ATTACHMENT A

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July 26, 2018

Jehiel Cass
Lahontan Water Board
15095 Amargosa Rd., Bldg 2, Ste 210
Victorville, CA 92392

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 permits.

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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US FDA, 2018. Food Additives and Ingredients - Additional Information about High-Intensity Sweeteners Permitted for Use in Food in the United States. URL https://www.fda.gov/Food/IngredientsPackagingLabeling/FoodAdditivesIngredients/ucm397725.htm (accessed 6.10.18).

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

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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 ^{o}N, 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).

[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

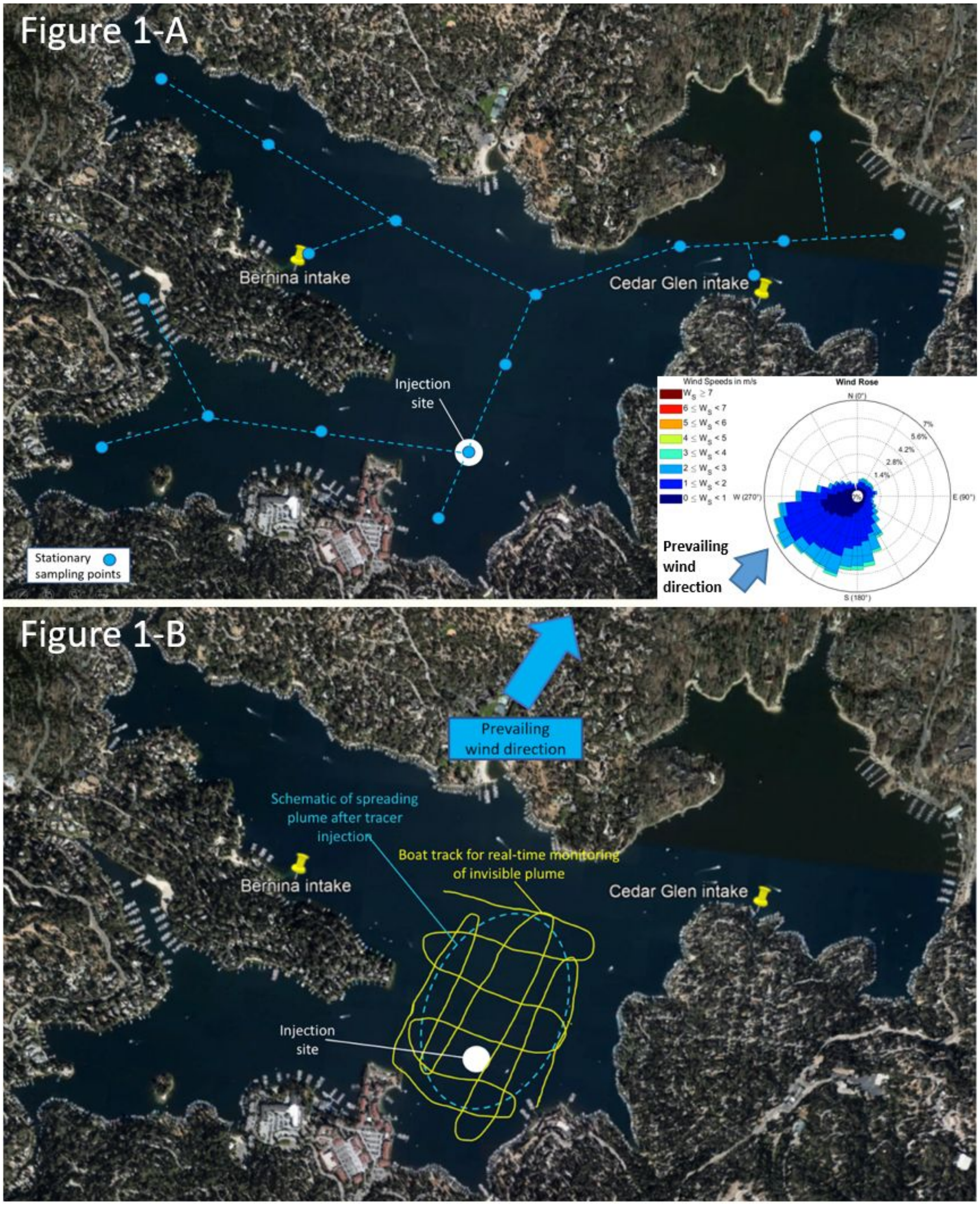
Location	Site Name	North Latitude	West Longitude	Shortest distance to proposed tracer release site (feet)	Site elevation (1929 NGVD) (feet)**	Water depth at summer 2018 lake level (feet)***
Proposed tracer release location	Village Bay East of Village Point	34° 15' 13"	117° 11' 10"	N/A	5,022	85.7
Bernina 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[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 miles for the Bernina intakes in North Bay, and 1.9 to 2.2 miles for the Cedar Glen intakes in

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

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_v= 0.0015-0.0075 m^2/s and horizontal diffusion coefficients in the range of k_h= 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_h= 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[5], 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

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[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).

concentration. Weekly water quality monitoring in Lake Arrowhead in summer 2018 has 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 = $\dfrac{[(\text{dye mass, lbm}) \times 0.453\text{kg/lbm} \times 1\text{x}10^9\ \text{ug/kg}]}{(\text{target concentration in } u\text{g/Liter})}$

then

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

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:

$$\textit{Volume of water in liters} = \frac{[(8.62\ lbm) \times 0.453 kg/lbm \times 1 \times 10^9\ ug/kg]}{(70\ ug/L)}$$

$= 5.58 \times 10^7$ liters

then

$$\textit{Volume of water in acre-feet} = \frac{5.58 \times 10^7 \text{ liters}}{(28.3 \text{ liters/ft}^3) \times (43{,}560 \text{ ft}^3\text{/acre foot})}$$

= 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:

$$\textit{Volume of water in liters} = \frac{[(8.62\ lbm) \times 0.453 kg/lbm \times 1 \times 10^9\ ug/kg]}{(100\ ug/L)}$$

$= 3.91 \times 10^7$ 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 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 concentrations 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 22°C 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 24°C.

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 °C 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 = 0.09-0.20 m^2/s and vertical diffusion coefficients in the range of k_v = 0.0015-0.0075 m^2/s.

   b) For the meta and hypolimnion below 8.4 meters, horizontal turbulent diffusion coefficients in the range of k_h = 0.007-0.050 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 0.025 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

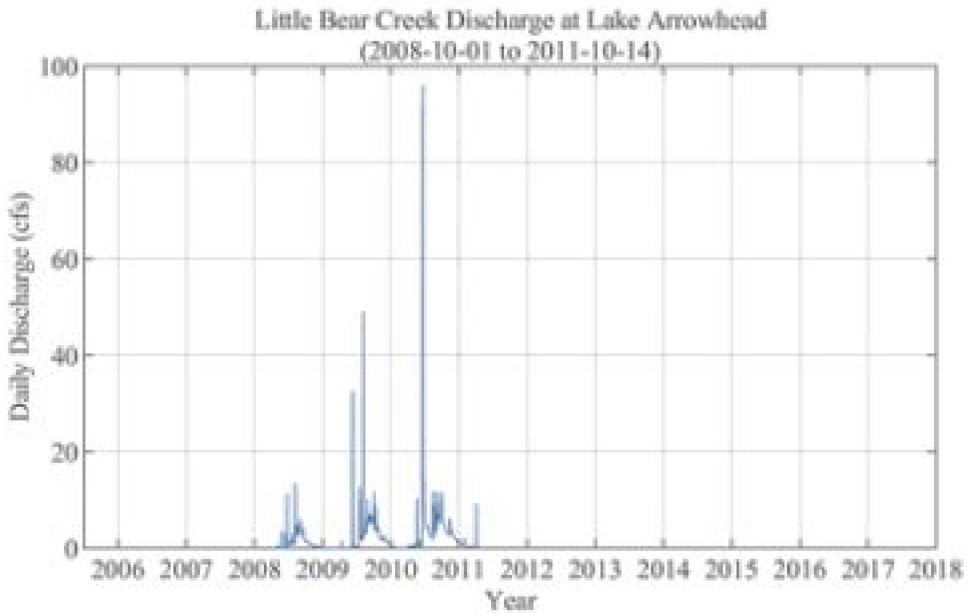


Figure A2 - USGS Grass Valley tunnel gauging station, episodic inflows to Lake Arrowhead, Meadow Bay. October 1, 2008 through July 2, 2018, showing low inflow rates, summer months

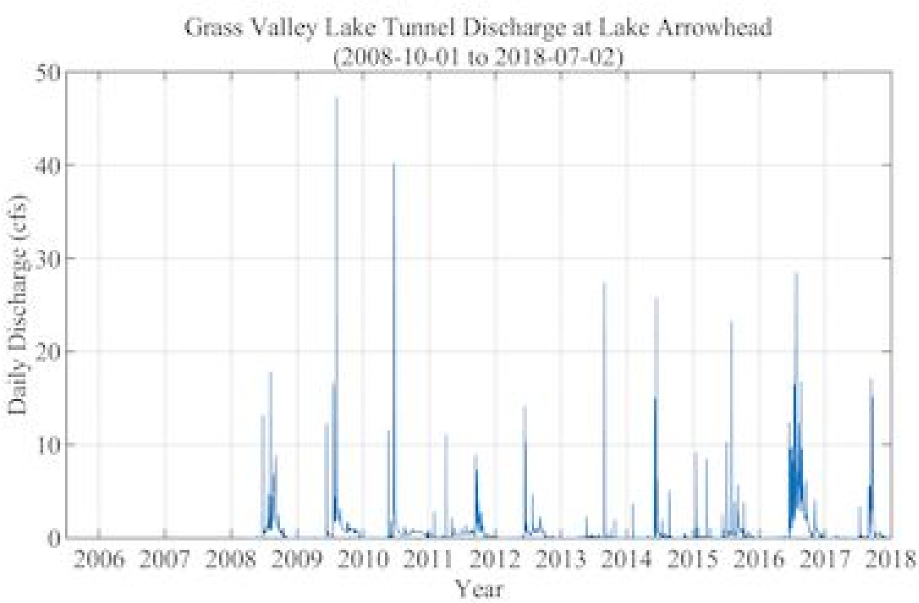


Figure A3. USGS Willow Creek gauging station, episodic outflows from Lake Arrowhead. October 1, 2008 through February 25, 2013

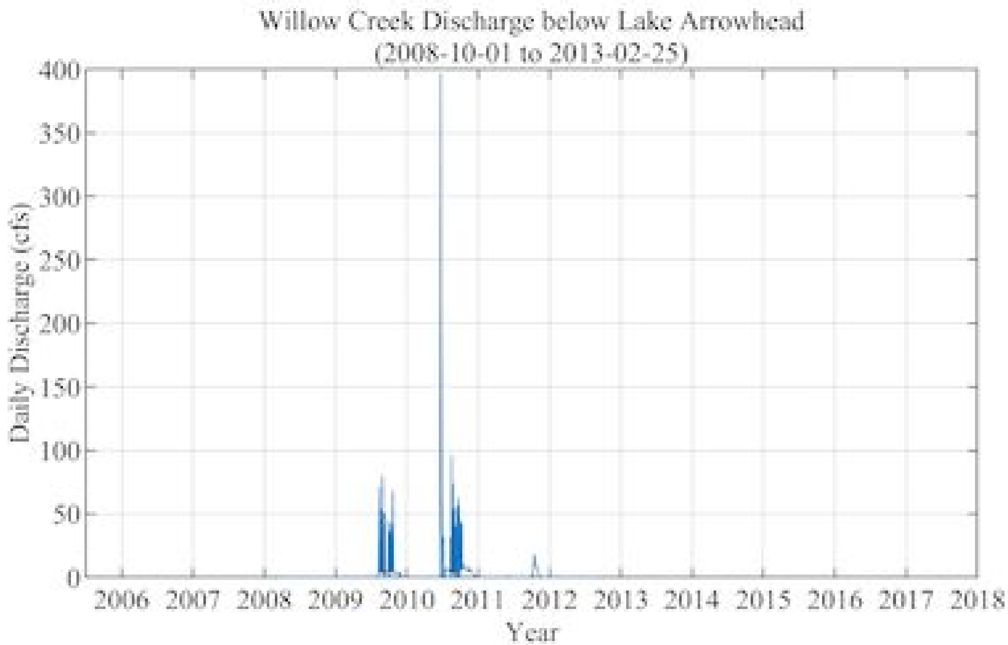


Figure A4 - Typical summertime wind velocities for south shore of Lake Arrowhead, UNLV Lollipop Park weather station.

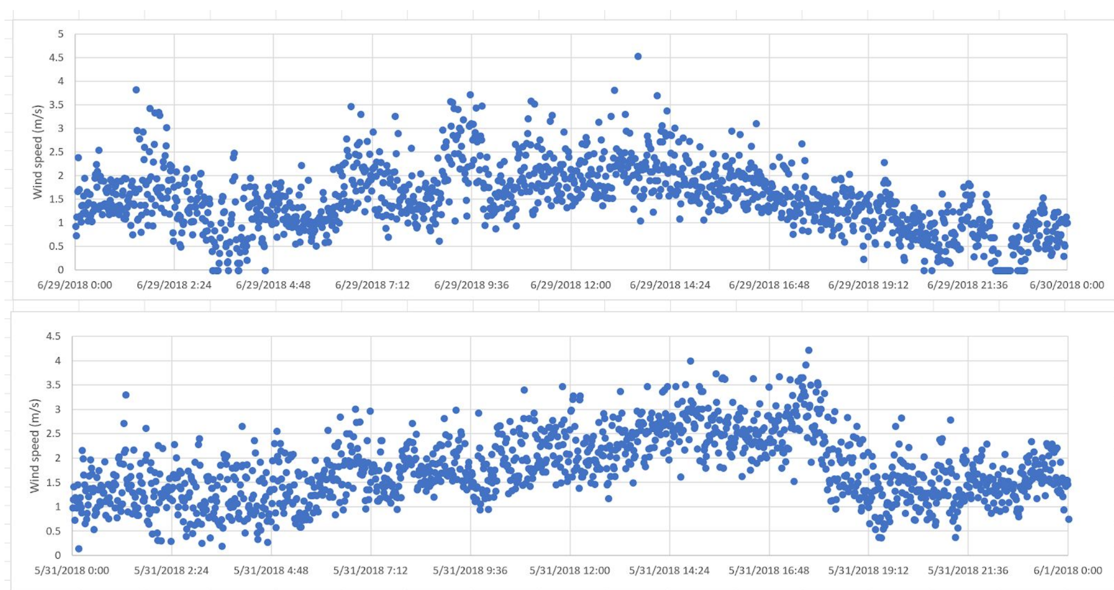


Figure A5 - Color-coded contour map of Lake Arrowhead's bathymetry. Black dots show proposed RWT and sucralose tracer sampling locations. Depth Color codes: Light green: > 100 feet. Green: 80-100 feet. Yellow: 60-80 feet. Red: 40-60 feet. Maroon: 20-40 feet. Grey: < 20 feet

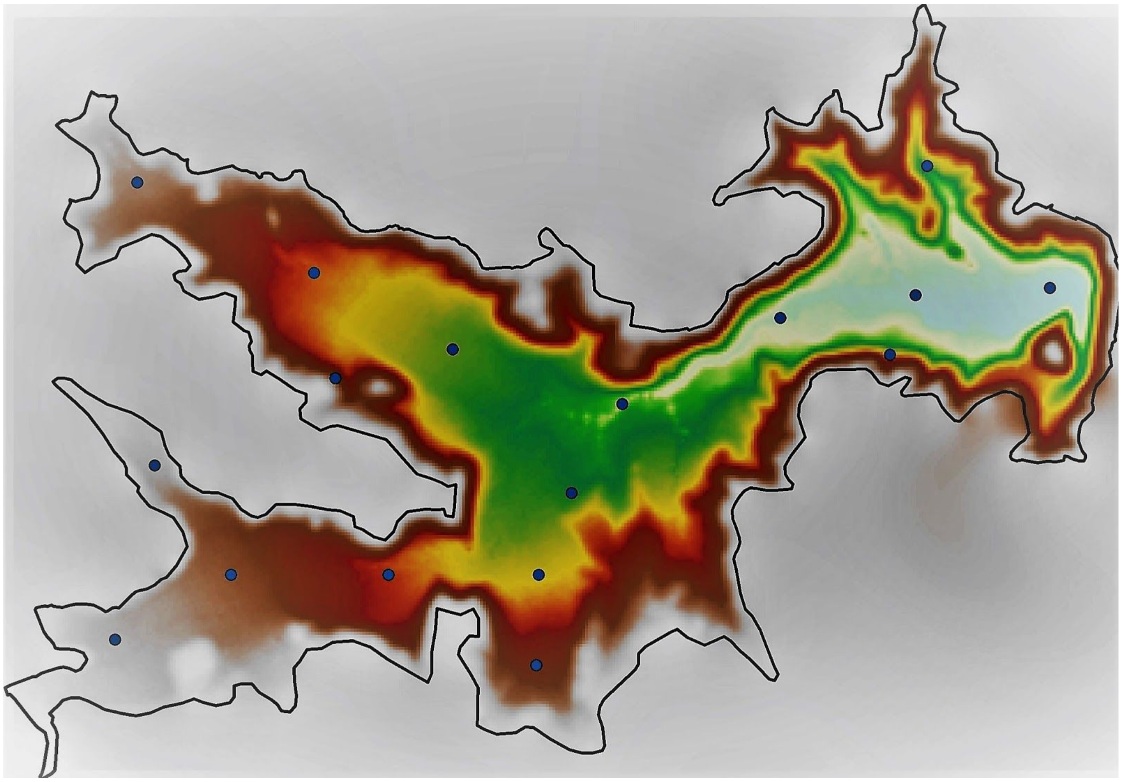


Figure A6 - Estimated minimum distance trajectory from proposed Village Bay point of tracer release to LACSD Bernina intake in North Bay. South-southeasterly wind - distance 1.55 miles

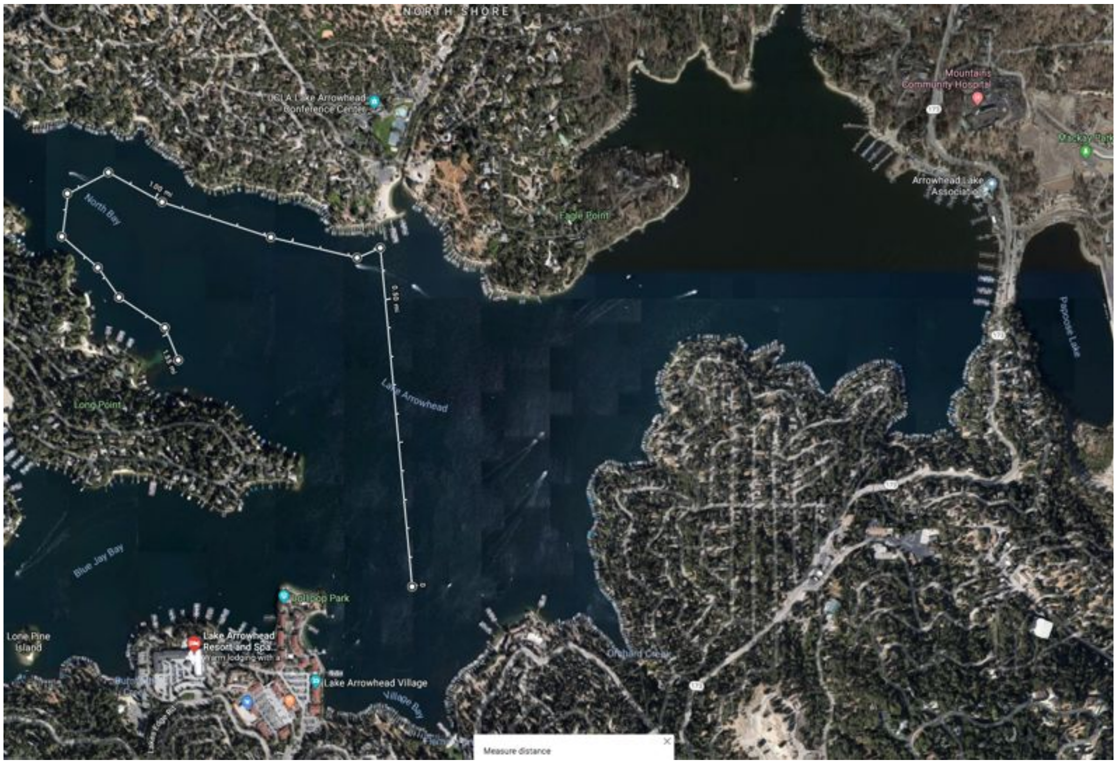


Figure A7 - Estimated medium distance trajectory from proposed Village Bay point of tracer release to LACSD Bernina intake in North Bay. Southerly wind - distance 1.60 miles

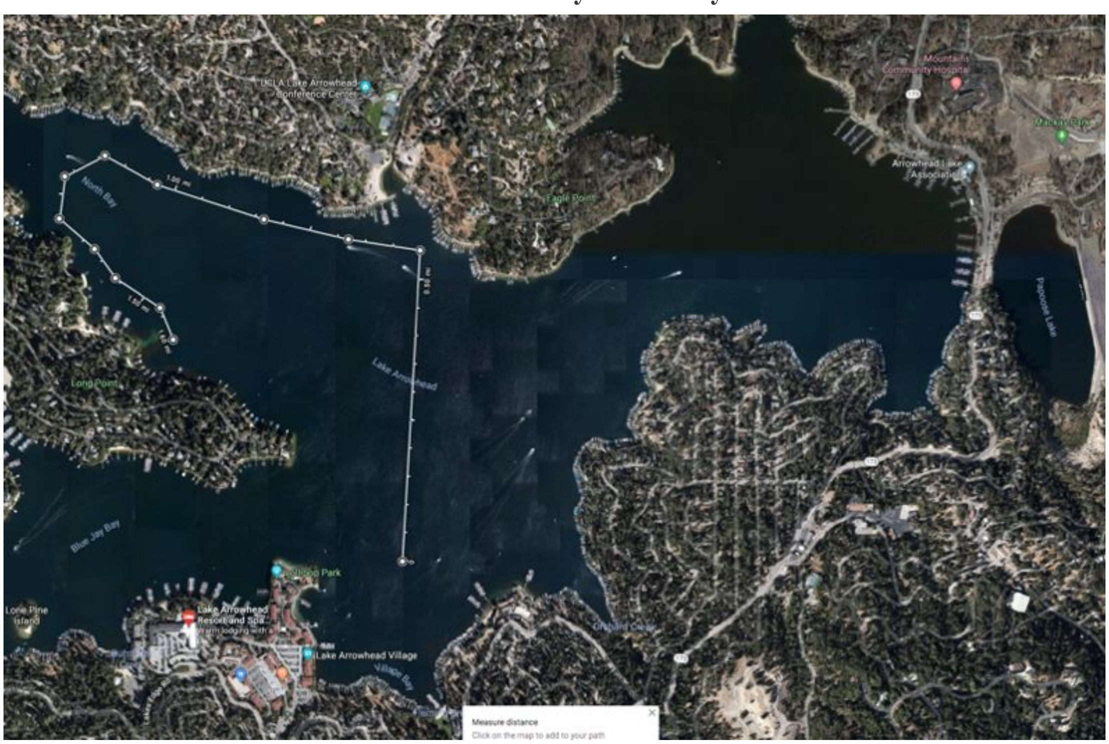


Figure A8 - Estimated maximum likely distance trajectory from proposed Village Bay point of tracer release to LACSD Bernina intake in North Bay. South-southwesterly wind - distance 1.63 miles

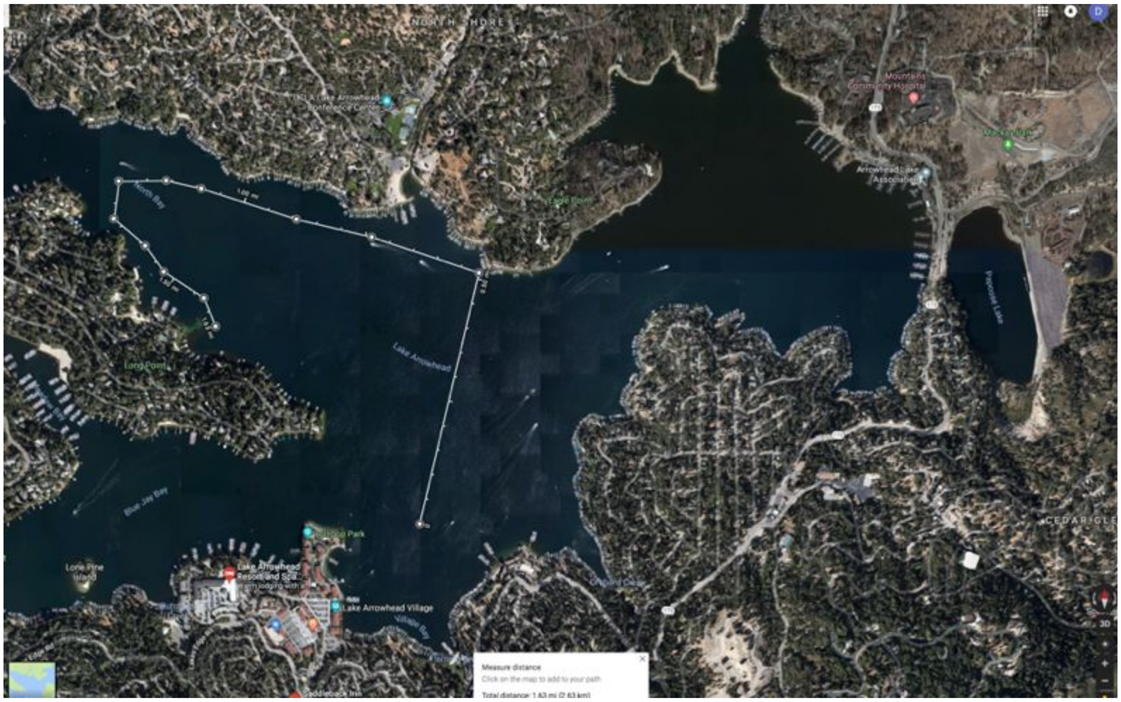


Figure A9 - Estimated minimum distance trajectory from proposed Village Bay point of tracer release to LACSD Cedar Glen intake in Emerald Bay. Southwesterly wind - distance 1.86 miles

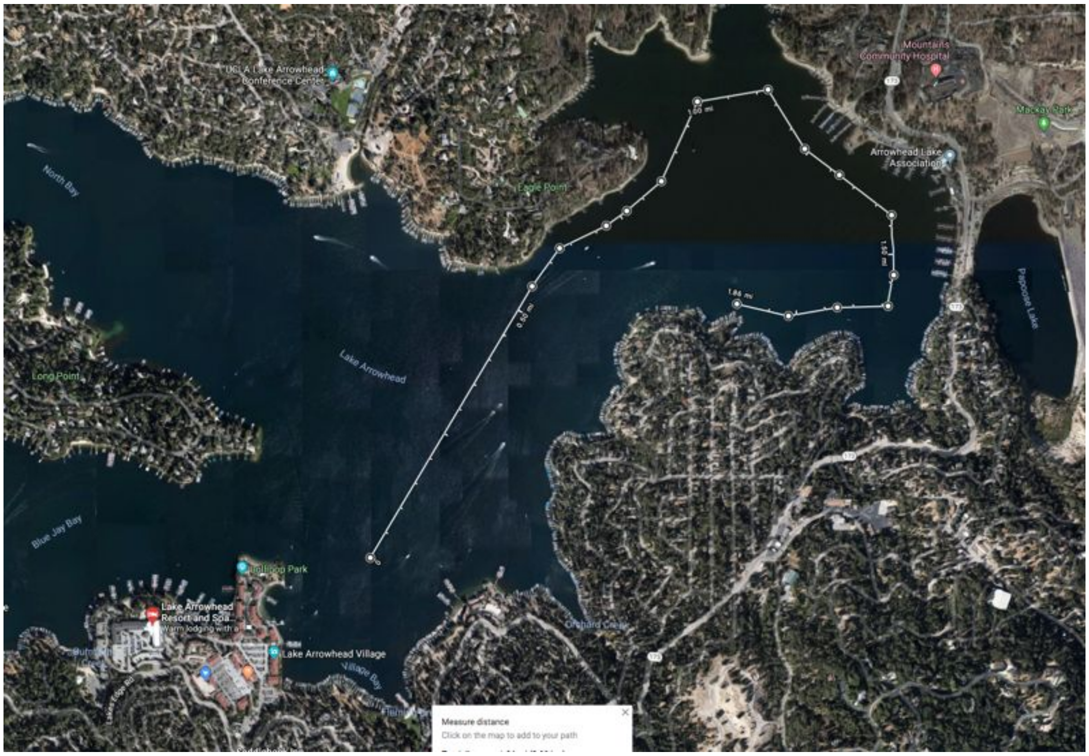


Figure A10 - Estimated medium distance trajectory from proposed Village Bay point of tracer release to LACSD Cedar Glen intake in Emerald Bay. South-Southwesterly wind - distance 1.94 miles

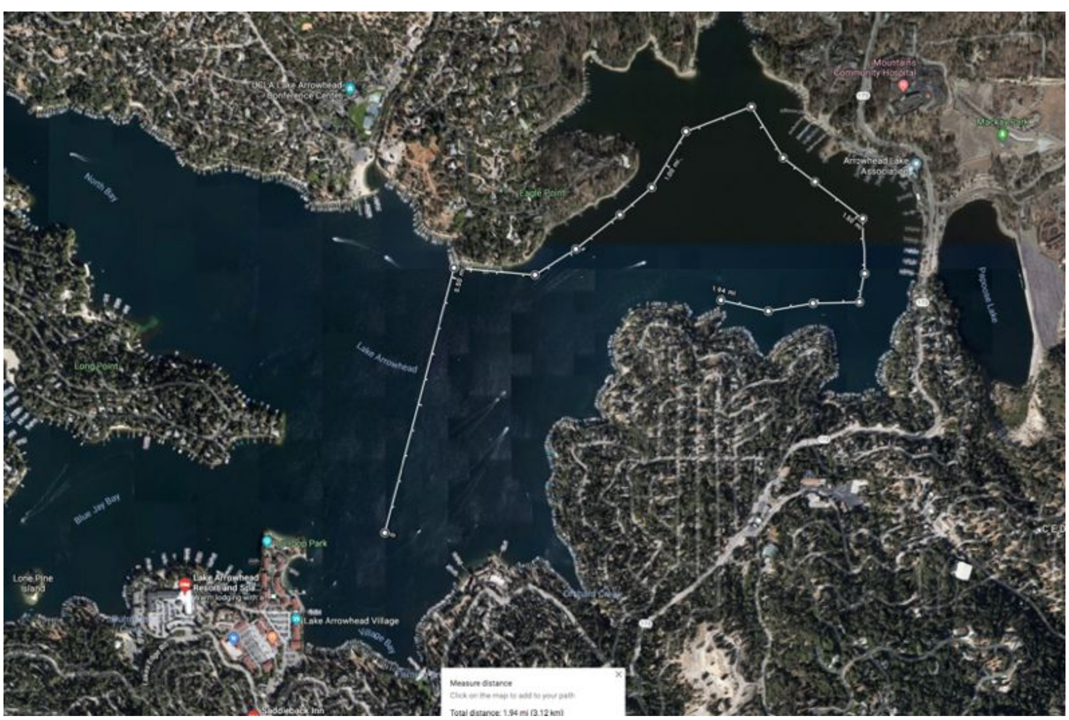


Figure A11 - Estimated maximum distance trajectory from proposed Village Bay point of tracer release to LACSD Cedar Glen intake in Emerald Bay. South-Southwesterly wind - distance 2.15 miles

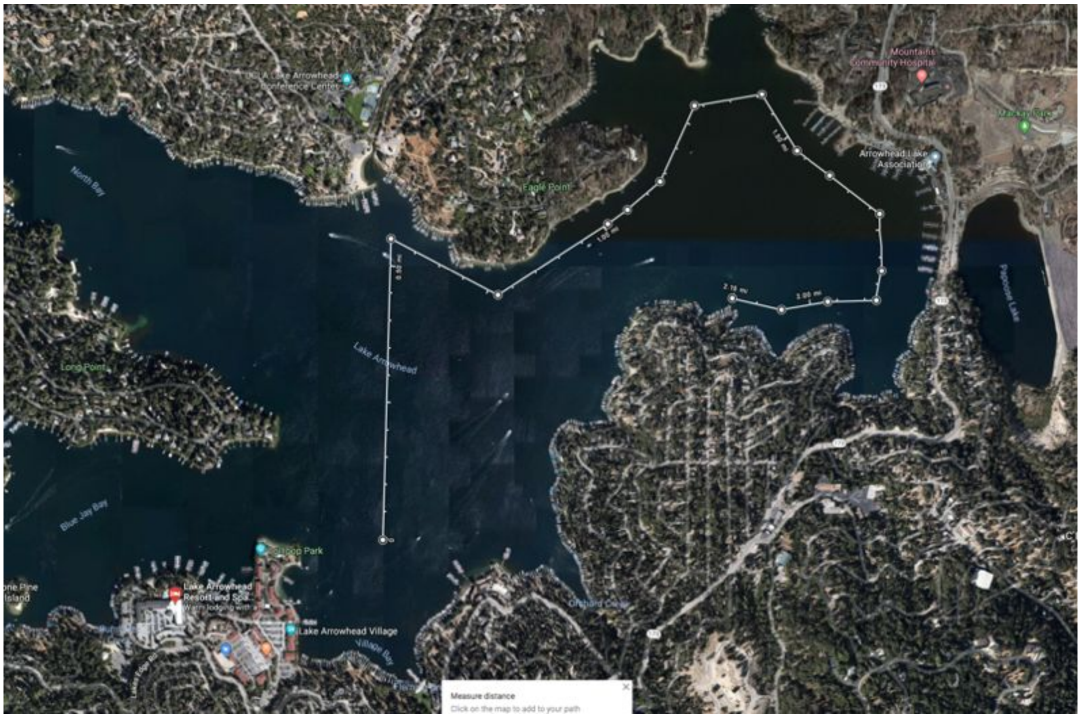
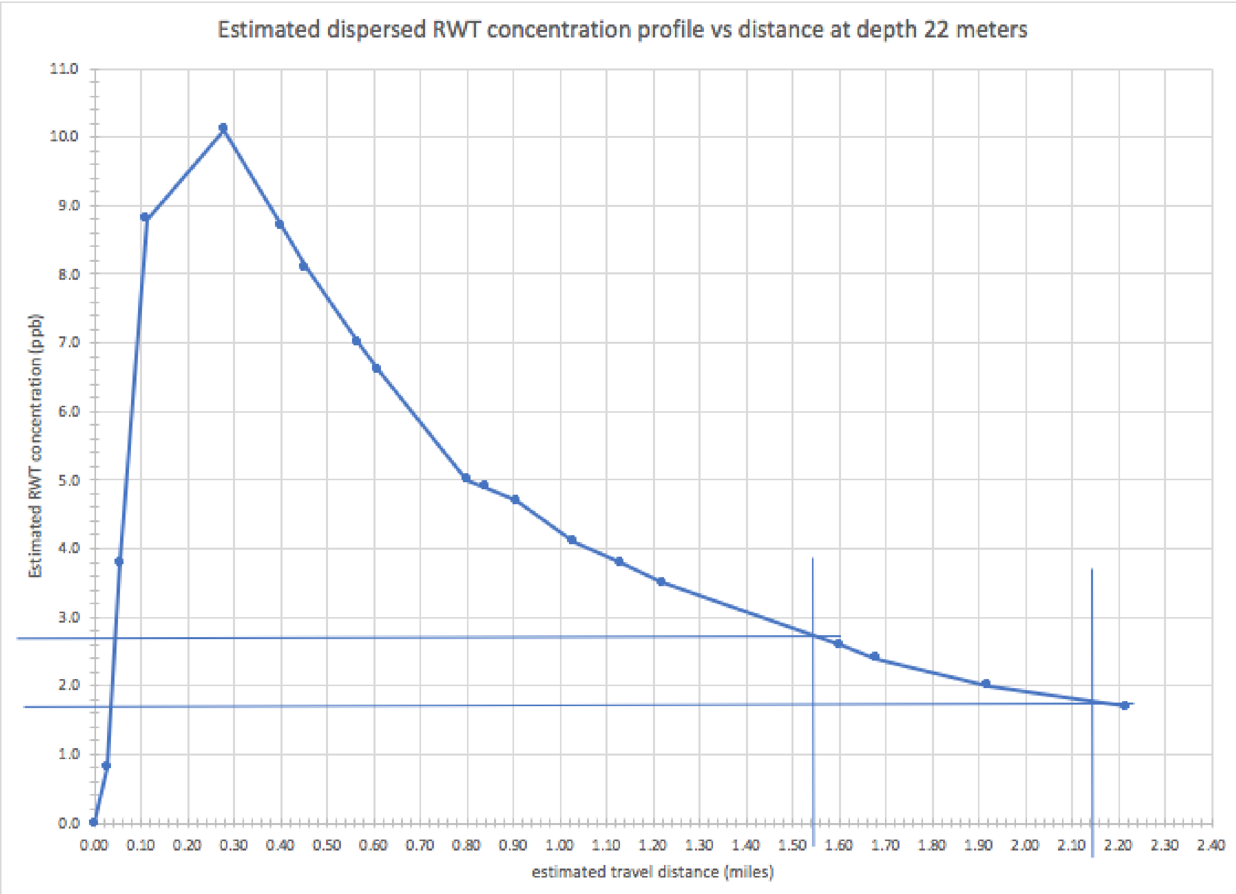


Table A4 - Estimated turbulent diffusion coefficients at different depth used in the finite-difference model for initial estimates tracer release spread over time. Note: K_x and K_y were assumed to be similar and their values correspond to the horizontal turbulent diffusivities K_h reported in the narrative,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

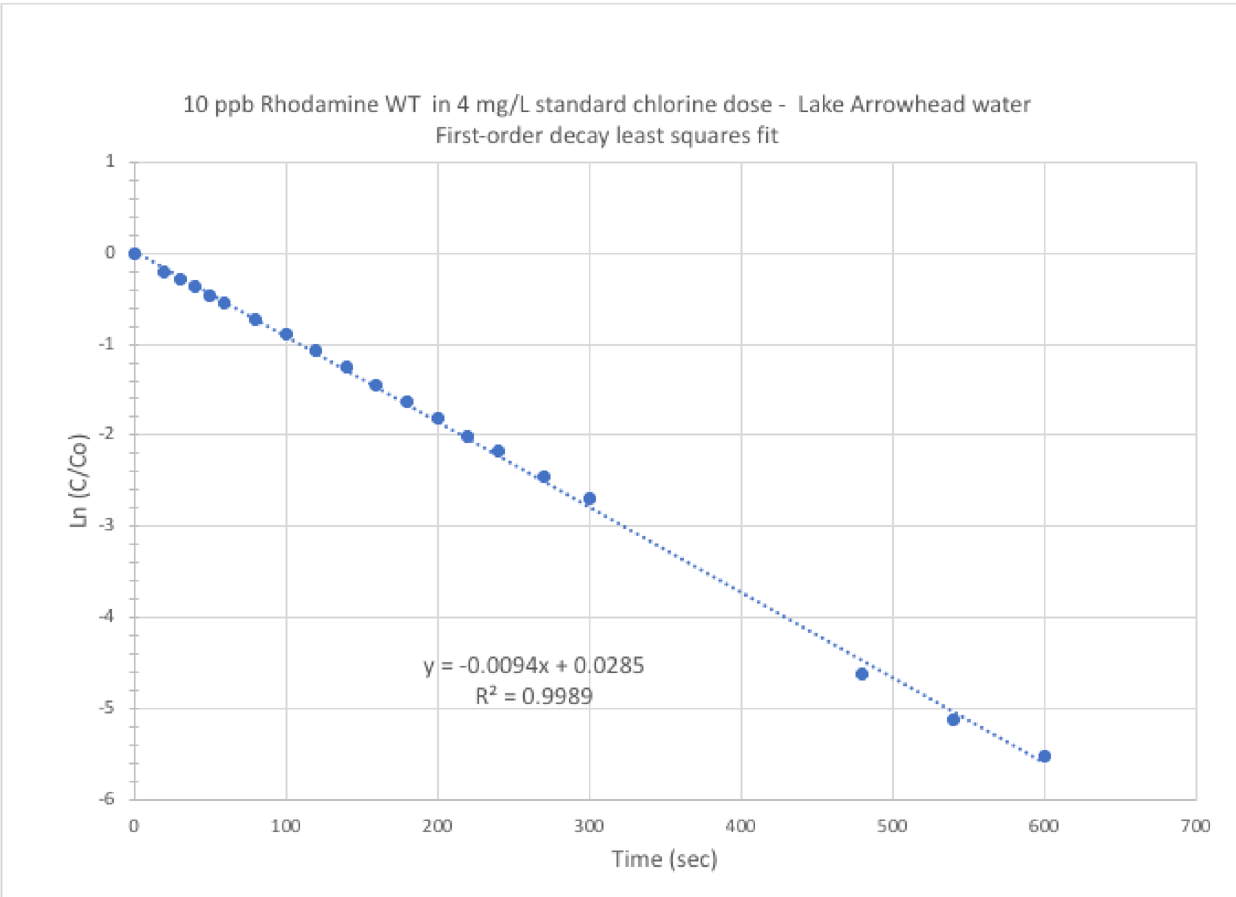
Discussion

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[1], 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

[1] 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[2] (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[3] of 0.025 meter/second at plume depth, (Bender 2012),

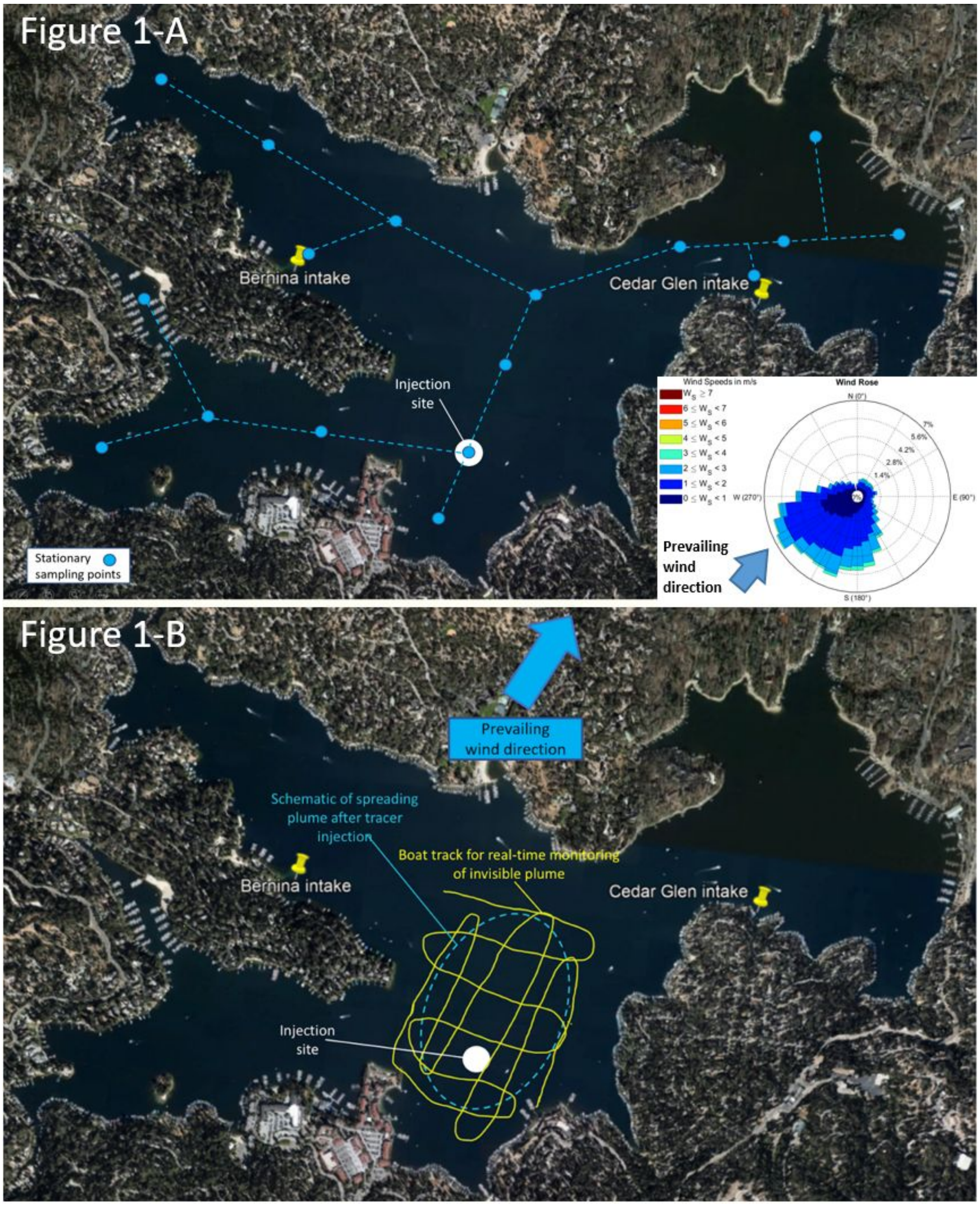
[2] The Ecological Structure Activity Relationships (ECOSAR) Class Program is a computerized predictive system that estimates aquatic toxicity. The program estimates a chemical's acute (short-term) toxicity and chronic (long-term or delayed) toxicity to aquatic organisms, such as fish, aquatic invertebrates, and aquatic plants, by using computerized Structure Activity Relationships (SARs).

[3] 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.

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)**.

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_v= 0.0015-0.0075 m^2/s and horizontal diffusion coefficients in the range of k_h= 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_h= 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[4], 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 a

[4] 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.

both Method Detection Limit (MDL) and Method Reporting Limit (MRL) of 0.005 ppb (**Appendix 3**).

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:

$$1.\ \textit{Volume of water in liters} = \frac{[(\textit{sucralose mass, lbm}) \times 0.453\,kg/lbm \times 1x10^{9}\ ug/kg]}{(\text{target concentration in } u\text{g/Liter})}$$

then

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

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 sucralose concentration of 70 ppb in a maximum depth of 50 feet, the calculations are:

$$\textit{Volume of water in liters} = \frac{[(8.62\ lbm) \times 0.453\,kg/lbm \times 1x10^{9}\ ug/kg]}{(70\ u\text{g/L})}$$

$= 5.58\ x10^7$ liters

then

$$\textit{Volume of water in acre-feet} = \frac{5.58x10^7\ \text{liters}}{(28.3\ \text{liters/ft}^3) \times (43{,}560\ \text{ft}^3\text{/acre foot})}$$

= 45.2 acre-feet

Water area required = 45.2 acre-feet / 50 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:

$$\textit{Volume of water in liters} = \frac{[(8.62\ lbm) \times 0.453\,kg/lbm \times 1x10^{9}\ ug/kg]}{(100\ u\text{g/L})}$$

$= 3.91\ x10^7$ liters

then

Volume of water in acre-feet = $\dfrac{3.91 \times 10^7 \text{ liters}}{(28.3 \text{ liters/ft}^3) \times (43{,}560 \text{ ft}^3\text{/acre foot})}$

= 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 concentrations 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.

Table 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.

Table 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 ($K_{ow}=10^{-49}$) suggests very low bioaccumulation potential. Predictions using the Arnot–Gobas bioconcentration factor[5] (BCF) and bioaccumulation factor[6] (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[7] (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

[5] The bioconcentration factor (BCF) is the ratio of the concentration of the substance in a specific genus to the exposure concentration, at equilibrium.

[6] 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.

[7] 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).

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 (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.

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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 A1: 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.