoring of RWT would take place using fluorometric methods to determine if any RWT entered the intakes. RWT decay rate data in chlorinated Lake Arrowhead water **(Appendix 5)** indicate that a 10 ppb RWT concentration would be reduced to the 0.10 ppb US EPA advisory drinking water limit in 8 minutes at a typical LACSD chlorination dose of 4 mg/L.

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Appendix 4 Figures and Tables

Figure A1 - USGS Little Bear Creek gauging station inflows to Lake Arrowhead, Blue Jay Bay October 1, 2008 through October 14, 2011, showing low inflow rates, summer months

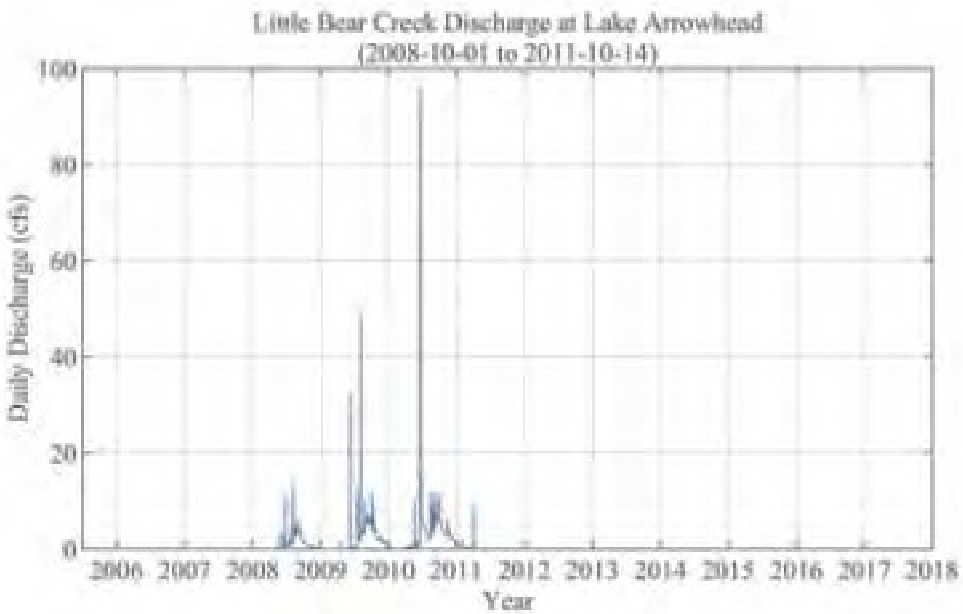


Figure A2 - USGS Grass Valley tunnel gauging station, episodic inflows to Lake Arrowhead, Meadow Bay. October 1, 2008 through July 2, 2018, showing low inflow rates, summer months

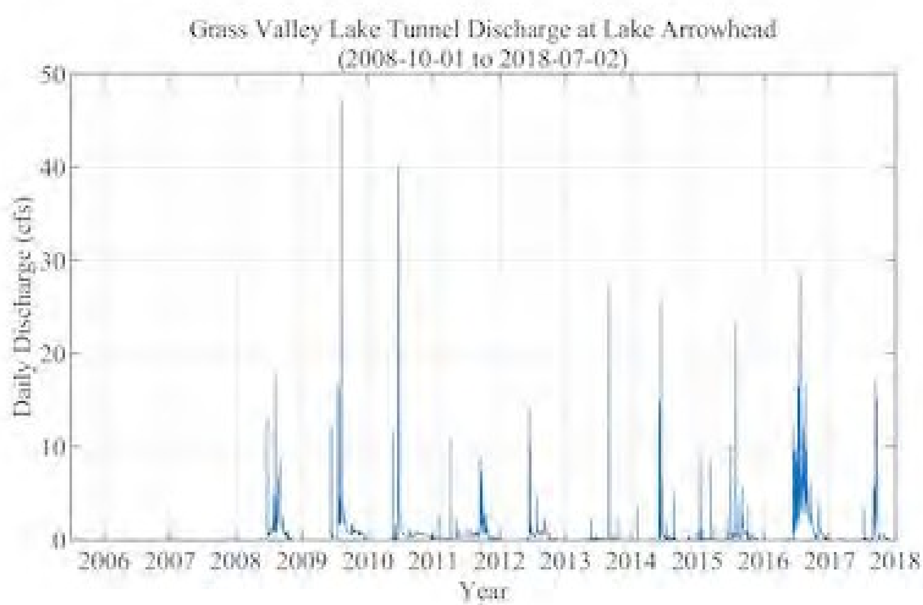


Figure A3. USGS Willow Creek gauging station, episodic outflows from Lake Arrowhead. October 1, 2008 through February 25, 2013

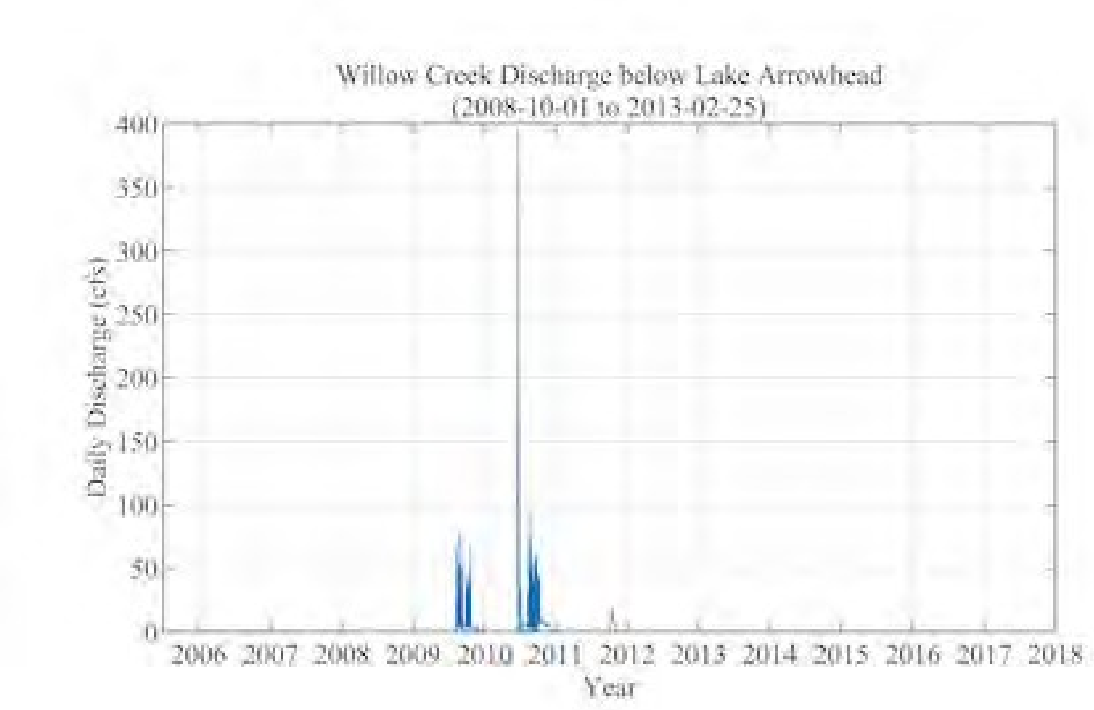


Figure A4 - Typical summertime wind velocities for south shore of Lake Arrowhead, UNLV Lollipop Park weather station.

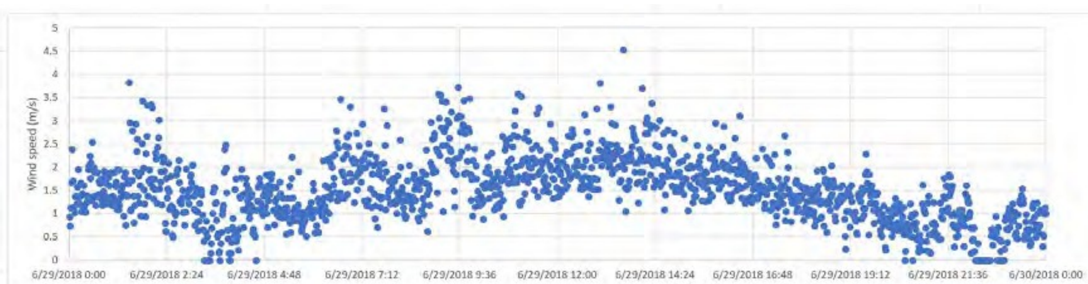


Figure A5 - Color-coded contour map of Lake Arrowhead's bathymetry. Black dots show proposed RWT and sucralose tracer sampling locations. Depth Color codes: Light green: > 100 feet. Green: 80-100 feet. Yellow: 60-80 feet. Red: 40-60 feet. Maroon: 20-40 feet. Grey: < 20 feet

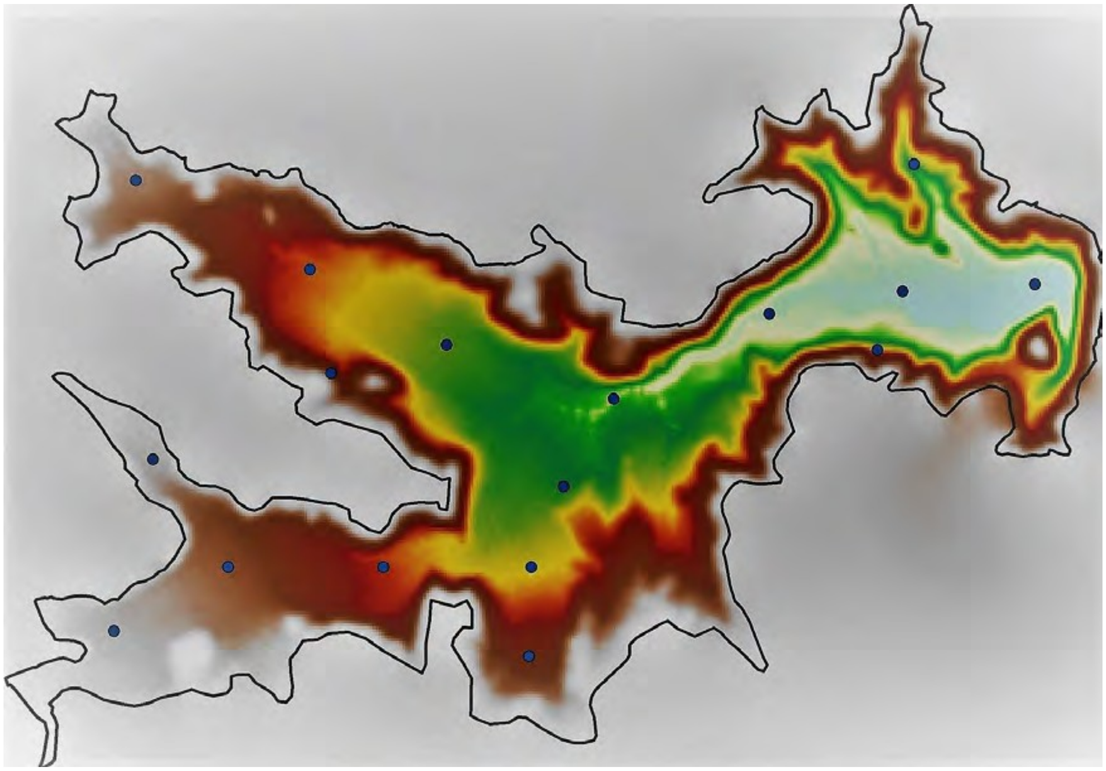


Figure A6 - Estimated minimum distance trajectory from proposed Village Bay point of tracer release to LACSD Bernina intake in North Bay. South-southeasterly wind - distance 1.55 miles

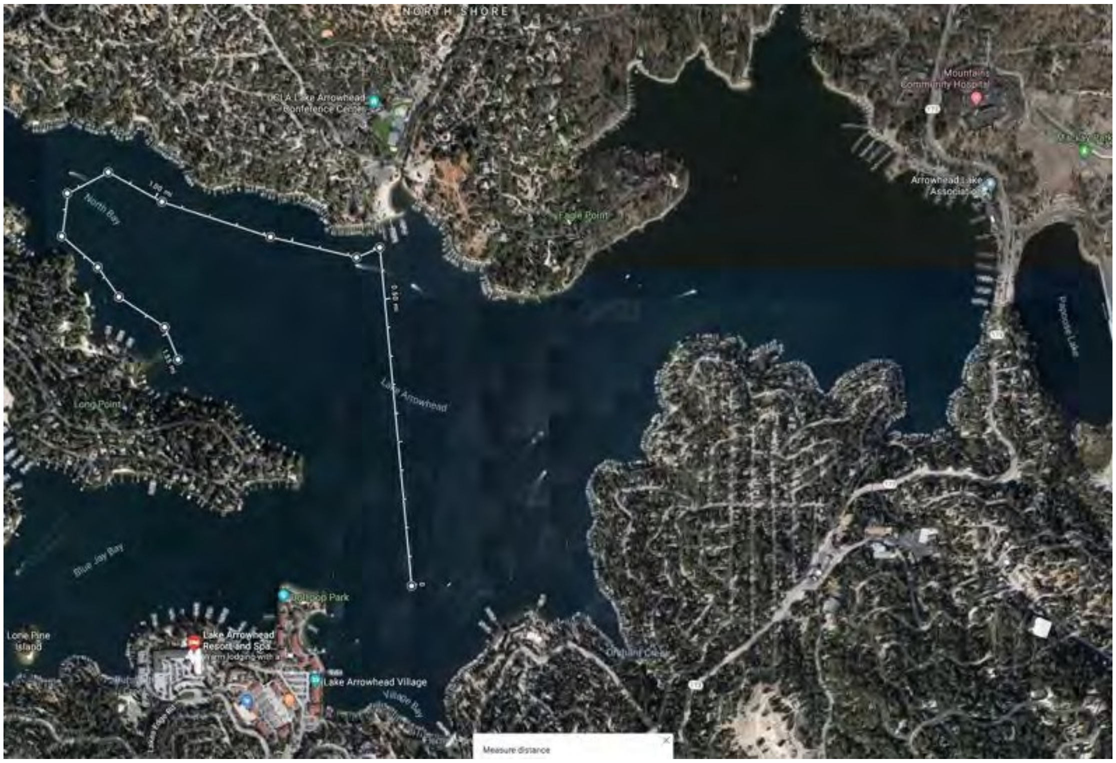


Figure A7 - Estimated medium distance trajectory from proposed Village Bay point of tracer release to LACSD Bernina intake in North Bay. Southerly wind - distance 1.60 miles

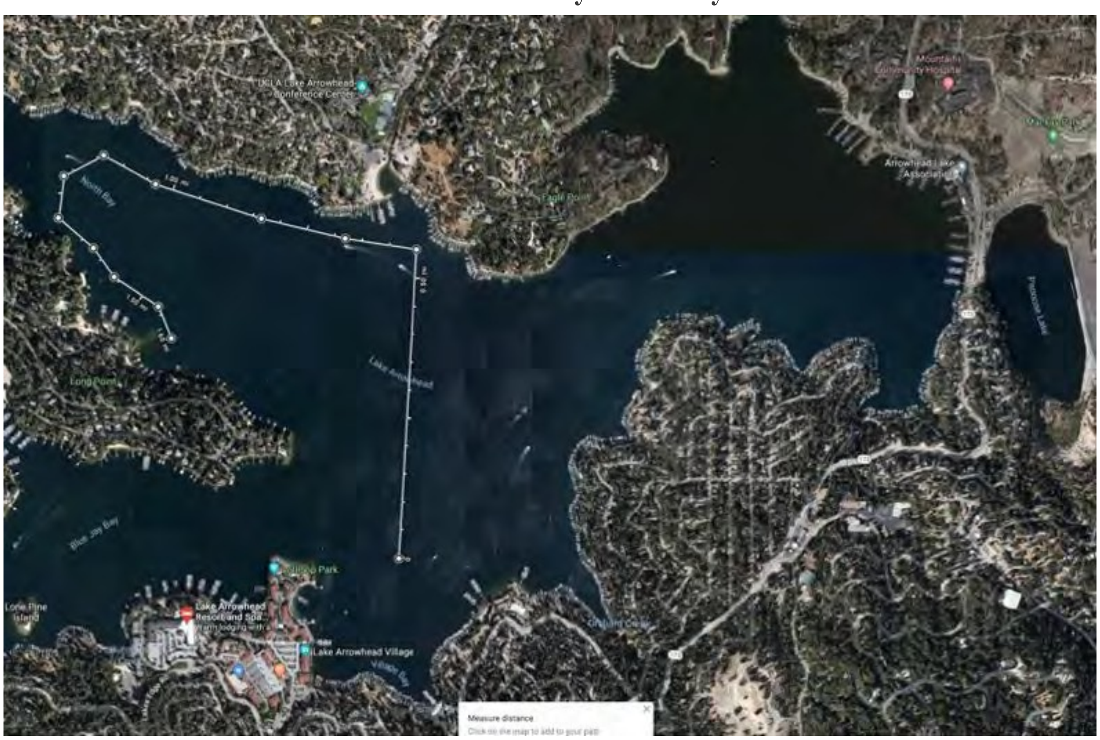


Figure A8 - Estimated maximum likely distance trajectory from proposed Village Bay point of tracer release to LACSD Bernina intake in North Bay. South-southwesterly wind - distance 1.63 miles

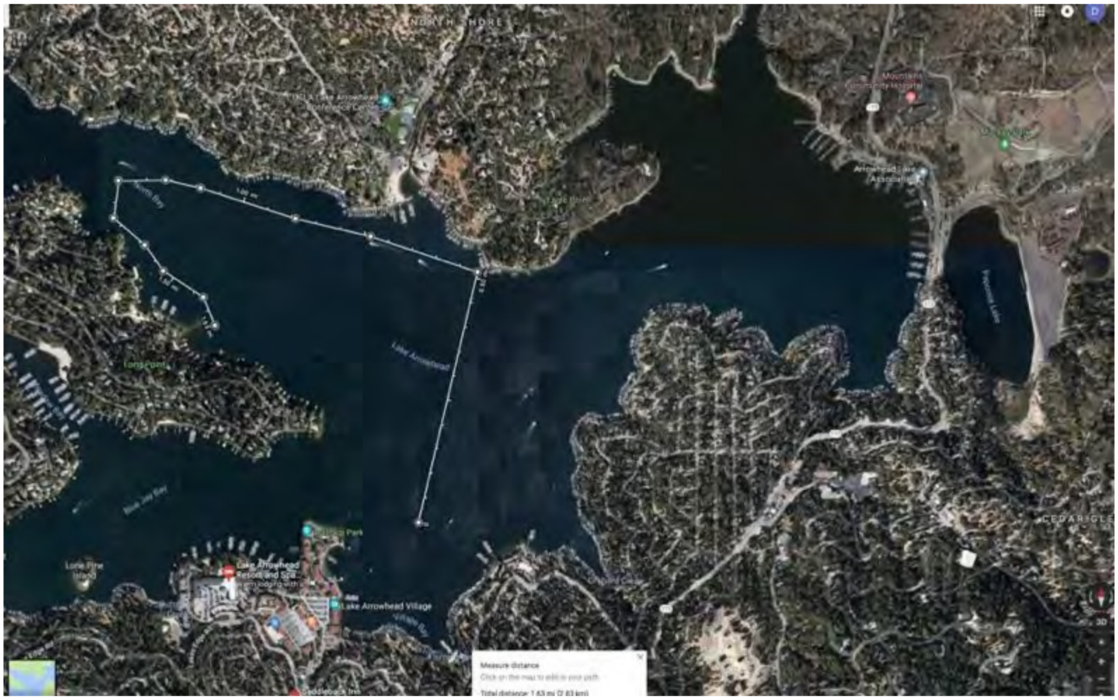


Figure A9 - Estimated minimum distance trajectory from proposed Village Bay point of tracer release to LACSD Cedar Glen intake in Emerald Bay. Southwesterly wind - distance 1.86 miles

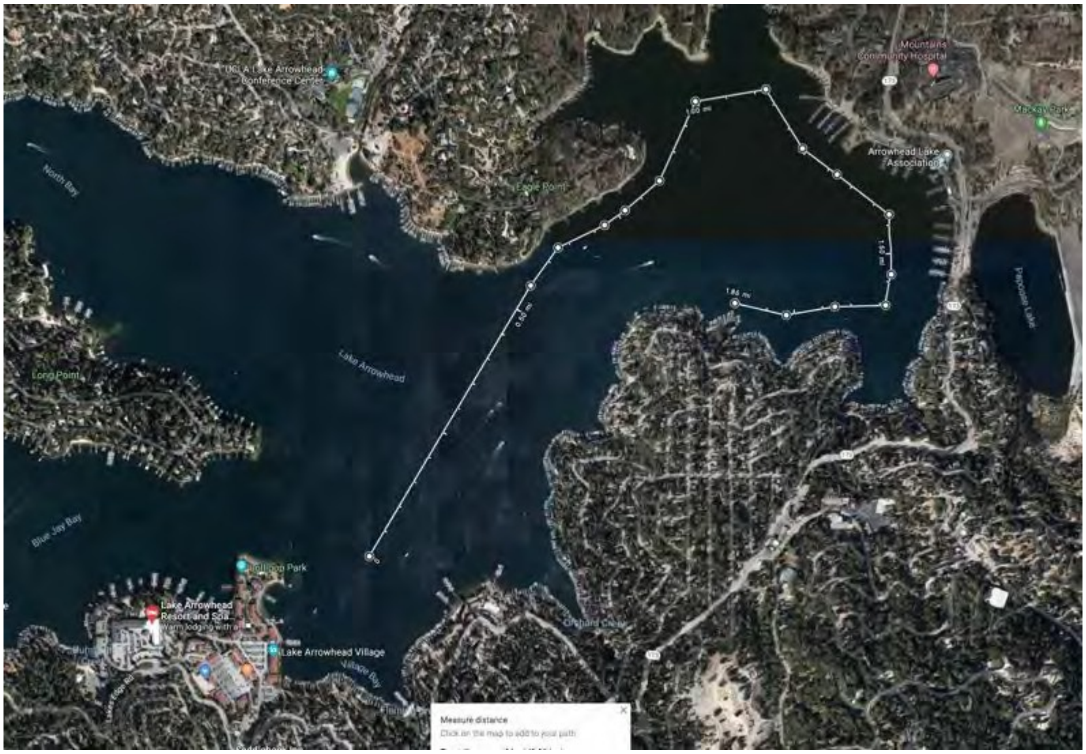


Figure A10 - Estimated medium distance trajectory from proposed Village Bay point of tracer release to LACSD Cedar Glen intake in Emerald Bay. South-Southwesterly wind - distance 1.94 miles

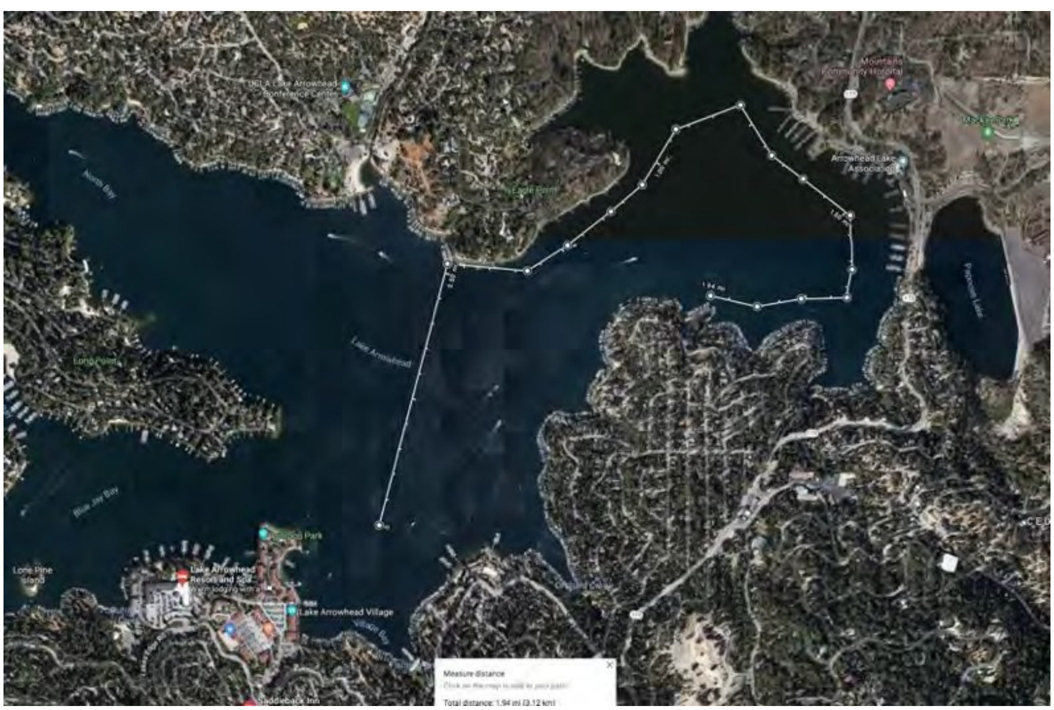


Figure A11 - Estimated maximum distance trajectory from proposed Village Bay point of tracer release to LACSD Cedar Glen intake in Emerald Bay. South-Southwesterly wind - distance 2.15 miles

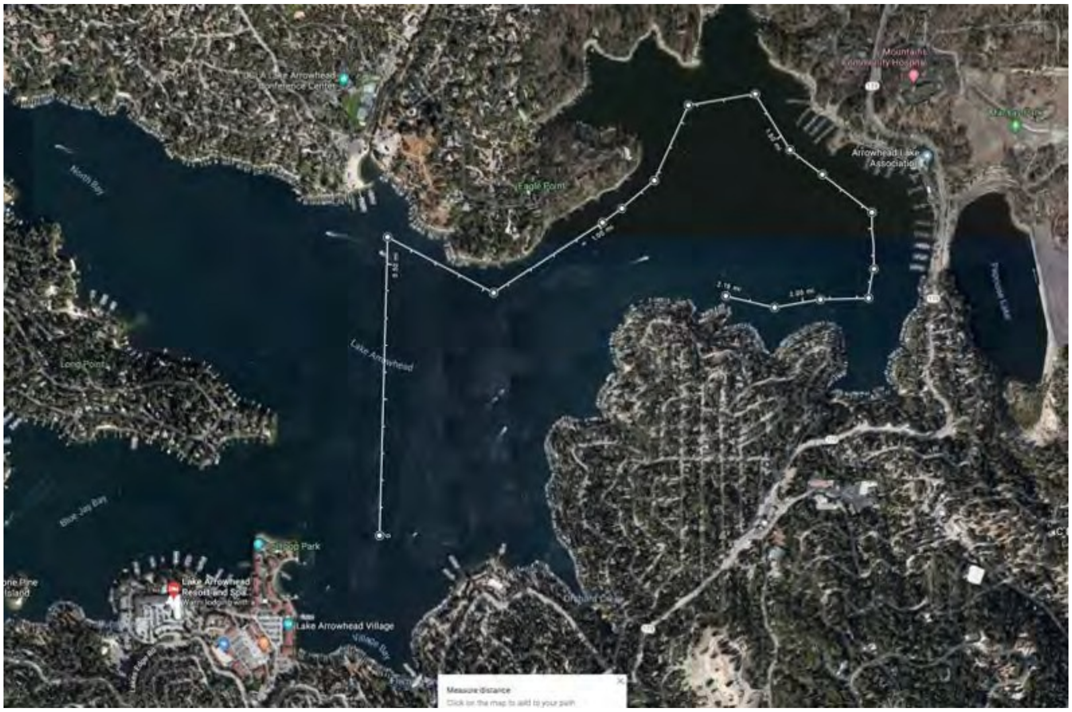
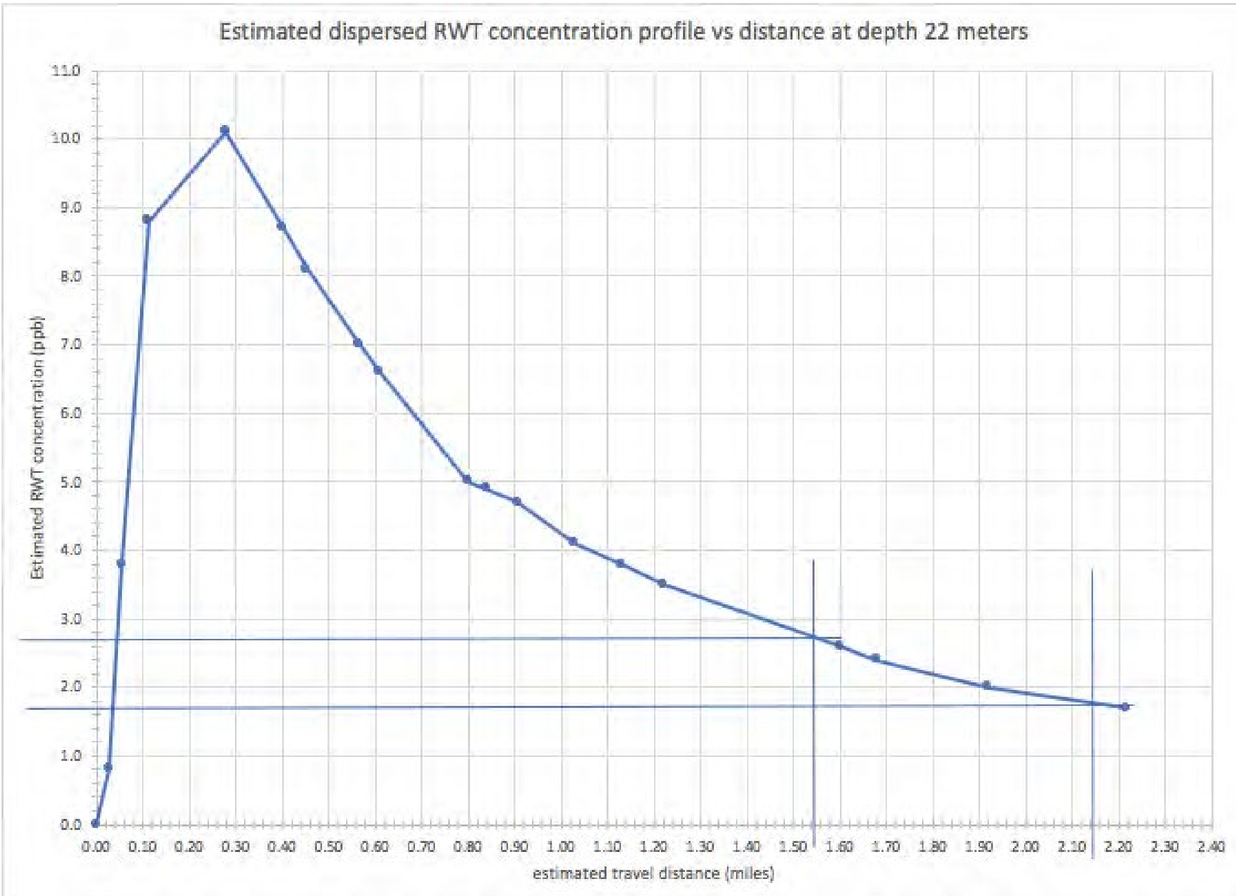


Table A4 - Estimated turbulent diffusion coefficients at different depth used in the finite-difference model for initial estimates tracer release spread over time. Note: K_x and K_y were assumed to be similar and their values correspond to the horizontal turbulent diffusivities K_h reported in the narrative, and the K_z values correspond to vertical turbulent diffusitivies, K_v.

Depth (m)	K_x (m^2/s)	K_y (m^2/s)	K_z (m^2/s)
0 m to 3 m	0.20	0.20	0.0075
3 m to 8.4 m	0.09	0.09	0.0015
8.4 m to 12 m	0.05	0.05	4 x 10^{-4}
12 m to 16 m	0.03	0.03	2 x 10^{-4}
16 m to 24 m	0.01	0.01	1 x 10^{-4}
24 m to 30 m	0.007	0.007	8 x 10^{-5}

Figure A12 - Finite Difference unsteady diffusion model result - Horizontal lines show range of estimated tracer concentration at depth 22 meters as as function of range of estimated travel distances to LACSD drinking water intakes, using turbulent diffusivities from **Table A4** and travel distances from **Figures A6 through A11,** assuming a constant 0.025 m/sec water current velocity



Appendix 5. Rhodamine WT (RWT) decay data in chlorinated Lake Arrowhead water

Executive Summary

The measured rate of RWT decay in Lake Arrowhead water was 8 minutes from 10 ppb to 0.1 ppb when treated with a representative chlorine dose of 4.0 mg/L used in the LACSD drinking water treatment plants. Decay followed first order kinetics with a half-life of 1.23 minutes. Decay to less than 0.01 ppb occurred in 11 minutes.

Objective

Determine time for a 10 ppb RWT concentration to decay to 0.1ppb, the US EPA Advisory limit for drinking water, in Lake Arrowhead water when exposed to standard Lake Arrowhead Community Services District (LACSD) standard added chlorine dose of 4 mg/L.

Materials and Methods

Lake Arrowhead raw water withdrawn from the lake on July 17, 2018 was transported to the University of Nevada Las Vegas. On July 19, a water sample spiked with 10 ppb RWT concentration, and then treated with a 4.0 mg/L dose (as added chlorine) by addition of bleach solution. RWT concentrations were monitored as a function of time with two calibrated Eureka Water probes TDX sondes equipped with Turner Designs' fluorometric detectors. One sonde was calibrated over a range of 0 to 1 ppb, and the other sonde was calibrated to a range of 0-10 ppb RWT with standard RWT solutions. The experiment was carried out at ambient laboratory temperature of 23 +/- 1 ºC.

Results

The change in RWT concentration vs time is tabulated below in **Table A5.** RWT concentrations declined rapidly, reaching the 0.1 ppb US EPA advisory drinking water limit in 8 minutes. RWT concentrations decayed to the RWT sonde's 0.01 ppb RWT detection limit in 11 minutes.

Evaluation of the decay kinetics for RWT via a plot of natural logarithm of the ratio of RWT concentration to starting RWT concentration vs time, indicate that at a starting concentration of 10 ppb, RWT decay followed first-order decay kinetics with a rate constant of $k = 0.0094\ sec^{-1}$, (or $0.564\ min^{-1}$), and an estimated half-life of 1.23 minutes (**Figure A13**).

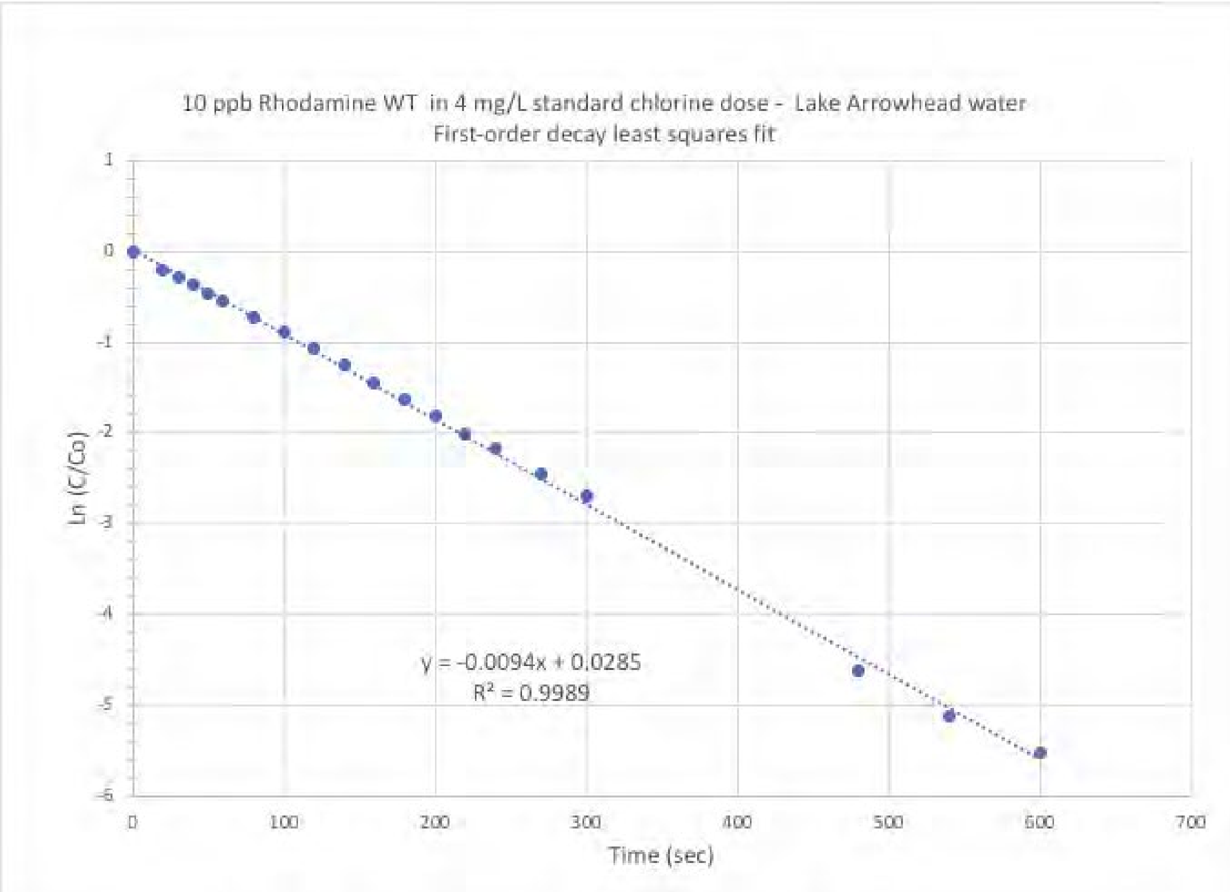
Discussion

Since LACSD reports (Brooks, personal communication, July 17, 2018) that detention times for chlorinated finished water in LACSD's 1.8 million gallon storage tanks range from 10 to 20 hours at delivery flow rates that range from 90,000 to 180,000 gallons per hour, it is concluded that, in the event that the planned closure of LACSD's intakes cannot be carried out with sufficient speed to prevent accidental trace RWT concentrations entering the treatment plant intake, a 4 mg/L chlorine dose (1.5 mg/L residual after usual chlorine demand) would rapidly destroy RWT tracer to non-detectable levels below the 0.1 ppb US EPA drinking water advisory limit.

Table A5 - Decay of 10 ppb Rhodamine WT vs time at 4 mg/L standard chlorine dose.

time (seconds)	time (minutes)	RWT concentration (ppb)	Comment
0	0	10.0	US EPA advisory limit - drinking water intakes
20	0.33	8.15	
30	0.50	7.49	
40	0.67	6.90	
50	0.83	6.24	
60	1.00	5.77	
80	1.33	4.85	Half life is 73 seconds (1.23 min)
100	1.67	4.08	
120	2.00	3.40	
140	2.33	2.84	
160	2.67	2.35	
180	3.00	1.95	
200	3.33	1.64	
220	3.67	1.35	
240	4.00	1.13	
270	4.50	0.87	
300	5.00	0.68	
480	8.00	0.10	US EPA advisory limit - drinking water
540	9.00	0.06	
600	10.00	0.04	
660	11.00	0.01	Detection limit of TDX sonde. Experiment stopped

Figure A13. First-order decay kinetics for 10 ppb Rhodamine WT in Lake Arrowhead water treated with 4 mg/L standard chlorine dose.



Sections 4 and 5

Request for Waiver of Report of Waste Discharge for a proposed sucralose tracer study

Request for Waiver of Report of Waste Discharge for a Proposed Sucralose Tracer study to Investigate Mixing and Assimilation Patterns in Lake Arrowhead

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Section 4:

a. Background - Sucralose as an Artificial Sweetener and Prior Use as a Tracer

Artificial sweeteners, known as sugar substitutes, are substances used instead of sucrose (table sugar) to sweeten foods and beverages. Among artificial sweeteners, sucralose and acesulfame potassium are the most stable sweeteners, and are widely used in beverages. As an example, there are typically between 60 and 70 milligrams of sucralose in a 335 mL (12 fluid ounce) sucralose-sweetened soda can (Sylvetsky and Dietz, 2014). Sucralose is marketed in the United States under the trade name Splenda™ (McNeil Nutritionals, LLC, Ft. Washington, PA). In 2005, Splenda™ was reported to have more than 50% of the market for artificial sweeteners (Karstadt, 2006).

Sucralose was approved as a sweetening agent by the Food and Drug Administration (FDA) for specific food types in 1998, followed by approval as a general-purpose sweetener in 1999. Sucralose has been studied extensively. The FDA reviewed more than 110 safety studies in support of its approval of the use of sucralose as a general-purpose food sweetener (US FDA, 2018).

Anthropogenic sucralose excretions are generally refractory to wastewater treatment and sucralose degrades at slow rates in lakes (Labare et al 1993, Labare and Alexander, 1994). Sucralose is primarily introduced to the environment in treated effluent discharges to receiving waters. Occurrence of sucralose in the United States' waters is widespread. It has been detected in treated municipal effluents, surface waters, groundwater and treated drinking water (tap water). Recent studies in the U.S. reported sucralose concentrations ranging from 0.8 ppb to 12 ppb and 0.05 ppb to 2.4 ppb in surface and drinking water (tap water), respectively **(Appendix 1)**. Sampling conducted by UNLV on May 10, 2018 of Lake Arrowhead's waters, and subsequent measurement, indicated that sucralose was present in the range of 0.030 ppb to 0.034 ppb, with one high measurement of 0.084 ppb **(Please see Section 2.3** of this proposal and **Appendix 3)**.

b. Use of artificial sweeteners to track wastewater and river water

Environmental occurrences of artificial sweeteners have been successfully used to track various water sources. Sucralose has been detected in some of the published literature. For example, Buerge et al (2009) used artificial sweeteners as markers to determine infiltration influence of river waters on Swiss groundwaters and consistently detected four sweeteners, typically in the order cyclamate > acesulfame > saccharin > sucralose. Spoelstra et al. (2013) used artificial sweeteners, including sucralose, as indicators to investigate effects of anthropogenic activities in different areas on water quality of Grand River, a large river in Southern Ontario, Canada. Spoelstra et al (2013) detected cyclamate, saccharin, sucralose and acesulfame, with the highest detected concentration for sucralose. Because acesulfame persists for long distances and behaves conservatively, they concluded that it was a reliable wastewater tracer in rivers.

Tran et al. (2014) followed the track of artificial sweeteners, including sucralose, in Singapore's surface waters. They found higher concentrations near residential and commercial areas and concluded that the sweeteners "acesulfame, cyclamate and saccharin can be used as potential indicators of raw wastewater contamination in surface water and groundwater."

Hillebrand et al. (2015) injected five compounds, including cyclamate, into a karst aquifer monitoring them for breakthrough at a distance of 3 kilometers. They found that cyclamate was not retarded in the aquifer and had the longest half-life of 1,400 hours. Bichler et al 2016, briefly summarized prior successful work using ambient concentrations of the artificial sweetener acesulfame potassium (also known as ace-K) as a tracer of river water infiltration into shallow aquifers. Bichler et al found that ambient concentrations of ace-K could successfully be used to estimate infiltration of river water into the aquifers.

c. Summary of Aquatic toxicity data

Sucralose's aquatic toxicity is very low. In a survey of published literature, Tollefsen et al (2012) found that the lowest numerical value for a No Observable Effect Concentration (NOEC) was 93 mg/L (93,000 ppb) for a 28-day exposure by mysid shrimp, as reported by Haggert and Stoddard (2011). Details of experimental and predicted toxicities of sucralose are summarized in **Appendix 2** of this document.

d. Purpose of this discharge report waiver request

This waiver request proposes to use a small mass (3.91 kilograms) of added sucralose, which when fully mixed with lake water would generate at sucralose concentrations elevated by a about a factor of two above Lake Arrowhead's current sucralose levels (**Appendix 1**) but similar to background values already found in many north american surface waters, to estimate water travel time and that magnitudes of horizontal and vertical dispersion coefficients in Lake Arrowhead, California.

Section 5: Tracer Release, Monitoring and Notification Plan - Sucralose

1. **Tracer release site location and size**
   The white circle in **Figures 1-A** and **1-B** shows the proposed tracer release site in Village Bay. The yellow pins show the locations of Lake Arrowhead's drinking water intakes. **Table 1** shows the coordinates of the proposed tracer release site and the two drinking water intakes using the World Geodetic System, 1984 datum (WGS 84). By nearest line of sight, the proposed tracer release location is 2,950 feet from the North Bay (Bernina) intakes and 4,235 feet from the Emerald Bay (Cedar Glen) intakes.

   The proposed Village Bay tracer release site will be a circular area with a diameter of 230 ft = 41,548 sq. ft (ca. 0.95 acre) located in the top portion of the lake's seasonal thermocline at a depth ranging from 33 to 50 feet. As is the case for for RWT, this depth range is proposed to both provide sufficient dilution before the released sucralose tracer reaches the water surface, and also to reduce the rate at which the tracer could spread vertically downwards into denser water at the depth level of the Lake Arrowhead Community Services District (LACSD) drinking water intakes, located in at a depth of approximately 68 feet at the current summer 2018 lake level (**Table 1**).

Table 1. GPS coordinates* of tracer release site and distances to the two LACSD drinking water intakes. *World Geodetic Survey, 1984 and California State Plane coordinates

Location	Site Name	North Latitude	West Longitude	Distance to proposed tracer release site (feet)	Site elevation (1929 NGVD) (feet)**	Water depth at summer 2018 lake level (feet)***
Proposed tracer release location	Village Bay East of Village Point	34° 15' 13"	117° 11' 10"	N/A	5,022	85.7
Bernina Intake	North Bay	34° 15' 37"	117° 11' 34"	2,950	5,040	67.7
Cedar Glen Intake	Emerald Bay	34° 15' 35"	117° 11' 34"	4,235	5,040	67.7

**Using the 1929 National Geodetic Vertical Datum (NGVD), which is 8.0 feet higher than the ALA datum[8], the full lake level is 5,114.7 feet. Mean bottom elevation at chosen site is 5,022 feet. As of June 27, 2018, summer 2018 lake level is 7 feet below full = 5,107.7 feet.

***tracer release site water depth = summer 2018 lake level – mean bottom elevation = 5,107.7-5022 = 85.7 feet

***Intake water depth = summer 2018 lake level – site elevation = 5,107.7 feet – 5,040 feet = 67.7 feet

If approved, sucralose would be injected simultaneously with the Rhodamine WT (RWT) tracer using a weighted 2-meter long diffuser attached to a pumping system that mixes 1,300 gallons of pumped lake water with 80 gallons of sucralose-RWT solution with 8.62 pounds of each tracer contained in a 100-gallon high density polyethylene mixing tank. The combined 1,380 gallons of sucralose-RWT solution would be injected over a 20-minute time period.

The 8.62 pound sucralose mass would be mixed as a powder into 80 gallons of water (into which had already been mixed the 8.62 pounds of RWT tracer) in the 100-gallon mixing tank on board the injection barge. The 80 gallons of sucralose-RWT solution would then be blended with 1,300 gallons of lake water withdrawn from the lake's surface and then discharged through the diffuser within a 230-foot diameter circle (41,548 sq.ft. area, 0.95 acres) at the designated

[8] USBR, 2009. *Lake Arrowhead 2008 Reservoir Survey. Technical Report No. SRH-2009-9.* URL: https://doi.org/https://www.usbr.gov/tsc/techreferences/reservoir/Lake Arrowhead 2009 Report.pdf

tracer release site. Based on depth from the water surface to the depth of dye release above the thermocline (33 to 50 feet), the tracer release rate of the dye through the diffuser within the 41,548 sq.ft. zone, and estimated wind-driven diffusivities in the lake's upper layers, the well-mixed dye concentration within the tracer release zone will be in the range 70 to 100 ppb (Table 2), several orders of magnitude below both the observed 93,000 ppb sucralose Lowest Observed Effect Concentration (LOEC) and No Observed Effect Concentration (NOEC) from aquatic toxicity tests, and also far below the U.S. EPA's Ecological Structure Activity Relationship Model, ECOSAR[9] (USEPA, 2010) that recommended a sucralose toxicity level of 1,123 mg/L (1,123,000 ppb).

2. **Estimated sucralose concentrations compared to available aquatic toxicity data**

There are two potable water intakes **(Figure 1)** in Lake Arrowhead:

1. The Bernina intake is located at North Bay, at a distance of 2,950 feet northwest from the proposed tracer release site.
2. The Cedar Glen intake is located at Emerald Bay approximately 4,235 feet northeast from the proposed tracer release site.

Both intakes are at elevations that position them in either the hypolimnion or the lower part of the seasonal metalimnion (depending on time of year) at an expected summer 2018 depth of 68 feet, at current lake levels. The current 68-foot summer 2018 intake water depth is approximately 18-35 feet below the proposed 33-50 foot depth range for tracer release. The intakes are also in colder denser water than at the level of tracer release. The denser more quiescent deep water should limit downward spreading of the sucralose tracer.

With prevailing summer southerly to southwesterly winds expected to occur during the tracer release, if authorized during late summer, neither drinking water intake is expected to be directly downwind of the proposed tracer release site. In the absence of a perennial stream inflow to the reservoir (Little Bear Creek and Grass Valley tunnel inflows are seasonal in winter time), water circulation is expected to be driven by predominant south to southwesterly winds, with estimated shoreline-following or depth contour-following wind-driven circulation travel distances of 1.5 to 1.6 miles for the Bernina intakes in North Bay, and 1.9 to 2.2 miles for the Cedar Glen intakes in Emerald Bay **(RWT waiver request - Appendix 4).** These estimated circulation distances are much longer than the direct line distances listed in **Table 1.**

At these estimated circulation distances, for a worst-case wind-driven all-day average current velocity[10] of 0.025 meter/second at plume depth, (Bender 2012), travel times are estimated to be on the order of 1.15 to 1.2 days for Bernina and 1.4 to 1.6 days for Cedar Glen **(RWT waiver request - Appendix 4)**.

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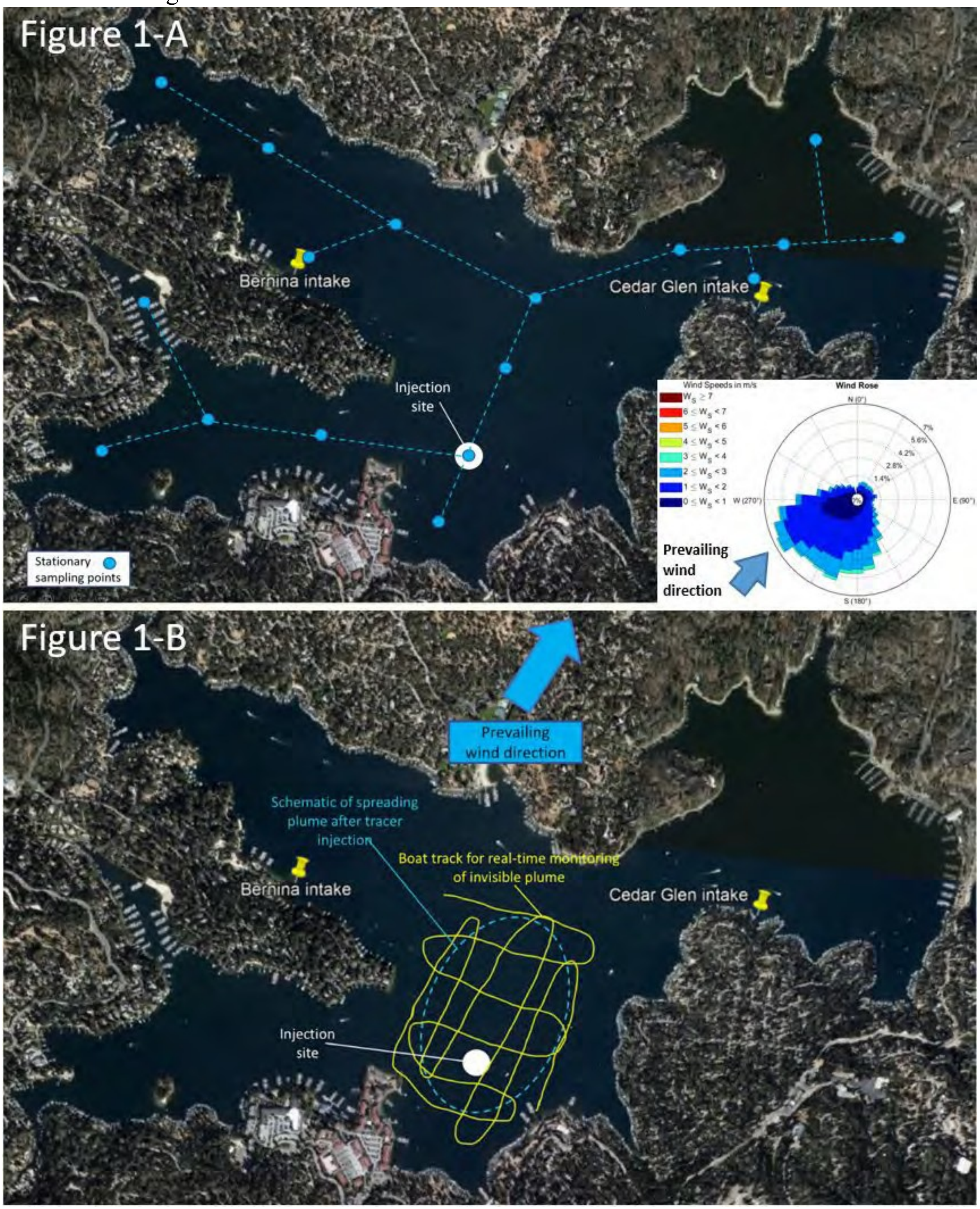
[9] The Ecological Structure Activity Relationships (ECOSAR) Class Program is a computerized predictive system that estimates aquatic toxicity. The program estimates a chemical's acute (short-term) toxicity and chronic (long-term or delayed) toxicity to aquatic organisms, such as fish, aquatic invertebrates, and aquatic plants, by using computerized Structure Activity Relationships (SARs).

[10] Note, summertime Lake Arrowhead winds vary diurnally in speed, with low wind speeds at night and in the early morning hours, and with winds building from the southwest throughout the day. A worst-case 0.025 meter/second (1.34 mile/day) current velocity is assumed to persist throughout the day and evening hours. Instead, it is more likely that this velocity magnitude would exist for a few hours in the afternoon when surface winds are strongest.

Figure 1.

a. Proposed tracer release site, locations of drinking water intakes, and fixed monitoring station locations (blue points).
b. Proposed tracer release site, and boat track (yellow pins) for real-time tracer monitoring.



At these estimated travel times, preliminary finite-difference numerical modeling, with vertical diffusion coefficients in the range of k = 0.0015-0.0075 m^2/s and horizontal diffusion coefficients in the range of k = 0.09-0.20 m^2/s for the top 8.4 meters (28 feet) of the water column (the approximate peak depth of the warm well-mixed epilimnion in summer), and k_v= $8x10^{-5}$ to $4.0x10^{-4}$ m^2/s, and k = 0.007-0.050 m^2/s for depths of 8.4 meters (28 feet) to the bottom of the lake, simulating spread of the tracer in Lake Arrowhead, assuming distances for tracer release that take into account prevailing summer southerly to southwesterly winds ,with advection and spreading that follows the lake shoreline or bathymetry back towards the drinking water intakes at a conservatively estimated (worst-case) maximum constant wind-driven current velocity of 0.025 meter/second, based on values modeled by Bender, (2012), and also assuming zero degradation[11], indicate that estimated worst-case mixed sucralose concentrations would reduce from the initial 70-100 ppb tracer concentrations to 2.4 to 2.7 ppb for Bernina and to 1.7 to 2.1 ppb for Cedar Glen before the tracer would reach either intake. Details of the assumptions and data used to generate these estimates can be found in the **RWT waiver request - Appendix 4**.

Sucralose degrades slowly in the environment. Papers by Labare et al (1993) and Labare and Alexander (1994) indicate that sucralose is slowly degraded by microbial co-metabolism. Labare et al (1993), studied degradation in five lakes with low organic concentrations, and found that initial sucralose concentrations of 100 ppb were 1.6% to 3.6% degraded in over a 65-day period. Labare and Alexander (1994) found that a 1,000,000 ppb solution degraded 2.5% in lake water in 93 days.

Assuming no or very slow degradation, the 3.91 kg (8.62 pound) added sucralose mass, if mixed completely into the entire 46,855 acre-foot lake volume, would result in an added concentration of 0.067 ppb. This concentration is on the order of background concentrations detected in US surface waters **(Appendix 1),** and is six orders of magnitude below the 93,000 ppb 28-day No Effect Concentration for mysid shrimp reported in Tollefsen et al (2012) **(Appendix 2)**.

3. **Sucralose background concentrations in Lake Arrowhead**

As Lake Arrowhead is used for recreational purposes, direct inputs of sucralose into the lake water by visitors are likely to occur. Direct mass inputs are likely due to human excretions and spills of sucralose-sweetened drinks into the lake water.

Background sucralose concentrations in Lake Arrowhead were evaluated by measuring sucralose concentration of water samples obtained from five different locations in Lake Arrowhead on May 10, 2018 at a depth of 50 ft (15.24 m). Sucralose concentrations were measured by ALS Environmental Laboratories, Kelso Washington, using Solid Phase Extraction (SPE) followed by Liquid Chromatography-Mass Spectrometry (LC-MS) with both Method Detection Limit (MDL) and Method Reporting Limit (MRL) of 0.005 ppb (**Appendix 3**).

[11] Note, sucralose degradation rates are known to be very slow, please see citations of work by Labare et al (1993) and Labare and Alexander (1994) in the next paragraph.

Background sucralose concentrations in Lake Arrowhead were found to be in the range of 0.030 to 0.034 ppb at four of the five sampled sites. The highest observed sucralose concentration was 0.084 ppb near the Dam. In order to be able to detect and track an added sucralose tracer, the tracer concentration must be sufficiently greater than the varying range of lake background concentration to be outside the uncertainty of an individual measurement. Considering that the volume of Lake Arrowhead, when full, is 57,795,000 cubic meters (46,855 acre-feet) (USBR, 2009), the proposed injected 3.91 kg (8.62 pounds) of sucralose mass would, if no degradation were to occur, result in final a concentration of 0.067 ppb when fully mixed within the lake. This mixed value provides a 2.0x elevation over the 0.030-0.034 ppb background concentrations observed at four of the five May 10, 2018 sampling sites.

4. Sampling locations and methods of measurement

As it is proposed that sucralose would be released simultaneously with the RWT tracer, determination of location and depth for sucralose sampling will be determined by real-time fluorometric monitoring performed with Eureka TDX fluorometric sondes with the RWT dye-specific sensors (please see **Section 2.4 of the RWT waiver request** for RWT measurement details).

Two boats, as well as the tracer-dispensing barge, will monitor tracer concentrations after addition to the lake. On-board fluorometric RWT concentration monitoring will be performed using Eureka TDX fluorometric sondes with RWT-specific sensors. Each boat and the barge will also be equipped with a Van Dorn bottle to collect water samples at designated depths, and labeled sample bottles in cooler chests to contain and preserve collected sucralose water samples.

Two sampling boats will monitor RWT concentration profiles on an hourly schedule at a fixed grid of 16 sampling points that follow the thalweg of the reservoir **(Figure 1-A).** They will also sample RWT at the LACSD drinking water intakes **(Figure 1)** on an hourly basis. The barge will track the plume by moving on a North-South East-West curving path (Figure 1-B) from one edge of the plume to the other edge to track RWT fluorescence in real time. Sampling locations will be adjusted over time as the tracer mass expands and dilutes in concentration. Van Dorn bottles will be dropped into the RWT tracer mass, initially at hourly intervals at depths determined by on RWT-sonde profiling data. Based on prevailing summer south to southwesterly winds (**Figure 1-A)** the tracer plume is expected to gradually move to the north-east. Sampling will be timed to track the plume as it moves through the lake over a period of 14-28 days.

Depending on wind intensity and rate of advection, RWT sampling will be continuous for the first 24-48 hours after tracer release as the dye mass spreads. Sucralose sampling will be on a sparser schedule; samples will be taken at hourly to every four-hour intervals over the first day.

Afterwards, sampling will occur every 4 to 6 hours at the Dam and at each major bay in the lake (Blue Jay Bay, North Bay, Tavern Bay, Village Bay, Emerald Bay) for the next 2 to 3 days, and after that daily until concentration profile changes are no longer detected. Complete mixing is expected to occur over a period of 14-28 days.

On a predetermined sampling schedule, when elevated RWT concentrations are detected by the profiling sondes, water samples will be collected at corresponding depths using Van Dorn bottles that use messenger weights that close the bottles at the designated depth. The Van Dorn bottles will be pulled back up to the surface, and water samples dispensed into labeled pre-washed amber glass sample containers kept in cooler chests.

Sucralose sampling will primarily occur on a fixed schedule at the predetermined sampling locations shown in **Figure 1-A.** Sampling would start at the nearest stations within one hour after tracer release. As with RWT fluorescence measurements, sampling locations and distances will be adjusted over time as the tracer plume gradually moves and expands under the influence of wind-driven lake circulation. Some samples might be collected on a plume-chasing track **(Figure 1-B, yellow line)** if early RWT-monitoring indicates that plume advection is occurring in a particular direction. The second sampling boat tasked to monitor RWT concentrations at the LACSD drinking water intakes will also be equipped with a Van Dorn bottle and sample containers, and will sample for sucralose if RWT concentrations approaching 10 ppb are detected.

5. **Sucralose measurement**

Collected water samples would then be transported to UNLV's environmental engineering laboratories. Sucralose will be concentrated from the water sample using a Solid Phase Extraction (SPE), and then detected and quantified by High Pressure Liquid Chromatography-Tandem Mass Spectrometry (HPLC-MS) with a Method Detection Limit (MDL) of 0.005 ppb and a Method Reporting Limit (MRL) of 0.005 ppb. The HPLC-MS instrument will be calibrated with standards of known sucralose concentration over the anticipated 0.01 ppb to 100 ppb concentration range.

Contour maps of the evolution of sucralose concentrations at several depths will be generated from laboratory measurements and compared to similar contour maps of RWT concentrations. Since sucralose is known to degrade at very slow rates in fresh surface waters (on the order of 1.6% to 3.6% in 65 days, Labare et al 1993, or 2.5% in 93 days,Labare and Alexander, 1994), it can be treated as a conservative tracer over the 14 to 28 day sampling period. At each sampling location, date and time, sucralose concentrations can be compared to RWT tracer concentrations to quantify RWT degradation.

6. **Measurement of Ambient Environmental Conditions**

1) Similar to the text in **Section 2.3 Injection, Monitoring and Notification Plan** of the RWT proposal, a Eureka Manta+30 7-parameter multiprobe will be used to measure and record profiles versus depth of conductivity, temperature, pH, photosynthetically active radiation, chlorophyll-a and dissolved oxygen at six predetermined sampling locations, one at the proposed tracer release location in Village Bay, and one in each of the other major bays of the lake (Blue Jay Bay, North Bay, Tavern Bay, Emerald Bay), as well as near the dam. Manta+30 profiles will traverse the entire water column from surface to bottom. The Manta+30 probe will be calibrated against laboratory standards before each deployment. Manta+30 profiles will be taken:

1. On the day before the tracer release;
2. On the day of tracer release, before the start of release, and every 3 hours during the first day of measurement; and
3. Once daily on subsequent days, until tracer concentrations measured with the RWT TDX probes drop below 1 ppb, assumed to be 10 days.

2) During the Manta+30 measurements, wind speed and direction will be recorded approximately five feet above the water surface by a hand-held monitor and compass.

3) Five-minute interval wind speed, direction, air temperature and total radiation will be obtained from two lakeshore meteorological stations operated by UNLV. One station is located on Lollipop Point near Village Bay on the south shore of the lake, and the other is located at Tavern Bay on the north shore of the lake.

7. Contingency Spill Plan

1) **Spill prevention**. To capture any spillage of tracer solution, the 100-gallon tracer mixing tank will be tied down inside a 16-inch high 200-gallon spill-containment pan. The 200-gallon containment pan will have sufficient capacity to capture the entire volume of tracer should a leak occur in the 100-gallon mixing tank. The mixing tank pump line with a valved shutoff will be routed over the top of the containment pan using a vertical U-bend to prevent accidental gravity drainage from the tank. In the event of a pump failure, a check valve in the main discharge line will automatically prevent the blended lake water plus tracer from flowing backwards into the lake through the surface intake.

2) **Spill pick up.** A shop vac will be used to pick up any spill of dry sucralose powder; the waste powder will be double bagged and put in municipal solid waste trash. Absorbent material and two 55-gallon drums, sufficient to capture the entire 80 gallons of tracer solution, will be on board the injection barge in case tracer solution escapes the spill-containment pan. The absorbent will be pre-positioned at the ALA docks prior to transfer of the tracer from shoreside to the barge. Since sucralose is water soluble, water-absorbent materials will be used.

3) **Spill reporting**. Any spillage escaping the containment tank, other than small drops that can be wiped/washed clean, will be reported to the Lahontan Regional Water Quality Control Board (LRWQCB) within 15 minutes of occurrence, and actions to clean up spills will be documented and reported to LRWQCB within 24 hours of occurrence.

4) **Unexpected movement monitoring and reporting**.

There are two potable water intakes **(Figure 1)** in Lake Arrowhead:

1. The Bernina intake **(Figure 1)** is located at North Bay, at a distance of 2,950 feet northwest from the proposed injection site.
2. The Cedar Glen intake **(Figure 1)** is located at Emerald Bay approximately 4,235 feet northeast from the proposed injection site.

Both intakes are at elevations that position them in either the hypolimnion or the lower part of the seasonal metalimnion (depending on time of year) at an expected summer 2018 depth of 68 feet, at current lake levels. The current 68-foot summer 2018 intake depth is approximately 18-35 feet below the proposed 33-50 foot depth range for tracer release. The intakes are also in colder denser water than at the level of tracer release, which should limit downward spreading of the tracer plume. With prevailing summer southerly to south-southwesterly winds expected to occur, neither intake is directly downwind of the proposed injection site. Dilution resulting from lateral and vertical spreading of the added tracer, at the worst-case (low) assumed travel time generated using a constant 3-3.5 meter/second wind velocity, is expected to reduce the 70-100 ppb average starting sucralose concentration to 1.7 to 2.7 ppb before the tracer were to reach either intake. Assumptions, data sources and calculational methods used to generate preliminary tracer concentration estimates in the vicinity of the intakes are described in **Appendix 4** of the RWT waiver request.

To verify tracer concentrations at the intakes, since sucralose tracer cannot be measured in real time, a TDX sonde-equipped monitoring boat will measure RWT fluorescence hourly by vertical profiling at the location of each drinking water intake over the first two days of the study. As sucralose and RWT tracers will be injected simultaneously, concentrations of the two tracer plumes are expected to be similar. Hence, sucralose concentration at each point can be estimated based on the real-time RWT fluorometric measurement. Measured concentrations at different locations will be compared to movement of the main body of the combined RWT and sucralose tracer by radio or cell phone communications between the monitoring boats. If a RWT tracer concentration near the EPA 10 ppb advisory limit appears to be approaching either water intake, sucralose samples will be taken and the the water purveyor, the Lake Arrowhead Community Services District, will be notified within 5 minutes and the LRWQCB will be notified within 15 minutes. Results indicating direction of movement and concentration of RWT will be provided to both LACSD and LRWQCB within one hour.

Please see also below: **8. Tracer Preparation, Transport and Mixing,** for additional steps to be taken to minimize magnitude of potential spills .Please see also below **10. Notification and Action Plan,** for steps to be taken should a tracer concentration near 10 ppb approach either LACSD drinking water intake.

8. Sucralose Tracer Preparation, Transport and Mixing to minimize magnitude of potential spills

Sucralose powder will be transported to the vicinity of Lake Arrowhead in two 5-pound bags, each packaged in a 1-gallon Zip-Loc™ bag to provide secondary containment protection against product bag breakage or accidental spills.

The needed 8.62 pound (3.91 kilogram) mass of sucralose powder needed for the intended tracer addition will be pre-weighed to the nearest gram on a top-loading analytical balance at the ALA offices and placed into a double bagged set of labelled 1-gallon Zip-Loc™ bags and stored at a location away from the Lake Arrowhead waterfront in a room at the Arrowhead Lake Association (ALA) administrative offices. Powder spills on-shore can be vacuumed up, placed in plastic double bags and disposed in the solid waste trash bin.

Only the mass of sucralose needed for the proposed tracer release (8.62 pounds, or 3.91 kilograms), will be transported in the double-bags from the ALA offices to the docks and loaded on the tracer injection barge. A portable vacuum cleaner will be pre-positioned at dockside near the barge before transport from the docks to the barge to pick up any sucralose powder spills. The powdered sucralose will be kept in the bags until the barge is anchored at the proposed release site. This approach minimizes the potential for a spill to the amount that would be injected in the site as planned.

The 8.62 pound sucralose mass will be mixed with water in the 100-gallon on-board mixing tank while the injection barge is anchored at the intended site of tracer release. In addition to on-board adsorbents, the 100-gallon tank will be surrounded by the 200-gallon containment pan to capture any tank leaks. The barge's gasoline powered pump will be able to withdraw lake water and have a T-fitting connecting to a spray nozzle and hose with sufficient length to cover the entire barge mixing area to wash off any spilled sucralose solution if the on-board adsorbents aren't able to capture all of a spill. This method ensures that only the maximum intended amount of sucralose could be spilled in the same area where it is planned to be released.

9. Sucralose tracer quantity, injection surface area and measurement procedures

a. Surface area and volume of water needed for discharge

1) The white circle in **Figures 1-A** and **1-B** shows the proposed tracer release site location and injection site surface area within Village Bay, comprising a circular diameter of 230 feet and a surface area of 0.95 acres **(Table 2).** At a minimum well-mixed depth of 33 feet and a maximum target initial mixed concentration of 100 ppb, this corresponds to a water volume of 31.2 acre-feet. These dimensions were chosen to obtain an acceptable initial RWT tracer concentrations. Since the sucralose, if approved, would be co-injected in the same mass quantity as the RWT dye tracer, the site dimensions and initial maximum sucralose tracer concentrations are the same as in the RWT portion of this proposal (See **Sections 3.1 and 3.2** of the RWT proposal).

2) **Table 2** shows the proposed tracer release location and, surface area, injection water depth, injection site water volume (acre-feet) and mass of sucralose to be released at the proposed site. **Note:** Some modifications to the proposed tracer release depth could be needed as result of potential variation in the depth to the top of the thermocline as a result of changes in weather or seasonal cooling, depending on the actual tracer release date. LWRQCB and LACSD will be notified of any proposed change in the injection depth.

b. Proposed quantity of added sucralose tracer.

The projected maximum amount of sucralose tracer, 8.62 pounds, or 3.91 kilograms, is sufficient to generate a detectable 0.067 ppb increase in lake sucralose concentration above the typical 0.030-0.034 ppb sucralose background if the added sucralose were to completely mix into the entire lake volume. This mass of sucralose would be mixed as a dry powder into a volume of 80 gallons of lake water contained in the 100-gallon mixing tank. The 80 gallons of mixed tracer solution will then be discharged from the mixing tank at a flow rate of 4.0 gallons/minute (gpm) and simultaneously blended with a 65 gpm stream of pumped clean lake water, for a total flow rate of 69 gallons/minute, and then injected into the lake at 33-50 meters depth via a 2-meter long diffuser. Mixing of the sucralose tracer over the intended 0.95 acre area in the water column will result in a dilution to a starting concentration of 70-100 ppb.

Note: The three-step formula sequence for calculating the volume of water needed to achieve a well-mixed target sucralose concentration in *u*g/L (ppb) is:

1. Volume of water in liters = $\dfrac{\text{[(sucralose mass, lbm) x 0.453kg/lbm x 1x10}^9\text{ ug/kg]}}{\text{(target concentration in ug/Liter)}}$

then

2. Volume of water in acre-feet = $\dfrac{\text{Volume of water in Liters}}{\text{(28.3 liters/ft}^3\text{) x (43,560 ft}^3\text{/acre foot)}}$

then

3. Area required = volume of water in acre-feet / maximum vertical mixed depth

Needed water surface areas are summarized in Table 2. Step by step calculations are shown below:

For an initial sucralose concentration of 70 ppb in a maximum depth of 50 feet, the calculations are:

Volume of water in liters = $\dfrac{\text{[(8.62 lbm) x 0.453kg/lbm x 1x10}^9\text{ ug/kg]}}{\text{(70 ug/L)}}$

= 5.58 x10^7 liters

then

Volume of water in acre-feet = $\dfrac{5.58\text{x}10^7\text{ liters}}{\text{(28.3 liters/ft}^3\text{) x (43,560 ft}^3\text{/acre foot)}}$

= 45.2 acre-feet

Water area required = 45.2 acre-feet / 50 feet = 0.90 acres

0.90 acres x 43,560 ft^2/acre = 39,423 ft^2 or a circular diameter of 224 feet.

For an initial sucralose concentration of 100 ppb at the minimum depth of 33 feet, the calculations are:

Volume of water in liters = $\dfrac{\text{[(8.62 lbm) x 0.453kg/lbm x 1x10}^9\text{ ug/kg]}}{\text{(100 ug/L)}}$

= 3.91 x10^7 liters

then

$$\textit{Volume of water in acre-feet} = \frac{3.91 \times 10^{7} \text{ liters}}{(28.3 \text{ liters/ft}^3) \times (43{,}560 \text{ ft}^3\text{/acre foot})}$$

= 31.2 acre-feet

Water area required = 31.2 acre-feet / 33 feet = 0.95 acres
0.95 acres x 43,560 ft^2/acre = 41,548 ft^2 or a circular diameter of 230 feet.

Results of the calculations are summarized in **Table 2**. As for the Rhodamine WT tracer, the more conservative (larger) diameter of 230 feet was chosen as the needed dimension for initial injection.

Table 2. Summary of calculations to estimate needed initial receiving water volume and surface area to be within the 100 ppb EPA-recommended RWT limit for surface waters. RWT limits are also applied to sucralose.

Tracer release condition (assumes tracer mixes completely from surface to water designated release depth	Concentration (ppb)	Depth (feet)	Volume of water (liters) for 3.91 kg (8.62 pounds)	Volume of water in acre-feet	Water surface area needed = Area (acre-feet) / Depth (feet)	Water surface area (square feet)	Circular diameter (feet)
Maximum concentration at minimum mixed depth of tracer release	100	33	3.91×10^{7}	31.2	0.95	41,812	230
Minimum concentration at maximum mixed depth of tracer release	70	50	5.58×10^{7}	45.2	0.90	39,423	224

c. Depth of tracer release

The tracer release depth at the proposed site in Village Bay will be on the top layer of the thermocline, which, if the study is conducted in the summer, will likely be in the 33-50 foot depth range. The exact depth range will be determined by conductivity-temperature-depth profiles measured by the Manta+30 multiprobe at the injection site on both the day before and the day of the tracer release. The goal is to release the tracer in the top half of the thermocline to limit downward spread to the level of the drinking water intakes. LRWQCB and LACSD will be notified of any changes in the proposed release depth range.

d. Aquatic vegetation

The depth of the water at the proposed Village Bay release site, approximately 85 feet on June 27, at lake water levels current for that date, 7 feet below the spillway, is below the 1% limit for the photic zone (at approximately 60 feet as measured in June profiling) for freshwater aquatic plants. We expect that submersed vegetation is neither expected to be found nor affected by the proposed sucralose tracer release.

e. Tracer mixing tank and spill containment

The on-board 100-gallon mixing tank containing 80 gallons of mixed RWT+sucralose solution is translucent to enable monitoring of the mixed tracer concentrate liquid level. The tank will be placed in a 200-gallon containment pan to capture any spills or leaks. An in-line flow meter will be placed in the discharge line from the 100-gallon mixing tank to monitor its evacuation flow rate of 4.0 gallons/minute (gpm). The 4.0 gpm flow rate from the mixing tank will be blended into a 65 gpm flow rate of lake surface water that is supplied by a gasoline-engine powered pump. The discharge side of the gasoline pump will inject the diluted RWT-sucralose solution at a rate of 69 gpm through a diffuser at the 33-50 foot depth range. Pump pressures and flow rates in both the mixing tank and lake water lines will be continuously monitored to ensure the correct mixing ratio and constant output rate of the blended flow through the diffuser.

f. Pump flow rate settings

The objective is to distribute the diluted tracer solution evenly throughout the midwater zone at the proposed tracer release site. Total flow rate will be adjusted so that the mixing tank solution blended with lake water can be injected into the lake over a 20-minute period at a total rate of 69 gpm. Flow rates will be controlled by valves on the discharge side of each pump. Valve settings for both the mixing tank line and the lake water line will be determined beforehand using plain water and verified with flow meters installed in each line to indicate flow rates of 4.0 gpm for the mixing tank pump and a combined 69 gpm for the blended flow from the main lake water pump. Output will be measured at least three times during the plain water verification phase to determine the correct settings. Static back pressure is expected to be negligible. Depending on the length of the discharge line and fitting losses, the pressure drop in the blended lake water discharge line is expected to be no more than 10 pounds per square inch (psi). Discharge pressure will be monitored with a pressure gauge.

10. Implementation Schedule

Table 3 shows the proposed implementation schedule, notification plans and reporting dates for late summer 2018. If permission is obtained after LRWQCB's review, a discharge date will be determined immediately after notification by LRWQCB, tracer release date will be selected that corresponds to minimum activity on the lake, probably a weekday early in the week. Any subsequent change in selected discharge date or notification plans will be communicated to both LACSD and LRWQCB within 24 hours of a decision to change and at least 24-hours prior to implementation. If the study can be conducted during late summer or early fall 2018, the interim report will be provided on March 31, 2019 and the final report will be provided on April 30, 2019.

11. Notification and Action plan

a. Village Bay tracer release site

Notification timing is summarized in **Table 3. Implementation Schedule**. If permission is obtained after LRWQCB's review, a discharge date will be determined immediately after notification by LRWCQB. If the study is approved, LRWQCB will be notified At least 7 days before the proposed tracer release is to take place, Lake Arrowhead property owners and community members will be notified by email and by posters located at LACSD and ALA offices. Public notices will be posted in the two Lake Arrowhead area newspapers, the Alpenhorn and the Mountain News. The location of the site will be provided in a map in the email and on the posters at the LACSD and ALA offices.

Any subsequent change in selected discharge date or notification plans will be communicated to both LACSD and LRWQCB within 24 hours of a decision to change and at least 24 hours prior to implementation. If the study can be conducted during late summer, the interim report will be provided on March 31, 2019 and the final report will be provided on April 30, 2019.

A buoy will be installed at the center of the injection site two (2) days before the proposed injection. Four buoys delineating the boundaries of the injection area will be positioned the afternoon before the day of injection. The buoys will remain in place for the day of the injection. If summertime south-southwesterly winds prevail (Figure 1-A) and influence lake water movement at the tracer release depth at maximum rates modeled by the US Bureau of Reclamation (Bender, 2012, estimated to be on average, about 0.025 meters/second, or 1.34 miles per day, advection of the tracer plume to the northeast is expected to move the mass of released tracer away from the tracer release site within one day.

b. Lake Arrowhead Community Services District (water purveyor)

One potable water purveyor, the Lake Arrowhead Community Services District (LACSD) draws potable water directly from Lake Arrowhead using intakes located in North Bay, at approximately 2,950 feet from the proposed injection location, and in Emerald Bay at approximately 4,235 feet from the proposed tracer release location (**Figure 1-B, Table 1)**.

For prevailing summertime southerly to southwesterly winds, neither intake is directly downwind of the proposed release location. LACSD will be notified by email and telephone call 3 days before dye application. LACSD has the option to use alternative sources of supply, including both groundwater wells, and the State Water Project, if diversion is needed. The conditions for notification of LACSD were described in **Section 7.4 Contingency Spill Plan** - Unexpected movement monitoring and reporting, above.

c. Lake Arrowhead Community Services District (water purveyor) proposed action plan

The action plan is based on real-time monitoring of RWT. Concentrations of sucralose should be similar to RWT. Sucralose' toxicity is very low **(Appendix 2)**, and no adverse environmental or human effects are expected from sucralose concentrations resulting from addition of 3.91 kg (8.62 pounds) to the lake. Added sucralose will decay slowly in sunlight, being completely removed in 3 to 5 months. Upon notification of the potential approach to either intake of a RWT tracer concentration near 10 ppb, LACSD would take the following actions:

1. The potentially affected intake would be shut down.
2. Alternative water supplies would be obtained from the Crestline Lake Arrowhead Water Agency (CLAWA);
3. Samples would be taken from the raw water line inside the plant at the potential affected intake at the location where operators perform daily process control testing. RWT fluorescence would be measured with a RWT fluorometric probe to determine if any tracer reached the intake;
4. Lake water at the intake will be monitored if the closed intake does become impacted by a RWT concentration exceeding the 10 ppb US EPA advisory limit. The intake would remain shut down until the RWT concentration drops below the 10 ppb advisory level.
5. In the unlikely event that any RWT were to be drawn into the intakes, it would be rapidly consumed by the 4 mg/L standard applied chlorine dose in the treatment plant's finished water storage tanks before entering the distribution system. Please see, in the RWT tracer request, **8.d. Destruction of Rhodamine WT by chlorine dose - experimental results,** and **Appendix 5.**
6. Upon notification that the above-intake RWT concentrations had dropped below 10 ppb, once the intake is re-opened, RWT sampling would continue with measurement by the

fluorometric sonde in raw water and in the finished water to make sure that RWT concentrations are below EPA advisory levels for both drinking water intakes (10 ppb) and in finished drinking water (0.1 ppb).

Table 3. Proposed Late Summer 2018 implementation schedule

Action	Notification to LRWQCB	Emails and public notices at LACSD and ALA offices Media notices Signage placement	LACSD	Center Buoy placement	Boundary Buoy placement	Monitoring for sucralose	Interim Report	Final Report
	7 days prior	7 days prior	3 days prior	2 days prior	1 day prior	Day of tracer release until RWT concentration s drop to background levels assumed to be 14 days.[a]	3/31/19	4/30/19

[a]RWT can be rapidly measured by TDX probe *in situ* to determine status of tracer concentration elevation above background and guide sucralose sampling

12. References

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Appendix 1: Sucralose Concentrations in U.S. Waters

Summary

Tests of US surface waters show ambient sucralose concentrations vary from 0.002 to 2.9 ppb **(Appendix 1)**. Sucralose enters US waters via treated effluent, runoff/leaching from septic systems, and direct human input. Detected concentrations appear to be far below values at which even no-effect level concentrations have been determined **(Appendix 2).** From one day of sampling Lake Arrowhead's ambient sucralose concentrations sampled at a depth of 50 feet indicate sucralose concentrations in the range of 0.030 to 0.034 ppb, with one high values of 0.084 ppb. Because there are no direct or nonpoint source treated wastewater inputs into Lake Arrowhead, these values are on the low end of of the range of detected sucralose concentrations.

Mawhinney et al. (2011) measured sucralose concentrations in 19 U.S. drinking water systems using liquid chromatography tandem mass spectrometry (LC-MS/MS). Their study found sucralose present in the influent of 15 out of 19 drinking water treatment plants (DWTPs) at concentrations ranging from 47–2,900 *n*g/L. It was detected in the effluent of 13 out of 17 tested DWTPs at concentrations ranging from 49–2,400 *n*g/L. Sucralose was detected in distribution system water for 8 out of 12 DWTPs tested at concentrations ranging from 48-2,400 *n*g/L. Sucralose was also found to be present in source waters with known wastewater influence and/or recreational usage (Mawhinney et al., 2011).

Tollefsen et al (2012) surveyed the available literature and found published reports of surface water sucralose concentrations ranging from < 0.002 to 1.9 ppb in surface freshwater, 0.6-2.4 ppb in groundwater and 0.05 to 2.4 ppb in drinking water (please see below Table A1, copied from Tollefsen et al's 2012 supplementary data).

Compared to the results Tollefsen et al's 2012 literature survey (cited in **Table A1** below), Lake Arrowhead's May 10, 2018 background sucralose concentrations of 0.030 to 0.034 ppb, with one high value of 0.084 ppb **(Appendix 3)** are on the low end of the range of previously-reported values for North American surface waters.

Figure A1. Concentrations of sucralose in μg/L (ppb) in various environmental compartments (obtained from Tollefsen et al., 2012's, Supplementary data table)

Matrix[1]	Country	Concentration (ug/L)	Reference
Sewage influent	SE	1.7-4.1	(Brorström-Lunden et al., 2008a)
Sewage influent	SE	3.5-7.9	(Brorström-Lunden et al., 2008b)
Sewage influent	GE	1.5-16	(Scheurer et al., 2009)
Sewage influent	NO	1.9-5.5	(Green et al., 2008)
Sewage effluent	NO	0.4-7.3	(Dye et al., 2007)
Sewage effluent	SE	0.7-4.9	(Brorström-Lunden et al., 2008a)
Sewage effluent	SE	1.8-11	(Brorström-Lunden et al., 2008b)
Sewage effluent	US	119	(Mead et al., 2009)
Sewage effluent	US	27	(Oppenheimer et al., 2011)
Sewage effluent	GE	< 1	(Scheurer et al., 2009)
Sewage effluent	NO	2.2-5.9	(Green et al., 2008)
Receiving water	SE	0.03-0.5	(Brorström-Lunden et al., 2008a)
Receiving water	SE	0.004-3.6	(Brorström-Lunden et al., 2008b)
Receiving water	US	0.8-1.8	(Ferrer and Thurman, 2010)
Receiving water	US	0.12-10	(Oppenheimer et al., 2011)
Receiving waters	CN	1.1-2.0	(Heeb et al., 2012)
Receiving water	NO	0.007-0.030	(Green et al., 2008)
Surface water	SE	<0.002-0.007	(Brorström-Lunden et al., 2008a)
Surface water	SE	<0.004	(Brorström-Lunden et al., 2008b)
Surface water	US	0.8-1.8	(Ferrer and Thurman, 2010)
Surface water[2]	EU	0.01-0.91	(Loos et al., 2009)
Surface water	US	0.001-1.9	(Mead et al., 2009)
Surface water	GE	0.02-0.11	(Scheurer et al., 2009)
Surface water (sea water)	NO	0.007-0.030	(Green et al., 2008)
Surface water (sea water)	US	0.07-0.39	(Mead et al., 2009)
Groundwater	US	0.6-2.4	(Ferrer and Thurman, 2010)
Drinking water	US	0.05-2.4	(Mawhinney et al., 2011)

[1]Sewage influent- collected prior to the treatment, sewage effluent – collected after the last treatment step and before dilution in the environment, receiving waters- waters being assumed to be impacted by sewage effluents, ground water – collected from water wells, drinking water - collected from the source, final treatment or distribution systems of a drinking water treatment plant. [2]Correct values proposed being 50% higher due to lack of correction for LC-MS ion suppression.

Appendix 2: Ecotoxicity and decay rates of sucralose

1. Summary of Reviewed Literature and Recommendation

Overall, aquatic toxicity of sucralose is very low, meaning that very high concentrations are needed to have any discernible effect on test organisms. The lowest concentration rated for a No Effect or Lowest Observable Effect was 93,000 ppb for a 28 day exposure for mysid shrimp, Huggett and Stoddard (2011). While there have been some reports of changes in feeding behavior of zooplankton in aquatic toxicity tests, ambient sucralose concentrations in receiving waters are, to date, far below any reported effects on test organisms. Additional research is ongoing.

2. Annotated Bibliography

Huggett and Stoddard (2011) evaluated the effects of sucralose on the survival, growth and reproduction of *Daphnia magna* (water flea) and *Americamysis bahia* (mysid shrimp). They found that survival or reproduction of *D. magna* was not reduced even at concentrations as high as 61.8 g/L (61,800,000 ppb). Jenkins, 1984, cited in Tollefsen et al 2012, found that the 48-hour No Observable Effect Concentration (NOEC) and Lowest Observable Effect Concentration (LOEC) for *D. magna* were 1,800 mg/L and greater than 1,800 mg/L respectively. Survival, growth, and reproduction of the mysid shrimp were not affected by concentrations of 693 mg/L (693,000 ppb) of sucralose. The 28-day NOEC and LOEC for the mysid shrimp were 93 mg/L and greater than 93 mg/L, respectively. Huggett and Stoddard (2011) concluded that the concentrations of sucralose detected in the environment are well below those required to elicit chronic effects in freshwater or marine water bodies.

Soh et al., (2011) reported that sucralose does not exhibit any adverse effects on the growth rate of *Lemna gibba* after 7 days at a concentration of 1,000 mg/L (1,000,000 ppb) (Soh et al., 2011).

Tollefsen et al., (2012) conducted a review of available published sucralose toxicity testing data for sucralose. Results are summarized in Table A2 (Tollefsen et al 2012’s, Table 4) and described below.

Figure A2. (Tollefsen et al., 2012's Table 4)

Modeled ECOSAR and Laboratory Ecotoxicological Results (EC/LC_{50}, NOEC and LOEC) for the intense sweetener sucralose.

	Protocol	Duration	EC/LC_{50} (mg/L)	NOEC (mg/L)	LOEC (mg/L)	Reference
*ECOSAR**						
D. magna		48 h	42,727	–	–	
D. magna		Chronic	–	2320 **	–	
Fish		96 h	100,006	–	–	
Fish		Chronic	–	10,799	–	
Green algae		96 h	5372		–	
Green algae		Chronic	–	1123	–	
*Lab studies****						
D. magna	OECD 202	48 h	>1800	1800	>1800	(Jenkins, 1984)
Trout	OECD 203	96 h	>2400	2400	>2400	(Willis, 1984)
Sunfish	OECD 203	96 h	>3200	3200	>3200	(Street, 1985a)
Green algae	OECD 201	96 h	>1800	1800	>1800	(Smyth, 1986)
L. gibba	OECD 221	7 days	>114	114	>114	(Lillicrap, 2011)
D. magna	OECD 202/211	21 days	>1800	1800	>1800	(Williams, 1986)
Mysid shrimp	EPA 850.1350	28 days	>93	93	>100	(Huggett and Stoddard, 2011)

* Based Neutral Organic SAR (baseline toxicity).
** Chronic value is geometric mean of NOEC and LOEC.
*** Conform to Good Laboratory Practices (GLP) and internationally recognized protocols.

Source: Tollefsen, K.E., Nizzetto, L., Huggett, D.B., 2012. Presence, fate and effects of the intense sweetener sucralose in the aquatic environment. Sci. Total Environ. 438, 510–516. https://doi.org/10.1016/j.scitotenv.2012.08.060

Tollefsen et al., (2012) also reported that "The low octanol–water partitioning coefficient of sucralose (K =10^{-49}) suggests very low bioaccumulation potential. Predictions using the Arnot–Gobas bioconcentration factor[12] (BCF) and bioaccumulation factor[13] (BAF) model from the EPIsuite prediction software (USEPA, 2010) clearly suggest that sucralose should not be expected to bioaccumulate either at the lower or upper trophic levels."

Tollefsen et al (2012) further stated that: "An initial ecotoxicological assessment of sucralose using U.S. EPA's Ecological Structure Activity Relationship Model, ECOSAR[14] (USEPA, 2010) provided acute and chronic values based on a structure activity relationship (SAR) for neutral organic compounds. In general, the ECOSAR data set suggests that sucralose may cause toxicity to aquatic organisms only at concentrations ≥ 1,123 mg/L (>1,123,000 ppb) **(Table A2)**. The ECOSAR prediction corresponded well with published standardized test protocol study results that were surveyed by (Tollefsen et al., 2012).

Comparing reports of standardized toxicity testing from Huggett and Stoddard (2011), Suh et al (2011) and Tollefsen et al (2012) with reports of sucralose occurrence in fresh waters (Table 1), published results to date show that sucralose does not alter survival, growth, or reproduction of aquatic organisms

[12] The bioconcentration factor (BCF) is the ratio of the concentration of the substance in a specific genus to the exposure concentration, at equilibrium.
[13] The bioaccumulation factor (BAF) is the ratio of a contaminant in an organism to the concentration in the ambient environment at a steady state, where the organism can take in the contaminant through ingestion with its food as well as through direct content.
14 The Ecological Structure Activity Relationships (ECOSAR) Class Program is a computerized predictive system that estimates aquatic toxicity. The program estimates a chemical's acute (short-term) toxicity and chronic (long-term or delayed) toxicity to aquatic organisms, such as fish, aquatic invertebrates, and aquatic plants, by using computerized Structure Activity Relationships (SARs).

(i.e., plants, algae, crustaceans, and fish) at concentrations up to 9,000 times higher than those detected in the environment.

In this proposed tracer study, a total sucralose mass of 3.91 kilograms (8.62 lb), identical to that proposed for use for Rhodamine WT, would be injected to Lake Arrowhead at the same time as the RWT. The initial proposed well-mixed sucralose concentration at the proposed injection site would be about 174 ppb. For a full-lake volume of 57,795,000 m^3 (46,855 acre-feet) (USBR, 2008), the proposed added mass of sucralose would result in a concentration of 0.067 ppb if it were to not degrade and completely mix with the entire volume of lake water.

Comparing the ECOSAR toxicity threshold of 1,123,000 ppb to either the 174 ppb initial sucralose concentration or the 0.067 ppb completely mixed concentration indicates that proposed mixed sucralose concentrations range from a maximum initial ratio of 100 ppb/1,123,000 ppb or 1/11,230 (0.0089%) of the predicted ECOSAR toxicity threshold to 0.067ppb/1,123,000 ppb or 0.0000000597 % of the predicted ECOSAR toxicity threshold level, sucralose is not expected to affect the aquatic environment in Lake Arrowhead.

Sucralose degrades slowly in the environment. Papers by Labare et al (1993) and Labare and Alexander (1994) indicate that sucralose is slowly degraded by microbial co-metabolism. Labare et al (1993), studied degradation in five lakes with low organic concentrations, and found that initial sucralose concentrations of 100 ppb were 1.6% to 3.6% degraded in over a 65-day period. Labare and Alexander (1994) found that a 1,000,000 ppb solution degraded 2.5% in lake water in 93 days.

References for Appendices 1 and 2

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USBR, 2009. *Lake Arrowhead 2008 Reservoir Survey. Technical Report No. SRH-2009-9* https://doi.org/https://www.usbr.gov/tsc/techreferences/reservoir/Lake Arrowhead 2009 Report.pdf

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Appendix 3: Background Sucralose Concentrations in Lake Arrowhead

Background sucralose concentrations in Lake Arrowhead were evaluated by collecting water samples at a depth of 50 ft (approximately 15 meters) at 5 different locations in Lake Arrowhead (Figure A1) on May 10, 2018. Sucralose concentrations were measured by ALS Laboratories, Kelso Washington, using Solid Phase Extraction (SPE) followed by Liquid Chromatography-Mass Spectrometry (LC-MS) with both a Method Detection Limit (MDL) and Method Reporting Limit (MRL) of 5 *n*g/L (0.005 ppb).

Figure A3: Sucralose concentration at different sampling locations in Lake Arrowhead.

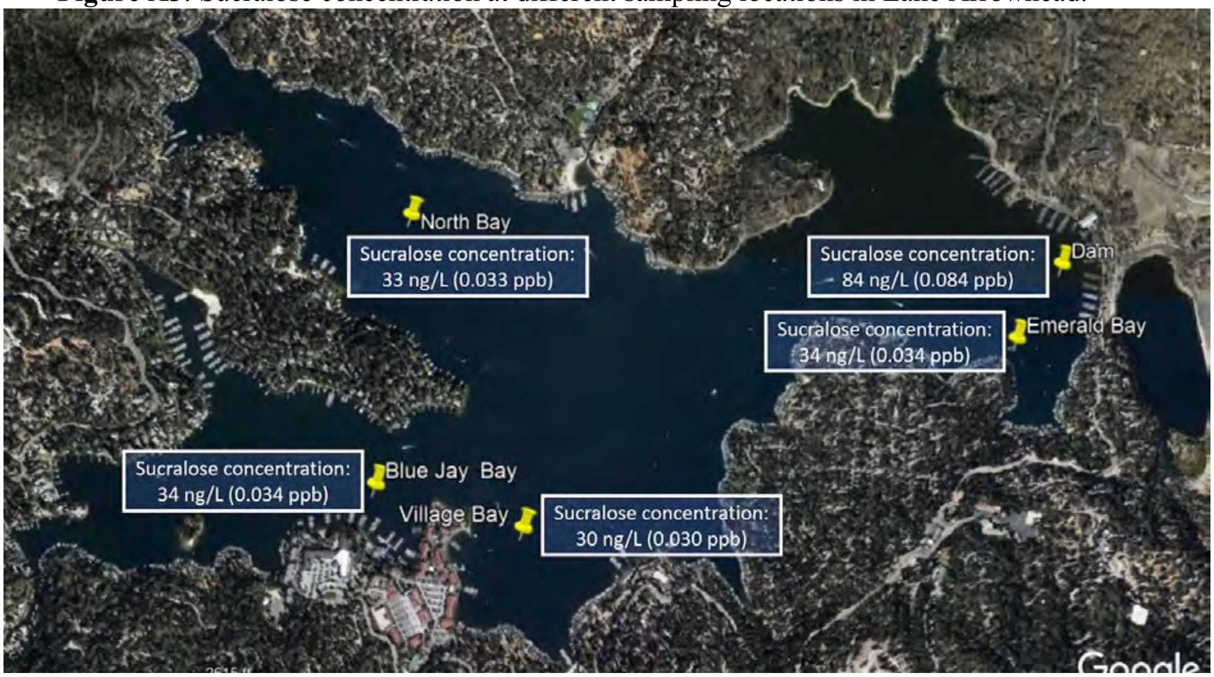

Figure A1. Background sucralose concentrations in Lake Arrowhead ranging from 30 to 84 *n*g/L (0.030 to 0.084 ppb), with four of five concentrations in the 30-34 ng/L range. Overall, with the exception of the sampling near the dam, sucralose distributions across the lake seem to be horizontally homogeneous. The high sucralose concentration of 84 *n*g/L near the dam could be due to a recent mass input prior to sampling.

Appendix 2.2 – Example Tracer Study Workshop Public Document Postings

Lake Arrowhead Tracer Study Public Outreach

Arrowhead Lake Association (ALA)

- August 8, 2019 - Publication in the Mountain News – ALA Public Notice of General Information Meeting Regarding the Lake Arrowhead Tracer Study scheduled for August 24, 2019
- August 15, 2019 - Publication in the Mountain News - ALA Public Notice of General Information Meeting Regarding the Lake Arrowhead Tracer Study Arrowhead scheduled for August 24, 2019
- August 22, 2019 - Publication in the Mountain News – ALA Public Notice of General Information Meeting Regarding the Lake Arrowhead Tracer Study scheduled for August 24, 2019
- August 24, 2019 - General Information Meeting Regarding the Lake Arrowhead Tracer Study held

Lake Arrowhead Community Services District (LACSD)

- August 2, 2019 - Information regarding Lake Arrowhead Tracer Study available on LACSD website www.lakearrowheadcsd.com
- August 13, 2019 - Social media post to Facebook LACSD Special Board Meeting Regarding Lake Arrowhead Tracer Study Public Workshop scheduled for August 27, 2019
- August 13, 2019 - LACSD Special Board Meeting Regarding Lake Arrowhead Tracer Study Public Workshop meeting notice emails sent to 80 LACSD e-subscribers
- August 14, 2019 and August 15, 2019 - Email blast notice of the LACSD Special Board Meeting regarding Lake Arrowhead Tracer Study Public Workshop scheduled for August 27, 2019, sent to 3,744 LACSD customers
- August 15, 2019 - Social media post to Facebook proposed Lake Arrowhead Tracer Study Information
- August 22, 2019 - Publication in the Mountain News Public Notice LACSD Special Board Meeting regarding the Lake Arrowhead Tracer Study Workshop scheduled for August 27, 2019
- August 22, 2019 - Publication in the Alpine Mountaineer Public Notice LACSD Special Board Meeting Regarding the Lake Arrowhead Tracer Study Workshop Meeting scheduled for August 27, 2019
- August 22, 2019 - LACSD Special Board Meeting Regarding Tracer Study Public Workshop agenda posted to LACSD website www.lakearrowheadcsd.com
- August 27, 2019 – LACSD Lake Arrowhead Tracer Study Public Workshop held

Public Inquiries and Comments Received

- August 14, 2019 - "What is a tracer?" Additional information provided via email on August 15, 2019
- August 15, 2019 - "I went to the link but still did not see anything that explained what a Tracer Study is." "Can you explain." Additional information provided via email on August 15, 2019
- August 15, 2019 - Tracer Study Description Facebook posting reply "most definitely attending! Thanks!
- August 15, 2019 - Tracer Study Description Facebook posting reply "Keep at the survey. We need IPR to keep the Lake Full!!!
- August 15, 2019 - LACSD Public Workshop Notice Regarding the Lake Arrowhead Tracer Study, comment "What is a tracer" received via Facebook, additional information provided via Facebook

obtained by sending a written request to the beneficiary within 10 days of the date of first publication of this Notice of Sale. If the sale is set aside for any reason, including if the Trustee is unable to convey title, the Purchaser at the sale shall be entitled only to a return of the monies paid to the Trustee. This shall be the Purchaser's sole and exclusive remedy. The purchaser shall have no further recourse against the Trustor, the Trustee, the Beneficiary, the Beneficiary's Agent, or the Beneficiary's Attorney. If you have previously been discharged through bankruptcy, you may have been released of personal liability for this loan in which case this letter is intended to exercise the note holders right's against the real property only. Nicole Richardson, c/o John G. Wurm, Esq., Law Offices of John G. Wurm, P.O. Box 1875, Lake Arrowhead, California 92352, (909) 337-2557. Trustee Sale No. 2019-1.

Published in the Mountain News August 1, 8 and 15, 2019

APN: 0340-052-43-0-000 TS No: CA06000225-18-1 TO No: 180592145-CA-VOI NOTICE OF TRUSTEE'S SALE

(The above statement is made pursuant to CA Civil Code Section 2923.3(d)(1). The Summary will be provided to Trustor(s) and/or vested owner(s) only, pursuant to CA Civil Code Section 2923.3(d)(2).) **YOU ARE IN DEFAULT UNDER A DEED OF TRUST DATED September 16, 2016. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDINGS AGAINST YOU, YOU SHOULD CONTACT A LAWYER. On August 28, 2019 at 01:00 PM, at the main (south) entrance to the City of Chino Civic Center, 13220 Central Ave, Chino, CA 91710**, MTC Financial Inc. dba Trustee Corps, as the duly Appointed Trustee, under and pursuant to the power of sale contained in that certain Deed of Trust recorded on **September 21, 2016** as Instrument No. **2016-0390132**, of official records in the Office of the Recorder of **San Bernardino** County, California, executed by **MICHAEL DUANE SNELSON, A SINGLE MAN**, as Trustor(s), in favor of MORTGAGE ELECTRONIC REGISTRATION SYSTEMS, INC. as nominee for LAND HOME FINANCIAL SERVICES, INC as Beneficiary, **WILL SELL AT PUBLIC AUCTION TO THE HIGHEST BIDDER**, in lawful money of the United States, all payable at the time of sale, that certain property situated in said County, California describing the land therein as: AS MORE FULLY DESCRIBED IN SAID DEED OF TRUST The property heretofore described is being sold "as is". The street address and other common designation, if any, of the real property described above is purported to be: **832 BERNE DRIVE, CRESTLINE, CA 92325** The undersigned Trustee disclaims any liability for any incorrectness of the street address and other common designation, if any, shown herein. Said sale will be made without covenant or warranty, express or implied, regarding title, possession, or encumbrances, to pay the remaining principal sum of the Note(s) secured by said Deed of Trust, with interest thereon, as provided in said Note(s), advances if any, under the terms of the Deed of Trust, estimated fees, charges and expenses of the Trustee and of the trusts created by said Deed of Trust. The total amount of the unpaid balance of the obligations secured by the property to be sold and reasonable estimated costs, expenses and advances at the time of the initial publication of this Notice of Trustee's Sale is estimated to be **$202,261.27** (Estimated). However, prepayment premiums, accrued interest and advances will increase this figure prior to sale. Beneficiary's bid at said sale may include all or part of said amount. In addition to cash, the Trustee will accept a cashier's check drawn on a state or national bank, a check drawn by a state or federal credit union or a check drawn by a state or federal savings and loan association, savings association or savings bank specified in Section 5102 of the California Financial Code and authorized to do business in California, or other such funds as may be acceptable to the Trustee. In the event tender other than cash is accepted, the Trustee may withhold the issuance of the Trustee's Deed Upon Sale until funds become available to the payee or endorsee as a matter of right. The property offered for sale excludes all funds held on account by the property receiver, if applicable. If the Trustee is unable to convey title for any reason, the successful bidder's sole and exclusive remedy shall be the return of monies paid to the Trustee and the successful bidder shall have no further recourse.

Notice to Potential Bidders If you are considering bidding on this property lien, you should understand that there are risks involved in bidding at a Trustee auction. You will be bidding on a lien, not on the property itself. Placing the highest bid at a Trustee auction does not automatically entitle you to free and clear ownership of the property. You should also be aware that the lien being auctioned off may be a junior lien. If you are the highest bidder at the auction, you are or may be responsible for paying off all liens senior to the lien being auctioned off, before you can receive clear title to the property. You are encouraged to investigate the existence, priority, and size of outstanding liens that may exist on this property by contacting the county recorder's office or a title insurance company, either of which may charge you a fee for this information. If you consult either of these resources, you should be aware that the same Lender may hold more than one mortgage or Deed of Trust on the property. **Notice to Property Owner** The sale date shown on this Notice of Sale may be postponed one or more times by the Mortgagee, Beneficiary, Trustee, or a court, pursuant to Section 2924g of the California Civil Code. The law requires that information about Trustee Sale postponements be made available to you and to the public, as a courtesy to those not present at the sale. If you wish to learn whether your sale date has been postponed, and, if applicable, the rescheduled time and date for the sale of this property, you may call **In Source Logic at 702-659-7766** for information regarding the Trustee's Sale or visit the Internet Web site address listed below for information regarding the sale of this property, using the file number assigned to this case, **CA06000225-18-1**. Information about postponements that are very short in duration or that occur close in time to the scheduled sale may not immediately be reflected in the telephone information or on the Internet Web site. The best way to verify postponement information is to attend the scheduled sale. Date: **July 12, 2019 MTC Financial Inc. dba Trustee Corps TS No. CA06000225-18-1 17100 Gillette Ave Irvine, CA 92614 Phone: 949-252-8300 TDD: 866-660-4288 Myron Ravelo**, Authorized Signatory SALE INFORMATION CAN BE OBTAINED ON LINE AT www.insourcelogic.com FOR AUTOMATED SALES INFORMATION PLEASE CALL: In Source Logic AT 702-659-7766 Trustee Corps may be acting as a debt collector attempting to collect a debt. Any information obtained may be used for that purpose. Order Number 62170, Pub Dates: **08/01/2019, 08/08/2019, 08/15/2019, MOUNTAIN NEWS**

TSG No.: 8751584 TS No.: CA1900284973 FHA/VA/PMI No.: APN: 0342-111-06-0-000 Property Address: 21820 JOBS PEAK ROAD CEDARPINES PARK, CA 92322 NOTICE OF TRUSTEE'S SALE

YOU ARE IN DEFAULT UNDER A DEED OF TRUST, DATED **05/28/2016**. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDING AGAINST YOU, YOU SHOULD CONTACT A LAWYER. On **08/14/2019 at 01:00 P.M.**, First American Title Insurance Company, as duly appointed Trustee under and pursuant to Deed of Trust recorded **06/03/2016**, as Instrument No. **2016-0217316**, in book , page , , of Official Records in the office of the County Recorder of **SAN BERNARDINO** County, State of California. Executed by: **JAMES RANDALL PHIPPS, A SINGLE MAN**, WILL SELL AT PUBLIC AUCTION TO HIGHEST BIDDER FOR CASH, CASHIER'S CHECK/CASH EQUIVALENT or other form of payment authorized by 2924h(b), (Payable at time of sale in lawful money of the United States) **At the main (south) entrance to the City of Chino Civic Center, 13220 Central Ave., Chino, CA 91710** All right, title and interest conveyed to and now held by it under said Deed of Trust in the property situated in said County and State described as: AS MORE FULLY DESCRIBED IN THE ABOVE MENTIONED DEED OF TRUST **APN# 0342-111-06-0-000** The street address and other common designation, if any, of the real property described above is purported to be: **21820 JOBS PEAK ROAD, CEDARPINES PARK, CA 92322** The undersigned Trustee disclaims any liability for any incorrectness of the street address and other common designation, if any, shown herein. Said sale will be made, but without covenant or warranty, expressed or implied, regarding title, possession, or encumbrances, to pay the remaining principal sum of the note(s) secured by said Deed of Trust, with interest thereon, as provided in said note(s), advances, under the terms of said Deed of Trust, fees, charges and expenses of the Trustee and of the trusts created by said Deed of Trust. The total amount of the unpaid balance of the obligation secured by the property to be sold and reasonable estimated costs, expenses and advances at the time of the initial publication of the Notice of Sale is **$ 52,045.07**. The beneficiary under said Deed of Trust has deposited all documents evidencing the obligations secured by the Deed of Trust and has declared all sums secured thereby immediately due and payable, and has caused a written Notice of Default and Election to Sell to be executed. The undersigned caused said Notice of Default and Election to Sell to be recorded in the County where the real property is located. **NOTICE TO POTENTIAL BIDDERS:** If you are considering bidding on this property lien, you should understand that there are risks involved in bidding at a trustee auction. You will be bidding on a lien, not on the property itself. Placing the highest bid at a trustee auction does not automatically entitle you to free and clear ownership of the property. You should also be aware that the lien being auctioned off may be a junior lien. If you are the highest bidder at the auction, you are or may be responsible for paying off all liens senior to the lien being auctioned off, before you can receive clear title to the property. You are encouraged to investigate the existence, priority, and size of outstanding liens that may exist on this property by contacting the county recorder's office or a title insurance company, either of which may charge you a fee for this information. If you consult either of these resources, you should be aware that the same lender may hold more than one mortgage or deed of trust on the property. **NOTICE TO PROPERTY OWNER:** The sale date shown on this notice of sale may be postponed one or more times by the mortgagee, beneficiary, trustee, or a court, pursuant to Section 2924g of the California Civil Code. The law requires that information about trustee sale postponements be made available to you and to the public, as a courtesy to those not present at the sale. If you wish to learn whether your sale date has been postponed, and if applicable, the rescheduled time and date for the sale of this property, you may call (916)939-0772 or visit this Internet Web site http://search.nationwideposting.com/propertySearchTerms.aspx, using the file number assigned to this case **CA1900284973** Information about postponements that are very short in duration or that occur close in time to the scheduled sale may not immediately be reflected in the telephone information or on the Internet Web site. The best way to verify postponement information is to attend the scheduled sale. If the sale is set aside for any reason, the Purchaser at the sale shall be entitled only to a return of the deposit paid. The Purchaser shall have no further recourse against the Mortgagor, the Mortgagee or the Mortgagee's attorney. Date: First American Title Insurance Company 4795 Regent Blvd, Mail Code 1011-F Irving, TX 75063 First American Title Insurance Company MAY BE ACTING AS A DEBT COLLECTOR ATTEMPTING TO COLLECT A DEBT. ANY INFORMATION OBTAINED MAY BE USED FOR THAT PURPOSE FOR TRUSTEES SALE INFORMATION PLEASE CALL (916)939-0772

NPP0356686 To: MOUNTAIN NEWS 07/25/2019, 08/01/2019, 08/08/2019

NOTICE OF TRUSTEE'S SALE TS No. CA-19-852463-BF Order No.: DS7300-19001113

YOU ARE IN DEFAULT UNDER A DEED OF TRUST DATED 6/6/2011. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDING AGAINST YOU, YOU SHOULD CONTACT A LAWYER. A public auction sale to the highest bidder for cash, cashier's check drawn on a state or national bank, check drawn by state or federal credit union, or a check drawn by a state or federal savings and loan association, or savings association, or savings bank specified in Section 5102 to the Financial Code and authorized to do business in this state, will be held by duly appointed trustee. The sale will be made, but without covenant or warranty, expressed or implied, regarding title, possession, or encumbrances, to pay the remaining principal sum of the note(s) secured by the Deed of Trust, with interest and late charges thereon, as provided in the note(s), advances, under the terms of the Deed of Trust, interest thereon, fees, charges and expenses of the Trustee for the total amount (at the time of the initial publication of the Notice of Sale) reasonably estimated to be set forth below. The amount may be greater on the day of sale. **BENEFICIARY MAY ELECT TO BID LESS THAN THE TOTAL AMOUNT DUE.** Trustor(s): **Joshua Strengberg and Brandi Strengberg, husband and wife as community property with right of survivorship** Recorded: **6/10/2011** as Instrument No. **2011-0236797** of Official Records in the office of the Recorder of **SAN BERNARDINO** County, California; Date of Sale: **8/27/2019** at **9:00 AM** Place of Sale: **At the North West Entrance in the Courtyard of the Chino Municipal Court, located at 13260 Central Avenue, Chino, CA 91710** Amount of unpaid balance and other charges: **$168,719.95** The purported property address is: **23196 BROOKSIDE ROAD, CRESTLINE, CA 92325** Assessor's Parcel No.: **0343-242-03-0-000 NOTICE TO POTENTIAL BIDDERS:** If you are considering bidding on this property lien, you should understand that there are risks involved in bidding at a trustee auction. You will be bidding on a lien, not on the property itself. Placing the highest bid at a trustee auction does not automatically entitle you to free and clear ownership of the property. You should also be aware that the lien being auctioned off may be a junior lien. If you are the highest bidder at the auction, you are or may be responsible for paying off all liens senior to the lien being auctioned off, before you can receive clear title to the property. You are encouraged to investigate the existence, priority, and size of outstanding liens that may exist on this property by contacting the county recorder's office or a title insurance company, either of which may charge you a fee for this information. If you consult either of these resources, you should be aware that the same lender may hold more than one mortgage or deed of trust on the property. **NOTICE TO PROPERTY OWNER:** The sale date shown on this notice of sale may be postponed one or more times by the mortgagee, beneficiary, trustee, or a court, pursuant to Section 2924g of the California Civil Code. The law requires that information about trustee sale postponements be made available to you and to the public, as a courtesy to those not present at the sale. If you wish to learn whether your sale date has been postponed, and, if applicable, the rescheduled time and date for the sale of this property, you may call **800-280-2832** for information regarding the trustee's sale or visit this Internet Web site **http://www.qualityloan.com**, using the file number assigned to this foreclosure by the Trustee: **CA-19-852463-BF**. Information about postponements that are very short in duration or that occur close in time to the scheduled sale may not immediately be reflected in the telephone information or on the Internet Web site. The best way to verify postponement information is to attend the scheduled sale. The undersigned Trustee disclaims any liability for any incorrectness of the property address or other common designation, if any, shown herein. If no street address or other common designation is shown, directions to the location of the property may be obtained by sending a written request to the beneficiary within 10 days of the date of first publication of this Notice of Sale. If the sale is set aside for any reason, including if the Trustee is unable to convey title, the Purchaser at the sale shall be entitled only to a return of the monies paid to the Trustee. This shall be the Purchaser's sole and exclusive remedy. The purchaser shall have no further recourse against the Trustor, the Trustee, the Beneficiary, the Beneficiary's Agent, or the Beneficiary's Attorney. If you have previously been discharged through bankruptcy, you may have been released of personal liability for this loan in which case this letter is intended to exercise the note holders right's against the real property only. Date: **Quality Loan Service Corporation 2763 Camino Del Rio South San Diego, CA 92108 619-645-7711 For NON SALE information only Sale Line: 800-280-2832 Or Login to: http://www.qualityloan.com Reinstatement Line: (866) 645-7711 Ext 5318** Quality Loan Service Corp. TS No.: **CA-19-852463-BF** IDSPub #0154933 7/25/2019 8/1/2019 8/8/2019

NOTICE

ARROWHEAD LAKE ASSOCIATION
GENERAL INFORMATION MEETING

Regarding the Lake Arrowhead Tracer Study.

This meeting is being held to notify members of plans to use a tracer in Lake Arrowhead to assist with research being conducted by the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation, the Arrowhead Lake Association, and the LACSD.

ALL ALA MEMBERS ARE INVITED TO ATTEND.

Saturday, August 24, 2019
10:30 A.M. - 11:30 A.M.
The Clubhouse at Burnt Mill Beach Club
(27910 Lakes Edge Rd., Lake Arrowhead)

The Lake Arrowhead Community Services District will also be holding an informational meeting on Tuesday, August 27, 2019 starting at 4:00 p.m. at their District Board Room located at 27307 St. Hwy. 189, Suite 104, Blue Jay, CA

To all residents served by Lake Arrowhead Community Services District Wastewater System:

Lake Arrowhead Community Services District will be conducting smoke tests of our wastewater system throughout the year. These tests will help us to identify sources of Inflow and Infiltration into the District's wastewater collection system. The District will post signage, on a daily basis, in the areas being tested. As a result of this testing, smoke will be emitted from the vent pipes on resident's roofs. In the event you experience smoke in your home, this smoke is harmless and non-toxic and may indicate a problem with your private wasteline plumbing. If you encounter smoke in your home please call the District at (909) 336-7100 and District staff will be happy to assist you in identifying the problem.

Published in the Mountain News August 8, 2019.

NOTICE:
You Are Invited to Attend and Participate

Aug 13th, 2019
5:30 p.m.

Regular Meeting of the Board of Directors

DISTRICT BOARD ROOM
27307 St. Hwy 189, Suite 104
Blue Jay, CA 92317

Agendas are available 5 days prior to public meetings at the District office and on the website. E-notice available by subscription.

Note: Audio of the proceedings will be posted to the District website

The Lake Arrowhead Community Services District Board of Directors may be contacted as follows: P.O. Box 700, Lake Arrowhead, CA 92352

(909) 336-7100 or www.lakearrowheadcsd.com

2019 BOARD OF DIRECTORS ELECTION

Come Get to Know Your Candidates!

North District and At Large A Seat

CANDIDATES MEET & GREET
August 17, 2019
Ralph Wagner Bldg. Noon to 2:00 PM
(870 N. State Highway 173, Lake Arrowhead)

CANDIDATES FORUM
August 24, 2019
1:00 PM to 3:00 PM
The Clubhouse at Burnt Mill Beach Club
(27910 Lakes Edge Rd., Lake Arrowhead)

that the Zoning Administrator of the County of San Bernardino, at its regular meeting on **Thursday, August 29, 2019**, will conduct a public hearing to consider:

Proposal: Minor Use Permit to convert an existing 3,115 square foot storage warehouse building into a brewery and retail tasting room situated within a 1.08 acre site, located at 329 Villa Way, in the community of Lake Arrowhead (APN: 0335-101-39).

Project #P201900269, Date filed: May 14, 2019.

Applicant: Travis Lanthier.

Environmental Determination: A Notice of Exemption will be considered for compliance with the California Environmental Quality Act.

Time and Place of Hearing: 9:00 a.m. or thereafter, in the Joshua Room, County Government Center, 385 North Arrowhead Avenue, First Floor, San Bernardino, CA.

Hearing Participation: Any person affected by this application may submit their concerns in writing prior to the hearing or appear in person and be heard in support of or in opposition to the proposal at the time of the hearing.

If you challenge any decision regarding the above proposal in court, you may be limited to raising only those issues you or someone else raised at the public hearing described in this notice or in written correspondence delivered to the Zoning Administrator at, or prior to, the public hearing. Due to time constraints and the number of persons wishing to give oral testimony, time restrictions may be placed on oral testimony at the public hearing regarding this proposal. You may wish to make your comments in writing to assure that you are able to express yourself adequately.

The proposed project application and environmental finding may be viewed at the Planning Division at: 385 N. Arrowhead Avenue, San Bernardino, CA 92415-0187 from 8:00 a.m. until 4:30 p.m., Monday Thru Friday. To assure that someone will be available to assist you; staff requests that you call the Planning Division at (909) 387-8311 to set a time to review the documents. NOTE: The Zoning Administrator in its deliberation could approve an alternative proposal for the above Project.
8/15/19

CNS-3282310#
MOUNTAIN NEWS

TSG No.: 190780596-CA-MSI
TS No.: CA1900285085
APN: 0340-031-34-0-000
Property Address: 24737 BASEL DRIVE CRESTLINE, CA 92325
NOTICE OF TRUSTEE'S SALE

YOU ARE IN DEFAULT UNDER A DEED OF TRUST, DATED **06/19/2016**. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDING AGAINST YOU, YOU SHOULD CONTACT A LAWYER. On **08/21/2019** at **01:00 P.M.**, First American Title Insurance Company, as duly appointed Trustee under and pursuant to Deed of Trust recorded **06/24/2016**, as Instrument No. **2016-0249880**, in book , page , of Official Records in the office of the County Recorder of **SAN BERNARDINO** County, State of California. Executed by: **MORVILLE C. WESTENHAVER AND WENDY WESTENHAVER, HUSBAND AND WIFE AS JOINT TENANTS**, WILL SELL AT PUBLIC AUCTION TO HIGHEST BIDDER FOR CASH, CASHIER'S CHECK/ CASH EQUIVALENT or other form of payment authorized by 2924h(b), (Payable at time of sale in lawful money of the United States) At the main (south) entrance to the **City of Chino Civic Center, 13220 Central Ave., Chino, CA 91710** All right, title and interest conveyed to and now held by it under said Deed of Trust in the property situated in said County and State described as: AS MORE FULLY DESCRIBED IN THE ABOVE MENTIONED DEED OF TRUST **APN# 0340-031-34-0-000** The street address and other common designation, if any, of the real property described above is purported to be: **24737 BASEL DRIVE, CRESTLINE, CA 92325** The undersigned Trustee disclaims any liability for any incorrectness of the street address and other common designation, if any, shown herein. Said sale will be made, but without covenant or warranty, expressed or implied, regarding title, possession, or encumbrances, to pay the remaining principal sum of the note(s) secured by said Deed of Trust, with interest thereon, as provided in said note(s), advances, under the terms of said Deed of Trust, fees, charges and expenses of the Trustee and of the trusts created by said Deed of Trust. The total amount of the unpaid balance of the obligation secured by the property to be sold and reasonable estimated costs, expenses and advances at the time of the initial publication of the Notice of Sale is **$ 278,018.89**. The beneficiary under said Deed of Trust has deposited all documents evidencing the obligations secured by the Deed of Trust and has declared all sums secured thereby immediately due and payable, and has caused a written Notice of Default and Election to Sell to be executed. The undersigned caused said Notice of Default and Election to Sell to be recorded in the County where the real property is located. **NOTICE TO POTENTIAL BIDDERS:** If you are considering bidding on this property lien, you should understand that there are risks involved in bidding at a trustee auction. You will be bidding on a lien, not on the property itself. Placing the highest bid at a trustee auction does not automatically entitle you to free and clear ownership of the property. You should also be aware that the lien being auctioned off may be a junior lien. If you are the highest bidder at the auction, you are or may be responsible for paying off all liens senior to the lien being auctioned off, before you can receive clear title to the property. You are encouraged to investigate the existence, priority, and size of outstanding liens that may exist on this property by contacting the county recorder's office or a title insurance company, either of which may charge you a fee for this information. If you consult either of these resources, you should be aware that the same lender may hold more than one mortgage or deed of trust on the property. **NOTICE TO PROPERTY OWNER:** The sale date shown on this notice of sale may be postponed one or more times by the mortgagee, beneficiary, trustee, or a court, pursuant to Section 2924g of the California Civil Code. The law requires that information about trustee sale postponements be made available to you and to the public, as a courtesy to those not present at the sale. If you wish to learn whether your sale date has been postponed, and if applicable, the rescheduled time and date for the sale of this property, you may call (916)939-0772 or visit this Internet Web site http://search.nationwideposting.com/propertySearchTerms.aspx, using the file number assigned to this case **CA1900285085** Information about postponements that are very short in duration or that occur close in time to the scheduled sale may not immediately be reflected in the telephone information or on the Internet Web site. The best way to verify postponement information is to attend the scheduled sale. If the sale is set aside for any reason, the Purchaser at the sale shall be entitled only to a return of the deposit paid. The Purchaser shall have no further recourse against the Mortgagor, the Mortgagee or the Mortgagee's attorney. Date: First American Title Insurance Company 4795 Regent Blvd, Mail Code 1011-F Irving, TX 75063 First American Title Insurance Company MAY BE ACTING AS A DEBT COLLECTOR ATTEMPTING TO COLLECT A DEBT. ANY INFORMATION OBTAINED MAY BE USED FOR THAT PURPOSE. FOR TRUSTEES SALE INFORMATION PLEASE CALL (916)939-0772

NPP0356992 To: MOUNTAIN NEWS 08/01/2019, 08/08/2019, 08/15/2019

NOTICE OF TRUSTEE'S SALE
TS No. 2019-1, Order No. One.

YOU ARE IN DEFAULT UNDER A DEED OF TRUST DATED 12/17/2015. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDING AGAINST YOU, YOU SHOULD CONTACT A LAWYER.
A public auction sale to the highest bidder for cash, cashier's check drawn on a state or national bank, check drawn by state or federal credit union, or a check drawn by a state or federal savings and loan association, or savings association, or savings bank specified in Section 5102 to the Financial Code and authorized to do business in this state, will be held by duly appointed trustee. The sale will be made, but without covenant or warranty, expressed or implied, regarding title, possession, or encumbrances, to pay the remaining principal sum of the note(s) secured by the Deed of Trust, with interest and late charges thereon, as provided in the note(s), advances, under the terms of the Deed of Trust, interest thereon, fees, charges and expenses of the Trustee for the total amount (at the time of the initial publication of the Notice of Sale) reasonably estimated to be set forth below. The amount may be greater on the day of sale. BENEFICIARY MAY ELECT TO BID LESS THAN THE TOTAL AMOUNT DUE. Trustor(s): **Thomas Hopper**. Recorded **12/17/2015** as Instrument No. **2015-0551569** of Official Records in the office of the Recorder of **SAN BERNARDINO** County, California. Date of Sale: **9/6/2019** at **10:00 AM**, Place of Sale: **THE LAW OFFICES OF JOHN G. WURM, located at 27321 North Bay Road, Blue Jay, California 92317**. Amount of unpaid balance and other charges: **$11,529.00**. The purported property address is: **0 Hemlock, Big Bear City, California 92314. Assessor's Parcel No. 315-143-01. NOTICE TO POTENTIAL BIDDERS:** If you are considering bidding on this property lien, you should understand that there are risks involved in bidding at a trustee auction. You will be bidding on a lien, not on the property itself. Placing the highest bid at a trustee auction does not automatically entitle you to free and clear ownership of the property. You should also be aware that the lien being auctioned off may be a junior lien. If you are the highest bidder at the auction, you are or may be responsible for paying off all liens senior to the lien being auctioned off, before you can receive clear title to the property. You are encouraged to investigate the existence, priority, and size of outstanding liens that may exist on this property by contacting the county recorder's office or a title insurance company, either of which may charge you a fee for this information. If you consult either of these resources, you should be aware that the same lender may hold more than one mortgage or deed of trust on the property. **NOTICE TO PROPERTY OWNER:** The sale date shown on this notice of sale may be postponed one or more times by the mortgagee, beneficiary, trustee, or a court, pursuant to Section 2924g of the California Civil Code. The law requires that information about trustee sale postponements be made available to you and to the public, as a courtesy to those not present at the sale. If you wish to learn whether your sale date has been postponed, and, if applicable, the rescheduled time and date for the sale of this property, you may call **(909) 337-2557** for information regarding the trustee's sale using the file number assigned to this foreclosure by the Trustee: **2019-1**. Information about postponements that are very short in duration or that occur close in time to the scheduled sale may not immediately be reflected in the telephone information or on the Internet Web site. The best way to verify postponement information is to attend the scheduled sale. The undersigned Trustee disclaims any liability for any incorrectness of the property address or other common designation, if any, shown herein. If no street address or other common designation is shown, directions to the location of the property may be obtained by sending a written request to the beneficiary within 10 days of the date of first publication of this Notice of Sale. If the sale is set aside for any reason, including if the Trustee is unable to convey title, the Purchaser at the sale shall be entitled only to a return of the monies paid to the Trustee. This shall be the Purchaser's sole and exclusive remedy. The purchaser shall have no further recourse against the Trustor, the Trustee, the Beneficiary, the Beneficiary's Agent, or the Beneficiary's Attorney. If you have previously been discharged through bankruptcy, you may have been released of personal liability for this loan in which case this letter is intended to exercise the note holders right's against the real property only. Nicole Richardson, c/o John G. Wurm, Esq., Law Offices of John G. Wurm, P.O. Box 1875, Lake Arrowhead, California 92352, (909) 337-2557, Trustee Sale No. 2019-1.

Published in the Mountain News August 1, 8 and 15, 2019

APN: 0340-052-43-0-000 TS No: CA06000225-18-1 TO No: 180592145-CA-VOI NOTICE OF TRUSTEE'S SALE

(The above statement is made pursuant to CA Civil Code Section 2923.3(d)(1). The Summary will be provided to Trustor(s) and/or vested owner(s) only, pursuant to CA Civil Code Section 2923.3(d)(2).) **YOU ARE IN DEFAULT UNDER A DEED OF TRUST DATED September 18, 2016. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDINGS AGAINST YOU, YOU SHOULD CONTACT A LAWYER. On August 28, 2019 at 01:00 PM, at the main (south) entrance to the City of Chino Civic Center, 13220 Central Ave, Chino, CA 91710**, MTC Financial Inc. dba Trustee Corps, as the duly Appointed Trustee, under and pursuant to the power of sale contained in that certain Deed of Trust recorded on **September 21, 2016** as Instrument No. **2016-0390132** of official records in the Office of the Recorder of **San Bernardino** County, California, executed by **MICHAEL DUANE SNELSON, A SINGLE MAN**, as Trustor(s), in favor of MORTGAGE ELECTRONIC REGISTRATION SYSTEMS, INC. as nominee for LAND HOME FINANCIAL SERVICES, INC as Beneficiary, **WILL SELL AT PUBLIC AUCTION TO THE HIGHEST BIDDER**, in lawful money of the United States, all payable at the time of sale, that certain property situated in said County, California describing the land therein as: AS MORE FULLY DESCRIBED IN SAID DEED OF TRUST The property heretofore described is being sold "as is". The street address and other common designation, if any, of the real property described above is purported to be: **832 BERNE DRIVE, CRESTLINE, CA 92325** The undersigned Trustee disclaims any liability for any incorrectness of the street address and other common designation, if any, shown herein. Said sale will be made without covenant or warranty, express or implied, regarding title, possession, or encumbrances, to pay the remaining principal sum of the Note(s) secured by said Deed of Trust, with interest thereon, as provided in said Note(s), advances if any, under the terms of the Deed of Trust, estimated fees, charges and expenses of the Trustee and of the trusts created by said Deed of Trust. The total amount of the unpaid balance of the obligations secured by the property to be sold and reasonable estimated costs, expenses and advances at the time of the initial publication of this Notice of Trustee's Sale is estimated to be **$202,261.27** (Estimated). However, prepayment premiums, accrued interest and advances will increase this figure prior to sale. Beneficiary's bid at said sale may include all or part of said amount. In addition to cash, the Trustee will accept a cashier's check drawn on a state or national bank, a check drawn by a state or federal credit union or a check drawn by a state or federal savings and loan association, savings association or savings bank specified in Section 5102 of the California Financial Code and authorized to do business in California, or other such funds as may be acceptable to the Trustee. In the event tender other than cash is accepted, the Trustee may withhold the issuance of the Trustee's Deed Upon Sale until funds become available to the payee or endorsee as a matter of right. The property offered for sale excludes all funds held on account by the property receiver, if applicable. If the Trustee is unable to convey title for any reason, the successful bidder's sole and exclusive remedy shall be the return of monies paid to the Trustee and the successful bidder shall have no further recourse.
Notice to Potential Bidders If you are considering bidding on this property lien, you should understand that there are risks involved in bidding at a Trustee auction. You will be bidding on a lien, not on the property itself. Placing the highest bid at a Trustee auction does not automatically entitle you to free and clear ownership of the property. You should also be aware that the lien being auctioned off may be a junior lien. If you are the highest bidder at the auction, you are or may be responsible for paying off all liens senior to the lien being auctioned off, before you can receive clear title to the property. You are encouraged to investigate the existence, priority, and size of outstanding liens that may exist on this property by contacting the county recorder's office or a title insurance company, either of which may charge you a fee for this information. If you consult either of these resources, you should be aware that the same Lender may hold more than one mortgage or Deed of Trust on the property. **Notice to Property Owner** The sale date shown on this Notice of Sale may be postponed one or more times by the Mortgagee, Beneficiary, Trustee, or a court, pursuant to Section 2924g of the California Civil Code. The law requires that information about Trustee Sale postponements be made available to you and to the public, as a courtesy to those not present at the sale. If you wish to learn whether your sale date has been postponed, and, if applicable, the rescheduled time and date for the sale of this property, you may call **In Source Logic at 702-659-7766** for information regarding the Trustee's Sale or visit the Internet Web site address listed below for information regarding the sale of this property, using the file number assigned to this case, **CA06000225-18-1**. Information about postponements that are very short in duration or that occur close in time to the scheduled sale may not immediately be reflected in the telephone information or on the Internet Web site. The best way to verify postponement information is to attend the scheduled sale. Date: **July 12, 2019 MTC Financial Inc. dba Trustee Corps TS No. CA06000225-18-1 17100 Gillette Ave Irvine, CA 92614 Phone: 949-252-8300 TDD: 866-660-4288 Myron Ravelo**, Authorized Signatory SALE INFORMATION CAN BE OBTAINED ON LINE AT www.insourcelogic.com FOR AUTOMATED SALES INFORMATION PLEASE CALL: In Source Logic AT 702-659-7766 Trustee Corps may be acting as a debt collector attempting to collect a debt. Any information obtained may be used for that purpose Order Number 62170, Pub Dates: **08/01/2019, 08/08/2019, 08/15/2019, MOUNTAIN NEWS**

ORDER TO SHOW CAUSE RE: CHANGE OF NAME CASE NUMBER: CIVDS1922548

Published in the Mountain News August 8, 15, 22 and 29, 2019

T.S. No. 080974-CA

NOTICE OF TRUSTEE'S SALE

Published in the Mountain News August 22, 29 and September 5, 2019

NOTICE OF TRUSTEE'S SALE

YOU ARE IN DEFAULT UNDER A DEED OF TRUST DATED 03/22/2004. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDING AGAINST YOU, YOU SHOULD CONTACT A LAWYER.

NOTICE TO POTENTIAL BIDDERS:

NOTICE TO PROPERTY OWNER:

NOTICE TO POTENTIAL BIDDERS: If you are considering bid-

NOTICE OF TRUSTEE'S SALE

YOU ARE IN DEFAULT UNDER A DEED OF TRUST DATED 8/3/2017. UNLESS YOU TAKE ACTION TO PROTECT YOUR PROPERTY, IT MAY BE SOLD AT A PUBLIC SALE. IF YOU NEED AN EXPLANATION OF THE NATURE OF THE PROCEEDING AGAINST YOU, YOU SHOULD CONTACT A LAWYER.

NOTICE TO PROPERTY OWNER:

This office is enforcing a security interest of your creditor. To the extent that your obligation has been discharged by a bankruptcy court or is subject to an automatic stay of bankruptcy, this notice is for informational purposes only and does not constitute a demand for payment or any attempt to collect such obligation EPP 29665 Pub Dates 08/22, 08/29, 09/05/2019

Lake Arrowhead
August 13 at 4:12 PM ·

Lake Arrowhead Community Services Public Workshop Notice

Regarding the Lake Arrowhead Tracer Study

Lake Arrowhead Community Services District will be holding a Public Workshop on Tuesday, August 27, 2019, starting at 4:00 p.m. at the Lake Arrowhead Community Services District Board Room, located at 27307 St. Hwy. 189, Suite 104, Blue Jay, CA.

The Public Workshop is being held to notify residents of plans to use a tracer in Lake Arrowhead to assist with research being conducted by the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation and Arrowhead Lake Association. Arrowhead Lake Association will also be conducting an informational meeting on August 24, 2019. Please contact Arrowhead Lake Association for the meeting details.

More information can be found on our website at lakearrowheadcsd.com. #arrowheadwoods #rimforest #skyforest #crestpark #cedarglen #lakearrowhead

4 1 Comment

Share

Kathleen Field - 7117

From: do.not.reply=to.this.email@lakearrowheadcsd.com on behalf of Lake Arrowhead CSD <do.not.reply@to.this.email>
Sent: Tuesday, August 13, 2019 3:48 PM
To: Kathleen Field - 7117
Subject: Public Workshop Regarding the Lake Arrowhead Tracer Study

Lake Arrowhead Community Services Public Workshop Notice

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More information can be found on our website at lakearrowheadcsd.com.

Lake Arrowhead Community Services Public Workshop Notice

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More information can be found on our website at lakearrowheadcsd.com.

Lake Arrowhead

Tracer Study Description #arrowheadwoods #rimforest #skyforest #crestpark #cedarglen #lakearrowhead

Proposed Tracer Study in Lake Arrowhead

Researchers from the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation, the Arrowhead Lake Association and the Lake Arrowhead Community Services District are conducting a study of Lake Arrowhead. The purpose of the study is to create a manual for water purveyors across the country to understand how recycled water mixes into surface water. No recycled water will be put into Lake Arrowhead during the study.

The researchers have been collecting data from the local area, as well as the lake, and have created a three dimensional hydrodynamic model of Lake Arrowhead. They are proposing to insert two non-toxic tracers into the lake in early October, 2019. The two tracers include a diluted fluorescent dye called Rhodamine WT and sucralose, an artificial sweetener. The quantities of the tracers will not have any detrimental effect on the lake. The tracers will be inserted into the lake at a depth of 85 feet in the vicinity of Village Bay. Initially, the dye tracer will have a red tinge but will not be visible once it is diluted. A fluorometer will be used to detect the dye and determine its movement in the lake. Water samples will also be taken. The researchers will use the movement of the tracers to confirm or disprove the results from the hydrodynamic model. This method of tracing water movement has been used in similar applications around the country.

The manual that will be created will help water purveyors determine if augmenting an existing water body with recycled water is a viable option as an additional water supply. This is often referred to as Indirect Potable Reuse or IPR. Various applications of IPR are currently in operation. Typical applications include diluting recycled water into a water body or percolating it into groundwater from which it is later drawn out and treated for potable uses.

Arrowhead Lake Association and the Lake Arrowhead Community Services District have agreed to cooperate with the study to gather valuable information regarding the behavior of our lake. There are currently no plans to augment Lake Arrowhead with recycled water but the data from this study may be used to determine if it could be feasible at some point in the future.

August 15 at 8:33 PM · Public

Proposed Tracer Study in Lake Arrowhead

Researchers from the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation, the Arrowhead Lake Association and the Lake Arrowhead Community Services District are conducting a study of Lake Arrowhead. The purpose of the study is to create a manual for water purveyors across the country to understand how recycled water mixes into surface water. No recycled water will be put into Lake Arrowhead during the study.

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For more details, see the technical report below.

PROOF OF PUBLICATION

(2015.5 C.C.P.)

STATE OF CALIFORNIA
COUNTY OF SAN BERNARDINO,

I am a citizen of the United States and a resident of the County aforesaid; I am over the age of eighteen years,

and not a party to or interested in the above entitled matter. I am the principal clerk of **Mountain News**, a newspaper of general circulation, published by Hi Desert Publishing Co. Inc., in the unincorporated area of Lake Arrowhead, County of San Bernardino, and which newspaper has been adjudicated a newspaper of general circulation by the Superior Court of the County of San Bernardino, State of California, under date of October 5, 1950, Case Number 67902; that the notice, of which

published in each regular and entire issue of said newspaper and not in any supplement thereof on the following dates to-wit:
August 22, 2019

all in the year 2019.
I certify (or declare) under penalty of perjury that the fore going is true and correct.

Signature
Colleen Collins
08/22/19 Lake Arrowhead, CA

This Space is for the Stamp.

PROOF OF PUBLICATION

LAKE ARROWHEAD COMMUNITY SERVICES DISTRICT
LACSD
EST. 1978

Lake Arrowhead Community Services District Public Workshop Notice Regarding the Lake Arrowhead Tracer Study

Lake Arrowhead Community Services District will be holding a Public Workshop on Tuesday, August 27, 2019, starting at 4:00 p.m. at the Lake Arrowhead Community Services District Board Room, located at 27307 St. Hwy. 189, Suite 104, Blue Jay, CA.

The Public Workshop is being held to notify residents of plans to use a tracer in Lake Arrowhead to assist with research being conducted by the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation and Arrowhead Lake Association. Arrowhead Lake Association will also be conducting an informational meeting on August 24, 2019. Please contact Arrowhead Lake Association for the meeting details.

More information can be found on our website at lakearrowheadcsd.com.

Published in the Mountain News August 22, 2019

The Alpine Mountaineer
P.O. Box 4572
Crestline, CA 92325-4572
Phone: 909.589.2140
Email: info@thealpinemountaineer.com

Affidavit of Publication

State of California
County of San Bernardino

Michael T. Harris being duly sworn, deposes and says that...he is and at all times herein mentioned was a Citizen of the United States, over the age of twenty-one years, and that...he is not party to, nor interested in the above entitled matter, that...he is the principal clerk of the printers of The Alpine Mountaineer, a newspaper of general circulation, printed and published in the State of California, County of San Bernardino, and which newspaper at which at all times herein subscription lists of paying subscribers, and...which newspaper at regular intervals in the said State of California, County of San Bernardino, for a period exceeding one year next preceding the date of publication of the notice hereinafter referred to, and which newspaper is not devoted to nor published for the interests, entertainment or instruction of a particular class, profession, trade, calling, race or denomination or any number of same: that the notice of which the annexed is a printed copy, had been published in each regular and entire issue of said newspaper and not in any supplement thereof on the following dates, to wit

08/22/19

I certify and declare under penalty of perjury that the foregoing is true and correct

Michael T. Harris

Dated: 8-22-19

The Alpine Mountaineer was adjudicated a Newspaper of General Circulation on August 3, 2018, in the Superior Court of San Bernardino, Case No. SCVSS232612

Lake Arrowhead Community Services District
Public Workshop Notice
Regarding the Lake Arrowhead Tracer Study

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More information can be found on our website at lakearrowheadcsd.com.

LAKE ARROWHEAD COMMUNITY SERVICES DISTRICT MEETING AGENDA

SPECIAL MEETING OF THE BOARD OF DIRECTORS

LAKE ARROWHEAD TRACER STUDY PUBLIC WORKSHOP

***DATE*: August 27, 2019**
***TIME*: 4:00 p.m.**

LACSD BOARD OF DIRECTORS
P.O. Box 700
Lake Arrowhead, CA 92352

***POSTING*: This agenda was posted prior to 4:00 p.m. on August 22, 2019, at the Board Room, District Office, & the District Website**

MEETING LOCATION
LACSD Blue Jay Board Room
27307 State Hwy. 189, Suite 104
Blue Jay, CA 92317

A. CALL TO ORDER – John Wurm, President
B. PLEDGE OF ALLEGIANCE TO THE FLAG
C. AGENDA POSTING CERTIFICATION
D. ROLL CALL

In compliance with the Americans with Disabilities Act, if you need special assistance to participate in this meeting, please contact Kathleen Field, Board Secretary (909) 336-7117. Notification 24 hours prior to the meeting will enable the District to make reasonable arrangements to ensure accessibility to this meeting. (28 CFR 35.102-35.104 ADA Title II)
All public records relating to an agenda item on this agenda are available for public inspection at the time the records are distributed to all, or a majority of all, members of the Board. Such records shall be available at the District office located at 27307 State Highway 189, Suite 101, Blue Jay, CA 92317 and our website at www.lakearrowheadcsd.com

E. APPROVAL OF AGENDA (Additions and/or Deletions)

F. PUBLIC COMMENT

This portion of the agenda is reserved for the public to speak to the Board of Directors on matters within the jurisdiction of the Lake Arrowhead Community Services District that are not on the agenda. The Board, except to refer the matter to staff and/or place it on a future agenda, may take no action. It is in the best interest of the person speaking to the Board to be concise and to the point. **A time limit of five minutes per individual will be allowed.**

Any person wishing to comment on an item that is on the agenda is requested to complete a request to speak form prior to the item being called for consideration. The form is submitted to the Clerk of the Board.

A. <u>DISCUSSION ITEMS</u>

The Public Workshop is being held to notify residents of plans to use a tracer in Lake Arrowhead to assist with research being conducted by the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation and Arrowhead Lake Association.

Discussion topics:

1. **Methods of Conducting a Tracer Study.**
   (Presenter: David James, PhD, University of Nevada, Las Vegas)

B. <u>ADJOURNMENT</u>

LAKE ARROWHEAD COMMUNITY SERVICES DISTRICT

MEMORANDUM

DATE: **AUGUST 27, 2019**

TO: **BOARD OF DIRECTORS**
Lake Arrowhead Community Services District

FROM:
CATHERINE CERRI, General Manager

SUBJECT: **PROPOSED TRACER STUDY USING RHODAMINE WT AND SUCRALOSE AS CO-TRACERS TO INVESTIGATE MIXING AND ASSIMILATION PATTERNS IN LAKE ARROWHEAD**

A. RECOMMENDATION

This is an information item.

B. REASON FOR RECOMMENDATION

This is an information item.

C. BACKGROUND INFORMATION

Researchers from the University of Nevada, Las Vegas in cooperation with the United States Bureau of Reclamation, the Arrowhead Lake Association and the Lake Arrowhead Community Services District are conducting a study of Lake Arrowhead. The purpose of the study is to create a manual for water purveyors across the country to understand how recycled water mixes into surface water. No recycled water will be put into Lake Arrowhead during the study.

The researchers have been collecting data from the local area, as well as the lake, and have created a three-dimensional hydrodynamic model of Lake Arrowhead. They are proposing to insert two non-toxic tracers into the lake in early October 2019. The two tracers include a diluted fluorescent dye called Rhodamine WT and sucralose, an artificial sweetener. The quantities of the tracers will not have any detrimental effect on the lake. The tracers will be inserted into the lake at a depth of 85 feet in the vicinity of Village Bay. Initially, the dye tracer will have a red tinge but will not be visible once it is diluted. A fluorometer will be used to detect the dye and determine its movement in the lake. Water samples will also be taken. The researchers will use the movement of the tracers to confirm or disprove the results from the hydrodynamic model. This method of tracing water movement has been used in similar applications around the country.

The manual that will be created will help water purveyors determine if augmenting an existing water body with recycled water is a viable option as an additional water supply. This is often referred to as Indirect Potable Reuse or IPR. Various applications of IPR are currently in operation. Typical applications include diluting recycled water into a water body or percolating it into groundwater from which it is later drawn out and treated for potable uses.

Arrowhead Lake Association and the Lake Arrowhead Community Services District have agreed to cooperate with the study to gather valuable information regarding the behavior of our lake. There are currently no plans to augment Lake Arrowhead with recycled water but the data from this study may be used to determine if it could be feasible at some point in the future.

D. FISCAL IMPACT

There is no fiscal impact associated with this item.

E. ENVIRONMENTAL IMPACT

The use of US EPA-allowed Rhodamine WT (RWT), a fluorescent dye tracer, and sucralose, an artificial sweetener, are two environmentally safe tracers. The United States Bureau of Reclamation has prepared an impact study in accordance with the National Environmental Protection Act, issued under Categorical Exemption Number CEC-LC-19-01. The study received this categorical exclusion under 516 Departmental Manual 14.5 because it is a research activity. The Evaluation determined that there will be no significant effects.

The Lake Arrowhead Community Services District is not a responsible or lead agency of this project in accordance with CEQA since it has no discretion over the study. Lake Arrowhead Community Services District is supporting the study by providing data but currently has no plans to utilize the information from this study for any project.

F. ATTACHMENTS

-Lake Arrowhead Tracer Study Information
-Environmental Categorical Exclusion Checklist

Technical Report Removed for Brevity
See Attachment 1, Waiver Request

BUREAU OF RECLAMATION
LOWER COLORADO BASIN REGION
CATEGORICAL EXCLUSION CHECKLIST

CATEGORICAL EXCLUSION NUMBER: CEC-LC-19-01
WBS OR KEY WOID: SNT 7100
DATE: 10/01/2018

PROJECT NAME: Lake Arrowhead Tracer Study

PROJECT DESCRIPTION:

In 2017, The Bureau of Reclamation (Reclamation) entered into a cooperative agreement(# Rl7AC00041) with the University of Nevada, Las Vegas (UNLV) for a Science and Technology Program titled, *Evaluation of Approaches to Determine Mixing and Assimilation of Reuse Ejjluent.* The program proposes using two environmentally safe tracers to investigate the pattern and intensity of mixing in Lake Arrowhead, CA for potential use of recycled water for surface water supply augmentation. Tracer study results will be used to calibrate a three-dimensional hydrodynamic computer model that will be used to simulate dilution and assimilation of a hypothetical recycled water influent into Lake Arrowhead (Attachment A).

During 2017 and 2018, the study focused on research regarding water quality, bathymetry, hydrodynamics, and reservoir operating conditions of Lake Arrowhead. Research also focused on literature reviews, agency coordination, and model selection. UNLV now proposes injecting U.S. Environmental Protection Agency approved Rhodamine WT (RWT), a fluorescent dye tracer, and sucralose, an artificial sweetener also used as a tracer, into the lake. The dye and sucralose would be injected into the lake using either a tank-based injection system or a tank-less injection system, the latter would also include an intake component to mix lake water with the dye before injecting it into the lake.

Findings obtained from the combined tracer studies and computer simulations will be used as a basis for preparation of a guidance manual to support future studies of potential use of recycled water for surface water supply augmentation that can improve communities' drought resilience.

Continued under"Remarks"

EXCLUSION CATEGORY:
516 Departmental Manual 14.5
Categorical Exclusions - (A) 3. Research activities, such as nondestructive data collection and analysis, monitoring, modeling, laboratory testing, calibration, and testing of instruments or procedures and nonmanipulative field studies.

EVALUATION OF CRITERIA FOR CATEGORICAL EXCLUSION

1. This action or group of actions would have significant effect on the quality of the human environment. (40 CFR 1502.3) No..X..Uncertain_Yes_.

2. This action or group of actions would have highly controversial environmental effects or involve unresolved conflicts concerning alternative uses of available resources. (NEPA Section 102(2)(E) and 43 CFR 46.215 (c)) No...X...Uncertain_ Yes_ .

3. This action would have significant impacts on public health and safety. (43 CFR 46.215 (a)) No_,X_Uncertain_ Yes_ .

4. This action would have significant impacts on such natural resources and unique geographic characteristics as historic or cultural resources; park, recreation or refuge lands; wilderness areas; wild or scenic rivers; national natural landmarks; sole or principal drinking water aquifers; prime farmlands; wetlands (EO 11990); floodplains (EO 11988); national monuments; migratory birds; and other ecologically significant or critical areas. (43 CFR 46.215 (b)) No...X...Uncertain_ Yes_ .

5. The action would have highly uncertain and potentially significant environmental effects or involve unique or unknown environmental risks. (43 CFR 46.215 (d)) No_,X_Uncertain_Yes_.

6. This action would establish a precedent for future action or represent a decision in principle about the future actions with potentially significant environmental effects. (43 CFR 46.215 (e)) No...X...Uncertain_Yes_.

7. This action would have a direct relationship to other actions with individually insignificant but cumulatively significant environmental effects. (43 CFR 46.215 (f)) No...X...Uncertain_ Yes_ .

8. This action would have significant impacts on properties listed or eligible for listing on the National Register of Historic Places as determined by Reclamation. (43 CFR 46.215 (g)) No_,X_Uncertain_Yes_.

9. This action would have significant impacts on species listed or proposed to be listed, on the List of Threatened or Endangered Species or have significant impacts on designated Critical Habitat for these species. (43 CFR 46.215 (h)) No...X..Uncertain_Yes_.

10. This action would violate Federal, State, local, or tribal law or requirements imposed for protection of the environment. (43 CFR 46.215 (i)) No_,X_Uncertain_ Yes_ .

11. This action will adversely affect Indian Trust Assets (ITA). (S.O. 3175) No_x_Uncertain_Yes_.

12. This action would have a disproportionately high and adverse effect on low income or minority populations. (43 CFR46.215 (j)) No_X_Uncertain_ Yes_ .

13. This action would limit access to and ceremonial use of Indian sacred sites on Federal lands by Indian religious practitioners or significantly adversely affect the physical integrity of such sacred sites (EO 13007). (43 CFR 46.215 (k)) No_X_Uncertain_ Yes_ .

14. This action would contribute to the introduction, continued existence, or spread of noxious weeds or non-native invasive species known to occur in the area or result in actions that may promote the introduction, growth, or expansion of the range of such species (Federal Noxious Weed Control Act and EO 13112). (43 CFR46.215 (1)) No_X_Uncertain_ Yes_ .

NEPA Documentation:	Categorical Exclusion	X
	EA	
	EIS	

REMARKS:

The National Pollutant Discharge Elimination System (NPDES) permit program is delegated to the California Regional Water Quality Boards (CRWQB). Discharge reporting waivers for RWT and sucralose have been submitted to the CRWQB and are awaiting approval.

There will be no effect on proposed, Threatened or Endangered Species. There is no designated Critical Habitat in the project area.

The proposed action has been reviewed for possible effects to Indian Trust Assets (ITAs). ITAs have not been identified in the project area; so no impact to ITAs is anticipated.

The study proposes to use two environmentally safe tracers to investigate the pattern and intensity of water mixing. The undertaking has no potential to affect historic properties (NOPE) and meets NOPE Category 23: Monitoring of facilities, biota, or environmental condition where no ground or other physical disturbance occurs.

ENVIRONMENTAL COMMITTMENTS:

General

All Federal, State, and local required permits shall be obtained prior to the start of the project.

A NPDES Perm.it or reporting waiver shall be obtained from the appropriate CRWOB before the tracer study can proceed.

Biological

All project equipment that is used in water bodies, rivers or streams, or that mixes water from these sources shall be decontaminated prior to and after use to prevent the spread of Aquatic Invasive Species. Refer to decontamination protocols located in *Recommended Protocols and Standards for Watercraft Interception Programs for Dreissenid Mussels in the Western United States.* This document can be found at: htt ://www. smfc.or ro ram/ ro -4? id=17

To prevent the spread of noxious and invasive weeds, equipment used for this project shall be thoroughly cleaned prior to entering the project site. The cleaning process will ensure that all dirt and debris that may harbor noxious or invasive weeds seeds are removed and disposed of at an appropriate facility. Reclamation's *Inspection and Cleaning Manual fur Equipment and Vehicles to Prevent the Spread of Tnvasive Species: 2012 Edition* should be referenced for inspection and cleaning activities. The manual can be found at: http://www.usbr.gov/mussels/prevention/docs/Eguipmen tinspectionandCleaningManuaJ2 012.pdf

If biological issues or questions arise prior to or during project implementation contact Reclamation's Biological Services Coordinator at 702-293-8130.

Hazardous Materials

If there are any spills of a hazardous material during the tracer study contact the Lower Colorado Basin Region Hazardous Materials Coordinator at 702-293-8130 so that the appropriate notification can be made and cleanup procedures are followed.

Cultural

In the event of an unanticipated discovery, all operations in the area of the discovery will cease and a Reclamation archaeologist contacted at 702-293-8130. "Discovery" means the encounter of any previously unidentified or incorrectly identified cultural resource including, but not limited to, archaeological deposits, human remains, or places reported to be associated with Native American religious beliefs and practices.

Preparer's Name and Title: Date: 10/22/18.
Environmental Protection Assistant

Concurrence with Item 5 & 10: Date: 10/22/18.
Hazardous Materials Specialist

Concurrence with Item 4, 9 & 14: Date: 10/23/18
Biological Services Coordinator, Compliance

Concurrence with Item 8 & 13: James Kangas Date: 10/23/2018.
(required) Cultural Resources Management Professional

Concurrence with Item 11: James Kangas Date: 10/23/2018
(required) Designated Indian Trust Asset (ITA) Coordinator, Area Manager, or Office Director

Approved By: Date: 10/23/2018.
Environmental Compliance Group Manager, LC-2600

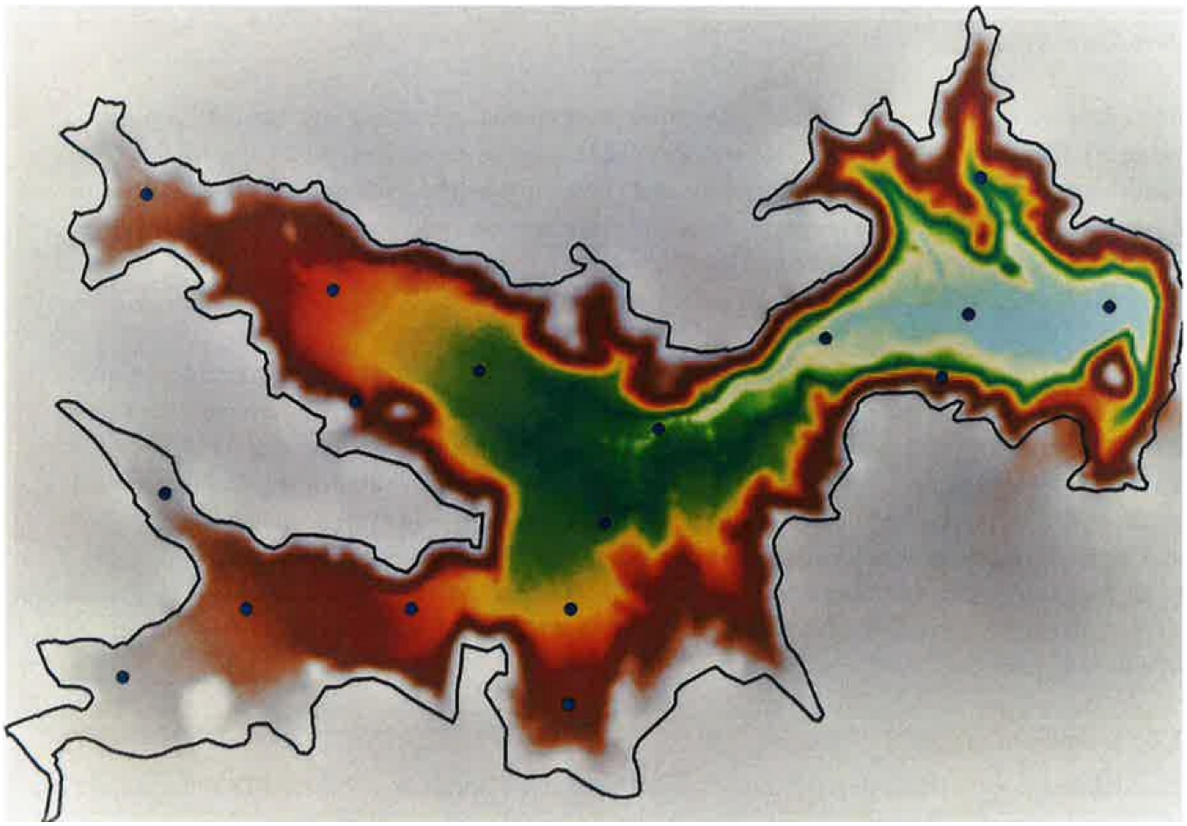
Attachment A

CEC LC-19-01

Introduction and Background - Needs and Benefits, Public Interest and Risk

Proposed Lake Arrowhead Tracer Study

Figure A. Color-coded contour map of Lake Arrowhead's bathymetry. Blue dots show proposed Rhodamine WT and sucralose tracer sampling locations. Depth color codes: Light green:> 100 feet. Green: 80-100 feet. Yellow: 60-80 feet. Red: 40-60 feet. Maroon: 20-40 feet. Grey: < 20 feet



1.1 About Lake Arrowhead

Lake Arrowhead reservoir (Figure IA and IB) was created by clearing Little Bear Valley and building a semi-hydraulic fill dam to impound inflows from Little Bear Creek. Stream inflows from Little Bear Creek and the subsequently completed Grass Valley Tunnel are ephemeral, primarily occurring winter rainfall and occasionally from spring snowmelt. The spillway is not at the dam but at Willow Creek on the north shore of the lake. According to the 2008 US Bureau of Reclamation Bathymetry survey[1] the reservoir, when full, has a storage capacity of 46,855 acre-feet and a surface area of 767 acres at a water surface elevation of 5,106.7 feet (ALA datum of 1917). The maximum depth of the lake is in excess of 150 feet. It has over 2,500 recreational boating docks on its 14 miles of shoreline. The lake's maximum width is 1.5 miles and length from east to west is about 2.2 miles.

[1] USBR, 2009. *Lake Arrowhead 2008 Reservoir Survey.* Technical Report No. SRH-2009-9 https://doi.or g/bttps ://w ww. usb r.gov/tsc/tech.references/reservoir/Lake Arrowhead 2009 Report. pdf

The lake serves as a water supply only for the community of Arrowhead Woods, with a 2010 census population of 12,424. The reservoir also provides recreational boating, swimming and fishing access. The lake is privately owned, and managed by the Arrowhead Lake Association (ALA). Water supply and treatment, along with sewage collection and treatment, are provided by the Lake Arrowhead Community Services District (LACSD). Sewage collection and treatment are provided by LACSD to the communities of Arrowhead Woods, Blue Jay, Cedar Glen, Skyforeest, Rim Forest, Deer Lodge Park and Arrowhead Villas.

The lake's water inflows are primarily from direct precipitation and streamflow. Net outflows are primarily from evaporation and withdrawal for potable water use from two intakes, one located on the south shore of North Bay, the Bernina intake, and one located on the south shore of Emerald Bay the Cedar Glen intake. In above average precipitation years, outflows will occur over the Willow Creek spillway. In drought years, the lake level may never reach the spillway. As of June 27, 2018, the lake level was 7.0 feet below the spillway elevation.

A prolonged trend of decreasing precipitation has prompted the community to begin evaluation of alternative sources of water supply to augment the lake level. LACSD can utilize groundwater from a couple of wells and purchase water from the Crestline Lake Arrowhead Water Agency (CLAWA). A third option would be to return wastewater effluent treated to near-potable standards, called recycled water, to the reservoir for additional residence time, a process called indirect potable reuse through surface water augmentation. It is the purpose of this request for a waiver of discharge reporting requirements to conduct a tracer study to evaluate the transport and mixing of tracer compounds over time so that mixing processes in the lake can be better understood and incorporated into a three-dimensional hydrodynamic model.

1.2 Summary of proposal

The attached proposal describes the use of US-EPA approved Rhodamine WT (RWT), a fluorescent dye tracer, and sucralose, an artificial sweetener, as two environmentally safe tracers (co-tracers) to investigate the pattern and intensity of mixing in Lake Arrowhead. The work would be carried out as a collaborative effort among UNLV (funded by the US Bureau of Reclamation, USBR), the Arrowhead Lake Association and the Lake Arrowhead Community Services District. If the requested waiver of discharge reporting requirements for use of the tracers is approved, tracer study results will be used to calibrate a three-dimensional hydrodynamic computer model that will be used to simulate dilution and assimilation of a hypothetical recycled water influent into Lake Arrowhead under different weather conditions. Findings obtained from the combined tracer study and computer simulations will he used as a basis for preparation of a USBR-guidance manual for water purveyors to support future studies of potential use ofrecycled water for surface water supply augmentation that can improve communities' drought resilience.

As this study proposes the use of two different tracers, this waiver of discharge reporting requirements application contains two distinct parts that can be separately reviewed:

- Sections 1 and 2: Request for a waiver for a proposed Rhodamine WT (RWT) tracer study, and
- Sections 3 and 4: Request for a waiver for a proposed sucralose tracer study.

The proposed RWT tracer study can be conducted if the proposed sucralose tracer study is not approved. However, if approved, implementation of sucra/ose as the second tracer (or co-tracer) depends on approval of the RWT tracer study, because RWT fluorescence will be used to determine where to sample for sucralose.
The proposed use of the two co-tracers will significantly increase the validity of findings, as each tracer result can be compared to the other. In addition, since RWT tracer will slowly photodegrade in well-illuminated surface waters, and sucralose is very stable, cross-validation with sucralose as a non-fluorescent tracer can be used to determine the overall rate ofRWT decay in Lake Arrowhead, improving the accuracy of dilution estimates.

After RWT tracer injection, Eureka fluorometric sondes with a resolution of 0.01 parts per billion (ppb) for RWT and a feasible detection limit of0.01 ppb for RWT, and a combined analysis method of Solid Phase Extraction (SPE) followed by High Pressure Liquid Chromatography-Tandem Mass Spectrometry (HPLC-MS) with a Method Detection Limit (MDL) of0.005 ppb for sucralose will be used to measure tracer concentrations. Due to the low detection limits of both the RWT sondes and the HPLC-MS methods, very small masses (3.91 kilograms or 8.62 pounds) of each tracer could be released and tracked in the lake. Assuming a full lake level, the final concentration of each tracer when completely mixed with lake water would be 0.067 ppb. These mixed concentrations are factors of several thousand to several million below the tracers' recorded toxicities for aquatic life. The completely mixed RWT concentration is well below the US EPA advisory opinion stating a 10 ppb limit for use as a tracer in the vicinity of drinking water intakes (Turner Designs website, document 998-5104). No adverse effects are expected on either human health or Lake Arrowhead's aquatic life at the proposed concentrations.

In this proposed study, if approved, both tracers would be released simultaneously. The primary tracer in this proposed study is the Rhodamine WT (RWT) dye. If approved, movement and dilution ofRWT would be measured in real-time after injection by repeatedly conducting vertical profiles Manta TDX fluorometric sondes at different locations on the lake. For the proposed second tracer, sucralose, I-liter water samples would be withdrawn from the lake at designated target depths using Van Dom bottles, and transported to UNLV's environmental engineering laboratory for chemical analysis. Since neither tracer will be visible, identification of sampling locations for the sucralose tracer will rely on the real-time fluorometric readings of the RWT tracer.

If the tracer study is approved, results of these two proposed tracer studies will be used to calibrate a three-dimensional hydrodynamic model that will be used to simulate dilution and assimilation of a hypothetical recycled water influent into Lake Arrowhead under different weather conditions. Findings obtained from the combined tracer studies and computer simulations will be used as a basis for preparation of a guidance manual to support future studies of potential use of recycled water for surface water supply augmentation that can improve communities' drought resilience.

1.3 Needs and Benefits

Many communities currently use surface water sources of varying quality to supply their drinking water, including sources that are subject to upstream discharges of treated wastewater. In an era of sustained drought, the need to develop additional sustainable water supplies to address growing populations and declining supplies, combined with recent advances in water reclamation technologies, has motivated study of recycled water (highly-treated wastewater treatment plant effluent) as a potential resource to augment drinking water supplies (Asano ct al., 2007). Currently, in the United States, direct use of recycled water for human consumption is not permitted. However, a growing number of communities are studying potential indirect potable reuse through surface water augmentation, with two-fold protection provided by advanced water reclamation technologies and blending recycled water in a lake or reservoir (Asano et al., 2007). In this context, the lake or reservoir acts as an environmental buffer, allowing the recycled water to undergo additional processes of degradation, dilution, and assimilation (Hawker et al., 2011). Hence, the degree of dilution of the recycled water discharge with the lake or reservoir and travel time to intakes are the two key components of a multiple barrier approach to reduce public health risks (Preston et al., 2014).

The University of Nevada, Las Vegas (UNLV) is conducting an applied research project, funded by the U.S. Bureau of Reclamation, on development of a guidance manual for communities to evaluate and use best-practice approaches to estimate the dilution and travel time ofrecycled water in lakes and reservoirs. In partnership with the Lake Arrowhead Community Services District (LACSD) and the Arrowhead Lake Association (ALA), this project is using Lake Arrowhead as a case study site to develop the best practice guidelines. The manual includes sections on environmental data collection, lake water quality monitoring, three-dimensional hydrodynamic modeling to simulate mixing and assimilation of recycled water, and the potential use of tracers to validate the hydrodynamic model. An ongoing water quality monitoring program has been initiated in May 2018 to generate input data for the hydrodynamic model by measuring recording and analyzing various properties of the lake. Measured water quality parameters include temperature, conductivity, chlorophyll-a, pH, dissolved oxygen (DO), and photosynthetically active radiation (PAR) versus depth at six locations to determine the intensity of horizontal and vertical mixing that exists in Lake Arrowhead.

This project proposes to use Rhodamine WT (RWT) fluorescent dye and sucralose, an artificial sweetener, as co-tracers to estimate dilution, travel time and mixing intensity in different parts of Lake Arrowhead. Results of this proposed dye tracer study will be used to estimate the magnitudes of both wind-driven mixing and coefficients of eddy diffusion that will serve as inputs to the three-dimensional hydrodynamic model. Subsequently, the calibrated model will be used to accurately determine travel time and simulate dilution of hypothetical recycled water discharges to Lake Arrowhead under representative variations in meteorological conditions.

1.4 Public Interest

This propose<l tracer stu<ly has the support of the Lake Arrowhead Community Service District (LACSD) and the Arrowhead Lake Association (ALA). The proposed discharge of tracer, and associated waiver of discharge reporting is in the public interest because, if approved, results of the proposed tracer study and associated numerical modeling would be used to prepare a best practice "how to" guidance manual for communities throughout California and the western United States that are interested in conducting water quality studies that would support decisions about augmenting their water supplies and improve their drought resilience. Results of the proposed tracer study could also serve as preparatory material for a future specific indirect potable reuse surface water augmentation study to support improvement of drought resilience for the Lake Arrowhead community.

1.5 Risk

The proposed RWT discharge will use calibrated high resolution (0.01 ppb) fluorometric sondes to assess the movement of low concentrations of Rhodamine WT tracer dye. US EPA's August 2, 1988 letter stated that they did "not anticipate any adverse health effects resulting from the use of Rhodamine WT as a fluorescent tracer in water flow studies when used within the following guidelines:

- A maximum concentration of 100 micrograms/liter Rhodamine WT is recommended for addition to raw water in hydrological studies involving surface and ground waters.
- Dye concentration should be limited to 10 micrograms/liter in raw water when used as a tracer in or around drinking water intakes.
- Concentration in drinking water should not exceed 0.1 micrograms/liter. Studies which result in actual human exposure to the dye via drinking water must be brief and infrequent. This level is not acceptable for chronic human exposure."

There are two water intakes in Lake Arrowhead, one 2,950 feet and another 4,235 feet from the proposed injection site. The intakes are at a summer 2018 depth of about 71 feet, approximately 21-38 feet deeper into denser waters in the thermocline than the proposed 33-50 foot injection depth in warmer less dense waters.

Preliminary worst-case estimates of travel time, dilution and movement of the dye tracer indicate that, since the tracer will continue to be diluted as it travels in longer indirect paths across the lake and then along the shoreline or follow bathymetry before turning back to the intakes, estimated concentrations of tracer will be in the range of 1.7 to 2.7 ppb at the level of the intakes if, in a worst-case scenario the tracer plume were to approach the drinking water intakes in the first 1.2 to 1.6 days of the study (please see **Appendix 4** of the Rhodamine WT request). Added tracer concentrations would be 0.067 ppb above background values when fully mixed with lake water, if, assuming conservatively, no degradation were to occur. There is no RWT in Lake Arrowhead, but background fluorescence due to algal pigments has been detected at levels as high as 0.05 ppb.

These predicted results show that it is very unlikely that RWT concentrations approaching the 10 ppb limit will occur at the drinking water intakes. In place will be monitoring and notification procedures, along with a plan by LACSD to divert to alternative supplies in the event that the 10 ppb limit is approached. The RWT tracer sections of the waiver request provide detailed information about plans to monitor the drinking water intakes for any increase in RWT that approaches the 10 ppb US EPA advisory limit. shut the intakes, and monitor in the plant for RWT. UNLV conducted an experiment using the standard LACSD 4 mg/L chlorine dose in Lake Arrowhead water and showed that even if the tracer plume with an RWT concentration of 10 ppb were to approach the drinking water intakes, the chlorinated water rapidly reacts with the RWT and the RWT concentration drops to the drinking water US EPA Advisory limit of 0.1 ppb in 8 minutes and to the 0.01 ppb detection limit in 11 minutes (please see **Appendix 5** of the Rhodamine WT waiver request). These reaction times that are far less than the 10-20 hour holding times in LACSD's storage tanks prior to release of treated water to the distribution system

Sucralose is approved by the Food and Drug Administration (FDA) as a safe general-purpose sweetener. Sucralose has been studied extensively, and the FDA reviewed more than 110 safety studies in support of its approval of the use ofsucralose as a general-purpose sweetener for food (US FDA, 2018).

Aquatic toxicity of sucralose is much lower than for RWT dye. Ecotoxicological assessments of sucralose using U.S. EPA's Ecological Structure Activity Relationship Model, ECOSAR (USEPA, 2010) suggest that sucralose may cause toxicity to aquatic organisms only at concentrations of 1.123 mg/L (1.123.000 ppb) (Tollefsen et al., 2012).

Comparing the toxicity threshold of 1,123.000 ppb to either starting concentrations of 70-100 ppb or to the final mixed concentration of 0.067 ppb that would be used in this tracer study, no adverse effects on aquatic environment in Lake Arrowhead are expected. From a May 11, 2018 sampling, background sucralose concentrations in Lake Arrowhead were found to range from 0.030 to 0.084 ppb.

Detailed descriptions of the proposed tracer addition, monitoring, notification and if needed, spill clean-up procedures are described in the attached requests for permit waivers that can be reviewed separately.

- Sections 1 and 2: Request for a waiver for a proposed Rhodamine WT (RWT) tracer study, and
- Sections 3 and 4: Request for a waiver for a proposed sucralose tracer study.

References

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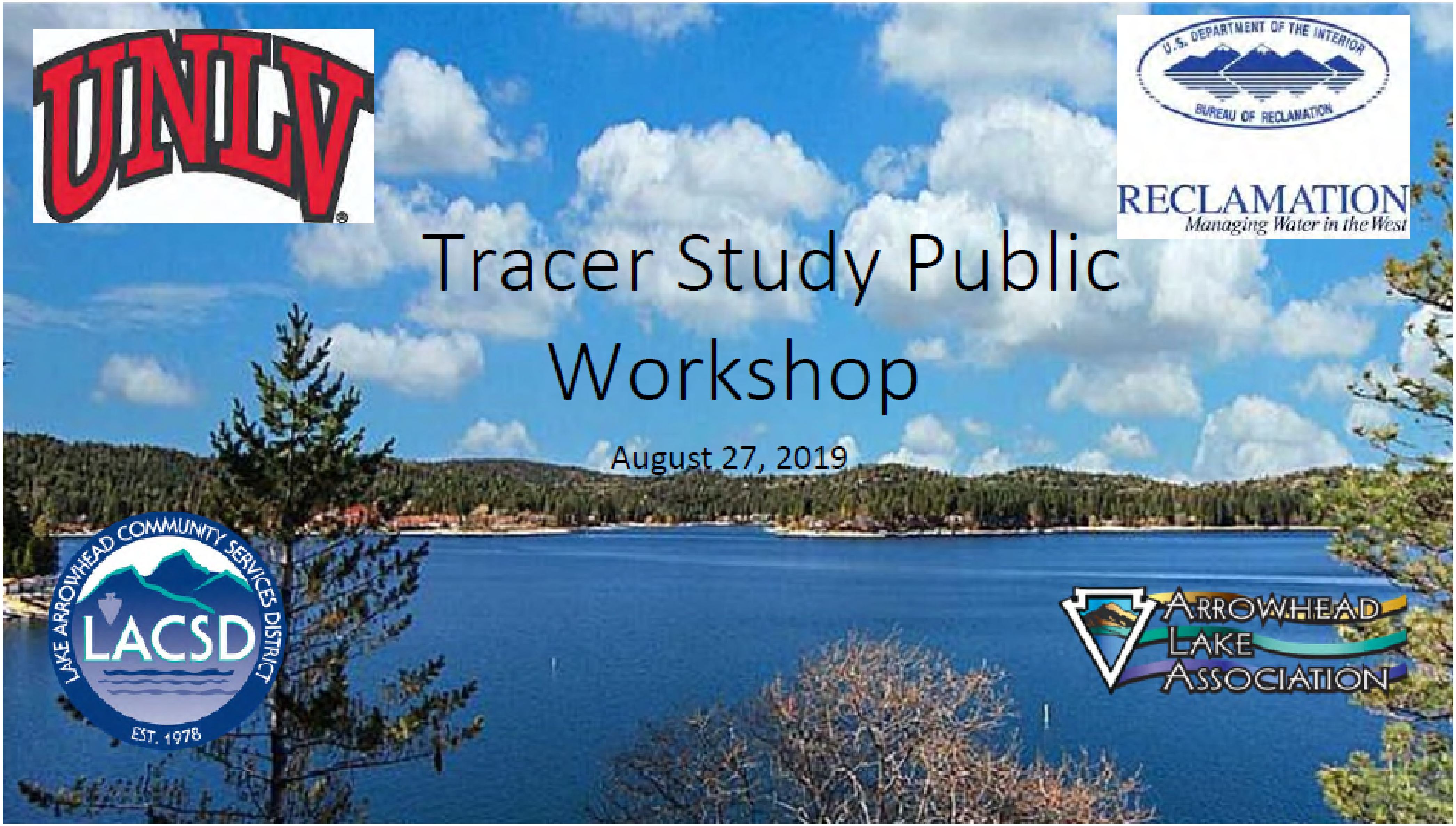
Appendix 3.1 – Lake Arrowhead Tracer Study Outreach Handout

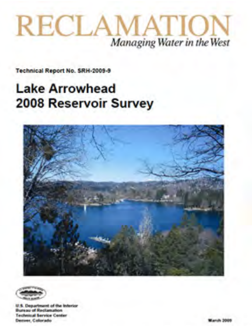

UNLV
U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION
RECLAMATION
Managing Water in the West
Tracer Study Public Workshop
August 27, 2019
LAKE ARROWHEAD COMMUNITY SERVICES DISTRICT
LACSD
EST. 1978
ARROWHEAD LAKE ASSOCIATION

Background

- Historic drought in US southwest since 2000, yet population has continued to grow. See: https://earthobservatory.nasa.gov/images/144216/drought-persists-in-the-us-southwest
- More people, less water – Water agencies need to find and develop alternative sources of supply to maintain quality of life, and resiliency of water supply system.
- One future option is mixing and dilution of recycled water into lakes, called Surface Water Augmentation (SWA) by Indirect Potable Reuse (IPR)
- For Arrowhead, SWA could potentially recover 1 foot of lake level
- Before even considering this future option, first need to evaluate travel time and mixing of water in the Lake.
- US Bureau of Reclamation mission includes partnerships with Western water agencies to assist with conservation and management of their water resources
- See: https://www.usbr.gov/main/about/mission.html

Recent partnerships

- US Bureau Reclamation has previously supported water resource work here
  - 2008 Bathymetry study in partnership with ALA to determine available volume of Arrowhead Reservoir



  - 2012 water quality model and study

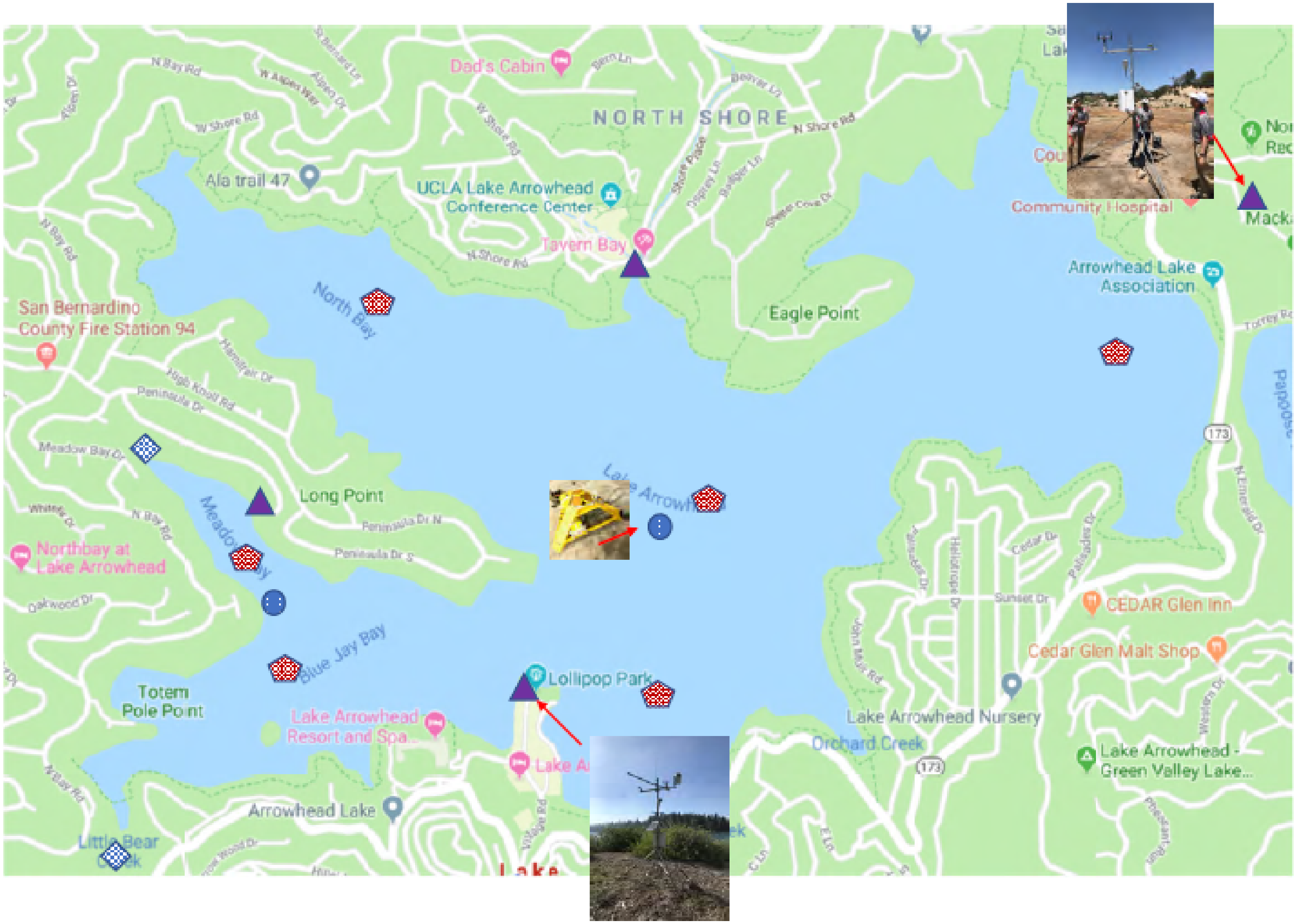
  - Recently completed study with LACSD on regional wells

  - Current study, Reclamation Denver loaning equipment and expertise for water movement measurement in two parts of Lake Arrowhead

Current partnership

- Reclamation seeks to develop a user ‘how-to’ manual of best practices for monitoring and modeling lake water movement as a first step in considering SWA. Completed manual to be available across all of Western US
  - 2017: ALA and LACSD agreed to collaborate as community partners where Arrowhead Reservoir serves as case study for the ‘how to’ manual
  - 2018-9: Reclamation Boulder City and Reclamation Denver offices loaning equipment and support for project
- Benefit to community: information generated about Arrowhead that could support follow-on studies if ALA and LACSD wish to evaluate future feasibility of IPR
  - UNLV role is to work with ALA and LACSD to obtain lake water and weather data, then analyze data and generate a report, shared with ALA, LACSD and Reclamation
  - ALA and LACSD knowledge of lake conditions and participation by maintenance, operations, safety personnel have been invaluable
  - Thanks ALA! Thanks LACSD!

What UNLV has been doing on the lake since May 2018 to understand overall water movements



- With ALA, monitoring lake water quality weekly at 5 locations
- Measure lake winds at McKay Park, Lollipop Park, Tavern Bay and Meadow Bay
- Reclamation measures vertical lake water movement in Meadow Bay and center channel
- Measure lake inflow properties at Little Bear Creek and Grass Valley tunnel/channel

Why a proposed tracer study?

- For the user manual, need to show how to measure travel time of water across the lake and mixing and dilution of water as it moves
- Closest analogy: stir cup of coffee or tea to more rapidly mix (stir) milk or sugar throughout the cup
- At Lake Arrowhead, stirring and water movements are wind-driven
- Best way to measure travel time and mixing is with a non-toxic tracer
- Plus, if Surface Water Augmentation is to be considered as a future option, California regulations require 2 years of intensive prior monitoring and a tracer study before applying for permission to design a system. See pages 29 and 30 at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/swa/apregtext.pdf
- Also, extensive additional treatment capability must be added, tested and continually monitored

What are the steps?

- Select non-toxic tracers that can be detected at low concentrations
- Monitor lake water and winds to anticipate rate and directions of water movement and determine background concentrations
- Select lake location and depth based on monitoring
- Build a tracer addition system to safely put tracer in lake at intended location and depth
- Develop plan to monitor added tracer
- Submit plan to Water Quality Control Board requesting permission
- Hold public comment workshops, forward information to Board
- Receive results of review by Water quality Board
- If yes, conduct study! Add tracer, monitor movement and concentration, calculate travel time and dilution and validate model
- Example, see City of San Diego North City Pure Water Project links at: https://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/Surface_Water_Augmentation_ Regulations.html
- Use validated model to run scenarios for recycled water release at different dates throughout at least one annual cycle

How would study be done at Lake Arrowhead?

- When: proposed for Oct 8, 2019
- How:
- Place barge with tracer system in center of lake
- Add tracer with pump at depth of about 40 feet where it can't come up to surface
- Monitor from boats stationed in lake
- for a week or until tracer can't be detected

What kinds of tracers are proposed?

- Rhodamine WT – fluorescent dye
- Amount added: 8.6 pounds
- How to Measure: Blue light makes it fluoresce in the yellow. Measure with a probe and computer
- Properties:
- Initial color in a thin layer of lake water at 33-50 foot depth like weak cranberry juice
- Detectable to very low concentrations (about 0.01 ppb) Lake background of fluorescing compounds is 0.2 ppb
- Effects:
- Nontoxic to algae and fish at added levels
- Will not stain fish at added levels
- What will happen:
- Added initial mixed concentration at 33-50 foot depth would be 200 ppb. (color weak pink lemonade).
- Within 10 hours, expect it to dilute to maximum of 10 ppb (colorless)
- Added dye concentration declines in lake water, by combination of dilution due to mixing and slow chemical decay due to sunlight and microbial action

What kinds of tracers are proposed?

- Sucralose – artificial sweetener – Add 8.6 pounds Sucralose background in L. Arrowhead is 0.030-0.034 ppb
- How to measure: Collect water samples at depth, pour into containers.
- Transport containers to UNLV and measure in lab with gas chromatograph
- Properties
- colorless, odorless
- Can detect to 0.01 ppb
- Effects:
- Non-toxic to shrimp and fish at added levels
- Below sweetness threshold at added levels
- What will happen:
- Added initial mixed concentration at 33-50 foot depth would be 200 ppb.
- Within 10 hours, expect it to dilute to maximum of 10 ppb (almost colorless)
- Why use this tracer too?
- Rhodamine can degrade 1-2% per day in sunlight. Sucralose degrades at much slower rate.
- Sucralose concentration decline almost entirely due to dlilution. Sucralose can check rate of Rhodamine WT decay

How we will put tracer into lake and prevent spills

Prepare for study

- Put tracer in tank at dockside
- Move ALA barge to Lake center in early morning
- When winds calm and
- Lake is smoothest, least turbulent
- Add tracer to water at depth
- ALA shoreline and patrol will support barge operation

Put tracer in lake

- With pumped stream of lake water from 33-50 feet
- Put diluted tracer into lake at same depth
- Have spill containment trough around tracer tank and spill control kits on barge

Monitor tracer movement

- Once tracer added
- Monitoring boats will circle addition area
- and also check for movement into Blue Jay, North Bay, and Emerald Bay/Dam

Information will help UNLV to

- Determine rates of
  - Horizontal movement of Arrowhead lake water at depth
  - Vertical mixing (stirring) of Lake Arrowhead
- Then
- validate computer model of lake water movement
- we would adjust the modeling values so that model matches what we measure

Arrowhead community will

- Have access to a validated hydrodynamic model that can be used for future work on:
- developing a plan for evaluating alternatives for surface water augmentation, such as potentially:
- where to return the recycled water,
- At what rate to return to lake
- When during year to return to lake

Thank you for your time and attention!

- I would be pleased to answer any questions

- Contact information:

- David E. James, PhD
- University of Nevada, Las Vegas
- Email: dave.james@unlv.edu
- Telephone: 702-895-5804

Appendix 3.2 – Public Outreach Question and Answer Summary

Catherine Cerri, General Manager

August 28, 2019

Jehiel Cass
Lahontan Regional
Water Quality Control
Board

Appendix 3.2 – Summary of Questions and Answers (Q&A) from public during Aug. 24, 2019 and Aug 27, 2019 public outreach meetings, scheduled 90 days prior to proposed Arrowhead tracer study date

Dear Mr. Cass,

On July 26, 2018, the Lake Arrowhead Community Services District (LACSD) submitted a waiver request (Attachment A) on behalf of the University of Nevada, Las Vegas (UNLV) to the Lahontan Regional Water Quality Control Board (Lahontan) to allow the use of two tracers in Lake Arrowhead. The purpose for the tracers is to calibrate a three-dimensional hydrodynamic computer model that will simulate dilution and assimilation of a hypothetical recycled water influent under different weather conditions. The two proposed tracers will be Rhodamine WT and sucralose. The scheduled date for the tracer release is October 8, 2019.

LACSD is assisting with the research that is being conducted by UNLV, and the United States Bureau of Reclamation (USBR) in cooperation with the Arrowhead Lake Association (ALA). Results of the research project will assist water purveyors with drought resiliency by generating a guidance manual to help them determine the feasibility of augmenting surface water with recycled water. The manual will provide guidelines for a consistent approach to surface water augmentation studies that may also assist regulators in their consideration of related permits.

LACSD and ALA conducted public outreach in accordance with the waiver request. Two public workshops were held on August 24, 2019 and August 28, 2019. A listing of the outreach activities is attached.

The first workshop was held by ALA immediately after a public Board of Directors meeting. Notices were posted on ALA's website, on site and were advertised in a local paper for three consecutive weeks. ALA also sent an email blast regarding the workshop to 5,449 email subscribers. Approximately 60 people were in attendance at the Board of Directors meeting, after which, an announcement was made regarding the tracer study public workshop. Only 15 members of the public remained.

LACSD held the second workshop. Notices were posted on site and advertised in two local newspapers the week before. Notices were also posted on the website, Facebook, and Twitter. 3,824 emails were sent out to subscribers. Only one public member attended.

At both of the workshops, Dr. David James from UNLV presented the information that was included on the handout attached to this letter. He also brought samples of the tracers proposed for the study and the method for detecting them in the lake.

Below is a summary of the questions that were posed at the workshops and the answers that were given. All of the questions were answered to their satisfaction. The public conveyed their appreciation for the significant safety measures that would be deployed.

- Q: A study was done at Cal Poly Pomona using pond lilies to reduce turbidity. How will suspended solids affect your study?
    - A: We are not familiar with that study but would be interested to learn more about it. We will be using the thermocline to keep the tracer below the surface. Compounds accumulate at the bottom of the epilimnion. Turbidity does not affect the ability by the probes to detect Rhodamine WT.
- Q: There is too much boat traffic and churning of the water in the summer. When do you plan to conduct the study?
    - A: The study needs to be conducted while the thermocline is still strong but after the busy boating season. The plan is currently to deploy the tracers on October 8, 2019.
- Q: Lake Arrowhead is unique in that it captures most of the runoff in the watershed. Some members of the community don't think augmenting the lake with recycled water is a good idea. Will there be public participation before this is done? Will this study allow for recycled water to be put in the lake?
    - A: No. This study will not be sufficient to determine the feasibility of adding recycled water to the lake and will not allow for recycled water to be put into the lake without public participation. It may provide good information but not enough to apply for a permit.
- Q: Have ALA or LACSD paid any money for this study?
    - A: No. They have provided data and some staff time but have not paid any money for the study. It is being funded by USBR.
- Q: I have a sensitivity to dyes. Will the tracer get into the drinking water system? If so, can it be removed by LACSD's treatment process or by home filtration?
    - A: The conservative plan for LACSD to fill its water reservoirs so that the water treatment plant intakes may be turned off on the day of the tracer release. There will be constant monitoring for the tracer near the intakes, and the raw water will be also be monitored before it enters the treatment plant. If tracer is detected, the pump station will be turned off.
- Q: Can the dye stimulate algal growth?
    - A: No.
- Q: How long will it take for the tracers to disappear?
    - A: Rhodamine WT degrades at a rate of 1% per day so it is anticipated to disappear in approximately 50 days. Sucralose is much more stable and degrades 1% per week. At this rate it would take 2 years to dissipate but it will dilute to the same as current levels much sooner than that.
- Q: How much more work would need to be done after this research to complete a feasibility study for a permit?
    - A: An engineer licensed in California would need to prepare a study. They could use the model that is being created but would need to add some additional data points such as point of entry, quantity, quality and rate. They would then need to model several scenarios using different weather patterns and stratification to determine the retention time and dilution before it reaches the water intakes.

- Q: Would the dilution be greater if the recycled water was placed into Grass Valley Lake first?
    - A: Yes, the dilution would be greater but Grass Valley Lake is a small water body with two outlets. It would be quickly filled and overflowing.

We appreciate your attention to this waiver request. We would like to move forward with the planned release date of October 8, 2019.

Sincerely,

Catherine Cerri
General Manager

<u>Attachments</u>

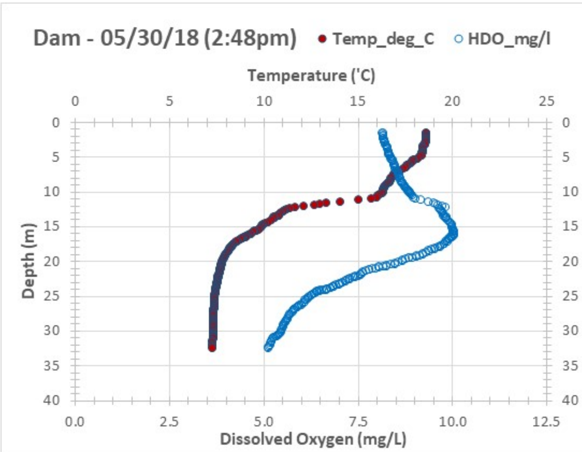
1. Waiver Application
2. Presentation regarding tracer study
3. ALA Notices
4. LACSD Notices

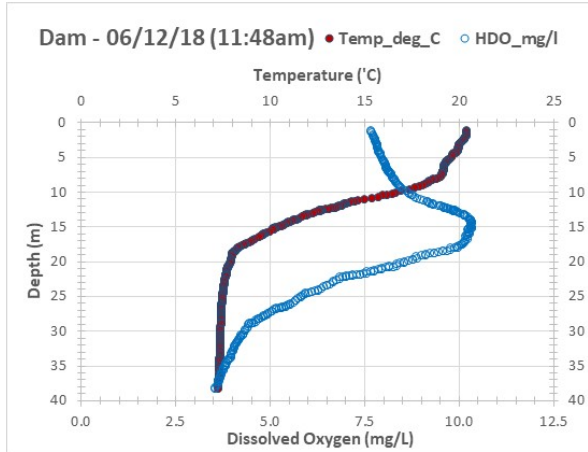
Lake Arrowhead Community Services District ■ P.O. Box 700, Lake Arrowhead, CA 92352 ■ (909) 336-7100
www.lakearrowheadcsd.com

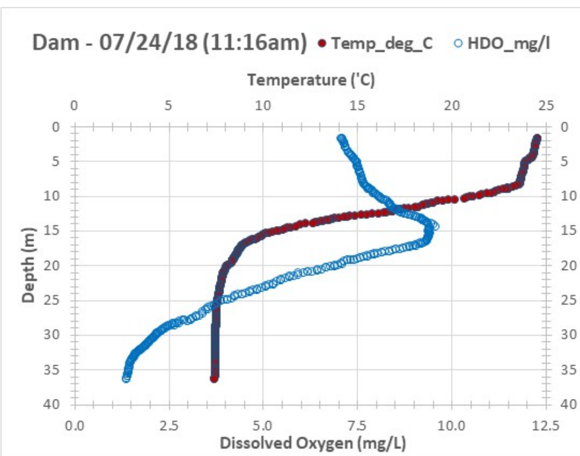
Appendix 6.1 – Example monitoring profiles for Hydrodynamic Model calibration

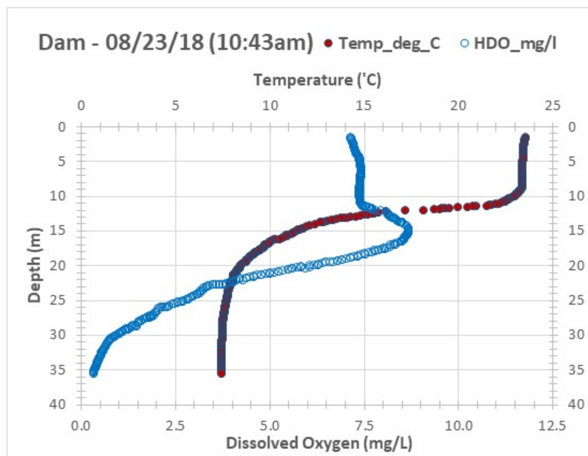
Appendix 6.1 – Two years' monthly monitoring depth profiles dissolved oxygen & fluorometric chl-a– Lake Arrowhead, Ca.

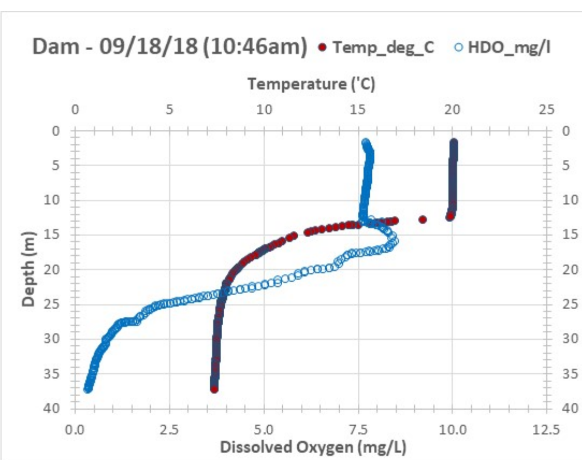
The first 12 figures (this page and the next page) show stratification build-up in summer 2018, development of deep water anoxia, then fall-winter destratification & deep water reoxygenation, then reestablishment thermocline Spring 2019. Note: HDO in legend means Dissolved Oxygen (DO).

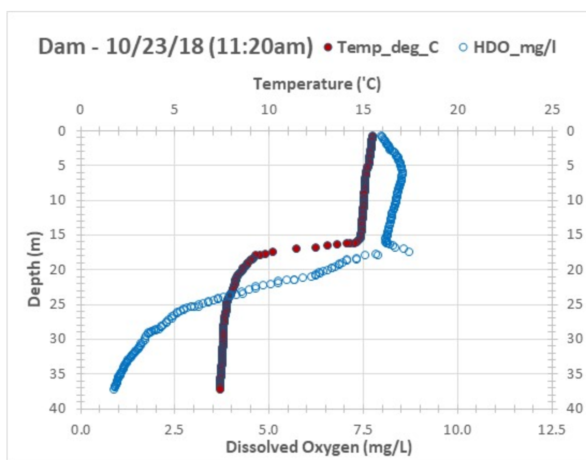


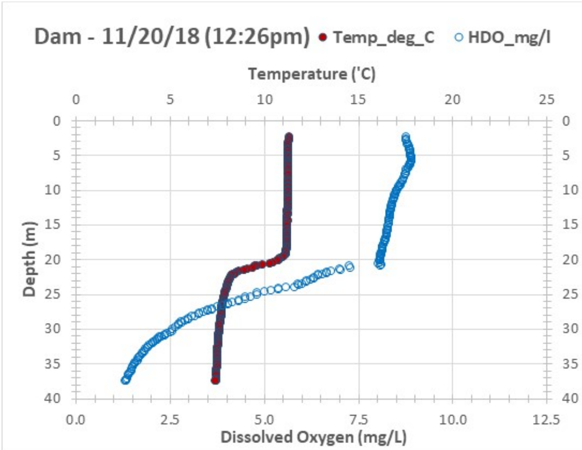








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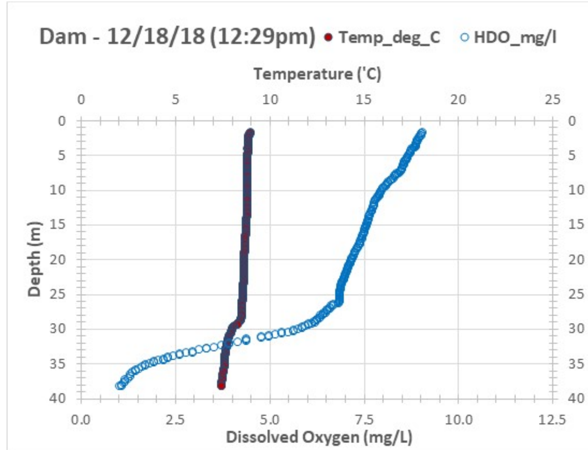
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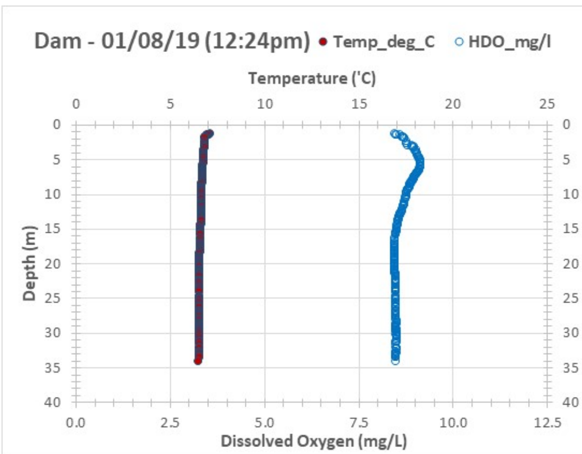
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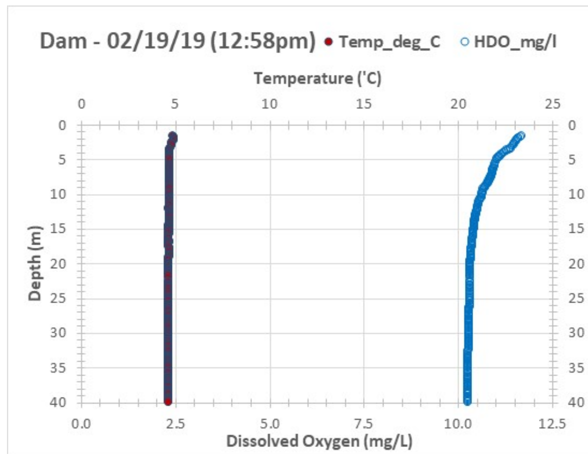
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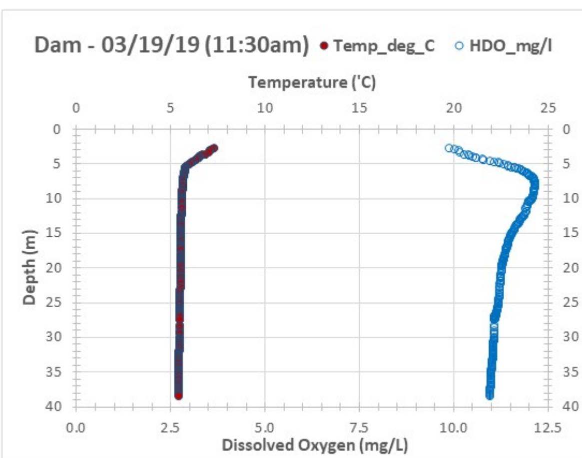
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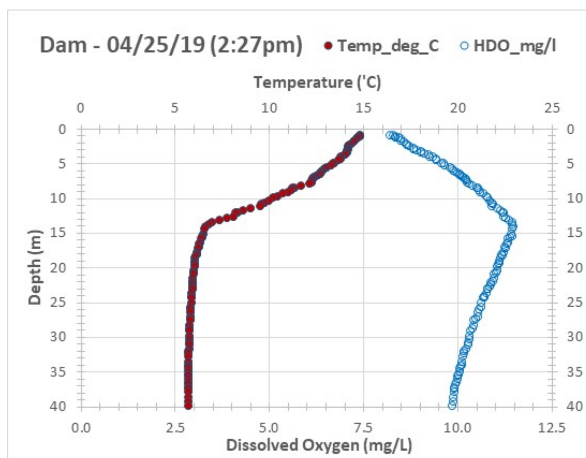
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Temp_deg_C
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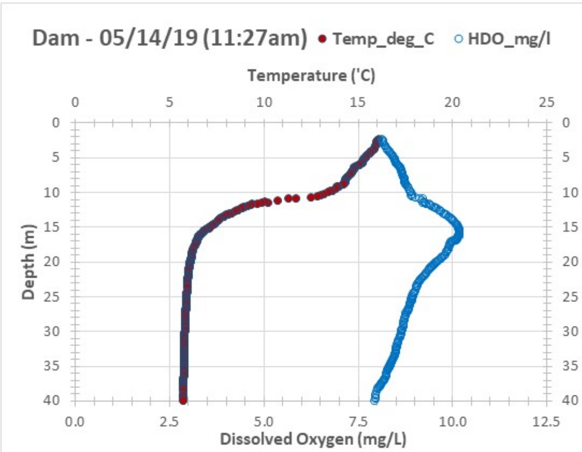
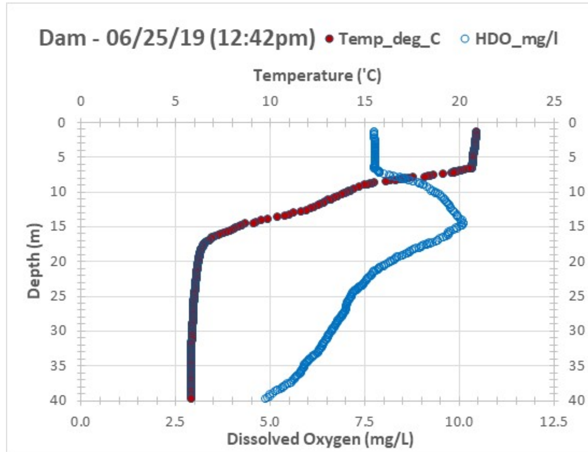
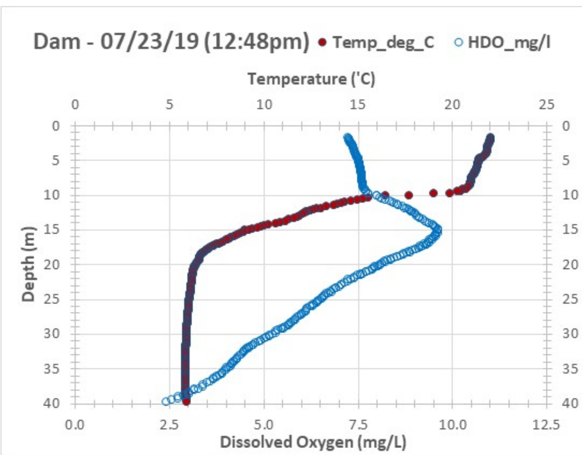
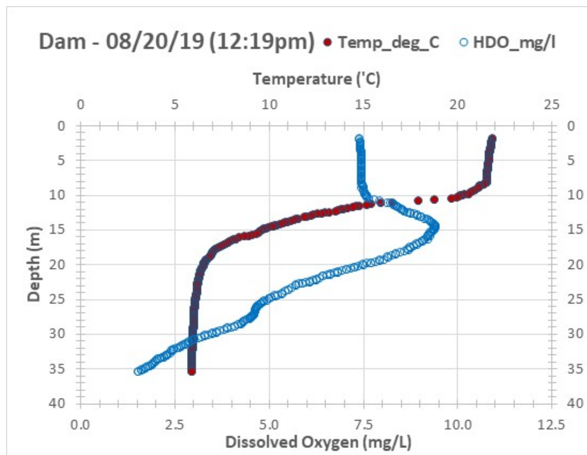
Temperature ('C)
Depth (m)
Dissolved Oxygen (mg/L)

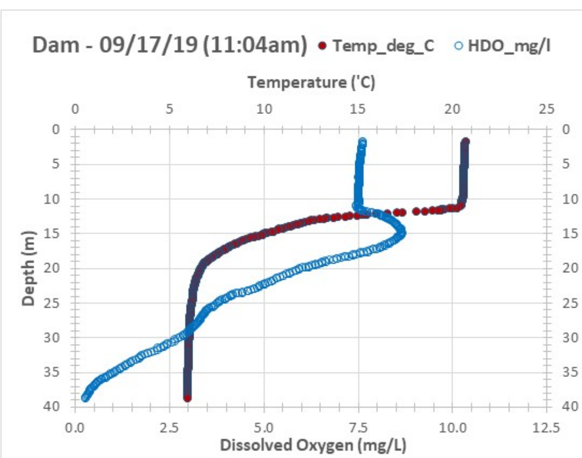
The next 12 figures (this page and the next page) show 2019-2020 stratification, anoxia, turnover and reoxygenation pattern similar to the 2018-2019 pattern depicted in the figure above. Note: HDO in legend means Dissolved Oxygen (DO).

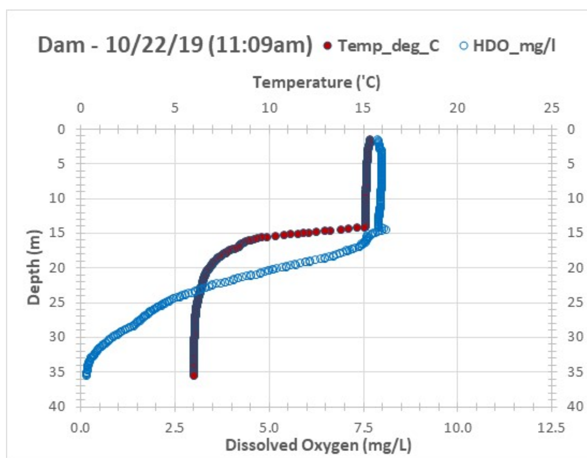


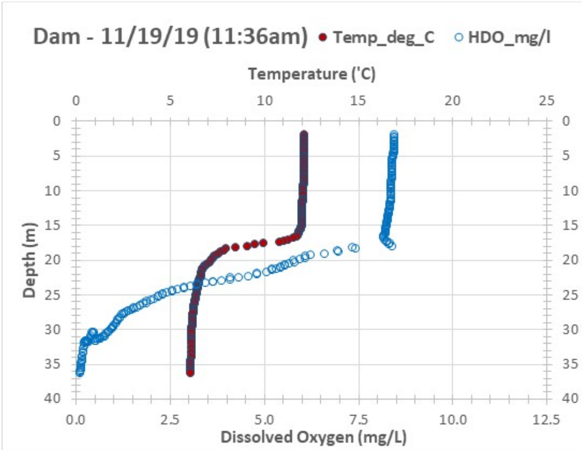








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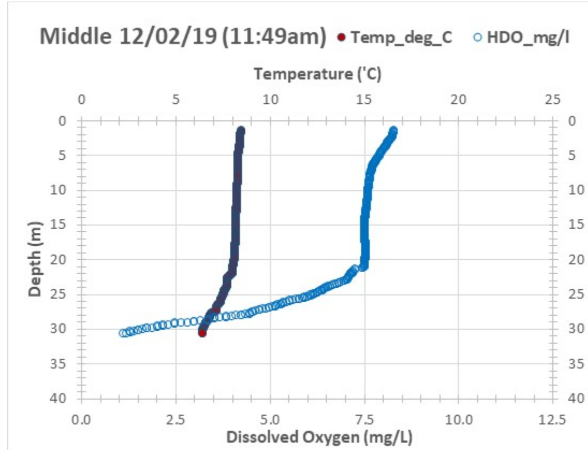
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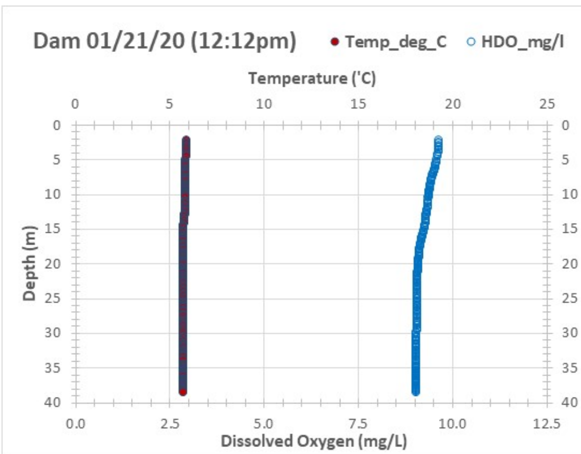
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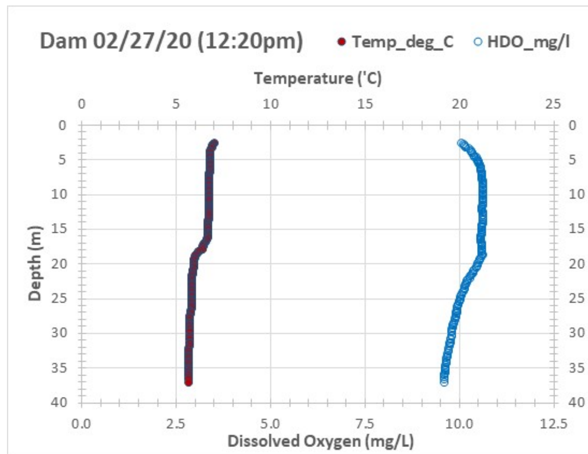
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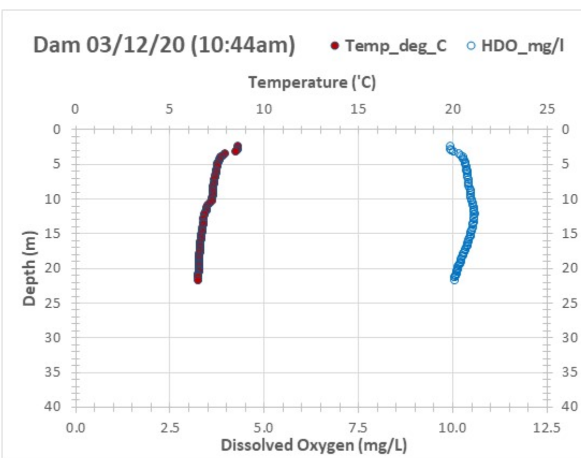
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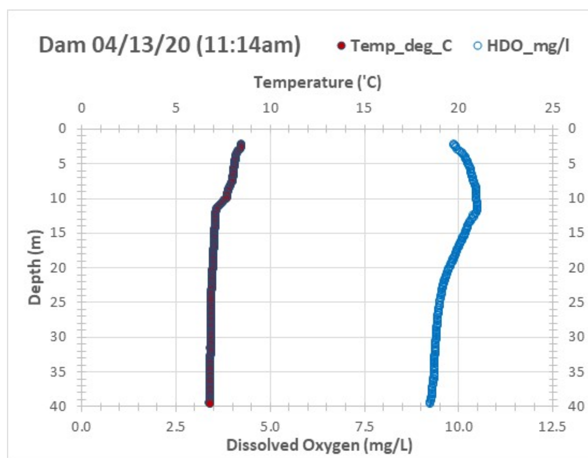
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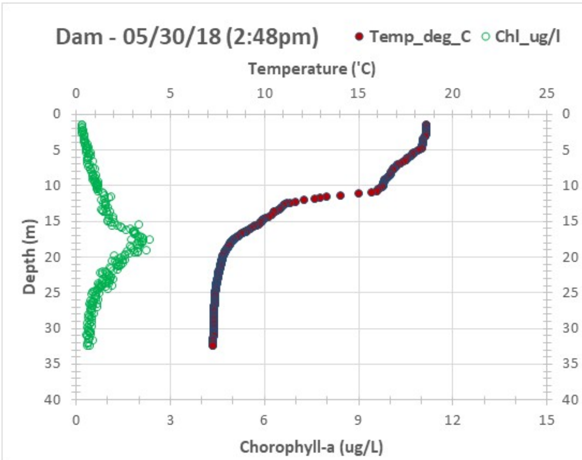

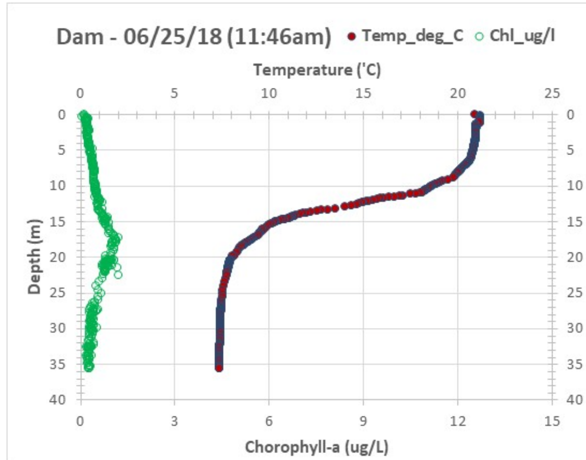

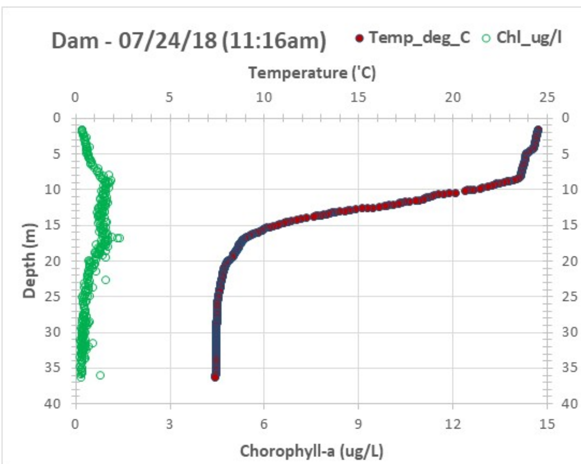

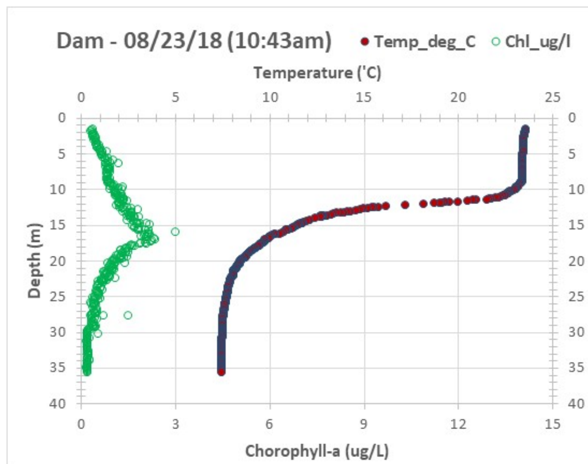

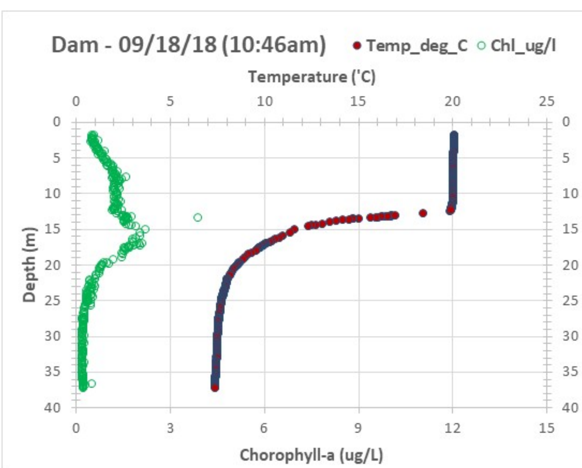

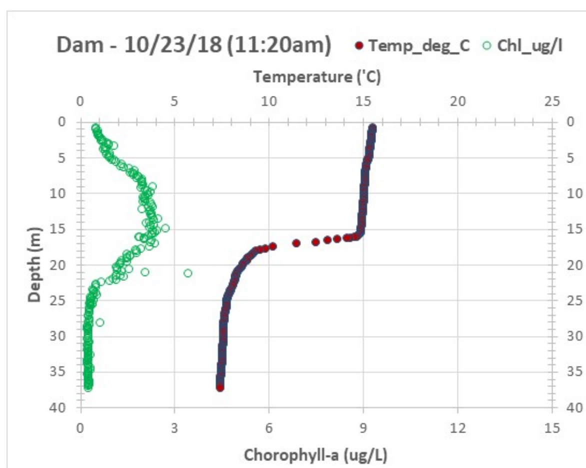

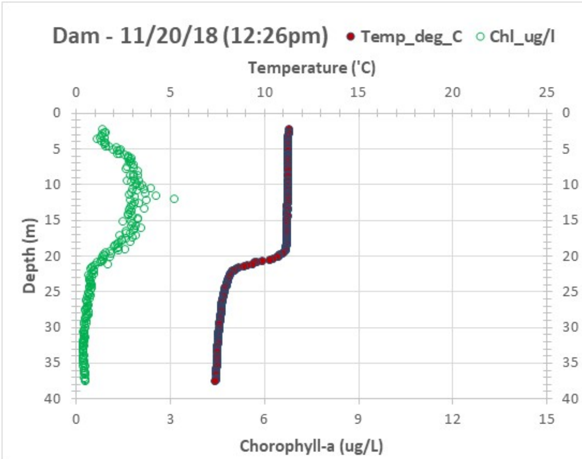
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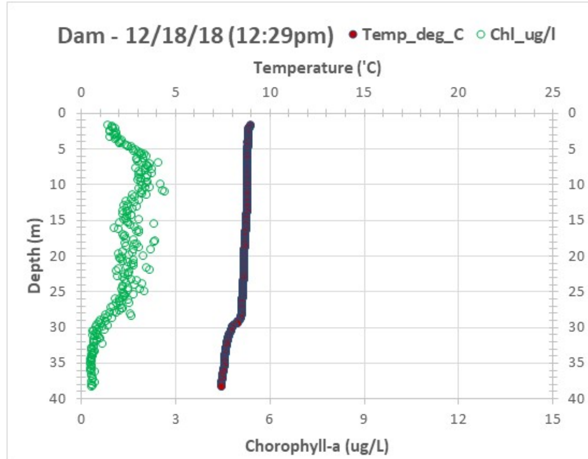
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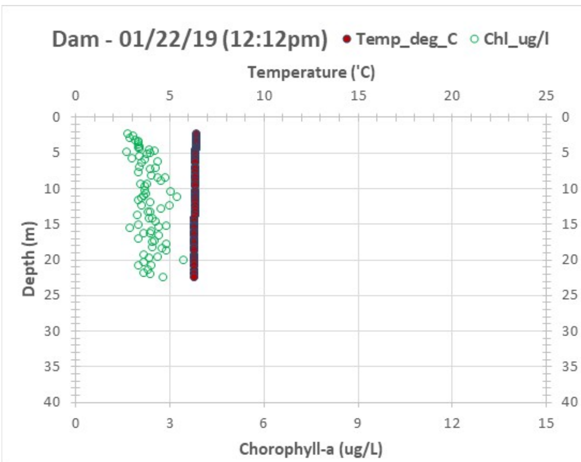
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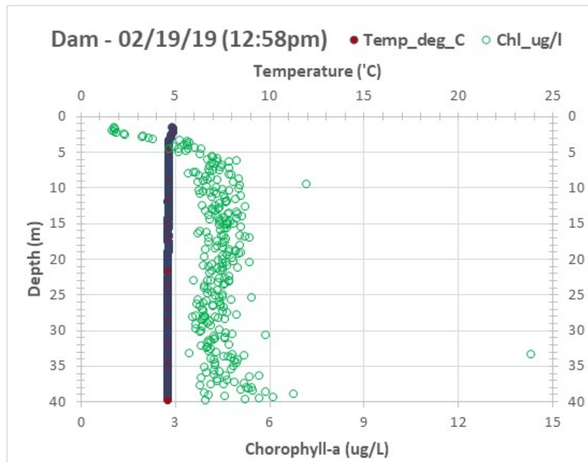
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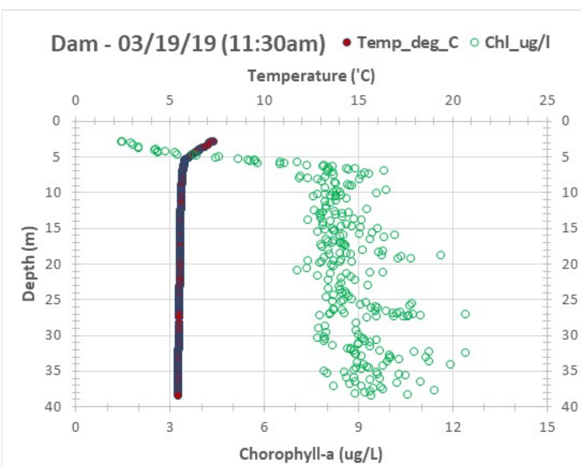
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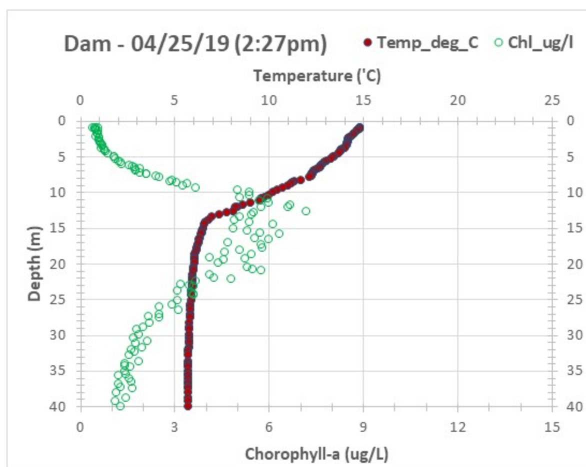
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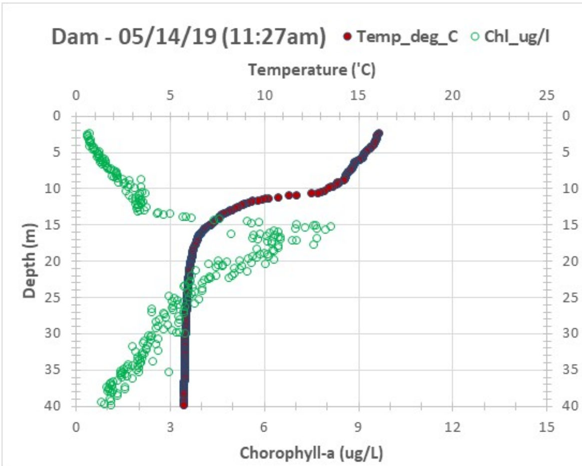
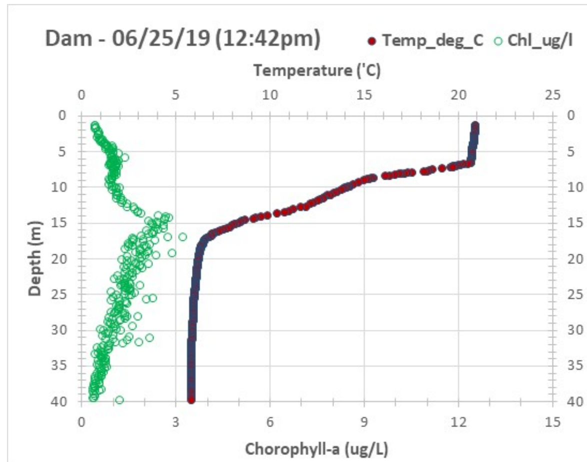
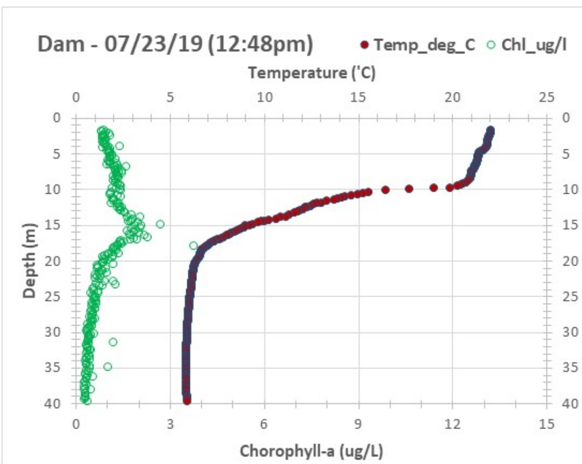
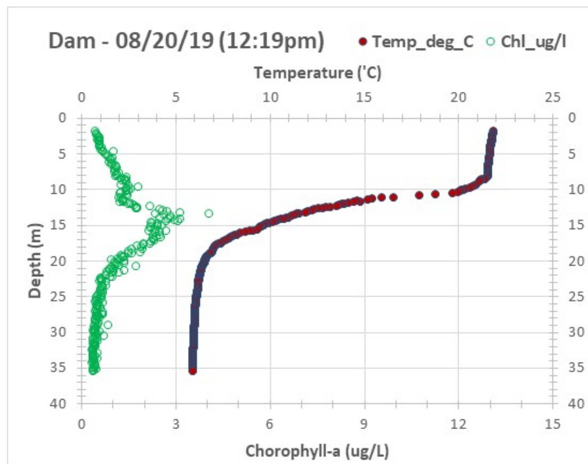
Chorophyll-a (ug/L)

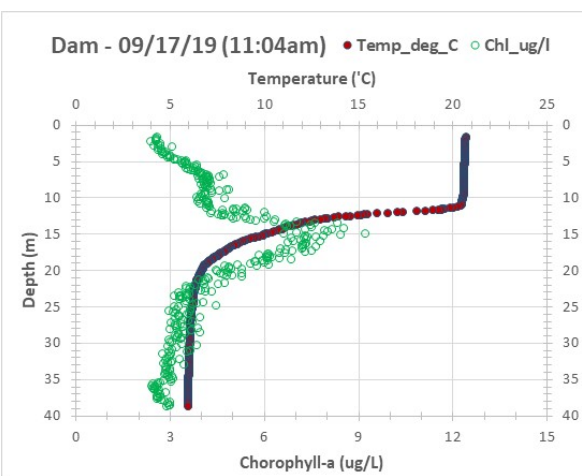
The next 12 figures (this page and the next page) show 2019-2020 build-up of chl-a fluorometric signal maxima in lower part of thermocline during summer stratification, then mixing throughout water column with winter destratification.

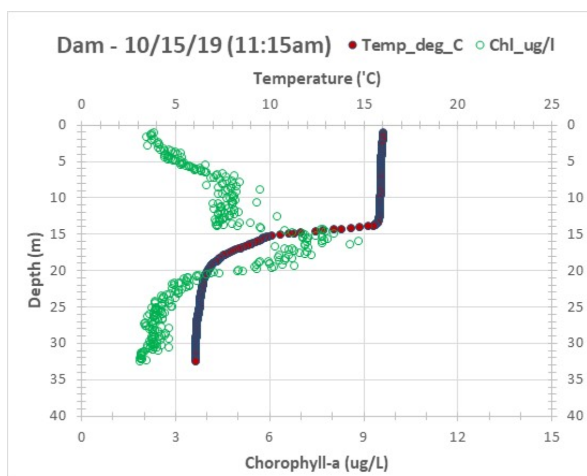


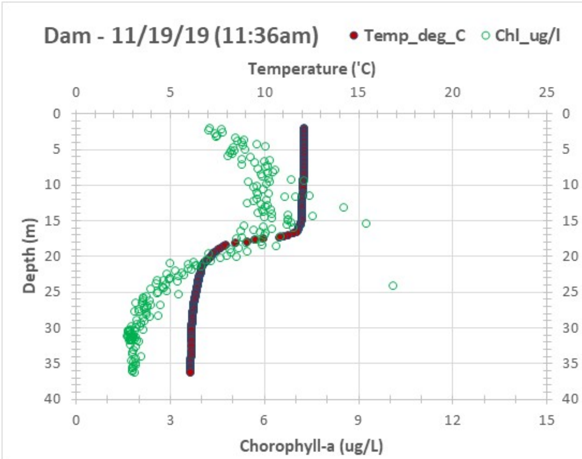








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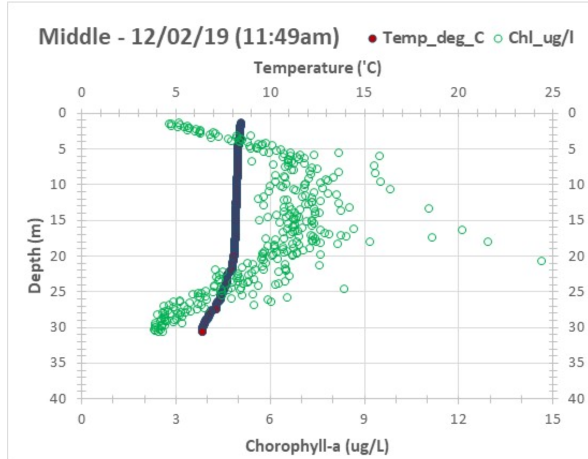
Temperature ('C)
Depth (m)
Chorophyll-a (ug/L)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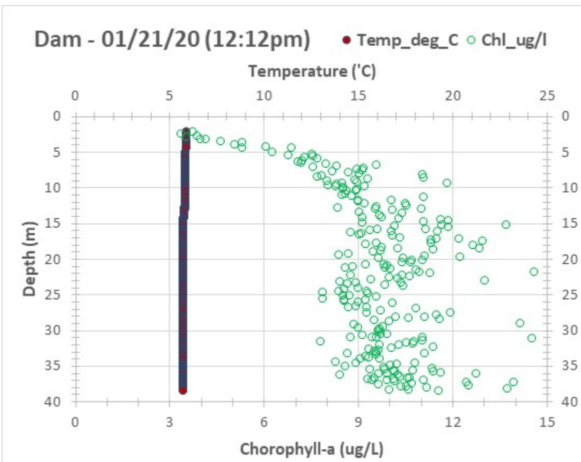
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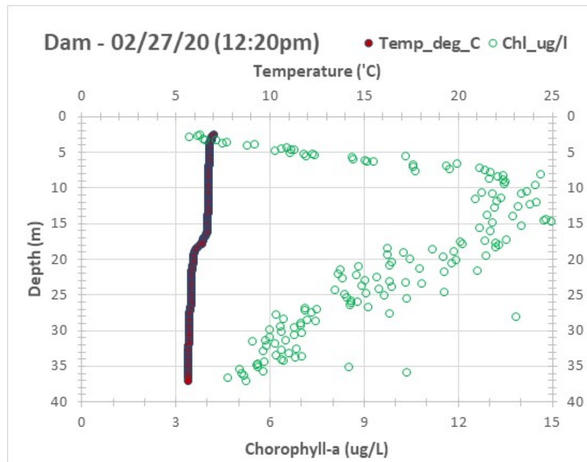
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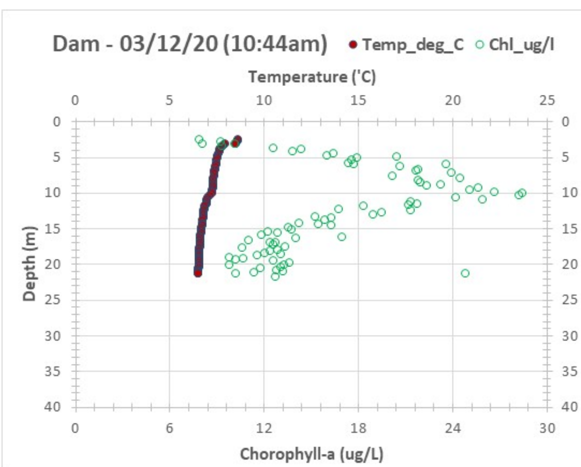
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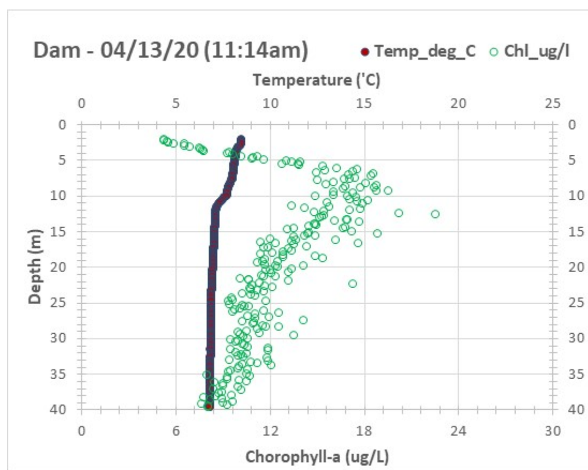
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Chorophyll-a (ug/L)

Appendix 6.2 – Personnel briefing document for Lake Arrowhead tracer study

Appendix 6.2 Final Arrowhead Reservoir Experimental Plan: Details 11/29/2019

The following detailed experimental plan was developed for the 2019 Reclamation-University of Nevada Las Vegas (UNLV) Arrowhead Reservoir tracer study, where the Rhodamine WT-sucralose tracer is injected directly at depth in the reservoir. Yellow highlighted portions are for LACSD treatment plant operations staff review. Except for one paragraph grey highlighted portions are mostly draft notification procedures based on our August 2018 submission to Lahontan Water Quality Control Board.

1) **Location of tracer injection**:
   a) The tracer will be injected at Station Village Bay 2 (VB2) shown on the maps of Lake Arrowhead (Figure 1).
   b) The tracer will be released at a depth of 10 meters using a submerged 4-arm diffuser with 1-meter arms perforated with 4 sets of 1.25 cm holes (at 90 degree angles) every 17 centimeters, located at a depth above the fall seasonal thermocline, yet deep enough that no color will be visible at the surface. This depth is intended to be set at 10 meters below the surface.
2) **Survey reservoir in the week(s) prior to tracer release** for temperature profiles (to establish knowledge of current stratification conditions and also use for hydrodynamic model initial conditions) and to confirm background RWT-like concentrations using Eureka Trimeter® fluorometers. This survey will consist of:
   a) Temperature, conductivity, chlorophyll-a signal, pH, dissolved oxygen, photosynthetically active radiation high resolution (within 0.1 meter) depth profiles at the six (6) standard stations (Dam, Center Channel, North Bay, Village Bay, Blue Jay Bay, Meadow Bay) on the day before the tracer injection using the Eureka Manta30+ probe. In addition, background RWT-like concentrations will be determined using the Eureka Trimeter® probe at all six stations.
   b) Repeat the Manta 30+ and Trimeter® profiles the morning before the tracer is added.
   c) Establish background RWT-like concentrations by online raw-water monitoring at the LACSD drinking water intakes starting one week before the tracer injection, continuing through the tracer injection and one week after.
3) **Use ALA barge to mix and release RWT and sucralose at the injection station:**
   a) Load all equipment and materials, including RWT and sucralose, at ALA's maintenance yard the day before the planned injection.
   b) Set up and flow test the equipment with clean water at dock.
      a) Be sure everything that's needed is on board the barge and working before proceeding.
      b) Once the system and all equipment are set up and tested, navigate barge to the tracer release site at VB2, the day before the tracer is released to begin the tracer study, and test again in full field conditions (wind and waves), evaluating the stability of diffuser and intake system.

c) On the day of the study, transfer the correct measured quantities of RWT and sucralose to the injection tank on ALA's barge at the ALA's docks:

  a) Add the tracer(s) to the tank at dockside, mix the bulk tracer with 50 gallons of lake water,

  b) pilot the barge to the VB2 injection point.

  c) make sure there is no spill/leak/release of tracer from anywhere on the barge to the lake while moving from the ALA's docks to the injection site.

  d) at this point, minimize boat traffic back and forth to the platform, set up ALA Lake Safety patrol boat with lights flashing to establish a no-go perimeter zone.

  e) Release tracer into the lake as described in sections 4, 6, and 7, below.

d) After the tracer has been released, undertake the following steps to avoid accidentally spreading tracer to other parts of the reservoir, which would confuse the results if it happened.

  a) make sure the entire tracer volume has been released. Then flush the tank with 50 gallons clean lake water from the dump hose, and discharge the flush water through the diffuser. Repeat until all visible color is removed from the tank.

  b) before leaving the injection site, make sure there is no spill/leak/release of tracer from anywhere on the barge to the lake.

  c) Deploy Lagrangian drifters with sea anchors set to tracer release depth (nominally 10 meters) to record lake water movements at release site and also visually mark on surface the estimated plume location

  d) Return the barge to the ALA docks, limiting departing barge speed and boat speeds after the dye release in the vicinity of the injection point to less than 0.5 mph within 150- yard diameter.

  e) Replace the barge with the plume-chasing boat and begin measurements to identify the depth and extent of the initial plume 'pancake' in the lake

  f) maintain the perimeter with ALA lake safety to ensure that no boat traffic in the vicinity of injection point until 1.5 hours after the tracer release.

  g) boat speeds in the estimated vicinity of the plume during the tracer study must be less than 2 mph.

  h) personnel who worked with the tracer release should leave the site, clean up and change clothes, before coming back to do any follow-on work at the reservoir.

  i) any unused sucralose and RWT tracers should be kept in ALA's maintenance shop, away from the lake.

4) **Tracer injection equipment, set up and testing**:

  a) All of the tracer injection equipment is mounted on the barge.

  b) The basic components of tracer injection system are:

a) Tracer bulk tank, which is a 100-gallon horizontal closed top high-density polyethylene chemical tank, marked at 20-gallon increments, located in a 200-gallon containment trough.

b) Emergency 100-gallon horizontal closed top high-density polyethylene 'dump' tank, identical to bulk tank, located in a separate 200-gallon containment trough.

c) Either tank can be connected to the main gasoline powered water pump for injection.

d) Water pump, 158 gpm max flow rate (600 liters/minute), powered by a gasoline engine, drawing water from either the screened lake intake for filling tanks, or drawing water from tanks for injection into lake via diffuser.

e) Inlet hose, 3" ID, 32' long, with inlet screen.

f) Outlet hose, 3" ID, 60' long.

g) Wash down hose, 3" ID, 20' long with adjustable nozzle

(1) Inlet, outlet and wash down hoses fitted with Camlok® quick connectors.

h) 9 gallons per minute (gpm) (36 liter/minute, (Lpm)) electric pump metering system that draws tracer-mixed water from the 100-gallon chemical tank or the 100-gallon dump tank.

i) Flow control valves:

(1) Globe-type control valve on the outlet of the electric pump with inline 0-8 gpm flow meter.

(2) Ball-type control valve on outlet of gasoline pump with ultrasonic 0-120 gpm flow meter that is located just inboard of the line to the diffuser. This line conveys mixed flow (lake water plus tracer) to the diffuser.

j) Diffuser, 2" diameter Schedule 40 PVC branching with four 1-meter arms, four (4) sets of 1.25 cm holes (at 90 degree angles from each other) at 17-centimeter spacing. Arm ends are capped.

k) Lines, rigging, and hardware to suspend the inlet and outlet hoses at fixed depths, using the barge cleats as attachment points

c) Configure, connect, and deploy the tracer injection equipment (tanks, troughs, pumps, hoses, diffuser, intake) on the barge the day before the date of tracer addition.

d) Test the tracer injection equipment at nominal flow rates:

a) Fill the bulk tank with reservoir water; i.e., use reservoir water without tracer for the flow test.

b) place the screened inlet at ~7 meter (m) depth (actual depth to be determined by profiling). Secure inlet hose on a barge cleat.

c) detach the diffuser, place the outlet hose in the plastic drum, run pump at nominal speed.

d) flow rate calibration:

(1) with the gasoline pump running at nominal speed, set the overall system flow rate to 90 gpm (341 Lpm) using the ball-type flow control valve to adjust rate while discharging through the diffuser line with the diffuser disconnected. Record the flow rate as indicated on the ultrasonic meter

(2) adjust ball valves to switch lines to discharge to the dump tank. While discharging to the dump tank, measure and record change in volume with time, to compute flow rate

(3) Compare the results of steps (1) and (2)

(4) connect the diffuser to the main discharge line, adjust valves to switch back to the diffuser discharge and measure the flow rate with the digital meter with the diffuser connected. Apply any need correction from steps 1, 2 and 3

(5) deploy the diffuser to the lake and suspend the diffuser at 10m depth. Secure the outlet hose on a barge cleat using the diffuser rope harness

(6) Measure and record flow rate again with diffuser now connected and deployed at depth

e) Open ball valve to initiate flow from tracer bulk tank

f) use the globe valve to adjust the electric pump flow rate to draw down the bulk tank at 6 gallons/minute (23 Liter/minute).

(1) Measure and record main system flow rate again to verify effect of adding in electric pump on system discharge flow rate

5) **On the morning of the study,** prepare bulk RWT solution in tanks at dock side:

a) prepare the bulk RWT and sucralose solution in the tank as near to the time of injection as practical to keep the temperature of the bulk solution close to the temperature of the ambient reservoir water.

b) Using the screened inlet, turn on gasoline pump and add 50 gallons of reservoir water to the bulk tank.

c) Add the premixed RWT and sucralose dye solution from the yellow fuel dispensing tanks, rinse the tanks thoroughly with lake water and add each rinsate into the bulk tank. Repeat until the RWT dispenser is completely free of color.

d) Note any spill of RWT or sucralose. . . if any spill, use the provided clean-up absorbent socks to pick up the spill and deposit the used socks in the provided yellow waste disposal container.

e) collect a 1 liter sample of the bulk RWT-sucralose solution for subsequent dock-side and laboratory analyses.

(1) use a spray bottle of reservoir water to clean off the sample container, direct the rinse water back into the bulk tank.

(2) handle the sample with care; keep it contained during transport.

6) **DO NOT WASH DOWN anything into the lake, instead:**

   a) Leave any spilled or leaked RWT where it falls; if on the barge deck, contain it with the provided clean up adsorbent sock, soak up with rags and absorbent, and dispose into the yellow waste disposal container

   b) Do not wash off equipment, gear, gloves, clothing, etc. Instead put any contaminated adsorbent socks and clothing in the yellow waste disposal container

7) **To match the density of tracer solution to the density of the ambient reservoir water:**

   a) Measure the temperature and TDS in profile at the tracer release station using the Eureka Manta 30+ sonde at 10 meters depth

   b) Use a MatLab® code or spreadsheet to determine the ambient density at 10 meters depth.

   c) Set the depth of pump's intake screen, which is on the distal end of the inlet hose and secure at intended depth using the marked lift hose and tying it off on a barge cleat.

      a) If temperature profile of the lake allows for withdrawing water at a temperature different from the discharge depth, use the MatLab® code or spreadsheet, to determine the water temperature required to match densities [T_{match}].

      b) Referring to the temperature profile, lower the intake to the depth corresponding to T_{match}.

      c) Be sure to secure the inlet hose to the platform such that it will not slip downward.

   d) Check the outflow temperature.

      a) With the pump running at nominal flow rate, but no tracer being released, confirm that the density corresponding to the temperature of the outflowing water [$\square_{out}$] combined with tracer produces a density that matches the density with the reservoir at the discharge depth temperature required [ρ_{match}].

      b) During tracer release, monitor the temperature of the dye tank water every five minutes to ensure that the estimated density out ρ_{out} still matches density at discharge depth (ρ_{match}).

8) **Release the tracer:**

   a) With the pumps running at flow rate set in 4(d)(i) and 4(d)(vi), start the flow from the bulk tank to the electric pump.

   b) Record the beginning bulk tank volume and start time.

   c) Record the tank volume at five-minute intervals.

   d) Adjust the electric pump flow control valve as needed to keep the rate of drawdown of the bulk tank to 6 gallons per minute (gpm). 23 Liters per minute (Lpm).

   e) Record the time when the tank empties.

9) **Information to record during tracer release:**

a) Manta 30+ datasonde profile with depth, consisting of Temperature, conductivity, pH, dissolved oxygen (DO), chl-a, and PAR, before tracer release and at conclusion of tracer release.

b) General weather observations.

c) Start time and stop time.

d) Overall pump flow rate.

e) Tank volumes at five-minute intervals.

f) Any spills of tracers.

10) When all the tracer is released, refer to section 3 d) for immediate next steps.

11) Measurements of RWT and associated parameters:

a) Field measurements.

a) Fluorometric measurements of RWT will be made in profile at set sampling stations (Eulerian) as well as by plume chasing boat (Lagrangian).

b) Measurements will be made Eureka Trimeter® datasondes fitted with Turner Designs fluorometer sensors, initially calibrated to 0-10 *u*g/L, and 0-200 *u*g/L.

c) Data will be downloaded from the Trimeter® datasondes.

(1) to field capable laptop PCs,

(2) data will be downloaded after each round of field sampling and archived to a workstation at the project base camp, located in the 5th wheel trailer parked across California Highway 173 from the Dam in the ALA maintenance yard.

b) Laboratory measurements:

(1) Fluorometric measurements of RWT will be made in the lab (set up in ALA maintenance shed) for standardization and calibration, for the purpose of calibrating field instruments.

(2) Two bottle strings will be deployed at ALA docks to assess loss of RWT in ambient reservoir water due to photo degradation. Starting concentration will be 10 *u*g/L. One bottle string will be clear glass, deployed at depths of 0.5, 2.0, 4.0, 6.0, 8.0, 10 and 12 meters. The other bottle string will be brown glass to limit light penetration, deployed at identical depths. Each string has a 2.2 kg (5 pound) weight on the bottom to keep it vertical in the water column.

(3) Temperature and light profiles with the Eureka Manta30+ sonde will be taken periodically next to the bottle strings to record temperature and light levels.

b) Bottle RWT measurements will be made with Eureka Trimeter® datasondes fitted with Turner design fluorometric probe calibrated from 1 to 10 ppb

c) Calibration standards of RWT in ambient reservoir water will be prepared in the lab, following protocols laid out in publications by Turner Designs.

c) Assessment of loss to photodegradation.

  a) The loss of RWT to photo-decay will be measured beginning 1 day before release of the tracer and continuing through the monitoring period.

  b) See 11 b) and Attachment A for methods and materials for this step.

12) Sampling plan [See Attachment B]: This attachment includes

a) Sample sites and measurement locations

b) Sampling schedule

c) Sampling staff plan

13) Reservoir operations during tracer release and sampling:

a) It is intended that LACSD will fill their storage tanks with treated drinking water before the commencement of the tracer study and, will operate the intakes on the day of the tracer release until 5pm in the afternoon, or until advised by UNLV that the tracer plume is approaching to within 150 meters of the intakes. At worst case at-depth advection velocities of 2 cm/sec, this distance would allow for a 2-hour window to shut the intakes before the plume passes over the intakes. Note, with the plume added at 10 meters and the intakes at depths of about 22 meters, considerable vertical plume spread would also need to occur to reach the intakes. If community water demand is sufficiently low, LACSD will keep the intakes shut for the next 24 hours. On following days, during the tracer study, per advice of UNLV, the intakes will be opened and water withdrawn from the lake to meet community demand unless UNLV monitoring of RWT shows that a 1 *u*g/L added RWT tracer excursion above particulate Rhodamine backscatter background is nearing either intake. See Section 15.

b) Close communication between the tracer study team and the water treatment plant operators will be essential. Such communication is the responsibility of the tracer study team leader. A list of contact phone numbers and radio channels will be available on each sampling boat, the tracer barge, at base camp (ALA maintenance barn), in the ALA offices and at the LACSD treatment plants and LACSD Blue Jay offices. Important cell numbers will be added to contacts in all UNLV, ALA and LACSD mobile phones.

14) Other information to collect during tracer study:

a) Outflow rate from the lake at the two drinking water intakes when in operation

b) If any, imported water inflows to the reservoir at Little Bear Creek (estimated from UNLV level gauge and the prior USGS rating curve) and Grass Valley Tunnel (from USGS gauge).

c) Outflows from the Willow Creek spillway (if applicable, estimated from gate position and head over weir).

d) Meteorological station data (used as inputs for hydrodynamic modeling).

e) Daily water quality profiles using the Eureka Manta30+ datasonde.

f) Water circulation estimates using GPS-equipped Lagrangian drifters with sea anchors set to depth of tracer injection

15) Information collected during study by instrumentation but obtained afterwards.

a) Water temperature data measured at 10-minute intervals by the two thermistor strings, one in Center Channel and one in Meadow Bay.

b) Water current speed data measured for 10 minutes every hour by the two ADPs, one in Center Channel and one in Meadow Bay.

16) Monitoring in the lake and in the raw water sent to treatment plant and contingency operations plan.

a) The following measurements will be performed at least daily or with any change in overall plant flow: raw water RWT concentration at each plant influent when operating.

(1) The concentration of RWT will be measured at Stations DWI_N and DWI_B from boats using Eureka Trimeter® profiling datasondes with Turner Designs fluorometric RWT sensors, and

(2) Continuous Eureka Trimeter® fluorometric monitors will be operated and monitored at the raw water taps located at the start of each treatment plant's treatment train to ensure the added RWT concentration does not exceed one tenth of the US EPA 10 *u*g/L advisory limit (1 *u*g/L) above background near the drinking water intakes.

(3) If measured added RWT-tracer concentrations measured in the lake in the vicinity of either drinking water intake at their intake depths or measured in the raw water taps at the treatment plants approach a level of 1 *u*g/L above the monitored background RWT-particulate backscatter levels, that intake will be closed.

(4) If neither drinking water intake has reservoir water with added RWT tracer concentration less than one tenth the EPA 10 *u*g/L advisory level above background, then the flow from the reservoir to the Water Treatment Plant will be shut off, and community supply will be delivered from stored treated water, to be made up, if necessary, with a combination of treated LACSD well water or treated CLAWA (Crestline Lake Arrowhead Water Agency) water.

b) During the first day of the tracer study the treatment plant will run until the tracer plume reaches within 150 meters of the intakes, regardless of depth. At typical maximum at-depth water velocities of 2.0 cm/sec, this would give 15,000cm/2.0= 7,500 seconds or 125 minutes to shut the intakes before the plume reaches intake location (plume depth at a nominal 10 meters will be shallower than the depths of about 22 meters.

c) If plume movement is unidirectional, right at the intakes,

(1) For the Cedar Glen treatment plant intakes, at distance of 1.32 km (Figure 1) it is expected that the plume would take for a worst-case velocity of 2.0 cm/seconds, 132,000cm/2.0 = 66,000 seconds or about 18.3 hours to reach the intake location (arrival time would be 2 am on Wednesday for an 8 am Tuesday addition). At a more

typical at-depth velocity of 1.0 cm/sec the travel time would be 36.7 hours (or 1.5 days, or 1 day 12 hours), to arrive at the intakes (arrival time would be 8pm on Wednesday.

(2) For the North Bay intakes to the Bernina treatment plant, at a distance of 1.19 km (Figure 2) it is expected that the plume would take 119,000 cm/2.0 cm/sec = 59,500 seconds or 16.5 hours to reach the intake location (arrival time would be 1230am on Wednesday for an 8 am Tuesday addition). At a more typical at-depth velocity of 1.0 cm/sec, the travel time would be 33 hours or 1.38 days or 1 day 9 hours, (arrival time would be 5pm on Wednesday).

(3) Scheduled profiling of the plume will determine its thickness. Thickness will be determined by the 1 *u*g/L threshold above RWT background.

d) Treatment plant intakes will then remain off as the plume approaches and passes over the intakes until the plume concentration above the intakes drops below 1 *u*g/L above RWT background.

e) Following the initial 24-hour study, if intakes are re-opened, reservoir water will be drawn from the intake farthest from the added RWT plume, so long as an added RWT tracer excursion approaching 1 *u*g/L above RWT-particulate backscatter background is not detected in the vicinity of that intake.

(1) The total RWT concentration (particulate backscatter background plus combined) in the combined plant influent will be measured by continuous monitoring using 0-1 *u*g/L calibrated Eureka Trimeter® RWT sondes located in buckets containing a continuous inflow of raw reservoir water at the raw water taps located in each treatment plant. Raw water buckets will need to be periodically emptied and flushed to eliminate build-up of RWT-like particulate backscatter background.

(2) Per the Lahontan Water Quality Control Board letter of October 30, 2019, UNLV will use the on-lake monitoring RWT tracer measurements to generate hourly maps of added tracer extent in the lake.

f) In the event of either of the above exceedance situations [16.a) 3) or 16.a) 4)] flow from the lake to the water treatment plant will remain off, and the water treatment plant will use only imported CLAWA water or LACSD IX-treated well water, until monitoring shows that the added RWT tracer concentration at the depth of the selected outlet is below the 1 *u*g/L value above background RWT-particulate backscatter. At that time, intake flow from the lake can resume, and monitoring of the combined plant influent water will continue as above.

g) In the unlikely event that any significant RWT were to be delivered from the lake to the Water Treatment Plant, it would be rapidly consumed by the chlorine used as a pre-oxidant and as a disinfectant in treated water. Previous UNLV experiments in July 2018 indicated that 10 *u*g/L RWT added to Lake Arrowhead raw water would be reduced to non-detectable levels in less than 8 minutes by the standard 4.0 mg/L chlorine dose added by LACSD. The chlorine residual in finished water would also consume any remaining added RWT.

h) Upon notification that the above-intake RWT concentrations have dropped below 10 *u*g/L above background RWT-like particulate backscatter values, once the intake is re-opened, RWT sampling would continue with measurement by the Trimeter® probes in raw water and in the finished water to make sure that RWT concentrations are below one tenth of the EPA advisory levels for both drinking water intakes (10 *u*g/L above RWT-like background.

i) **Spill reporting**. Any spillage escaping the containment tank other than small drops that can be wiped/washed clean will be reported to the Lahontan Regional Water Quality Control Board (LRWQCB) within 15 minutes of occurrence, and actions to clean up spills will be documented and reported to LRWQCB within 24 hours of occurrence.

j) **Unexpected movement monitoring and reporting**. As described above, Trimeter® sonde-equipped monitoring boat will measure RWT fluorescence hourly by vertical profiling at the location of each drinking water intake over the first 2 days of the study. Measured RWT concentrations will be compared to movement of the main body of the tracer by radio or cell phone communications between the monitoring boats. If a RWT tracer concentration near one-tenth of the EPA 10 *u*g/L advisory limit appears to be approaching either water intake, the water purveyor, the Lake Arrowhead Community Services District, will be notified by telephone within 5 minutes and the LRWQCB will be notified by email within 15 minutes. Results indicating direction of movement and concentration of the RWT tracer will be provided to both LACSD by phone and LRWQCB by email within one hour.

k) As described in paragraph 3 on page 2 of the October 30, 2019 Lahontan Regional Water Quality Control Board letter, the technical report requested by Lahontan will include a "Brief summary of an operational problems encountered before, during, and/or after the dye application." This summary would include any equipment failures, spills or unexpected movement as identified in 16 g) and h) above.

Attachment A – RWT bottle test photo-decay protocol (written after the face, June 29, 2021)

1) Set up bottle strings
   a. Obtain a set of at least 7 clear and 7 amber 1-liter glass bottles with water-tight caps. The use of amber and clear bottles is recommended so that a distinction can possibly be made between photo decay and microbial decay in If a long duration experiment is expected, prepare an additional string of each kind of bottle
   b. Wash bottles using distilled water and Alconox(r) or similar low-residue analytical chemical detergent. Rinse three times with distilled water after washing to remove all residue
   c. Determine, from %PAR measurements the depth deployment range for each bottle string. The bottle deployment depths should span the depth range from full illumination to a depth below the value for 10% PAR. For Lake Arrowhead, on 12/1/2019, the 10% PAR value was at about 7.5 meters depth. UNLV chose a depth range from 0.5 meters to 12.0 meters
   d. Label bottles with planned depth of deployment for each bottle. Planned depths are: 0.5 meters, 2.0 meters, 4.0 meters, 6.0 meters, 8.0 meters, 10.0 meters and 12.0 meters.
   e. Using lake water to provide the proper chemical and biological matrix, collect sufficient lake water using a Van Dorn bottle from each planned depth in sufficient volume to fill each bottle
   f. Using Turner Designs 200 ppb Rhodamine WT standard, prepare, using volumetric glass ware, 1 liter (1,000 mL) of 20 ppb RWT solution by mixing 100 mL of 200 ppb standard with 900 mL of lake water.
   g. Prepare extra 20 ppb lake water solution to support calibration of the RWT probe in Step 2) below
   h. Prepare bottle string harness with a 8 kg weight at the bottom to hold each bottle string vertical in the water column with bottles at the intended deployment depths. Note, each liter of headspace in the bottles adds 1 kg of buoyancy to the string, so at least 8 kg are needed to keep a 7 bottle string negatively buoyant and deployed vertically in the water column if all water is withdrawn from the bottles. If using collapsible bottles, less weight is needed. A 2 kg weight will be sufficient for collapsible bottles.
   i. Deploy the strings off the end of a deep water pier or dock (at least 15 meters of water depth) so that the bottles hang vertically in the water column. Note the date, time, and weather (cloudy or sunny) of the deployment
2) Calibrate instrumentation and make initial measurements
   a. Using a Eureka Manta Trimeter(r) RWT probe, and plain lake water and a 20 ppb standard in lake water, calibrate the probe between 0 and 20 ppb. Calibrate a 2nd probe as a back up
   b. Make initial measurements of RWT concentrations in left over solution added to each bottle
   c. Next to the deployed bottles, measure water column temperature and PAR depth profiles with the 7-parameter Eureka Manta multiprobe at the time of deployment

3) Sample and record data during the tracer study,

   a. Check each probe for calibration stability by measuring with freshly made 20 ppb RWT standard solution in lake water. Adjust calibration if needed.

   b. At least an initial daily sampling interval is recommended for RWT measurement to determine if detectable microbial decay or photo decay is occurring in the water column during the period of rapid initial dispersion of the tracer. If no decay or very slow decay is observed, the sampling interval can be increased to preserver samples for the duration of the tracer study.,

   c. Withdraw each bottle string from the water column and remove 100 mL of sample from each bottle. Pour the sample into the calibration cup of the Trimeter(r) probe, cover with the sunlight shield (an inverted black insulated drink cup) and record RWT concentration using the calibrated probe. Rinse probe cup at least 3 times with distilled water between measurements and dry out with Kimwipes(r)or similar clean laboratory paper,

   d. Recap the bottle tightly and return the string to the water column. Note, additional air in the headspace will probably keep the decay solutions in an oxidizing condition. If active microbial decay is expected, it is best to use, instead of rigid glass bottles, collapsible plastic bottles that will minimize air in the head space as samples are withdrawn.

   e. Ideally, if conditions permit, allow all withdrawn samples to equilibrate to room temperature in the dark (about 1 hour) before measurement, and keep the RWT measuring probes at the same temperature. Fluorescence is a function of ambient temperature, and while the modern RWT probes equipped with Turner Designs sensors compensate for temperature it is best, for purposes of stable measurement, unaffected by drift, to measure solutions all at the same temperature with a temperature stabilized probe

   f. Record measured RWT concentration for each day. Record date, and time and weather conditions.

   g. Measure a lake temperature and %PAR profile each day at a fixed time of day

4) Analyze the data

   a. For each bottle depth and color (e.g. (Amber bottle, 4.0 meters) Prepare a summary table of measured RWT concentrations, with date, time, temperature and RWT on each row of an electronic spreadsheet such as Microsoft Excel(r)

   b. Using the spreadsheet's date/time functions, compute elapsed time since the start of the experiment in each row

   c. Plot the RWT concentration data vs time. If you have an estimate of experimental measurement uncertainty from probe specifications and/or due to observed concentration variations include that uncertainty as error bars in your measurements of remaining RWT concentration

   d. Examine the RWT concentration vs time plots to see if

      1. Any decay is occurring at all, and

2. If decay appears to occur, attempt transformations of the data to determine what overall decay kinetics may apply. Generally, for RWT, literature reports estimate either zero-order (straight line) for first-order decay coefficients.

    i. If no transformation is needed to obtain straight line decay, then zero order decay is likely, and you can report decay rates in units of ppb/day.

    ii. If a logarithmic transformation of(RWT at time x) (RWT at time zero) appears to generate a straight line, then first order decay is likely, and you can report decay rates in units of reciprocal time (1/day).

    iii. If neither data transformation generates straight line decay, other transformations that might work include plotting 1/RWT vs time (second order decay) or a straight log transformation of RWT vs time (power fit).

e. Plot observed rates of decay in ppb/day vs depth for each bottle string to determine if there is a pattern with depth. If photo decay is occurring it will likely be observed in the shallower bottles deployed in the photic zone.

f. Compare zone of observed photo decay with daily %PAR measurements to determine if high rates of shallow water decay (if they occur) correspond to the photic zone of the lake. Be aware that %PAR thresholds may change with time, if the lake experiences either calm conditions after storm events or increasing turbidity due to inflows and wind-driven mixing.

g. It is of value to record antecedent, and simultaneous weather conditions to determine if changes in %PAR can be attributed to varying meteorological or hydrologic conditions on the lake.

5) Experimental enhancements for additional analysis to better determine the cause of any observed RWT decay.

a. If weather conditions vary from day to day and light and temperature history in each bottle is needed to better estimate the origins of observed decay, it is possible to use small integrating light and temperature recorders in each bottle to track temperature and illumination levels in each bottle. One example of this kind of sensor is the Hobo(r) Tidbit(r) sensor available from Onset computing. The sensor is small enough to fit into wide mouth collapsible bottles and record static solution temperature and light levels

b. If microbial activity is suspected, a record of dissolved oxygen concentration in each bottle is advisable. Use a solid state sensor pre-calibrated to 100% saturation for your water altitude and temperature, then immerse the sensor in each bottle of the string when first it is removed from the water column, immediately after opening the bottle to collect that day's sample. If microbial decay is appreciable, depletion of dissolved oxygen below 100% saturation will be observed.

Attachment B – Lake Sampling

a) Table of Sample sites and measurement locations

Locations of samples stations and depths at nominal reservoir level referenced to the lake's full pool (at unregulated rim of Willow Creek spillway) Water Surface Elevation (WSEL) of ___5106.7___ft per ALA datum,

station	Depth at max WSEL, feet (3)	Deepest profile measurement, feet (4)	Lat (1,2)	Long (1,2)
BJ1	17.3	14.3	34° 15.133'N	117° 11.956'W
BJ2	34.6	31.6	34° 15.247'N	117° 11.746'W
BJ3	64.9	61.9	34° 15.274'N	117° 11.471'W
MB1	23.8	20.8	34° 15.410'N	117° 11.888'W
VB1	42.7	39.7	34° 15.110'N	117° 11.193'W
VB2	61.6	58.6	34° 15.217'N	117° 11.175'W
NB1	55.3	52.3	34° 15.797'N	117° 11.697'W
NB2	93.0	90.0	34° 15.599'N	117° 11.311'W
DWI_N	70.1	67.1	34° 15.623'N	117° 11.576'W
MD1	89.6	86.6	34° 15.384'N	117° 11.076'W
MD2	102.2	99.2	34° 15.522'N	117° 10.934'W
MD3	123.7	120.7	34° 15.671'N	117° 10.734'W
ALA1	134.5	131.5	34° 15.738'N	117° 10.167'W
ALA2	130.0	127.0	34° 15.738'N	117° 10.356'W
ALA3	101.6	98.6	34° 15.878'N	117° 10.568'W
DWI_B (Cedar Glen)	61.8	58.8	34° 15.611'N	117° 10.550'W
Tracer release site outer Village Bay	70.0	67.0	34° 15.197'N	117° 11.100'W

The depths in this table will need to be corrected for actual lake level. As of this writing November 20, 2019, the lake elevation is at 5,103.88 feet, down 2.82 feet, so the above depths would need to be reduced by 2.82 feet to reflect actual conditions.

1) Coordinate system is NAD 1983 State Plane California Zone **VI FIPS 0406 feet**
2) 2) Lat & Long from GPS, read by Juniper Amphibian, using both GPS and GLONASS satellites; XY positional accuracy approximately +/- **15 ft**
3) Depth from hand-held sonar depth finder [Hawkeye H1]; accuracy approximately 0.2 ft.
4) The deepest measurement is planned to be 3 feet off the bottom, to ensure the Trimeter® fluorometric probes are not contaminated by contact with bottom mud.

Figure 1. Chart of sample sites

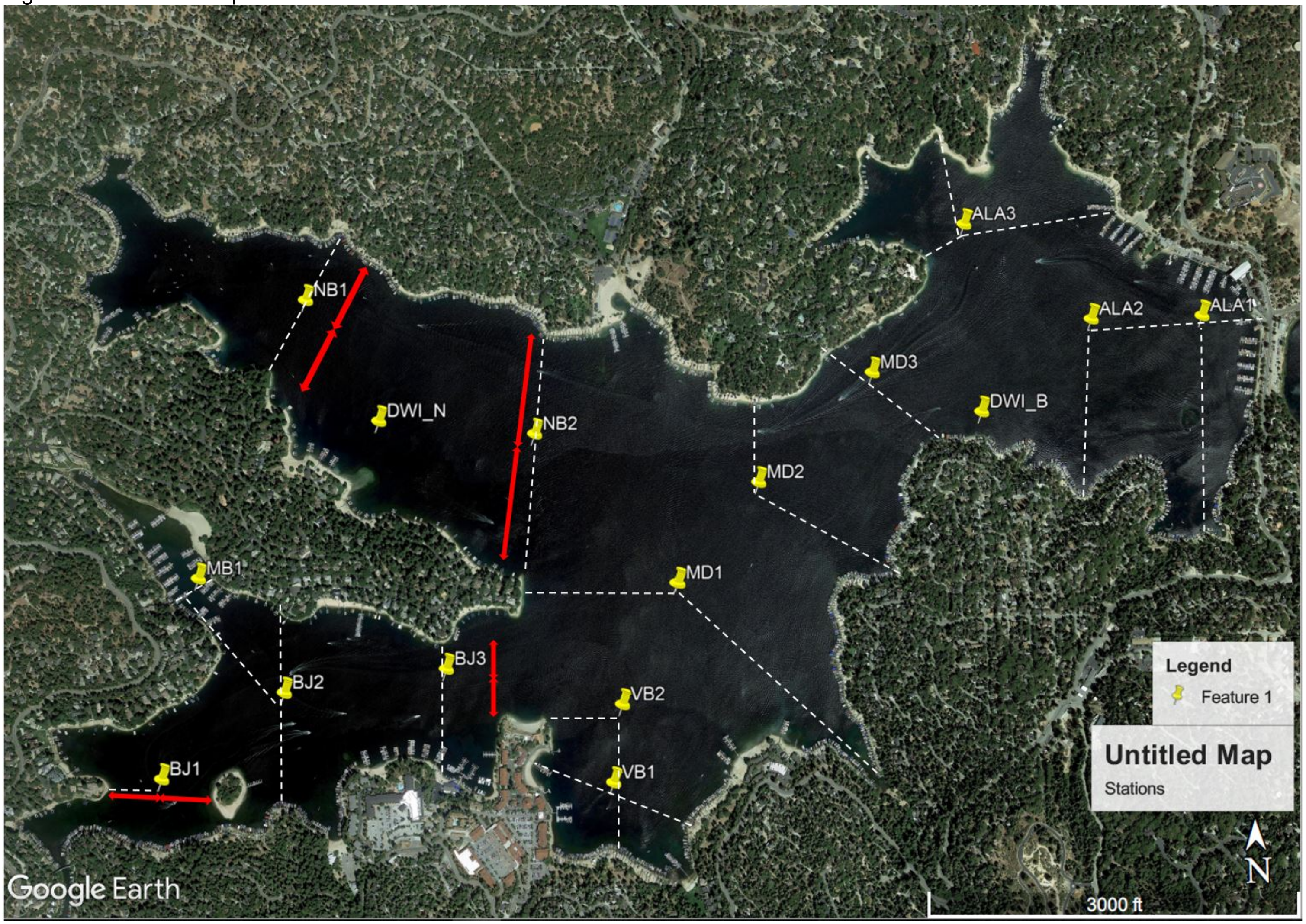

Figure 2. Chart of sample sites with bathymetry

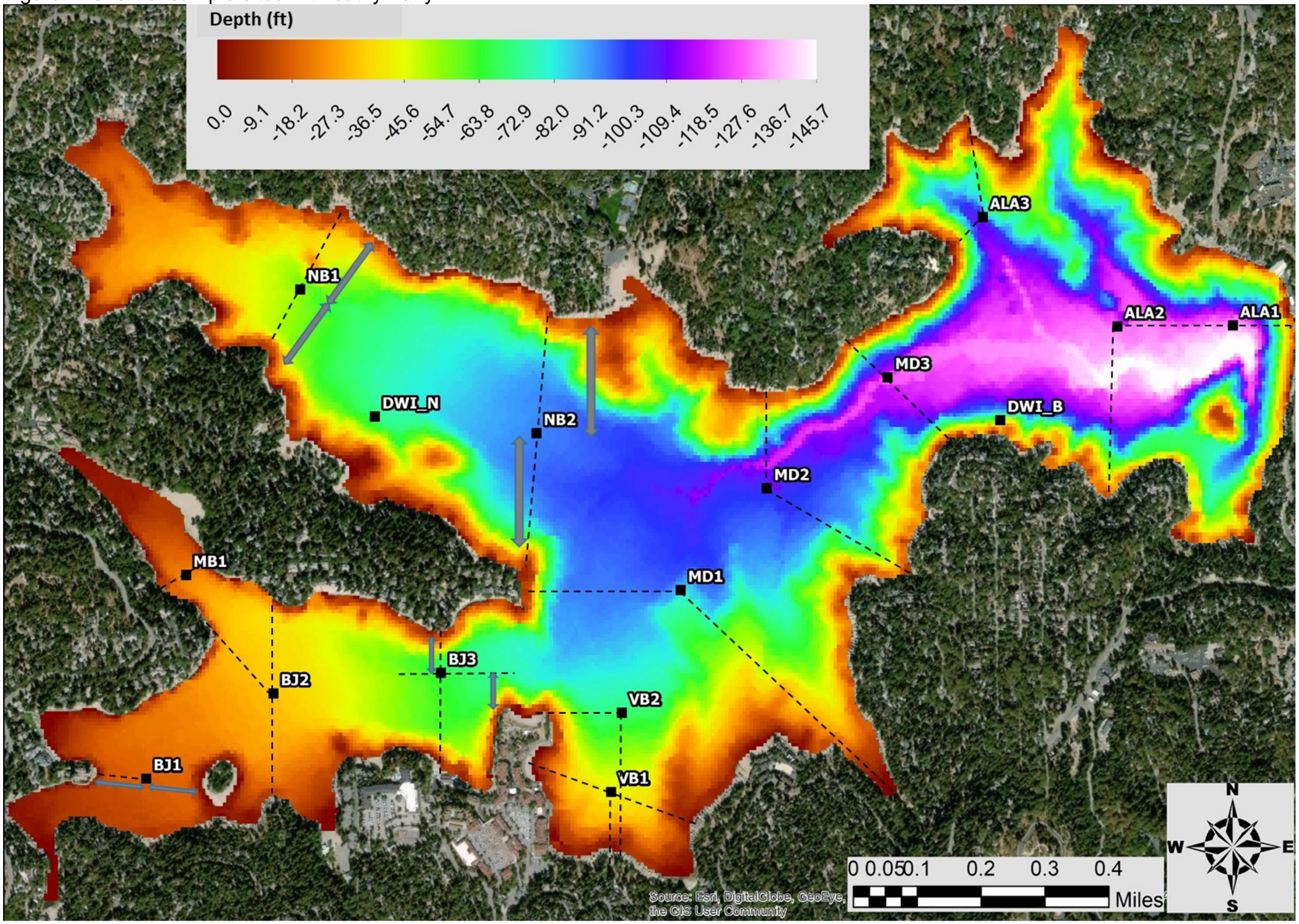

Figure 3: Estimated distance, release site to Emerald Bay intakes for LACSD Cedar Glen Treatment plant

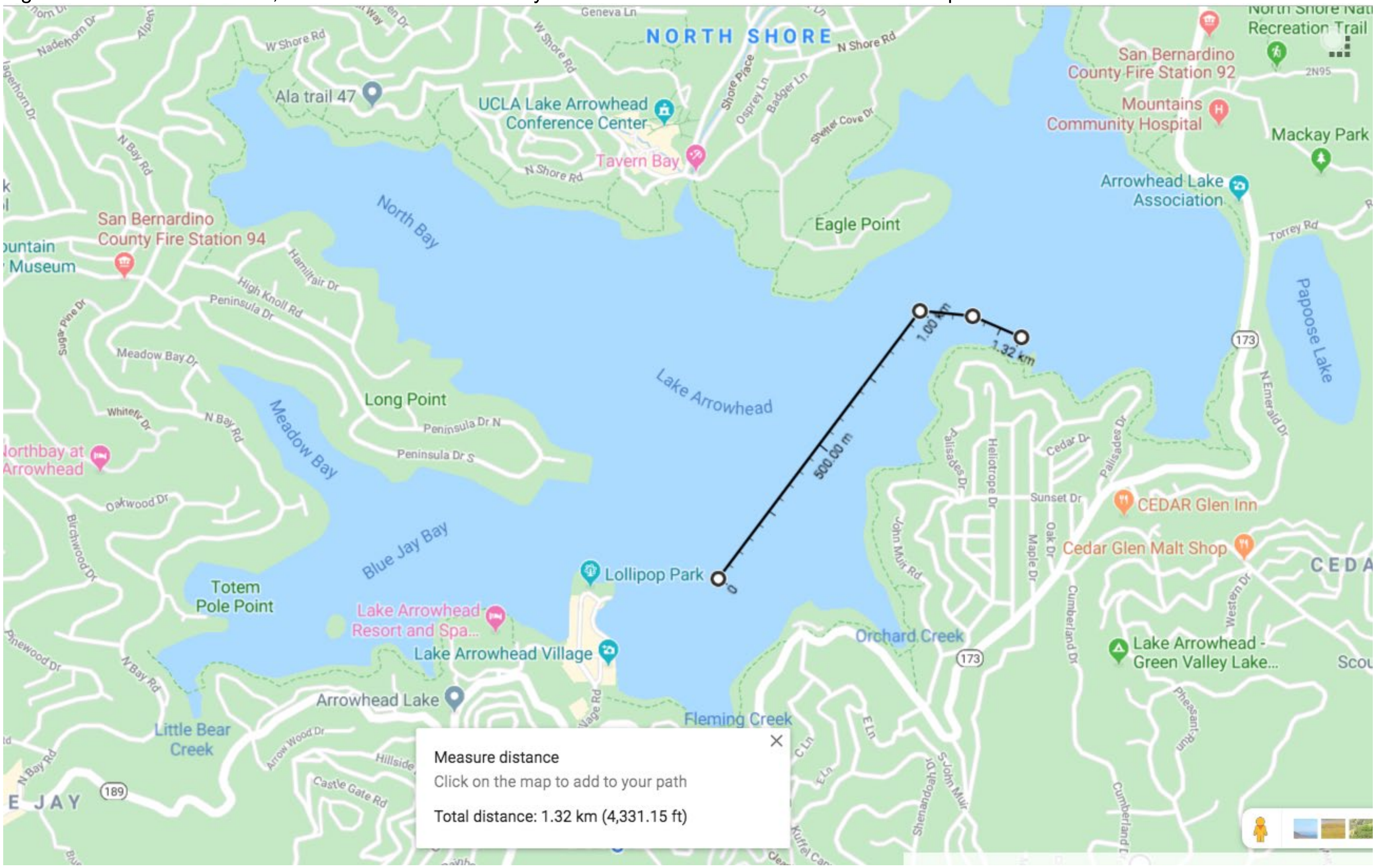

Figure 4. Estimated distance, release site to North Bay intakes to LACSD Bernina Treatment plant

b) Proposed staffing schedule for monitoring

Figure 5: Camera photo of UNLV/ALA planning meeting outcomes 10/31/2019

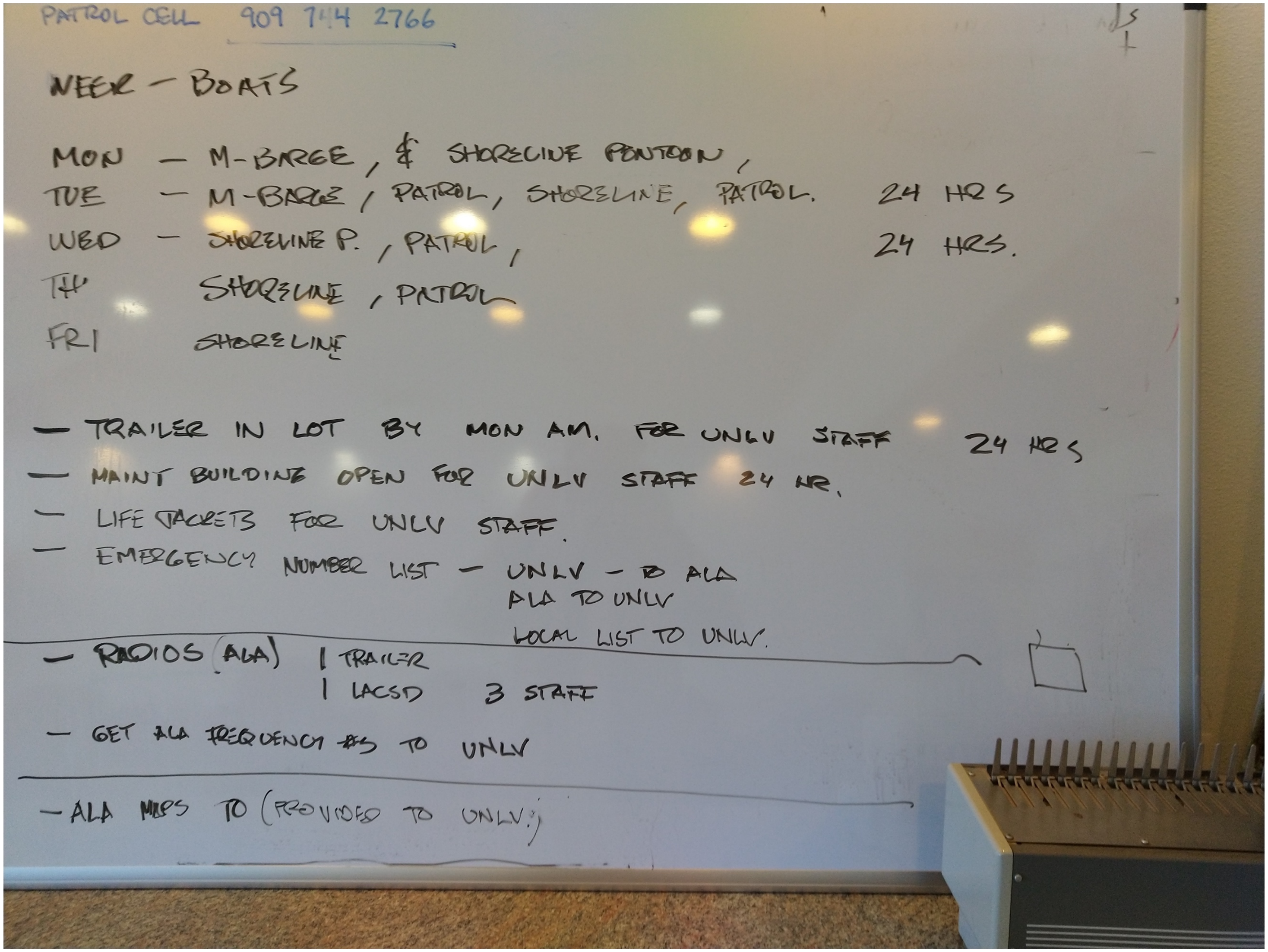

Table 2: Scheduling and staffing table derived from Figure 5

Date	Day	Boats	Activity	ALA/UNLV Crew needed	DRAFT People assigned	Monitoring frequency
12/2/2019	Mon	Maintenance Barge and Shoreline Pontoon	Barge – construct and test dye addition system Shoreline Pontoon – monitoring at all lake stations	Barge – 2/2 for testing Pontoon -2/1 for monitoring 2/2 – pontoon, usual monitoring	ALA – Barge – Brett? Shoreline – Chris and Mike?	N/A Duty cycle: 8 hours or less Barge probably only ½ day
12/3/2019	Tues	Maintenance Barge – Patrol, Shoreline-Patrol	Barge- put dye in lake and return – patrol to guard with lights on Shoreline – chase plume and monitor several nearby fixed locations Patrol 1 – monitor fixed locations west lake Patrol 2 – monitor fixed locations east lake	Barge – 2 for tracer addition Shoreline – 2/1 Patrol 1 – 1/1 Patrol 2 – 1/1 Base camp – UNLV 1	ALA – Barge – Brett? Shoreline – Chris and Mike? Patrol – John? Eddie?	Plume chaser – hourly right after addition unless movement slower or faster. By nightfall probably every 2 hours Shoreline 1 and Shoreline 2 – every 2-3 hours at fixed positions unless plume moves slower or faster Duty cycle – 24 hours Barge probably ½ day
12/4/2019	Wed	Shoreline, Patrol	Shoreline – chase plume and several fixed locations if possible, Patrol – monitor fixed locations	Shoreline – 1 / 2 Patrol – 1 /1 Base camp – UNLV 1-2	ALA Shoreline –Chris or Mike in shifts? Patrol – John? Eddie?	Every 2 – 4 hours depending on rate of plume movement Duty cycle: 24 hours (worst case)
12/5/2019	Thurs	Shoreline, Patrol	Shoreline – chase plume if it still hasn't mixed across lake and several fixed locations if possible, Patrol – monitor fixed locations	Shoreline – 1 / 2 Patrol 1 / 1 Base camp – UNLV 2	ALA Shoreline – Chris or Mike in shifts? Patrol – John or Eddie?	Every 3 hours during daylight hours Duty cycle, 10 hour
12/6/2019	Friday	Shoreline,	Shoreline –monitor fixed locations	Shoreline – 1 / 2	ALA Shoreline- Chris or Mike?	Every 3 hours during daylight hours Duty cycle, 10 hour
12/7/2019	Sat	None	UNLV packs up goes home	UNLV – all 4	None	None

b) Project Staff contact information

Arrowhead Tracer Study Team	Mobile Number	Office Number
Dave James, PI, UNLV	redacted	702-895-5804
PhD student, UNLV	redacted	n/a
Lab Chemist, UNLV	redacted	n/a
Undergrad engineer student, UNLV	redacted	n/a
2nd faculty investigator, UNLV	redacted	redacted
Grad student – field geologist, UNLV	redacted	
Risk Manager, UNLV	redacted	redacted
ALA Lake Supervisor	redacted	redacted
ALA Safety/Patrol Supervisor		redacted
ALA Maintenance Supervisor	redacted	redacted

Emergency and Non-Emergency Numbers	Mobile number	Office Number
Mountains Community Hospital ER		redacted
Cedar Glen Treatment Plant		redacted
Bernina Treatment Plant (Matt)		redacted
LACSD Main # and after hours	n/a	redacted
Arrowhead Lake Association Main #	n/a	redacted
LACSD - Operations Manager	redacted	redacted
LACSD – Operations Manager home #	redacted	
LACSD – Operator – Bernina plant	redacted	
LACSD - General Manager	redacted	redacted
ALA - General Manager	redacted	redacted
ALA 800 MHz radio channel	1	1

Appendix 6.3 – Crew Overboard document for Lake Arrowhead tracer study

Appendix 6.3 - LAKE ARROWHEAD TRACER STUDY – Crew Overboard, Departure Briefing, and Equipment checklist

Derived from similar procedures developed by J. Pasek, City of San Diego Pure Water, 2019

Crew Overboard, COB

- ✔ **STOP** forward motion of the boat
- ✔ **LOCATE** the person, **POINT** continuously
- ✔ Throw **FLOTATION** to the person in the water
- ✔ Assign roles to people in the boat
- ✔ Boat operator to remain at controls
- ✔ No other person in the water, ever
- ✔ Approach from downwind [wind over bow]
- ✔ Stop the engine when the person is alongside
- ✔ Pull person aboard, remove outer clothing and wrap in towels and blankets, return to the dock immediately and get the person to warming station in ALA maintenance shed and/or 5th wheel

Float Plan and Pre-departure Briefing

Be sure each boat knows:
Objective: what are we doing?
Destinations: where are we going?
Times: when will we return?
Risk: Expected conditions and hazards
Who is: Person overall in-charge of each mission (note ALA operator always in charge of boat safety and operations)
Crew: Roles and responsibilities
Communications plans: routine and emergency
Equipment: Run Equipment and gear checklists
Safety: Go over Crew Overboard procedures (above)
Questions?

Equipment Check List Keep the boat clear, don't take extra stuff

- ✔ PFD [type III, life vest] for each person
- ✔ Lines [dock lines, etc.]
- ✔ Personal protective gear: hat, glasses, jacket, gloves, sunscreen
- ✔ Mobile phone and radio, and GPS
- ✔ Radio on ALA-designated channel (for cellular dead spots) - Know your call sign!
- ✔ Sampling instruments
  - Waterproof cable and charged Bluetooth battery
  - Laptop computer with Bluetooth and Manta software
  - Back up - Juniper handheld computer
  - Handheld Trimble GPS (if not using Juniper)
  - Quick start guides [s] for laptop, Manta software, Probe
  - Depth finder

- ✔ Tool Box
  - knife, pliers, screwdriver ,floating lamp, GPS, lighted headbands, extra batteries, at minimum
- ✔ Water sampling gear, as appropriate
  - Van Dorn bottles lines and messenger weight
  - Sample containers
  - Cooler chest
- ✔ Drifters with bubble wrap, sea anchor, correct line, GPS unit, quick links
- ✔ Notebook, field sheets, pen, permanent markers, or pencil, label tape and clear tape
- ✔ Laminated Station map and guide on clipboard

Arrowhead Tracer Study Team	Mobile Number	Office Number
Dave James, PI, UNLV	redacted	702-895-5804
PhD student, UNLV	redacted	n/a
Lab Chemist, UNLV	redacted	n/a
Undergrad engineer student, UNLV	redacted	n/a
2nd faculty investigator, UNLV	redacted	redacted
Grad student – field geologist, UNLV	redacted	
Risk Manager, UNLV	redacted	redacted
ALA Lake Supervisor	redacted	redacted
ALA Safety/Patrol Supervisor		redacted
ALA Maintenance Supervisor	redacted	redacted

Emergency and Non-Emergency Numbers	Mobile number	Office Number
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LACSD – Operations Manager home #	redacted	
LACSD – Operator – Bernina plant	redacted	
LACSD - General Manager	redacted	redacted
ALA - General Manager	redacted	redacted
ALA 800 MHz radio channel	1	1

Priority of Methods of Communication (by order of preference)	Protocol for Communication
#1 - Spoken word face-to-face #2 - Spoken word using telephone #3 - Text message	State: ● Your Name ● Location ● Purpose of the communication ● Names of others Describe the **situation** Describe what is **the need** **Confirm** the actions of the other party **Agree to end** the communication with the other party

Appendix 2 – Lake Arrowhead Acoustic Doppler Profiling Data Collection and Preliminary Analysis, 2019

Hydraulic Laboratory Technical Memorandum, PAP-1194

Lake Arrowhead Acoustic Doppler Profiling Data Collection and Preliminary Analysis, 2019

U.S. Department of the Interior
Bureau of Reclamation
Technical Service Center
Hydraulics Investigations and Laboratory Services Group
Denver, Colorado

December 2020

Hydraulic Laboratory Technical Memorandum PAP-1194

Lake Arrowhead Acoustic Doppler Profiling Data Collection and Preliminary Analysis, 2019

Prepared by: Tracy B. Vermeyen, P.E. Date

Hydraulic Engineer
Hydraulic Investigations and Laboratory Services
Group, 86-68460

Peer review: Michael Horn, PhD Date

Manager,
Fisheries and Wildlife Resources Group, 85-82900

Purpose

The purpose of the acoustic Doppler profiling in Lake Arrowhead was to provide water current profile data to support hydrodynamic modeling and tracer studies that will be used to assess risks associated with proposed indirect potable reuse (IPR) for surface water augmentation (SWA) at Lake Arrowhead. The purpose of this Reclamation Science and Technology funded project (ST-19-7100) is to develop best practices for conducting data collection, hydrodynamic modeling and tracer studies that can provide guidance to water utilities as they conduct IPR-SWA studies in their reservoirs.

Acoustic Doppler profilers (ADPs) were deployed at two locations in Lake Arrowhead to develop an understanding of reservoir currents during periods of thermal stratification for 2019. The ADP data sets will provide information to develop an understanding of reservoir current patterns during mixing events caused by wind, inflows, and pumping station withdrawals.

Introduction

Lake Arrowhead and its dam are located in the San Bernardino National Forest in San Bernardino County, California. The reservoir is located on Little Bear Creek about 30 miles east of Redlands. Lake Arrowhead was originally named Lake Little Bear with initial development in the 1890's to provide a diverted water supply for the San Bernardino area. These water diversions were never approved, so the completed reservoir was renamed Lake Arrowhead and became a popular resort community. Recreational use of the privately-owned reservoir is controlled by the Arrowhead Lake Association (ALA). The Lake Arrowhead Community Services District (LACSD) withdraws water from the reservoir for treatment and distribution to local residents for potable use.

In 2019, the Technical Service Center's Hydraulic Investigations and Laboratory Services Group (86-68560) deployed two ADPs in Lake Arrowhead at locations selected to provide calibration/validation data for a 3-D hydrodynamic reservoir model that is being developed for Science and Technology project ST-19-7100. The project team leader is Dr. David James from the University of Nevada Las Vegas (UNLV).

Methods and Materials

Acoustic Doppler Profiling Locations

A Sontek 500 kHz ADP was initially deployed mid-lake on April 25, 2019. Likewise, a Sontek 1,500 kHz Pulse Coherent ADP (PC-ADP) was deployed from a dock in Meadow Bay (MB) on April 24, 2019. Figure 1 is a map of Lake Arrowhead with the approximate locations of the two ADP deployments. On April 25, 2019 a test deployment of the ADP was conducted during a preliminary test of the UNLV drifters. Several current profiles were measured at 5 different sites in Lake Arrowhead. These data were provided to UNLV for comparison to their drifter data.

The GPS coordinates for the mid-lake ADP site are N34.25744°, W117.185510°. The approximate reservoir bottom elevation of the ADP site was computed to be 5001.02 ft (ALA 1917 datum[1]). The GPS coordinates for the Meadow Bay PC-ADP are N34.256355°, W117.197749°. Note: all GPS coordinates in this report are for the NAD83 datum. The PC-ADP reservoir bottom elevation was computed by subtracting the PC-ADP depth from the reservoir elevation on April 24, 2019. The reservoir bottom elevation at the PC-ADP location is approximately 5,079.1 ft.

ADP deployments and retrievals

Divers retrieved the mid-lake ADP on July 26, 2019 around 2:00 p.m. The divers reported the ADP was lying on its side when they found it. The ADP's tilt sensor data confirmed the ADP tipped over just after it was set on the bottom. It is likely the ADP was pulled over when the intermediate anchor was being deployed. Consequently, no usable current profiles were collected from the mid-lake ADP for the first deployment. Both ADPs were serviced on August 13 to replace their battery packs.

The PC-ADP was re-deployed on August 13, 2019 at 10:00 a.m. at the same location as the previous deployment. The reservoir bottom elevation was computed to be 5080.47 ft. The second mid-lake ADP deployment was delayed until September 26, 2019 because of scheduling conflicts between UNLV and the divers. The ADP was placed on the bottom and leveled by the divers after the intermediate anchor was set. For the second deployment, the computed reservoir bottom elevation for the mid-lake ADP was 5001.0 ft.

On Jan 16, 2020 the PC-ADP was retrieved from the Meadow Bay dock by the ALA-UNLV crew. On January 17, 2020, divers and the ALA-UNLV crew

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[1] Bureau of Reclamation, Lake Arrowhead 2008 Reservoir Survey, Technical Report No. SRH-2009-9. On page 2 it states that the 1917 Lake Arrowhead vertical datum, established during construction, is about 8.0 feet lower than NGVD29 and 11.2 feet lower than NAVD88.

retrieved the mid-lake ADP. Both ADPs were stored in an Arrowhead Lake Association shed until they could be serviced by Reclamation staff. Both ADPs were serviced on February 6, 2020. The ADPs were packed up and shipped back to Denver on February 7, 2020.

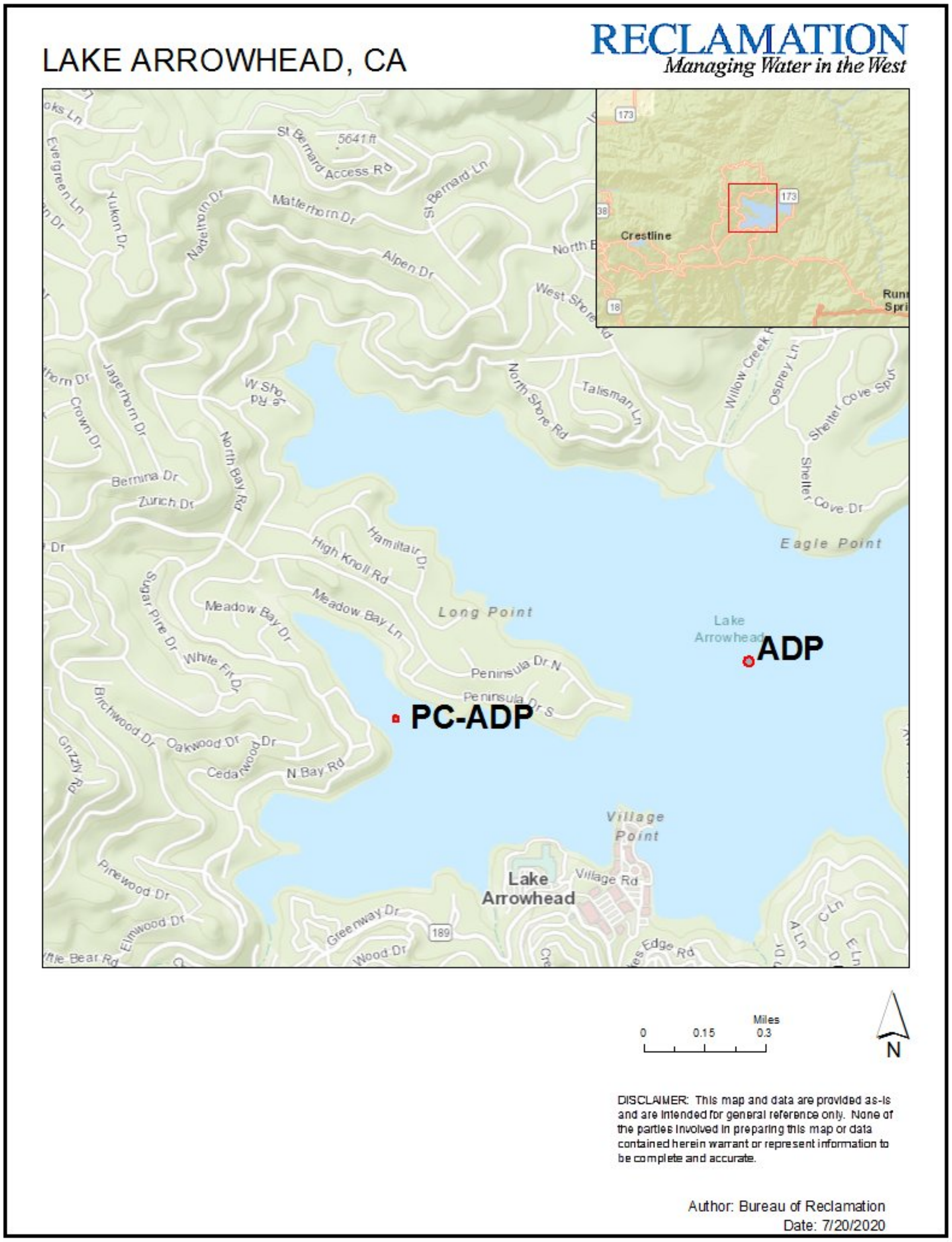

Figure 1. Lake Arrowhead map showing the Meadow Bay PC-ADP and mid-lake ADP sites.

Mid-Lake ADP Configuration

For the 2019 field season, the 500 kHz ADP (serial number C34) was set up for 30 depth cells with a 1.0 m cell size. The ADP was configured for an uplooking deployment for a depth of 30.0 meters (98.4 ft). The blanking distance was 1.0 m while the sensor depth was set to 0 m. For the first deployment, the profiling schedule was to measure current profiles with an averaging interval of 300 seconds and a profiling interval of 1200 seconds. This resulted in a velocity profile averaged over 5 minutes collected every 20 minutes. For the second deployment, the profiling schedule was to measure current profiles with an averaging interval of 300 seconds and a profiling interval of 900 seconds. This resulted in a velocity profile averaged over 5 minutes collected every 15 minutes. For this sampling configuration, the uncertainty in the horizontal velocity measurement was about ±1.0 cm/sec. Note: the second deployment was started on August 13, 2019, but the ADP wasn't deployed by divers until September 26, 2019 due to problems with scheduling the divers. As a result, the first 4220 velocity profiles were measured in air and are meaningless.

This ADP was equipped with a pressure sensor to measure depth, a temperature probe for water temperature measurements and sound speed calculation, and a compass so the 3D velocities can be referenced to east, north, and up coordinates. A complete listing of the ADP system and second deployment configuration is in Appendix 1.

Note: Reclamation's ADP is an older model with firmware that has the "2011 clock bug" where the ADP's internal clock gets reset to a default value if the year is later than 2011 (2019 in this case) and the ADP enters AutoSleep mode. A Sontek support engineer suggested setting the ADP date with a 2009 year instead of 2019. As a result, the raw ADP data will have time-stamped profiles with the year 2009 instead of 2019. This clock bug was not an issue with the PC-ADP deployments.

It is important to note that the mid-lake ADP's compass calibration utility failed to complete the calibration process for the 2019 deployments. The compass offset was estimated by comparing the ADPs compass reading with the digital compass on a mobile phone. When the ADP was oriented due north its compass reading was 242° or the offset was -118°. Similarly, when the ADP was oriented due south its compass reading was 71.5° or the offset was -108.5°. When the ADP was deployed on September 26, 2019 the compass reading after the divers positioned the ADP mount was 177°. To correct the ADP current direction data the value was reduced by -108.5°. This compass calibration technique is less than ideal, but it was the only option available for this data set. It is important to note that while the current direction may have a calibration offset, the relative current direction during any single profile is unaffected by the compass offset.

Meadow Bay PC-ADP Configuration

For the 2019 field season, a 1,500 kHz PC-ADP (serial number H33) was set up for 18 depth cells with a 0.50 m cell size. The ADP was configured for an uplooking deployment in a depth of 9.0 meters (29.5 ft). The blanking distance was 0.50 m while the sensor depth was set to 0 m. Assuming minimal settlement of the PC-ADP mount, the sensor distance from the reservoir bottom is 0.38 meters. For the first deployment, the profiling schedule was to measure current profiles with an averaging interval of 300 seconds and a profiling interval of 1,200 seconds. This resulted in a velocity profile averaged over 5 minutes collected every 20 minutes. For the second deployment, the averaging interval was 300 seconds and a profiling interval of 1,800 seconds. This resulted in a velocity profile averaged over 5 minutes collected every 30 minutes. The profiling interval was set to 1800 seconds to prolong the battery life for the second deployment. For this sampling configuration, the uncertainty in the horizontal velocity measurement is less than ±1.0 cm/sec.

The PC-ADP was equipped with a pressure sensor to measure depth, a temperature probe for water temperature measurements and sound speed calculation, and a compass so the 3D velocities can be referenced to east, north, and up coordinates. The compass calibration was successfully completed before each deployment. A complete listing of the PC-ADP system and deployment configuration is in Appendix 1.

Vertical Temperature Profiles

Vertical temperature profiles are used to monitor the thermal stratification of a water body. Stratification can influence reservoir currents and inflow and outflow mixing processes. High-resolution temperature profiles can detect short-term events, like seiches or destratification (turnover).

Mid-Lake Profiles

UNLV deployed a temperature profiling string in Lake Arrowhead near the mid-lake ADP site to collect high-resolution vertical temperature profiles. Temperature logger spacing varied from 1m near the water surface to 3m near the reservoir bottom. The GPS coordinates for the temperature profiling buoy are N34.25825°, W117.18494°. The temperature profiling string was equipped with 18 Onset HOBO® U22-001 water temperature loggers which used the Onset factory calibration with ±0.21°C from 0°C to 50°C. Profiles were collected every 5 minutes from April 24, 2019 until January 31, 2020. Note: the mid-lake temperature profiling buoy was vandalized and sank to the lake bottom on July 7. The temperature profiling string wasn't repaired and redeployed until September 26, 2019. As a result, temperature profiling data are not available at this location from July 7 through September 26, 2019.

Meadow Bay Profiles

Reclamation was responsible for deploying the temperature profiling string at the Meadow Bay PC-ADP location. The string was located directly above the PC-ADP location shown in Figure 1. Profiles were collected every 5 minutes from April 24, 2019 to January 11, 2020. The temperature profiling string was equipped with HOBO Tidbit® temperature loggers with a 1 meter vertical spacing. The GPS coordinates for the Meadow Bay temperature profiling string are N34.256355° and W117.197749°. The Meadow Bay temperature string had 10 loggers which were calibrated in Reclamation's hydraulics laboratory in Denver, Colorado prior to the initial deployment. All Tidbit® temperature loggers were calibrated to within the manufacturer's specified accuracy of ±0.2°C.

Lake Arrowhead Reservoir Operations

For the 2019 field seasons, Lake Arrowhead Reservoir operations data were collected by Arrowhead Lake Association and were provided to UNLV. For this report, the reservoir surface elevation was used to convert the temperature logger depths to elevations.

Weather Stations

UNLV established a network of weather stations around Lake Arrowhead to support this project. Reclamation was not involved with collecting or analyzing weather station data. Weather station wind speed and direction data can be used to analyze the vertical temperature profile data to understand the influence of wind on the stratification and the formation of seiches. Likewise, wind data are also a key driver in reservoir water currents.

Data Analysis and Results

Reservoir Operations

Figure 2 is a plot of the Arrowhead Lake reservoir elevations during the ADP measurements and vertical temperature profiling. Reservoir elevations are necessary for data analysis to exclude ADP depth cell data that are biased by boundary (water surface) interference. Other reservoir operations data pertinent to this report are the Grass Valley Tunnel inflows to Meadow Bay, especially during a storm event on December 4, 2019 when UNLV was conducting a dye tracer experiment in Lake Arrowhead. UNLV deployed a water temperature and specific conductance logger in the Grass Valley Tunnel inflow channel just upstream from Lake Arrowhead. Figure 3 shows the USGS gage (10260855) inflow hydrograph for Grass Valley Lake Tunnel releases into Meadow Bay at Lake Arrowhead. The peak discharge during the dye tracer study was 30 cubic feet per second (CFS) on December 4, 2019.

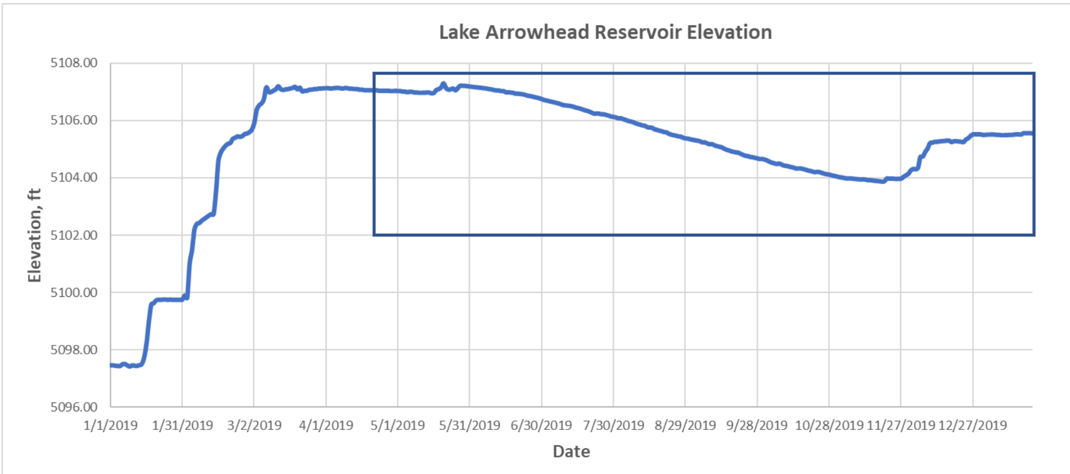

Figure 2. Lake Arrowhead reservoir elevation from January 1, 2019 to January 21, 2020 (ALA vertical datum 1917). The rectangle illustrates the study period, April 24, 2019 to January 15, 2020.

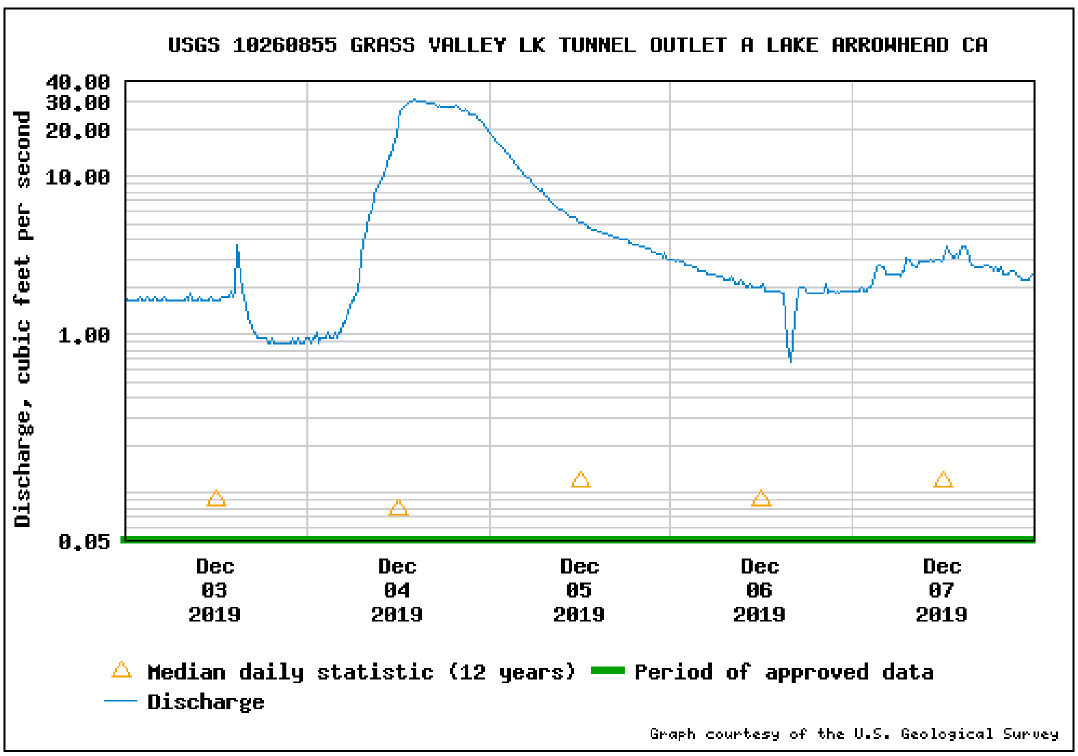

Figure 3. Plot of USGS Grass Valley Lake tunnel outlet that discharges into Lake Arrowhead's Meadow Bay during a storm event that coincided with UNLV's dye tracer study. Source: USGS website.

Arrowhead Lake Wind Data Analysis

UNLV was responsible for the collection and analyses of the wind data. The wind field over Lake Arrowhead is an important input to the computer model used for modeling the reservoir. UNLV used wind data from several weather stations to define the wind field over the entire reservoir. In this report, wind data from LACSD pump station No. 8, McKay Park (BR1) and Tavern Bay (BR3) weather stations will be presented to support understanding of reservoir currents and thermal stratification (vertical temperature profiles) for Meadow Bay and mid-lake sites, respectively. Note: wind directions presented are converted from the direction the wind was blowing from to the direction the wind was blowing towards. This change was made so the wind direction would be consistent with the water current direction. For example, a sustained wind from the north should produce surface water currents in a southerly direction.

ADP Analysis

A detailed analysis of the ADP data collected at Lake Arrowhead was not included as part of the technical assistance to UNLV. However, a brief presentation of the ADP data and some general observations will be covered in this section. In general, the analysis for each ADP profiling site will be for the same time period.

Acoustic Doppler profile data are inherently noisy and usually require averaging to dampen out the acoustic noise. Lake Arrowhead ADP data were collected with a 5-minute averaging interval and a 20-minute profiling interval. Depth averaging and temporal averaging can be used to smooth the data which can assist with data interpretation.

Another data processing consideration was to exclude ADP cells near the water surface because they are biased by sidelobe interference. For this uplooking application the interference occurs at the water surface. The sidelobe energy from each 25° slant angle acoustic beam will encounter the water surface before the primary acoustic beam does because it travels a shorter path (vertically). Because the water surface is a strong acoustic reflector and these sidelobe returns occur in the same range (with respect to travel time) where the main lobe depth cell is located, they bias the backscattered signal in these near-surface depth cells. Unfortunately, there isn't a way to remove the bias from the sidelobe interference. Note: the PC-ADP has a 15° slant angle so it is not as susceptible to sidelobe interference.

At Lake Arrowhead, the reservoir water surface elevation dropped slowly throughout the data collection period (see figure 2). As a result, the ADP data have to be processed to account for sidelobe interference occurring in different depth cells as the water surface elevation drops. Consequently, the ADP velocity profiles do not contain the surface water velocity generated by the wind.

However, the near-surface velocity measurements should behave similarly to the wind-driven surface velocities.

Mid-Lake ADP Analysis

ADP data were collected continuously between September 26, 2019 and January 9, 2020. A total of 10,060 velocity profiles were collected for this 105-day deployment. For the data shown in this section the ADP current directions have been adjusted in an attempt to correct for the compass offset, as previously described.

Figure 4 shows the complete 2019 mid-lake ADP data record along with a plot of the wind speed and direction data from the McKay Park weather station (BR1). In general, these contour plots show mostly low currents with some near-bottom currents which appear to be expanding upward with time. It is important to note that the mid-lake current speeds are biased high by about 1 to 2 cm/sec because the mid lake ADP has a higher measurement standard deviation when compared to the PC-ADP data (Figure 4). In other words, the ADP current measurements cannot accurately resolve water currents less than 1 to 2 cm/sec because of the random acoustic noise that is inherent with the ADP signal processing. It appears on figure 7 that on or around day 330 (November 26, 2019) there was a strong wind event that changed the bottom currents. It is likely that this wind event caused the reservoir stratification to break down.

Figure 5 contains plots for days 329 to 332 which confirms that a strong wind event blowing towards the northwest disrupted the relatively stable current pattern at the mid-lake location. Winds of over 12 m/sec toward the northwest created near-surface current speeds up to 8 cm/sec on November 27, 2019 (day 331). However, these currents dissipated quickly when the wind slowed and changed direction.

Figure 6 shows a 6-day period for calendar days 336 to 342 (December 2-7, 2019) which includes the December 3-7 UNLV dye tracer study period. These ADP contour plots help visualize the effects of a December 4 (day 238) storm event on surface and bottom currents at the mid-lake site. On day 338 there was increased current speed mid depth (El. 5040 ft), but it was short lived. It is interesting that the strong winds at BR1 did not create stronger surface water currents. It is also important to note the reservoir stratification was breaking down and Lake Arrowhead was essentially iso-thermal during the dye tracer study.

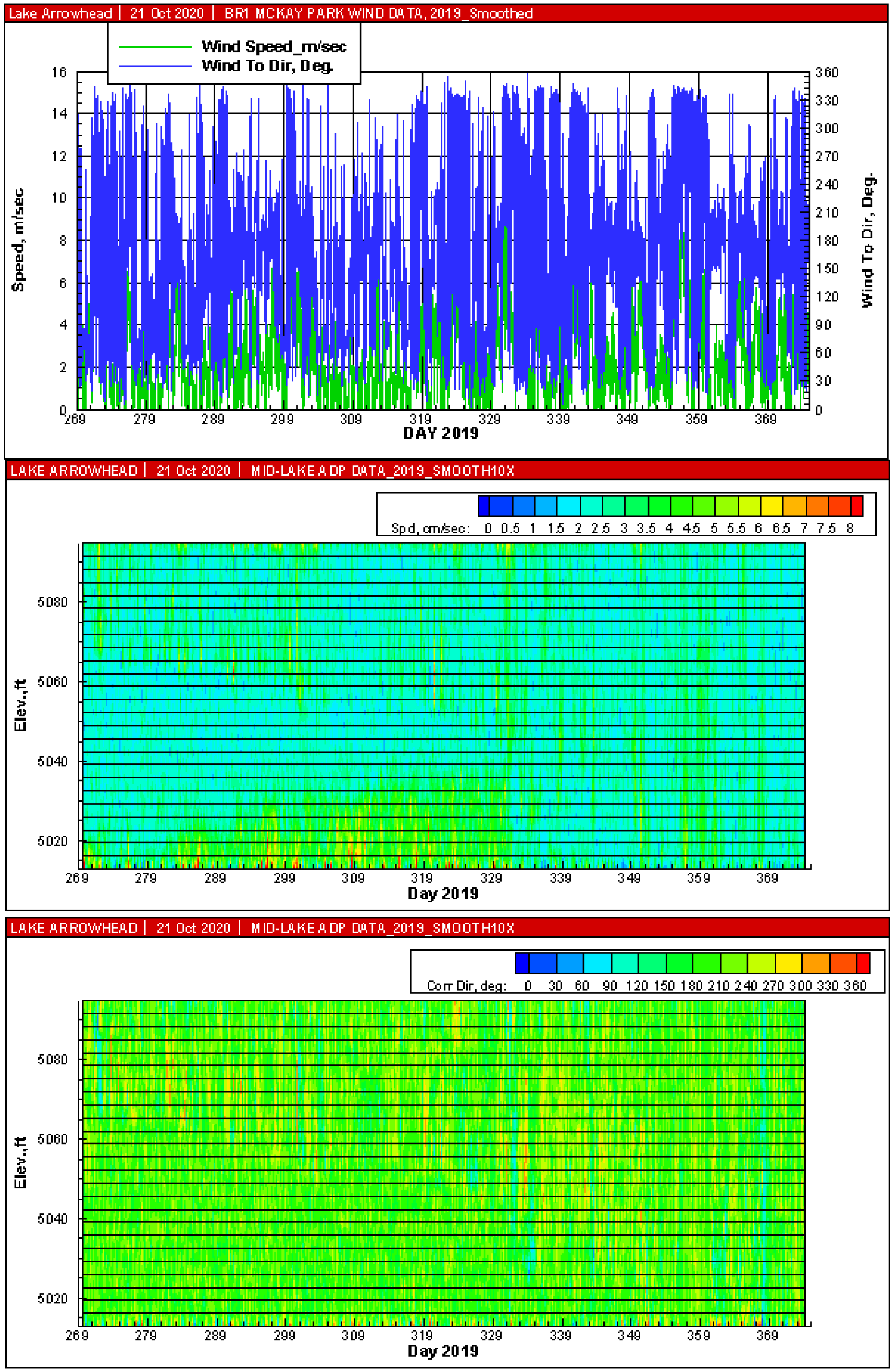

Figure 4. Complete record of ADP current speed and direction contour plots from calendar day 269 to 374 (September 26, 2019 to January 9, 2020). The BR1 weather station's wind speed and direction (toward) data for the same time period are included in the top plot. The black dots represent ADP depth cell locations.

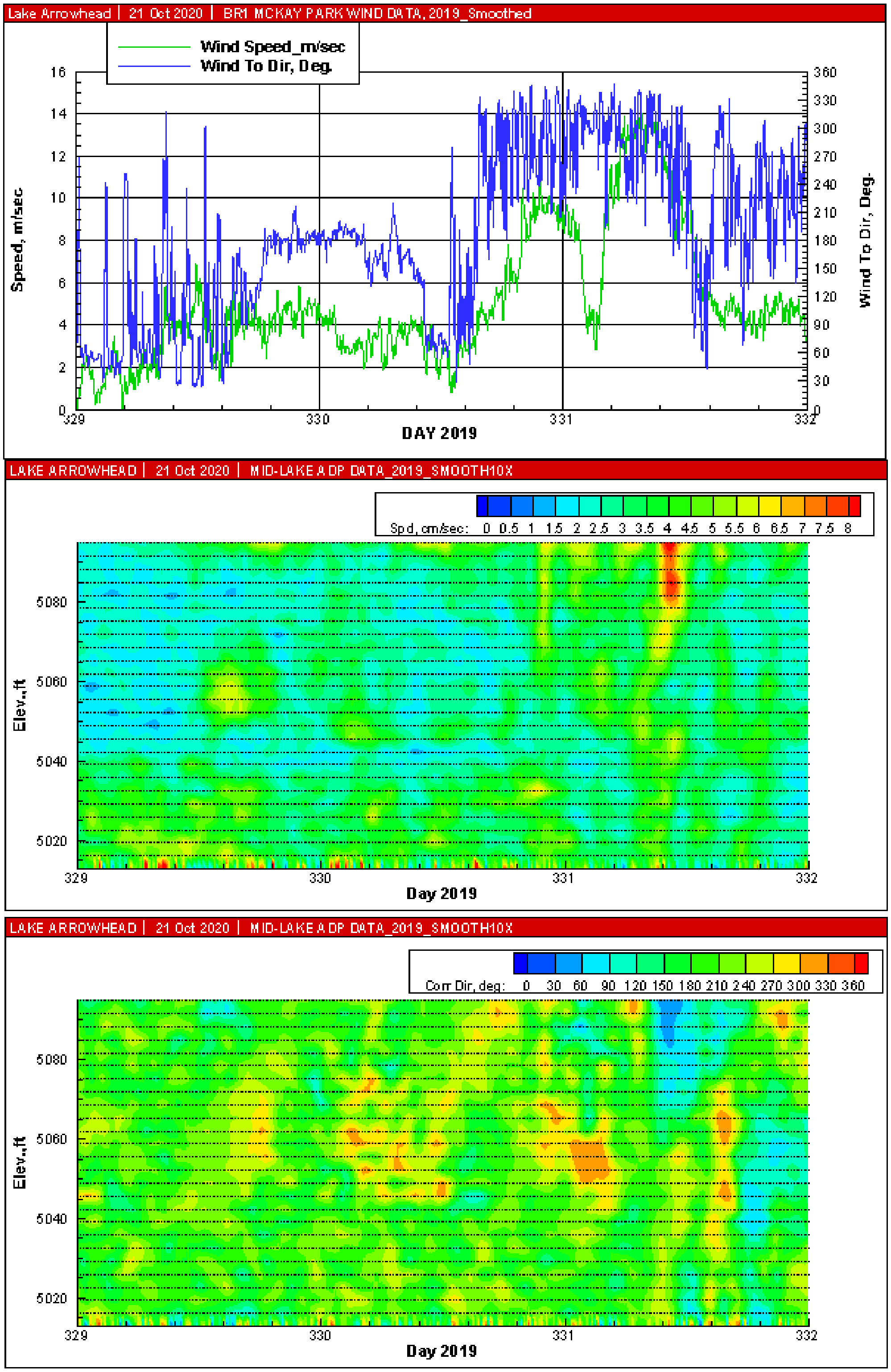

Figure 5. Three-day record of ADP current speed and direction contour plots for calendar day 329 to 331 (November 25-27, 2019). This shorter window of time allows for a detailed inspection of surface and bottom currents during a strong wind event measured at the BR1 weather station. The black dots represent ADP depth cell locations.

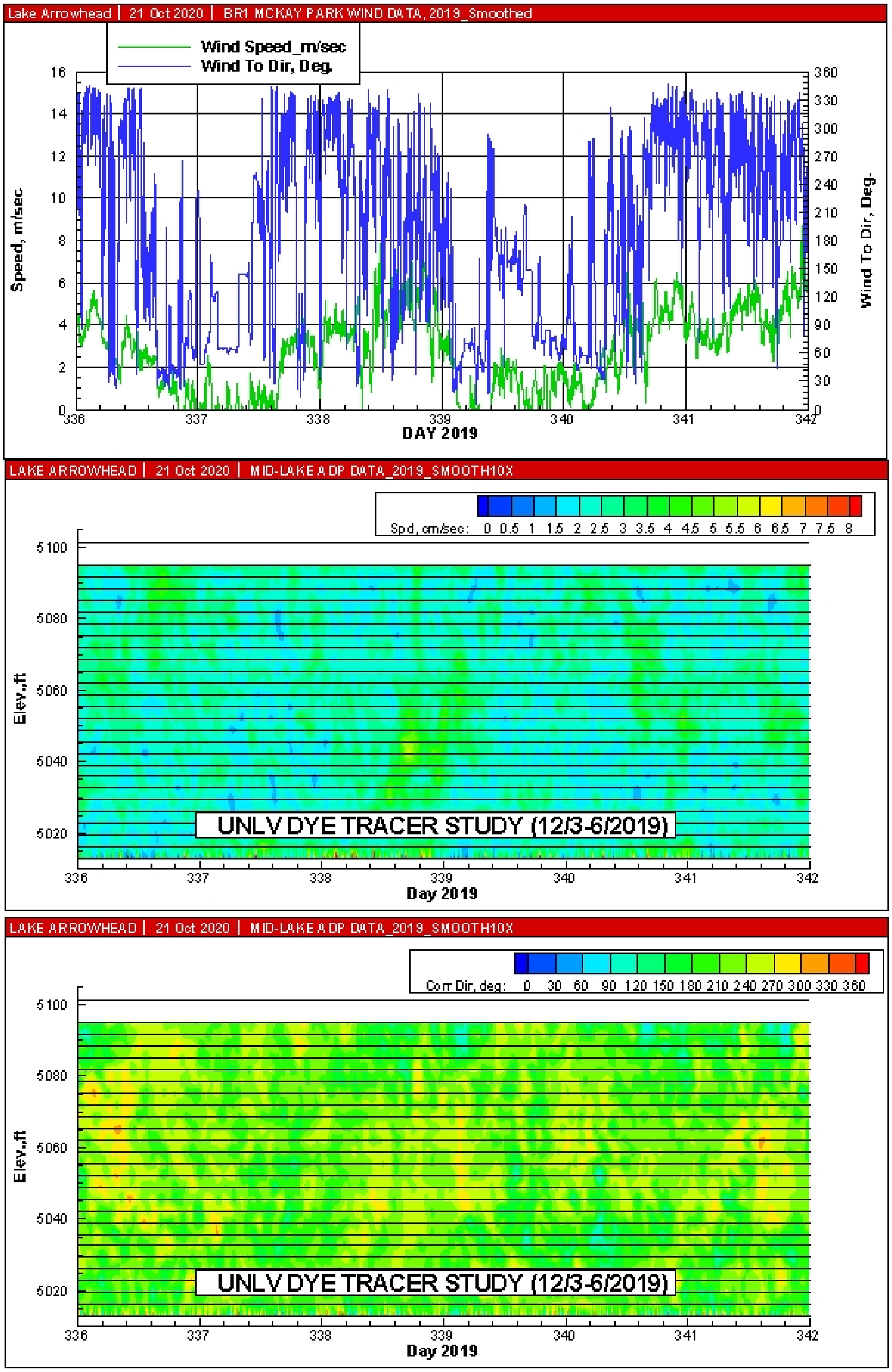

Figure 6. Plots of PC-ADP current speed and direction collected during the UNLV Dye Tracer Study on days 336-341 (December 2 -7, 2019). The McKay Park wind speed and direction (toward) data for the same time period are included in the top plot. The current direction data shows several reversals in direction near the reservoir surface and bottom. The current speed data do not show any strong currents generated by the storm events.

Meadow Bay PC-ADP Analysis

Meadow Bay PC-ADP data were collected continuously between April 24, 2019 and January 15, 2020. A total of 16,033 velocity profiles were collected for this 266-day deployment. For this report, Meadow Bay PC-ADP data collected between April 24, 2019 and January 15, 2020 will be presented.

Figure 7 shows the complete 2019 PC-ADP data record along with a plot of the wind speed and direction data from the LASCD pump station No. 8 wind sensor. In general, these plots show the dynamic currents with many wind events that generate near surface water currents up to 4 to 5 cm/sec. In contrast, the currents measured near the reservoir bottom only occasionally exceeded 4 cm/sec. The velocity direction data is the most informative as it shows frequent reversals in current direction throughout the water column.

Figure 8 shows a 1-day period for calendar day 186 (July 5, 2019) which helps to visualize the effects of sustained wind events on surface and bottom currents at the Meadow Bay site. This type of plot can assist with the calibration and validation of the reservoir model to evaluate if the model current profiles are representative of the field measurements. The PC-ADP data shows reversals in current direction as the wind picks up in the afternoon and subsides in the evening. The near-surface currents pick up to 7 cm/sec when the Meadow Bay average wind speeds increase to 4 m/sec during the middle of the day.

Figure 9 shows a 6-day period for calendar days 336 to 341 (December 2-7, 2019) which includes the dye tracer test conducted by UNLV. These plots help visualize the effects of a December 4 (day 238) storm event on surface and bottom currents at the Meadow Bay site. It is important to note that the reservoir stratification was breaking down and Meadow Bay was essentially iso-thermal during the dye tracer study. When interpreting the PC-ADP data the current direction contours are red/orange when water is moving into Meadow Bay. Conversely, the contours are light blue when water is moving out of Meadow Bay and into Lake Arrowhead.

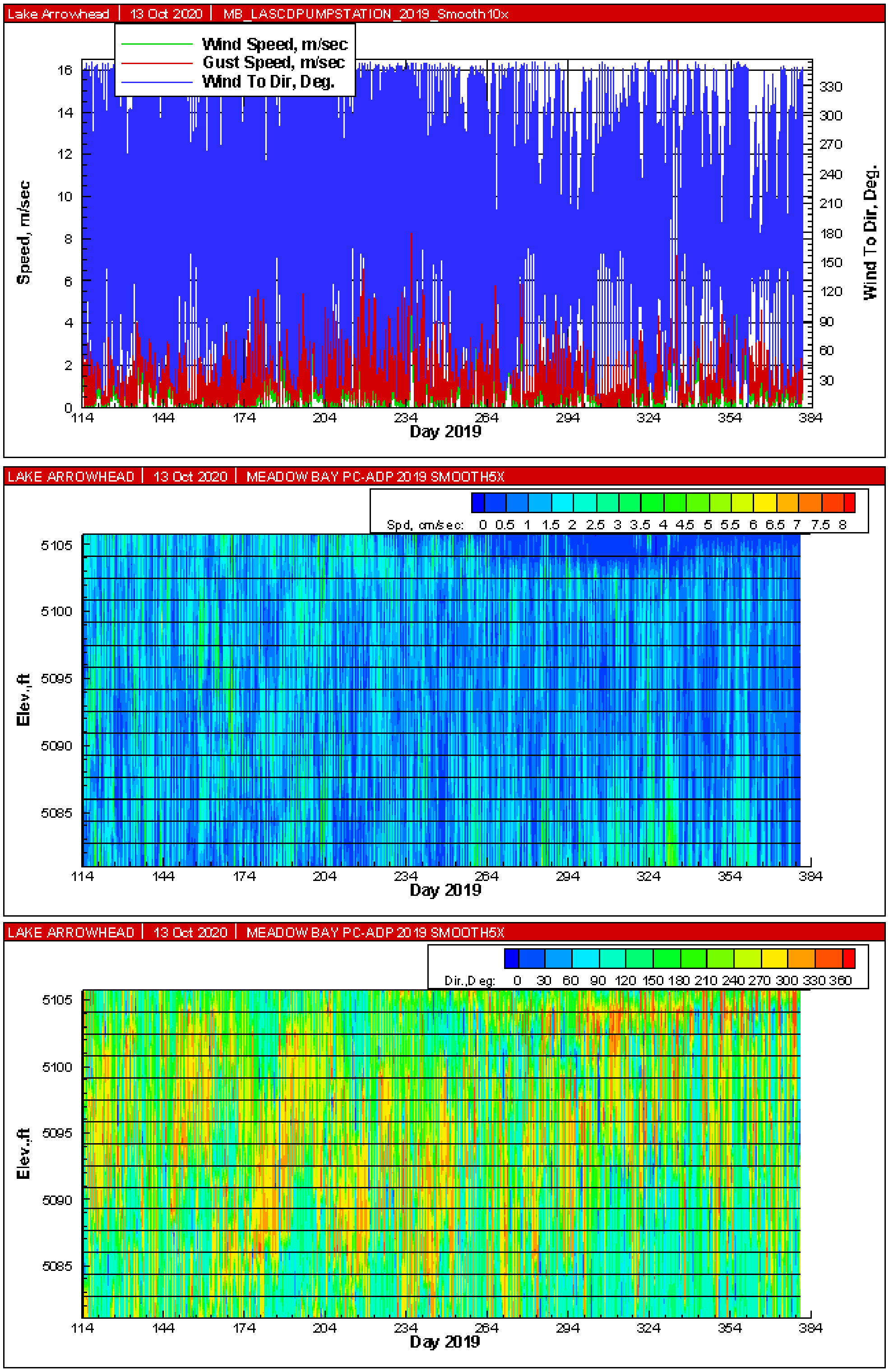

Figure 7. Plots of wind speed and direction (top panel) and PC-ADP current speed and direction contour plots at the Meadow Bay site. The period of data collection was from April 24, 2019 (day 114) to January 15, 2020 (day 380). Both wind and PC-ADP data were smoothed to remove spikes from the data. The black lines on the PC-ADP plots are the depth cell elevations. The black dots represent PC-ADP depth cell locations.

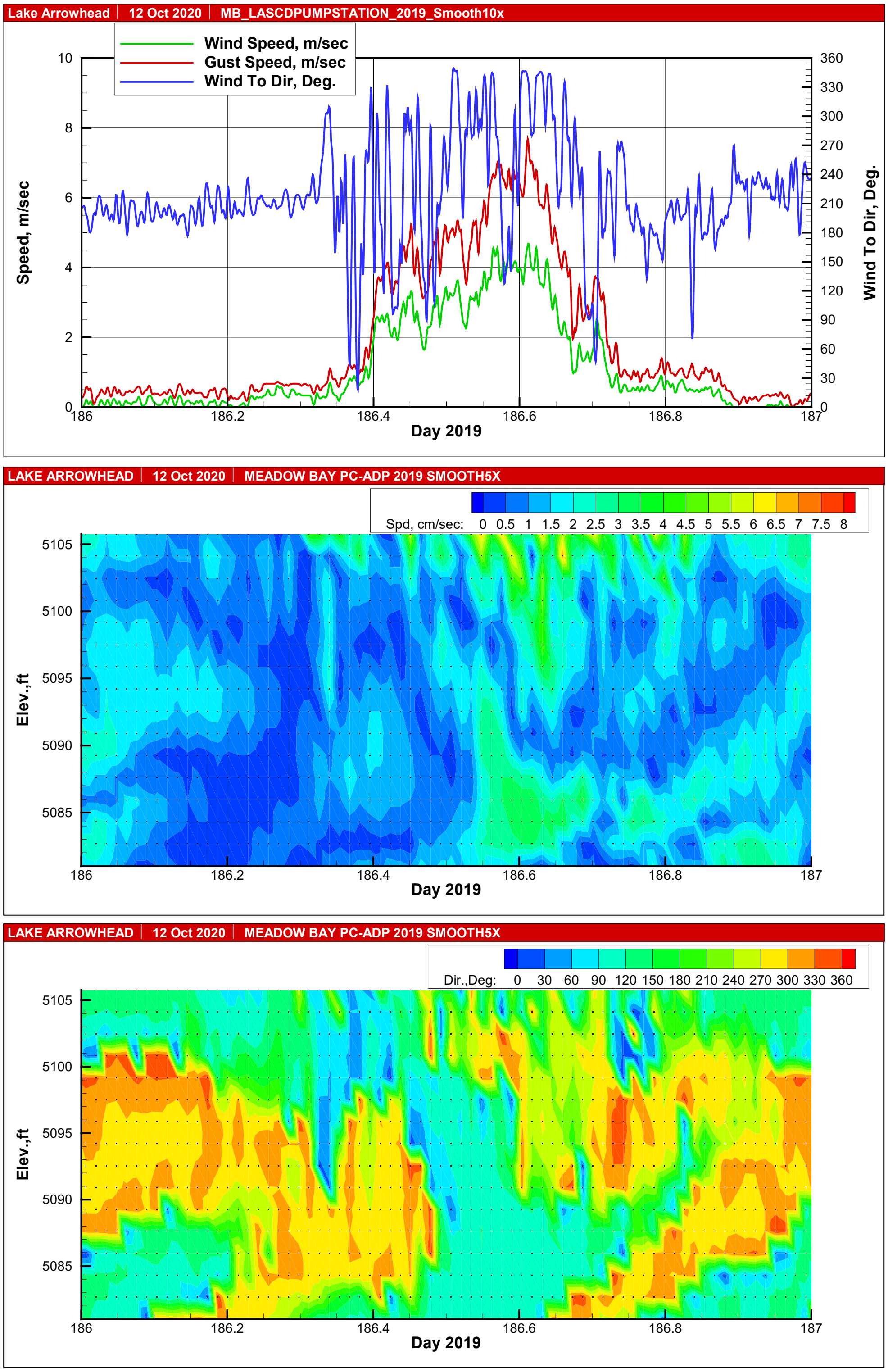

Figure 8. Plots of PC-ADP current speed and direction contour plots for calendar day 186 (July 5, 2019). The Meadow Bay wind speed and direction (toward) data for the same time period are included in the top plot. The current direction shows several reversals in direction near the reservoir bottom. The current speed near the water surface increases when the wind speed increases in the middle of the day.

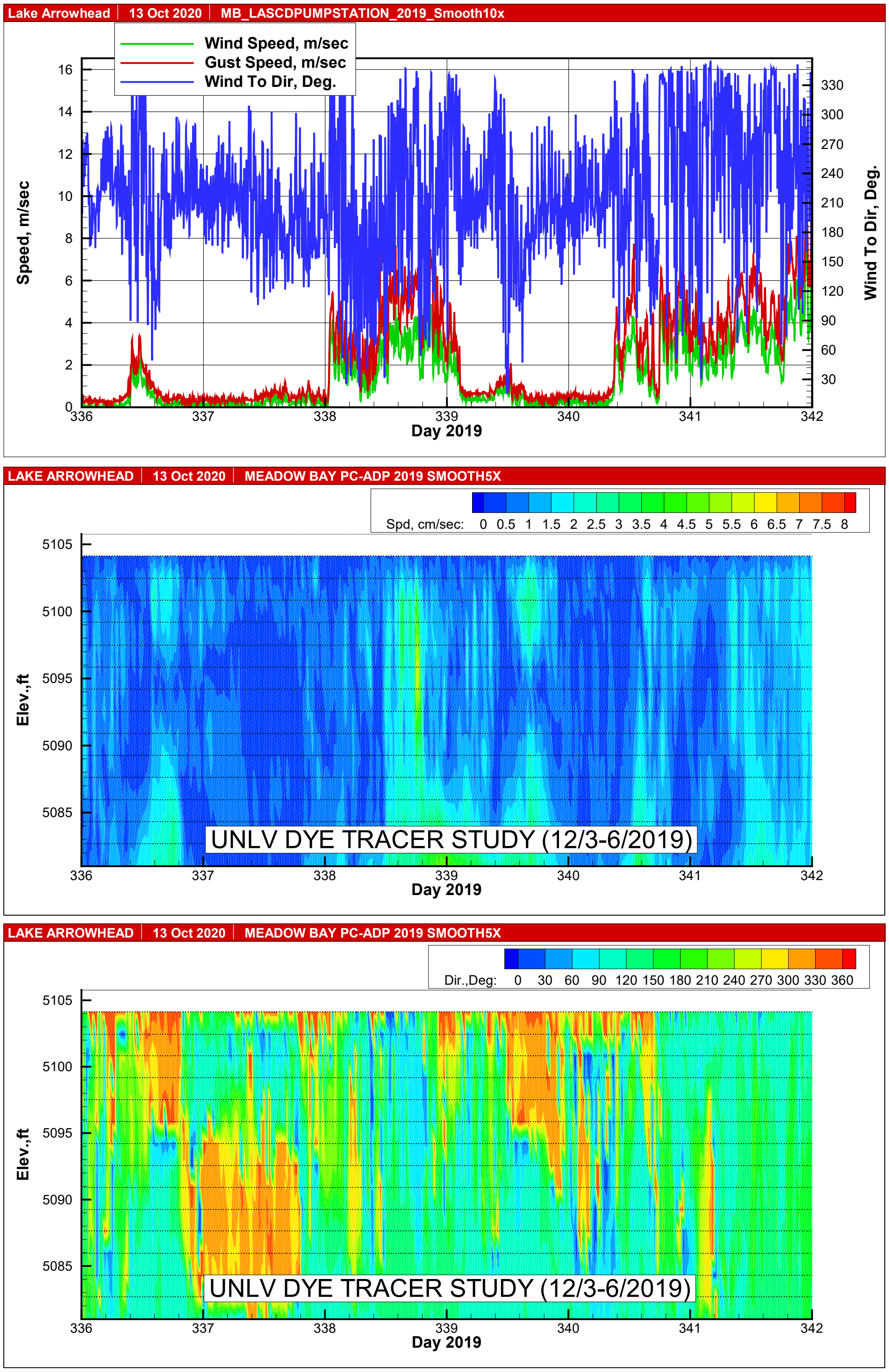

Figure 9. Plots of PC-ADP current speed and direction contour plots for data collected during the UNLV Dye Tracer Study days 337-341 (December 3 - 7, 2019). The Meadow Bay wind speed and direction (toward) data for the same time period are included in the top plot. The current direction contours show flow reversals near the reservoir surface on days 336, 338 339 and 340 and bottom on days 337 and 341. Likewise, the current speed contours show a circulation forms when the wind speed increases during the high wind events on days 338 and 341.

ADP Signal Amplitude Analyses

ADP signal strength amplitudes can provide an indication of the suspended particle density and distribution in the water column at the time of each profile measurement. The signal amplitude unit is in counts which can range from 0 to 255 counts. Particles can be suspended sediments, organic matter, or fish. There is no simple way to differentiate the composition or size of the particles. However, signal amplitudes can be used to identify suspended particle events that occur in the water column in Meadow Bay or the mid-lake sites. Signal amplitudes were measured for each depth cell in the three acoustic beams. The depth cell signal amplitudes for each beam were averaged to obtain the values used in this analysis.

As an example, figures 10 and 11 show the of signal amplitude profiles collected during the UNLV dye tracer study at Meadow Bay and mid-lake profiling sites, respectively. These contour plots of signal amplitude indicate there were more significant events at Meadow Bay where suspended particles increase throughout most of the water column during the storm events. In contrast, most of the higher signal amplitudes at the mid-lake location were confined to the lower half of the water column. It is likely the increase in signal amplitudes in Meadow Bay were related to increased inflows from Grass Valley tunnel (see figure 3) and higher inflow turbidities. At the mid-lake site, signal amplitudes increased closer to the reservoir bottom during the winter storm event of December 3-5, 2019 which may indicate a density current of sediment laden water coming from stormwater inflow or particles resuspended from the reservoir bottom.

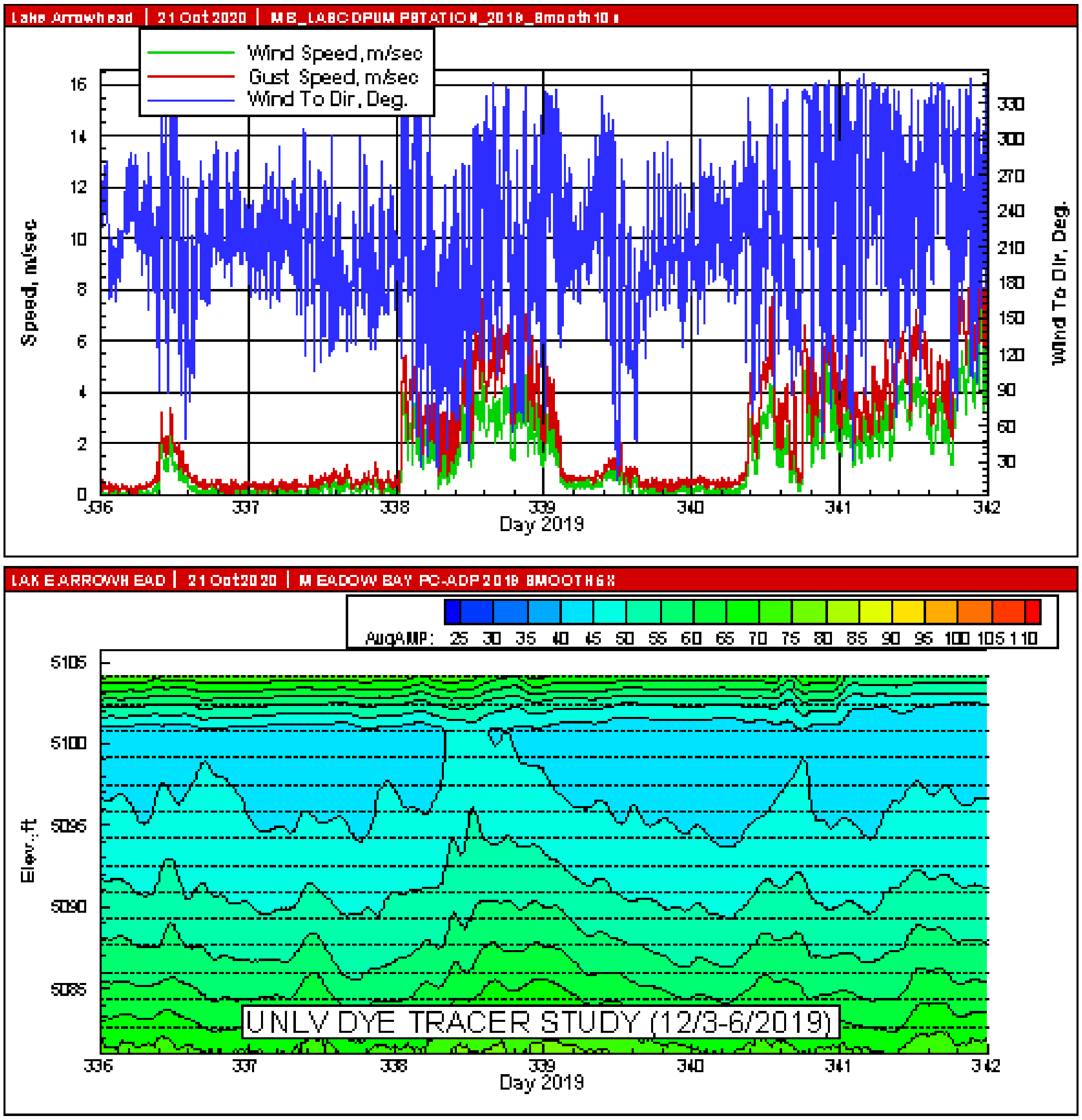

Figure 10. Plots showing six days of wind speed data and signal amplitude contours at the Meadow Bay PC-ADP site. Signal amplitudes increased through most of the water column during the winter storm event of December 4, 2019 (day 338) and again on December 6 (day 340).

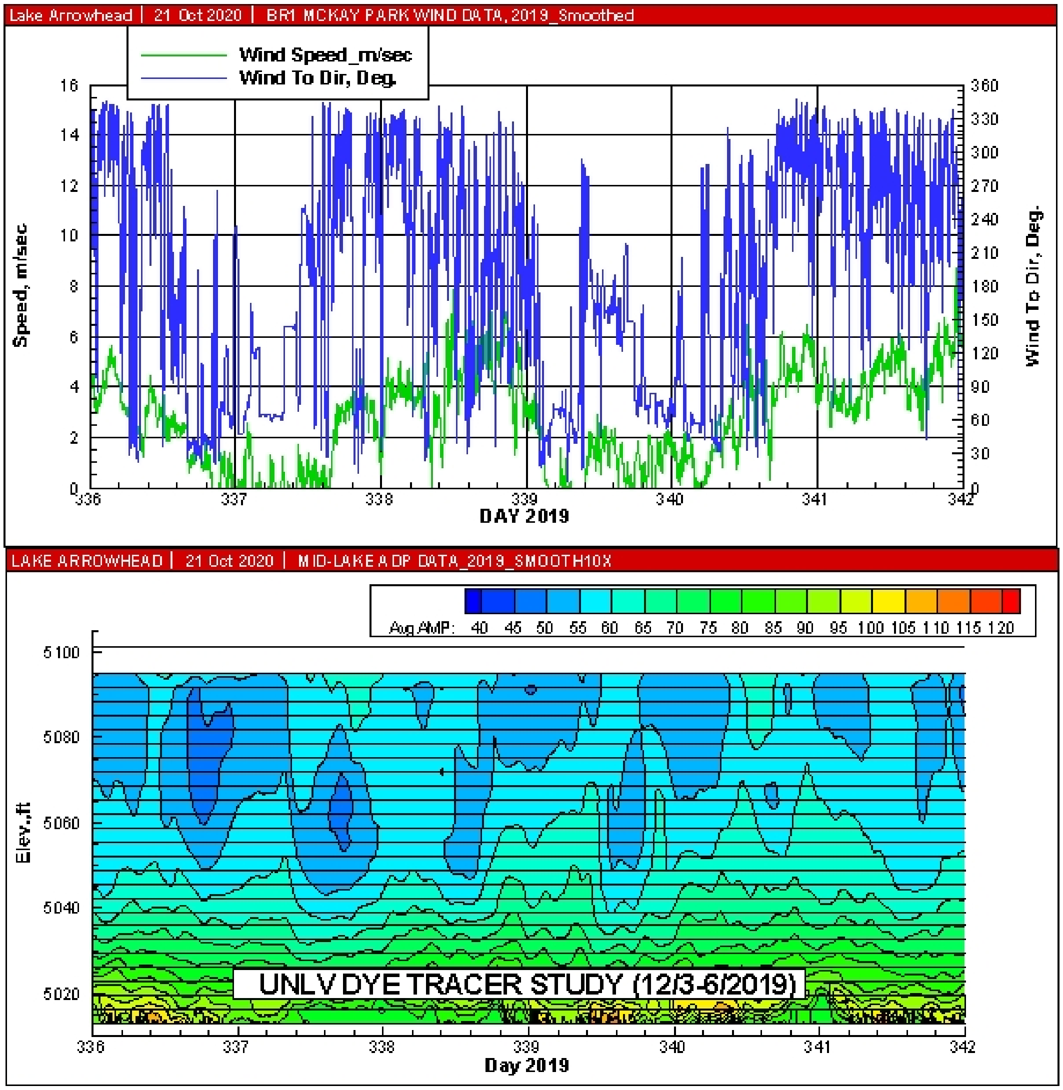

Figure 11. Plots showing six days of wind speed data and signal amplitude contours at the mid-lake ADP site. Signal amplitudes increased closer to the reservoir bottom during the winter storm event of December 3-5, 2019 (day 337-339) which may indicate a density current of sediment-laden water or particles were suspended from the reservoir bottom.

Analysis of Temperature Profiling Sites

A detailed analysis of the vertical temperature profiles collected at Lake Arrowhead was not included in the scope of work for the technical assistance to UNLV. However, temperature profile data were processed to aid in the visualization of Lake Arrowhead's thermal stratification over the course of the study. A brief presentation of the vertical temperature profile data that supplements the ADP date presented earlier will be covered in this section.

Mid-Lake Vertical Temperature Profiles

Mid-Lake temperature profiles were collected every 5 minutes between April 24, 2019 and January 31, 2020. However, profile data were interrupted when the surface buoy sunk on July 7, 2019 and the profiling string was dropped to the lake bottom. The profiling string was re-deployed on September 26, 2019. A total of 57,660 temperature profiles were collected over the 201-day deployment. For this report, mid-lake temperature profiles collected between April 24, 2019 and January 11, 2020 will be briefly discussed.

High-resolution temperature profiling data are useful for understanding the current dynamics in a reservoir or lake. These temperature profile data, along with the wind data from a nearby weather station (Tavern Bay, BR3) allows the analysis of seiches and wind mixing events during high wind events. Even though mid-lake ADP data were not collected from late April to September 26, 2019 the mid-lake temperature profiles (when available) can be used to infer surface currents and seiches generated by strong wind events.

Figure 12 shows the complete 2019 temperature profile record for the mid-lake site and the time periods of lost data. Note: the black horizontal lines are the temperature sensor depths. The temperature contours illustrate the onset of strong thermal stratification which begins around June 6th (day 157). In early July (around day 185) the thermal stratification stabilized with an epilimnion thickness of 7.5 meters with a temperature of 20.2°C. When the profiling string was re-deployed in late September the epilimnion had increased to 11.5 meters thick with an average temperature of 19.1°C. Throughout autumn, the thermal stratification slowly broke down until about the end of November (day 332) when the thermocline rapidly dissipated during a strong wind event – sustained 10 m/sec wind from the north.

Figure 13 shows a 1-day period for calendar day 186 (July 5, 2019) which helps to visualize the how a sustained wind to the NNW does little to change the stable thermal stratification at the mid-lake profiling site. This high-resolution temperature profile data shows the epilimnion warms from 19.9 to 20.4°C during the wind event with speeds up to 6 m/sec. However, the wind event creates no discernable displacement of the thermocline.

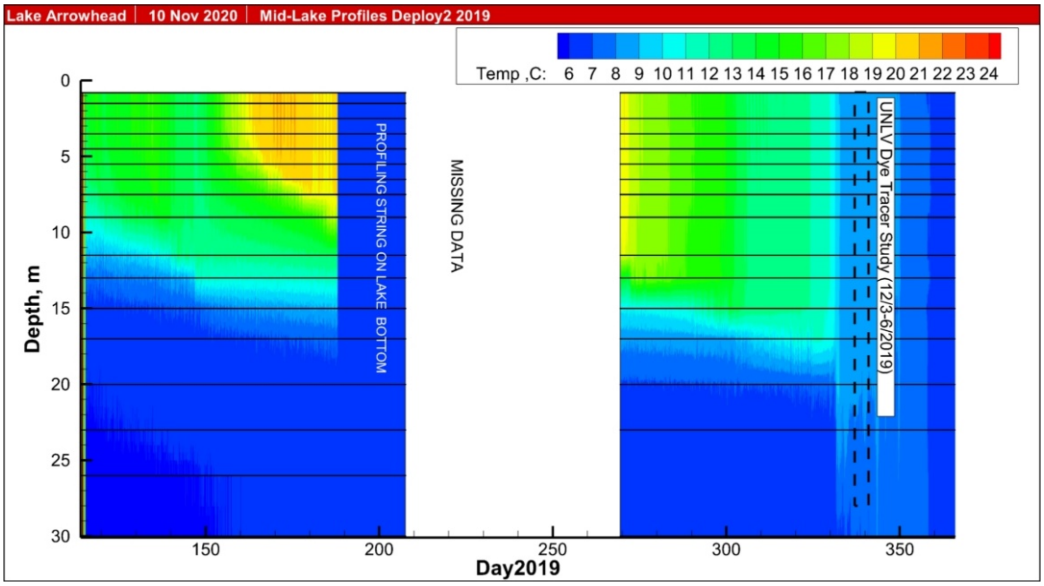

Figure 12. Water temperature profiles measured near the mid-lake ADP site. The temperature contours illustrate the strong thermal stratification which begins around June 6th (day 157). Near the end of November (day 332) the thermal stratification begins to break down after a strong wind event.

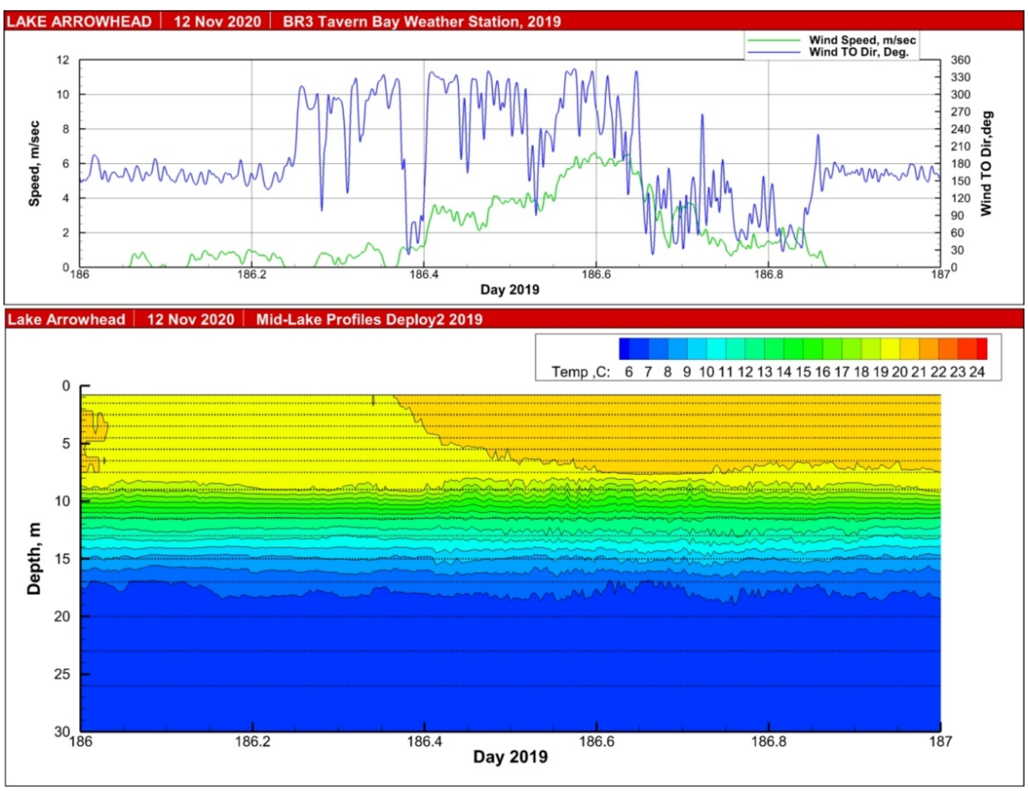

Figure 13. Plots of mid-lake temperature profile contours for calendar day 186 (July 5, 2019). The Tavern Bay (BR3) wind speed and direction (toward) data for the same time period are included in the top plot. The temperature profiles show that the wind toward the NNW warms the surface water at the mid-lake location but has no discernable impact on the stability of the thermocline.

Figure 14 shows a plot of temperature profile contours during the UNLV dye tracer study in early December 2019. The Tavern Bay (BR3) wind speed and direction (toward) data for the same time period are included in the top plot. The temperature profiles show that when the wind speed increases (day 338) the epilimnion is mixed to a depth of 20 meters but the weak thermal stratification from 20 to 30 meters remains unaffected. It is interesting to note that there is a short period of time when cool water (6.8°C) shows up near the reservoir bottom (as detected by the logger at 30 meters depth) on December 4, 2019 (day 338) around 1:00 pm. This could be the same cool water underflow related to the releases from the Grass Valley Lake tunnel or other ungauged inflows. According to UNLV's instream temperature logger the inflow water temperature was about 3°C when the inflow peaked at 30 CFS (see figure 3).

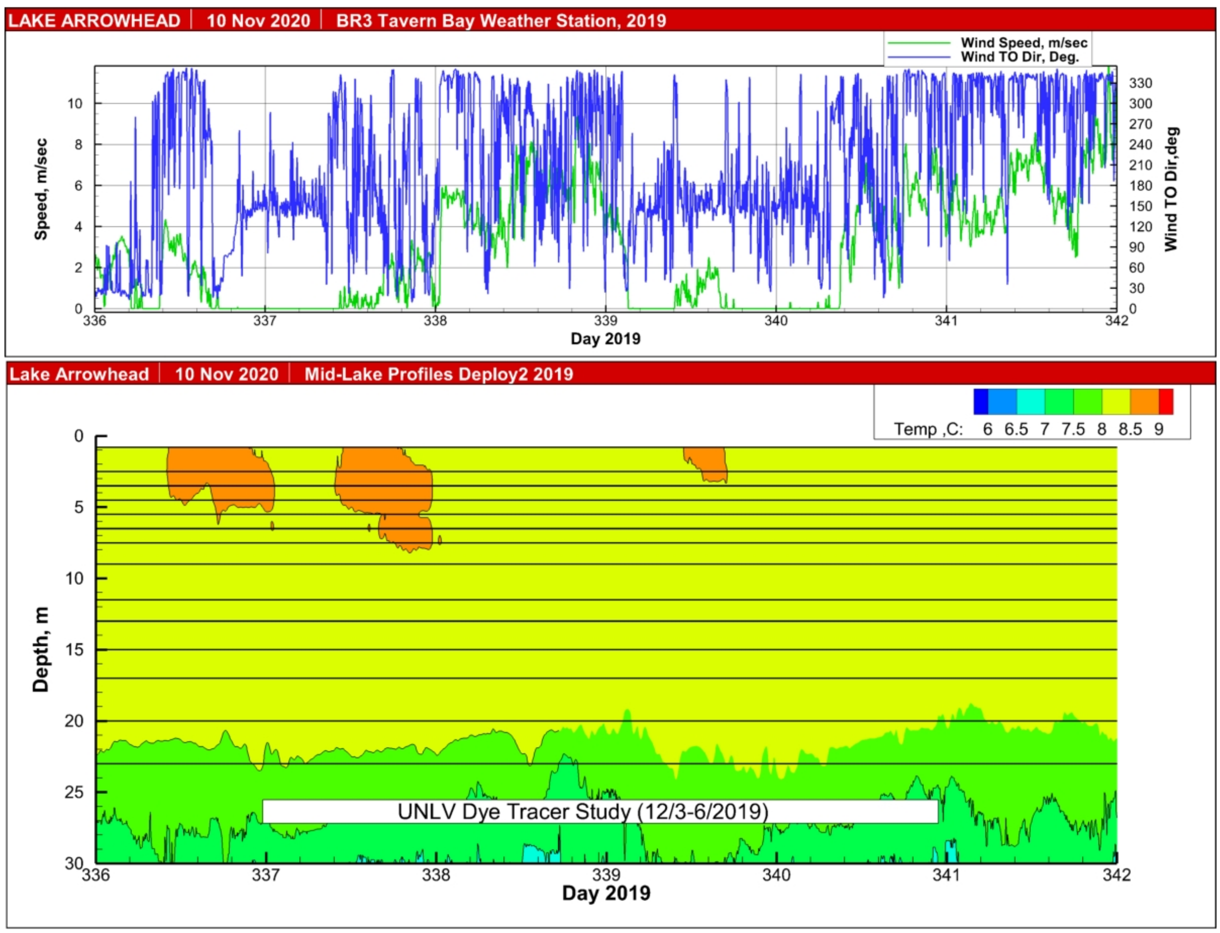

Figure 14. Plots of mid-lake temperature profile contours during the UNLV dye tracer study December 2-7, 2019. The Tavern Bay (BR3) wind speed and direction (toward) data for the same time period are included in the top plot. The temperature profiles show that when the wind speed increases there is some mixing in the surface layer, but the thermal stratification is not completely broken down. The cool water measured near the bottom on day 338.6 could be an underflow produced by Grass Valley Lake Tunnel inflows or other inflows.

Meadow Bay Vertical Temperature Profiles

Meadow Bay temperature profiles were collected continuously (every 5 minutes) between April 24, 2019 and January 11, 2020. A total of 75,320 temperature profiles were collected for this 263-day deployment. For this report, Meadow Bay temperature profiles collected between April 24, 2019 and January 11, 2020 will be briefly discussed.

Figure 15 shows the complete 2019 data record for the Meadow Bay site. The temperature contours illustrate the relatively weak thermal stratification which begins around June 1st (day 152). Later in the summer the water column at the Meadow Bay site is primarily in the epilimnion or the well-mixed surface layer.

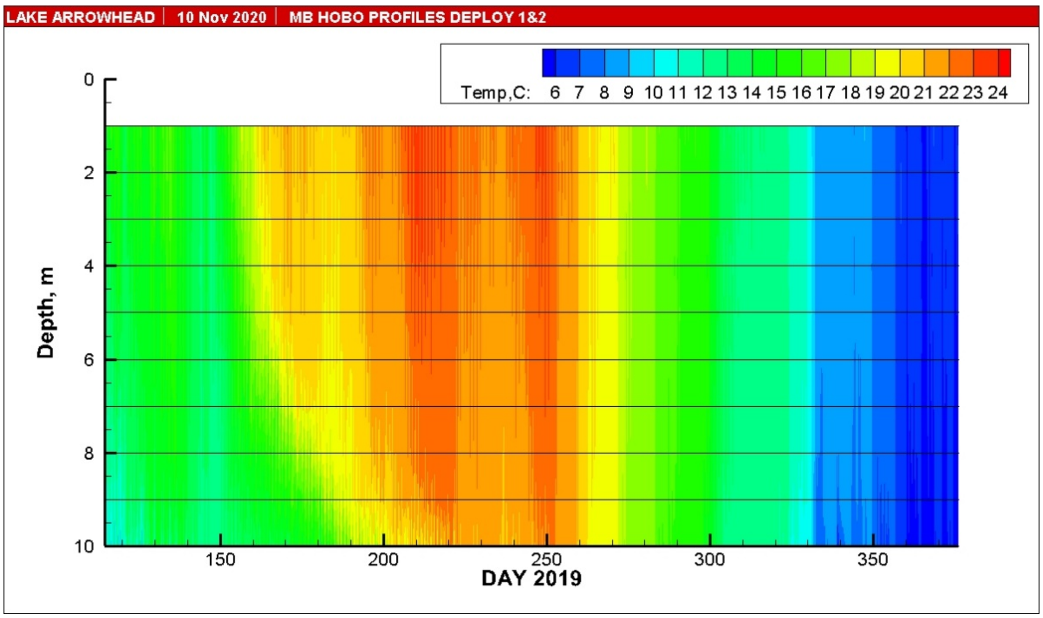

Figure 15. Water temperature profiles measured at the Meadow Bay PC-ADP site. The temperature contours illustrate the weak thermal stratification which begins around June 1st (day 152). Later in the summer the entire water column at the Meadow Bay site is within the epilimnion, or the well-mixed surface layer.

Figure 16 shows a 1-day period for calendar day 186 (July 5, 2019) which helps to visualize the how a sustained wind to the north changes the thermal stratification at the Meadow Bay site. This high-resolution temperature profile data shows warm surface water moving into the Meadow Bay that creates a stronger stratification in the surface layer as a cooler water layer moves in near the reservoir bottom. When the wind subsides, the unstable temperature gradient returns to a weakly stratified condition as the cooler water flows away from the Meadow Bay temperature profiling site. The change in the temperature stratification at this site agrees with the PC-ADP current speed and direction as presented in figure 8. For example, when cooler water moves along the reservoir bottom the current direction changes from southeast to northwest and back to southeast.

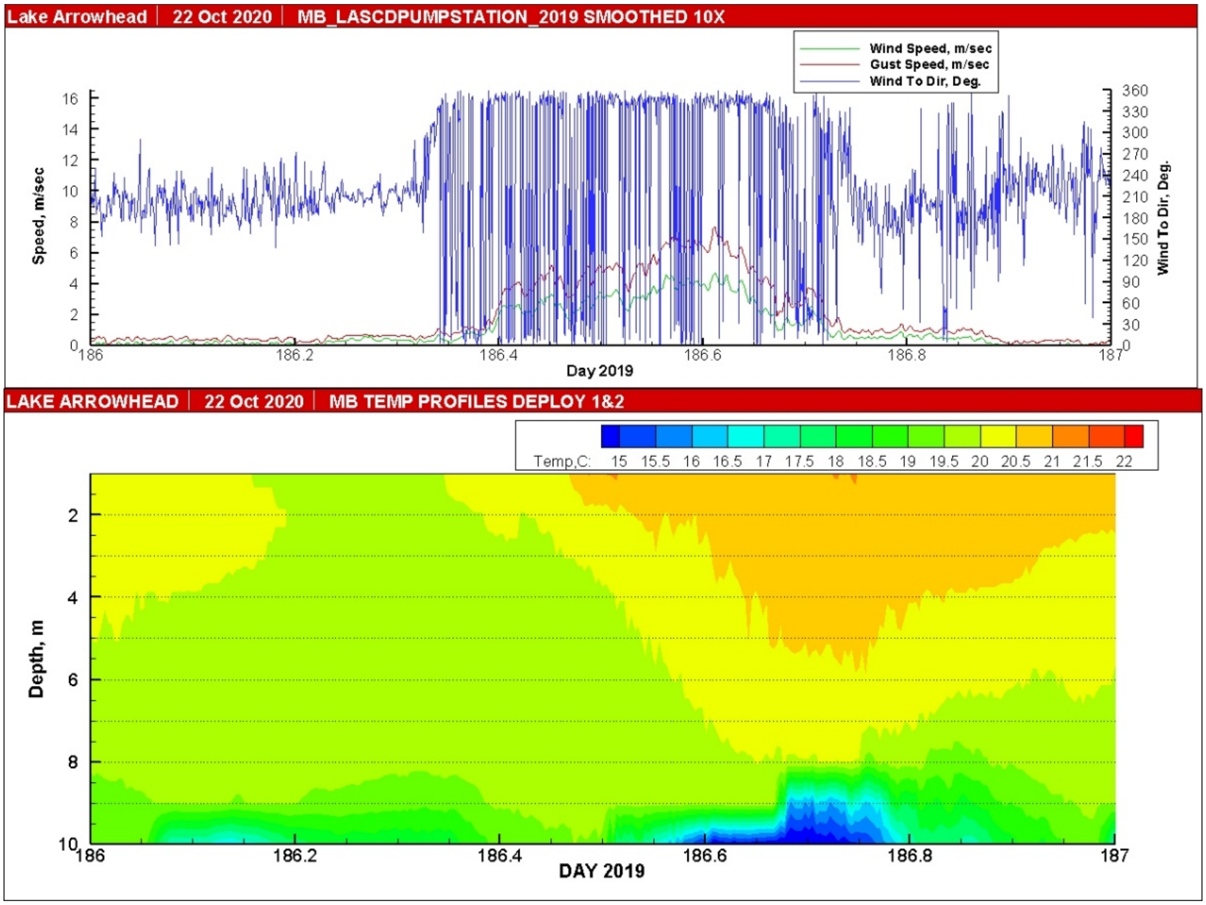

Figure 16. Plots of temperature profile contours for calendar day 186 (July 5, 2019). The Meadow Bay wind speed and direction (toward) data for the same time period are included in the top plot. The temperature profiles show that the wind toward the north creates a current that moves warm surface water into Meadow Bay and cooler water moves in near the bottom.

Figure 17 shows a plot of temperature profile contours during the UNLV dye tracer study in early December 2019. The Meadow Bay wind speed and direction (toward) data for the same time period are included in the top plot. The temperature profiles show that when the wind speed increases (day 338) the weak thermal stratification breaks down. The cool water that shows up near the reservoir bottom on December 4, 2019 (day 338) is a cool water underflow related to the releases from the Grass Valley Lake tunnel. According to UNLV's instream temperature logger the inflow water temperature was about 3°C when the inflow peaked at 30 CFS (see figure 3).

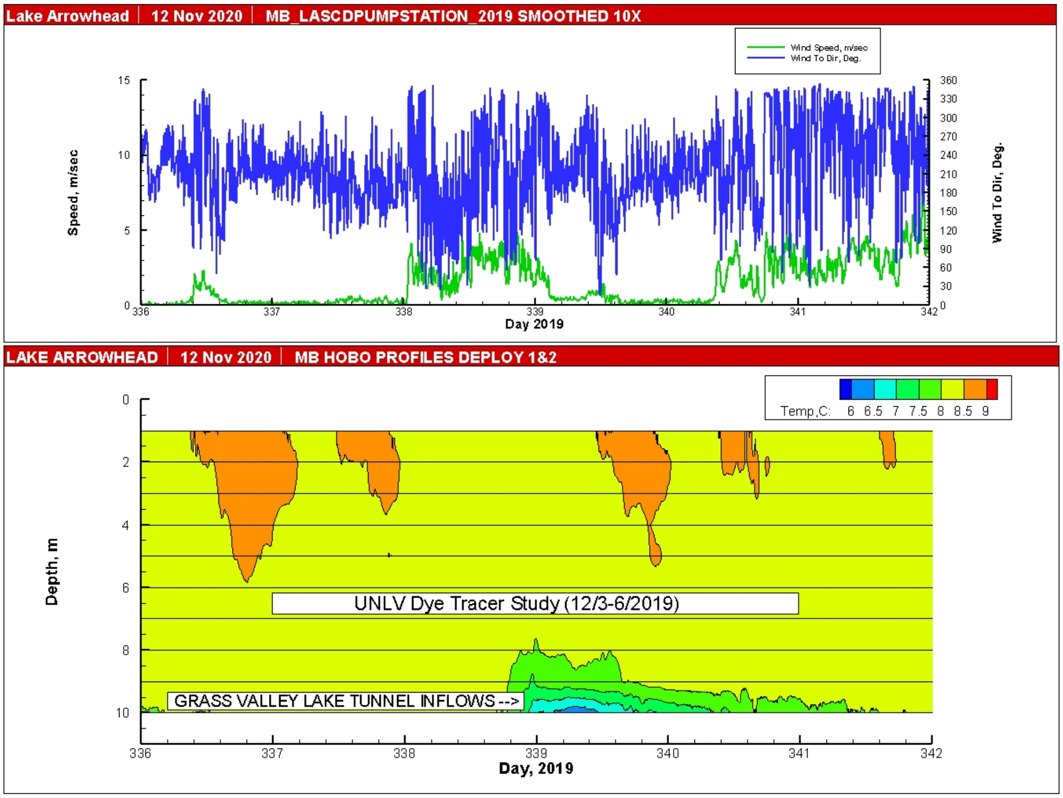

Figure 17. Plots of temperature profile contours during the UNLV dye tracer study in early December 2019. The Meadow Bay wind speed and wind direction (toward) data for the same time period are included in the top plot. The temperature profiles show that when the wind speed increases on day 338 weak thermal stratification was broken down (orange 8.5-9°C surface water shifts to yellow 8-8.5°C water). The cool water measured near the bottom on days 338-339 is likely an underflow produced by Grass Valley Lake Tunnel inflows (and possibly other ungaged inflow) which were about 3°C (see figure 3).

Conclusions and Recommendations

Two acoustic Doppler profilers were successfully deployed in Arrowhead Lake and collected continuous velocity profiles from late spring through late fall 2019. This current profile data will be useful for ground-truthing supporting data like nearby wind speed and direction and vertical temperature profiles.

The mid-lake ADP velocity profiles illustrated very weak reservoir currents within the hypolimnion during periods of strong thermal stratification. This observation was supported by mid-lake vertical temperature profile data that showed a very stable thermocline throughout the summer months. There were periods when currents were below the threshold where the ADP could accurately resolve water currents (1 to 2 cm/sec) because of the random acoustic noise that is inherent with the ADP signal processing. Using a PC-ADP instead of an ADP would allow for these low currents to be measured accurately.

Mid-lake ADP measurements were impacted by compass calibration problems. However, this only affects the current direction measurements with respect to magnetic north. A compass correction was applied in an attempt to correct the uncalibrated readings. The relative current direction data can provide information on flow reversals and overall circulation patterns in the reservoir. Measurements of current speed profiles were not affected and should provide a good indication the vertical current distribution throughout the water column. If future studies are warranted, it is recommended that the outdated Sontek 500 kHz ADP be replaced with a newer model with a fully functional compass.

Future deployments at a mid-lake location should be made with the assistance of divers to make sure the ADP is oriented properly and does not sink into the bottom sediment layer.

The Meadow Bay PC-ADP collected velocity profiles for almost 9 months without any issues. However, the location was too shallow to measure currents in the thermocline and hypolimnion during periods of strong thermal stratification because the epilimnion was thicker than the 9-meter depth at the deployment location.

The Meadow Bay PC-ADP velocity profiles illustrated periods of circulation (mixing) in the epilimnion in response to frequent mid-afternoon wind events. This observation was supported by vertical temperature profiles which showed seiching during the daily wind events.

If future ADP measurements are to be collected in Lake Arrowhead, it is recommended that high-resolution vertical temperature profiles be collected in close proximity to the ADP sampling sites to providing supporting data on currents which may be too weak to be measured accurately using the ADP, as well as, changes in lake stratification due to seiching events. The PC-ADP is capable of measuring much slower currents, but it is still prudent to have both sets of vertical temperatures profile data when interpreting velocity profile data.

Appendix 1

Configuration Parameters for Mid-Lake ADP Deployment

Filename ---------------------> LKARW007.ctl
File Size --------------------> 6313646 bytes
Number of profiles -----------> 14283
Time of first profile --------> 2009/08/13 15:17:12
Time of last profile ---------> 2010/01/09 09:47:09

ADP Hardware Configuration

CPUSoftwareVerNum ------------> 5.8
DSPSoftwareVerNum ------------> 4.0
BoardRev ---------------------> D
SerialNumber -----------------> C34
AdpType ----------------------> 500 kHz
Nbeams -----------------------> 3
BeamGeometry -----------------> 3_BEAMS
Slant Angle ------------------> 25.0 deg
Sensor Orientation -----------> UP
Compass Installed ------------> YES
Recorder Installed -----------> YES
Temperature Installed --------> YES
Pressure Installed -----------> YES
Pressure Offset --------------> -1.949000 dbar
Pressure Scale ---------------> 0.002436 dbar/count
Pressure Scale 2 -------------> 0.000000 pdbar/c^2
Ext Sensor Installed ---------> NO
Ext Pressure Sensor Installed > NONE
CTD Sensor Installed ---------> NO
Transformation Matrix

1.577	-0.789	-0.789
0.000	-1.366	1.366
0.368	0.368	0.368

ADP User Setup

Default Temperature ----------> 15.00 deg C
Default Salinity -------------> 0.10 ppt
Default Speed of Sound -------> 1465.20 m/s
No. of Cells -----------------> 30
Cell Size --------------------> 1.00 m
Blank Distance ---------------> 1.00 m
Sensor Depth -----------------> 0.00 m
Temperature Mode -------------> MEASURED

Averaging Interval -----------> 300 s
Profile Interval -------------> 900 s
Ping Interval ----------------> 0.00 s
Burst Mode--------------------> DISABLED
Burst Interval ---------------> 1200 s
Profiles per Burst -----------> 1
Coordinate System ------------> ENU
Pulse Coherent Mode ----------> NO
Bottom Track -----------------> NO
Magnetic Declination ---------> 0.00
Out Mode ---------------------> AUTO
Out Format -------------------> ASCII
Recorder Enabled -------------> ENABLED
Recorder Mode ----------------> NORMAL
Deployment Mode --------------> ON
Deployment Name --------------> LKARW
Deployment Start Date/Time ---> 2009/08/13 15:17:09

Configuration Parameters for Meadow Bay PC-ADP Deployment

Filename ---------------------> LAHMB003.ctl
File Size --------------------> 2666738 bytes
Number of profiles -----------> 7983
Time of first profile --------> 2019/04/24 12:09:32
Time of last profile ---------> 2019/08/13 08:49:29

ADP Hardware Configuration

CPUSoftwareVerNum ------------> 17.4
DSPSoftwareVerNum ------------> 4.0
BoardRev ---------------------> F
SerialNumber -----------------> H33
AdpType ----------------------> 1500 kHz
Nbeams -----------------------> 3
BeamGeometry -----------------> 3_BEAMS
Slant Angle ------------------> 15.0 deg
Sensor Orientation -----------> UP
Compass Installed ------------> YES
Recorder Installed -----------> YES
Temperature Installed --------> YES
Pressure Installed -----------> YES
Pressure Offset --------------> -2.171380 dbar
Pressure Scale ---------------> 0.000478 dbar/count
Pressure Scale 2 -------------> -44.000000 pdbar/c^2
Ext Sensor Installed ---------> NO
Ext Pressure Sensor Installed > NONE
CTD Sensor Installed ---------> NO
Transformation Matrix

2.576 -1.288 -1.288
0.000 -2.230 2.230
0.345 0.345 0.345
ADP User Setup

Default Temperature ----------> 20.00 deg C
Default Salinity -------------> 0.00 ppt
Default Speed of Sound -------> 1481.60 m/s
No. of Cells -----------------> 18
Cell Size --------------------> 0.50 m
Blank Distance ---------------> 0.50 m
Sensor Depth -----------------> 0.00 m
Temperature Mode -------------> MEASURED
Averaging Interval -----------> 240.0 s (300s for 2nd Deployment)
Profile Interval -------------> 1200.0 s (1800s for 2nd Deployment)
Ping Interval ----------------> 0.00 s
Burst Mode--------------------> DISABLED
Burst Interval ---------------> 1200 s
Profiles per Burst -----------> 1
Coordinate System ------------> BEAM
Pulse Coherent Mode ----------> YES

Pulse Coherent Setup:
Pulse length --- (m) ------> 1.00
Max range ----------- (m) ------> 9.55
User Prof Lag ------- (m) ------> 9.00
System Lag ---------- (m) ------> 10.71
MaxVertVel (ProfLag) - (m/s) ----> 0.03
MaxHorizVel (ProfLag) -(m/s) ----> 0.13
User Res Lag --------- (m) ------> 4.00
System Res Lag ------- (m) ------> 4.01
MaxVertVel (ResLag) -- (m/s) ----> 0.09
MaxHorizVel (ResLag) - (m/s) ----> 0.35
MinCorrLevel --------- (%) ------> 25

Bottom Track -----------------> NO
Magnetic Declination ---------> 0.00
Out Mode ---------------------> AUTO
Out Format -------------------> ASCII
Recorder Enabled -------------> ENABLED
Recorder Mode ----------------> NORMAL
Deployment Mode --------------> ON
Deployment Name --------------> LAHMB
1st Deployment Start Date/Time ---> 2019/04/24 12:00:00
(2nd Deployment Start Date/Time ---> 2019/08/13 10:02:01)