TECHNICAL MEMORANDUM

Prepared for the
Las Virgenes Municipal Water District

Draft Date: January 23, 2019

Authors: Liana Olivas
Israel Monroy
Bryan Trussell, P.E., BCEE

Reviewer: Eileen Idica, Ph.D., P.E.
Anya Kaufmann, P.E.
Li Ding, Ph.D., P.E. (Flow Science Inc)

Subject: Las Virgenes Reservoir Modeling Results

---

1 Introduction

The Las Virgenes-Triunfo Joint Powers Authority (JPA), consisting of Las Virgenes Municipal Water District (LVMWD) and the Triunfo Sanitation District (TSD), is pursuing an indirect potable reuse project (Project) to utilize the region's excess recycled water for surface water augmentation (SWA) of the Las Virgenes Reservoir (LVR). The goals of the Project are to (1) optimize its water supply portfolio, (2) curtail imported water costs, and (3) eliminate discharges to Malibu Creek. The Project will involve treating recycled water from the Tapia Water Reclamation Facility (WRF) at a new Advanced Water Treatment Plant (AWTP), conveying the AWTP effluent (purified water) to the LVR, and further treating this water at the Westlake Filtration Plant (FP).

The success of the Project will rely on its ability to comply with the stipulations in the SWA regulations (promulgated on October 1, 2018), including the criteria governing dilution and theoretical retention time of a reservoir, which are indicative of the total amount of treatment required for virus, *Giardia*, and *Cryptosporidium* (V/G/C). Table 1 summarizes the treatment requirements for V/G/C from the WRF through the FP based on the dilution and theoretical retention time of the reservoir.

Table 1. Summary of pathogen treatment, dilution and theoretical retention time criteria

Dilution	Theoretical Retention Time (months)	Total Log Removal Credit (V/G/C)
100:1	≥ 6	12/10/10
	< 6 - 4	12/10/10
	< 4 - 2	≥ 13/11/11
10:1	≥ 6	13/11/11
	< 6 - 4	13/11/11
	< 4 - 2	≥ 14/12/12

Trussell Technologies, Inc. (Trussell Tech), in conjunction with Flow Science Incorporated (Flow Science), was retained by the JPA to develop and calibrate a three-dimensional (3-D) hydrodynamic model of the LVR to evaluate the dilution of purified water in the reservoir and ensure future compliance under different operating scenarios. The 3-D hydrodynamic model was developed using the Estuary, Lake, and Coastal Ocean Model (ELCOM) computational program. Details on the model development and calibration can be found in Flow Science's hydrodynamic modeling report (Flow Science, 2017).

In October 2017, several operational scenarios were developed and simulated in the calibrated LVR model, including the Boundary Scenario. The Boundary Scenario represents the most aggressive regular use of the Project because (1) it assumes all potable reuse water is discharged into the LVR during the winter and the shoulder months (in spring and fall), (2) the Westlake FP withdraws continuously from the LVR, including during winter months, and (3) no other source waters are discharged to the LVR during this time. A summary of the Boundary Scenario conditions is shown in Table 2.

Table 2. Summary of the Boundary Scenario in the hydrodynamic model

Scenario	Maximum Potable Reuse Inflow (MGD)	Westlake FP Withdrawal (MGD)	Duration (Months)	Initial Conditions		Final Conditions		Regulatory Parameters	
				Level (ft)	Volume (MG)	Level (ft)	Volume (MG)	Min V/Q (Months)	Min Dilution
Boundary	6.0	7.0*	~16.5	1,041	2,760	1,000	1,095	> 8.5	1:100

*This includes 2 MGD of recirculation flow returned to the LVR and 5 MGD withdrawn to the Westlake Filtration Plant.

Table 3 outlines the results from 30 discrete 24-hour tracer releases using the Boundary Scenario. During these releases, the theoretical retention time was always greater than 8.5 months. In addition, all but one of the 30 tracer releases resulted in a dilution greater than 100, indicating that only 12/10/10 log removal may be required. However, one tracer release was below a dilution of 100 with a prevailing southeasterly wind, which would likely require consideration, either with additional treatment (e.g. 13/11/11), modifications to the operation of the reservoir (e.g., diffuser, air curtain), or operational constraints (e.g. no purified water discharge during southeasterly winds).

Table 3. Boundary Scenario modeling results (Flow Science 2017)

Tracer No.	Date	Minimum Dilution	Lag Time (days)	Tracer No.	Date	Minimum Dilution	Lag Time (days)
1	9/24/Y1	7,568	5.3	16	3/3/Y2	145	3.2
2	10/8/Y1	1,448	21.9	17	3/17/Y2	499	12.1
3	10/22/Y1	763	23.0	18	3/31/Y2	723	9.1
4	11/5/Y1	524	16.0	19	4/14/Y2	1,218	12.6
5	11/19/Y1	412	21.4	20	4/28/Y2	8,083	44.2
6	12/3/Y1	354	16.3	21	10/15/Y1	1,001	19.7
7	12/17/Y1	191	2.6	22	10/18/Y1	886	19.9
8	12/24/Y1	313	22.5	23	12/12/Y1	314	7.6
9	12/31/Y1	318	21.5	24	12/19/Y1	77	0.6
10	1/7/Y1	320	16.6	25	1/18/Y2	317	12.8
11	1/14/Y2	313	5.7	26	1/31/Y2	320	10.7
12	1/21/Y2	284	9.8	27	3/6/Y2	285	1.2
13	1/28/Y2	282	4.2	28	3/12/Y2	470	12.7
14	2/4/Y2	319	6.7	29	3/23/Y2	584	21.6
15	2/18/Y2	344	12.7	30	3/29/Y2	671	15.6

An Independent Advisory Panel (IAP) was convened to discuss the modeling results in May 2018. The IAP recommended further modeling to simulate the use of a subsurface, multi-port diffuser under the Boundary Scenario, as well as a probabilistic analysis of the dilution ratios achieved at the Westlake FP intake. The goal of the additional modeling and analysis was to "predict that dilution criterion would be met in even the most challenging meteorological conditions under the Boundary Scenario" (NWRI Independent Advisory Panel, 2018).

This technical memorandum presents the results of the new hydrodynamic modeling of the LVR and reassesses the dilution using a probabilistic analysis to assure the JPA and regulators that the Project will reliably satisfy the SWA regulations, in particular the dilution requirements.

2 Discharge Diffuser Assessment

2.1 Diffuser Preliminary Design Parameters

A diffuser was implemented to the Project design to improve initial mixing and consequently overall dilution of the purified water in the LVR. After iterations of diffuser design optimization, a multi-port diffuser was selected to be installed to release purified water at the bottom of the LVR at a seawater elevation of approximately 970 ft near the East side of the lake. The location of the diffuser, as shown below in Figure 1, is positioned such that it discharges water as deep as possible, while still maintaining proximity to the expected discharge location of the AWTP. As illustrated in Figure 2, the diffuser design includes a riser with two split-ports, each with a diameter of 8 inches. The port opening is angled at 10 degrees upward from the horizontal to avoid disturbing the sediment.

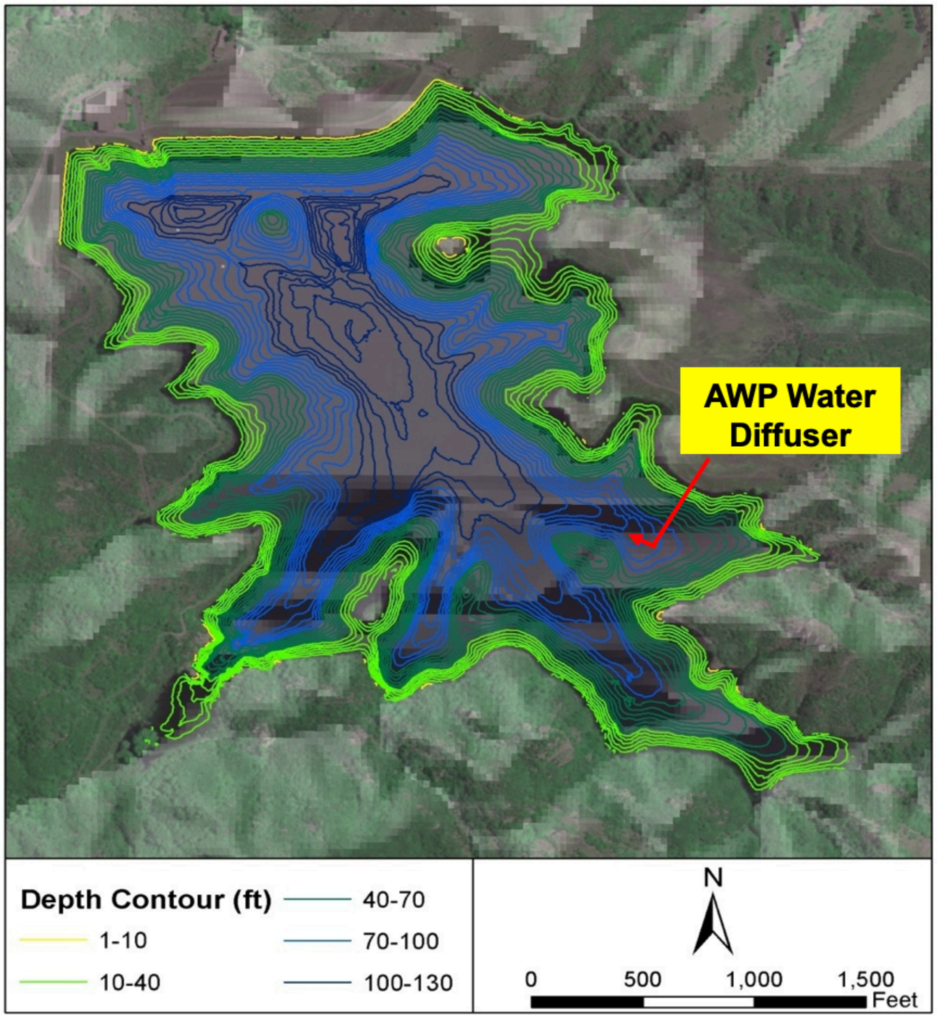


Figure 1. Location of multi-port diffuser

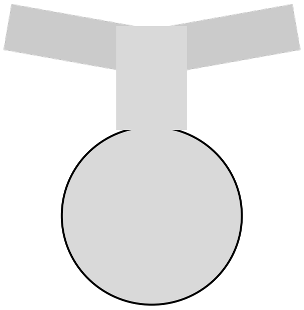


Figure 2. Multi-port diffuser design

2.2 EPA Visual Plumes Model

An EPA Visual Plumes Model was used to assess the optimal design parameters for the diffuser to maximize the initial dilution. As illustrated in Figure 3, the hydrodynamics of the purified water discharged through a diffuser can be conceptualized as a mixing process occurring in two separate regions: a near-field region and a far-field region. In the near-field region the purified water generally experiences a significant amount of mixing, and dilution occurs very rapidly. In this region, the initial jet characteristics of momentum flux, buoyancy flux, flow rate, as well as diffuser geometry greatly influence the purified water trajectory and degree of mixing. As the purified water plume travels further away from the source, the source characteristics become less important and the far-field region is attained. Mixing of the plume in this region is caused by spatial and temporal variations of ambient velocity fields and dilution generally occurs slowly over a long distance.

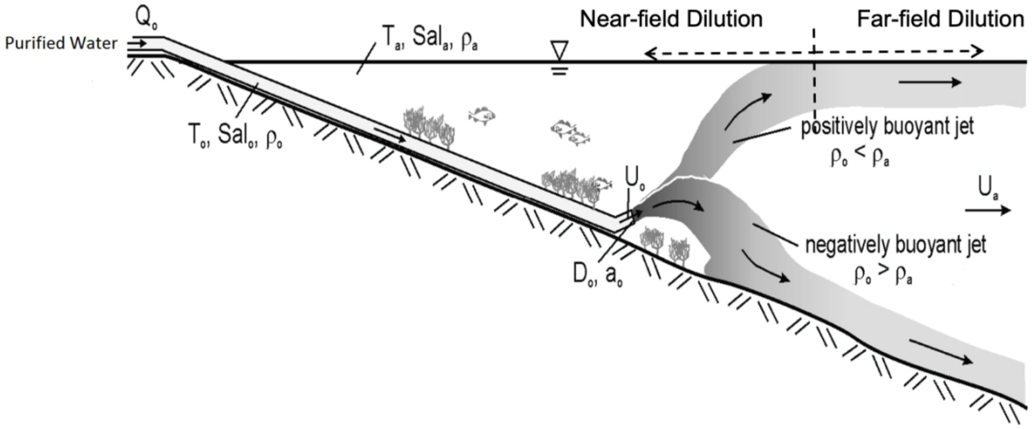


Figure 3. Near-field vs. far-field mixing zones (Institute for Hydromechanics, 2010)

The EPA Visual Plumes Model was used to estimate near-field dilutions for the multi-port diffuser during a worst-case scenario. To determine dilution under the most unfavorable conditions, the following conditions were simulated with the model:

- Smallest/Largest temperature difference between the ambient lake water and purified water
- The highest purified water flow rate of 6 million gallons per day (MGD)

The smallest and largest temperature differences between the ambient lake water and purified water will yield the lowest and highest discharge buoyancy, and therefore will serve as "book ends" on possible buoyancy-driven dilution and plume insertion depths. The highest purified water flow rate will likely result in the lowest dilution at the Westlake FP intake.

The temperature of the purified water was assumed to be the same temperature as the Tapia WRF effluent. The temperature of the ambient surface water was extracted from the previous model simulation. The temperature of the purified water and the predicted ambient surface water were plotted against each other over a year to determine the expected smallest and largest temperature difference between the two, as shown below in Figure 4. These two scenarios were run with the EPA Visual Plumes Model to determine their respective near-field dilution factors. Results of the near-field dilution of the purified water at different depths during these two scenarios can be seen below in Figure 5.

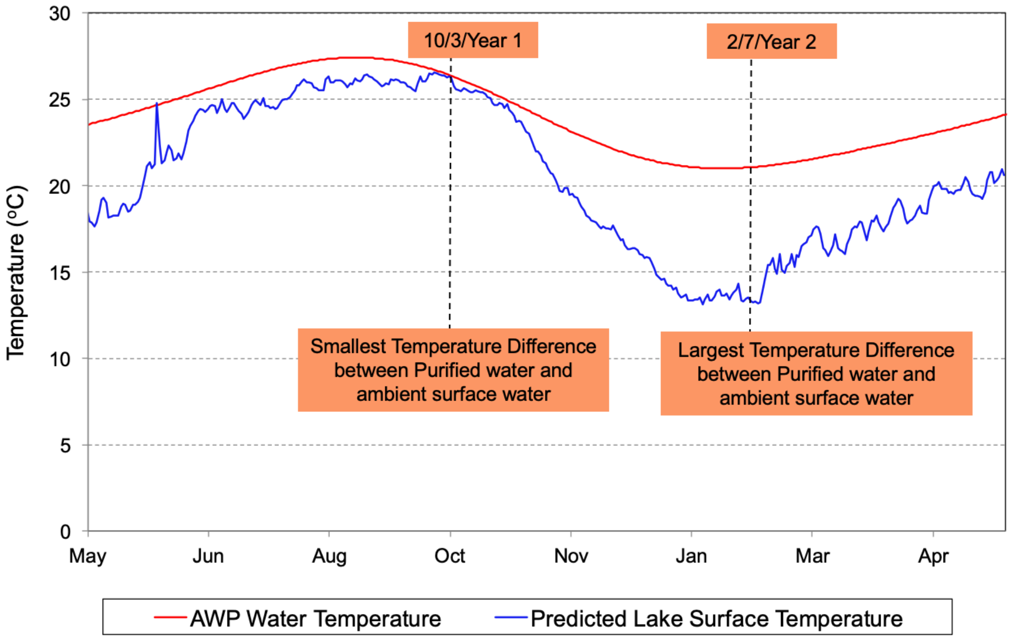
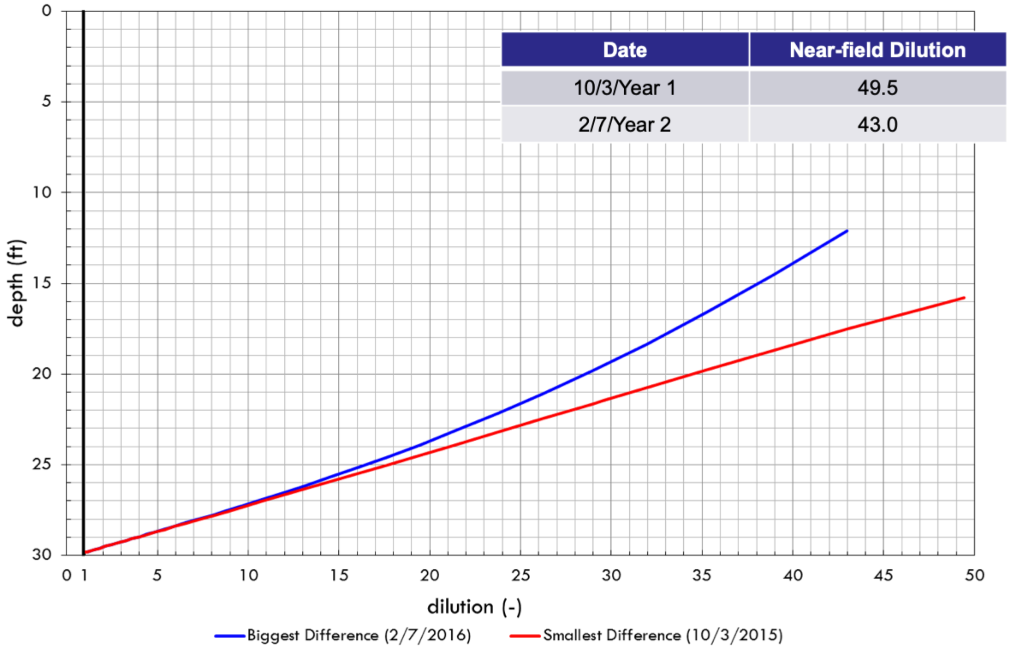


Figure 4. Predicted temperatures of purified water and LVR surface plotted over a year



Date	Near-field Dilution
10/3/Year 1	49.5
2/7/Year 2	43.0

Figure 5. Near-field dilution of purified water in the LVR under worst-case-scenario conditions

Based on the model, the largest temperature difference between the purified water and the LVR surface water yielded the least amount of initial dilution. Under this worst-case scenario, the EPA Visual Plumes Model resulted in a near-filed dilution of 43:1.

3 Modeling Results with Diffuser

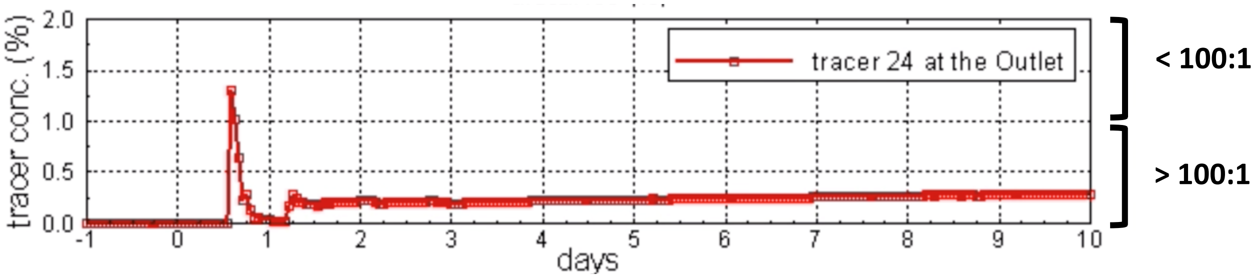
The same 30 discrete 24-hour tracer releases were applied to the Boundary Scenario with the diffuser incorporated (Table 4). In order to capture both near-field and far-field transport and mixing, the previously calibrated ELCOM model which serves as a far-field model was dynamically coupled with the near-field EPA Visual Plumes model to form a complete model and simulate the dilution of the tracers in both near-field and far-field regions. A detailed description of the coupling method is provided in Appendix A. The lowest minimum dilution observed was 226 during Tracer Release #25, whereas the lowest minimum dilution observed without a diffuser was 77 during Tracer Release #24, as was previously shown in Table 3.

Table 4. Modeling results of Boundary Scenario with the diffuser incorporated

Tracer No.	Date	Minimum Dilution	Lag Time (days)
1	9/24/Y1	10925	19.0
2	10/8/Y1	1484	19.0
3	10/22/Y1	776	13.9
4	11/5/Y1	531	15.0
5	11/19/Y1	422	14.0
6	12/3/Y1	354	9.5
7	12/17/Y1	329	10.4
8	12/24/Y1	317	10.7
9	12/31/Y1	318	9.8
10	1/7/Y1	315	7.7
11	1/14/Y2	314	5.3
12	1/21/Y2	302	3.8
13	1/28/Y2	311	3.8
14	2/4/Y2	312	3.3
15	2/18/Y2	355	7.8
16	3/3/Y2	284	3.5
17	3/17/Y2	508	8.1
18	3/31/Y2	740	12.8
19	4/14/Y2	1337	12.2
20	4/28/Y2	8252	22.0
21	10/15/Y1	1025	16.9
22	10/18/Y1	907	17.6
23	12/12/Y1	338	15.2
24	12/19/Y1	325	14.1
25	1/18/Y2	226	1.3
26	1/31/Y2	324	8.6
27	3/6/Y2	436	10.0
28	3/12/Y2	481	12.8
29	3/23/Y2	599	13.3
30	3/29/Y2	691	16.4

A comparison between the concentration of Tracer Release #24 at the outlet opening for Westlake FP with and without a diffuser is shown in Figure 6. As demonstrated below, the highest tracer concentration observed at the Westlake FP decreased from 1.3% to 0.3% during Tracer Release #24. This is equivalent to an increase in the minimum dilution from 77 to 325.

WITHOUT DIFFUSER



WITH DIFFUSER

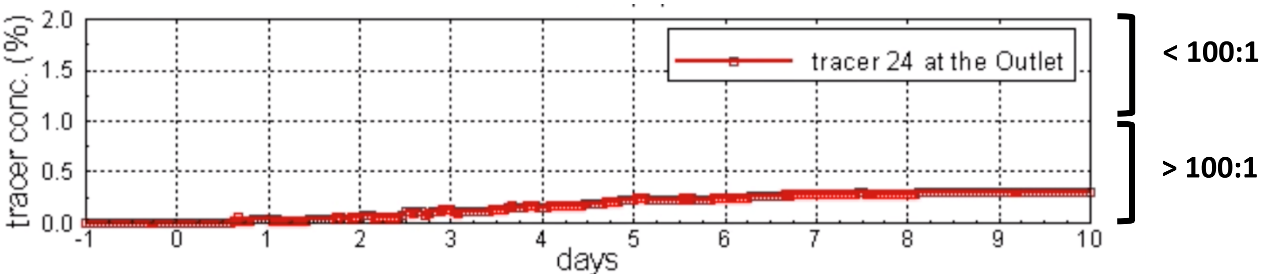


Figure 6. Tracer concentrations at the outlet opening of Westlake FP for Tracer Release #24 with and without a diffuser

The implementation of a diffuser successfully increased the minimum dilution factor of all 30 tracer releases above 100, including the tracer release that previously failed to meet this goal.

4 Probabilistic Analysis

To further assess the likelihood of failure based on environmental conditions beyond those simulated in the discrete 30 tracer pulses, the IAP recommended completion of a probabilistic analysis. A probabilistic analysis is a broader statistical assessment of the dilution to identify worst case scenarios. The probabilistic analysis approach here generally follows the cumulative frequency analysis that is commonly used to study the probability of flood and rainfall. It should be noted that this approach is consistent with the approach used by a similar purified water project at Miramar Reservoir at San Diego, CA, which has been peer-reviewed and approved by its IAP.

4.1 Probabilistic Analysis Approach

The Boundary Scenario was modeled to release one 24-hour pulse every other day throughout the duration of the test run (9/23/Y1 – 5/1/Y2), resulting in 110 tracer releases. The minimum dilution at the Westlake FP intake for each tracer release was derived from the model results and used to perform a statistical analysis with the goal to determine the 99.9% confidence interval. By ensuring that the 99.9% confidence interval exceeds the 1% (100:1) dilution requirement, it can provide regulators a statistical analysis that indicates that this threshold will not be exceeded the vast majority of the time. The resulting minimum dilution normal probability plot is shown below in Figure 7. A normally distributed data set will be a straight line in the normal probability plot. It is apparent that the minimum dilution from the Boundary Scenario does not come from a normal distribution.

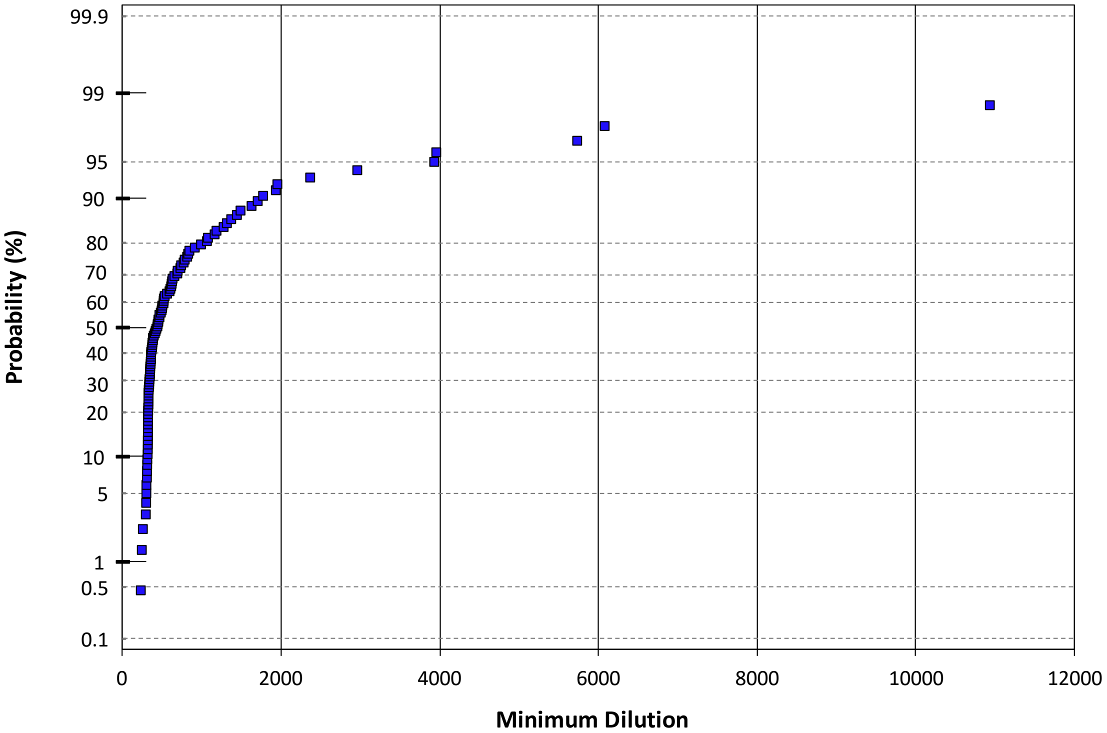


Figure 7. Minimum dilution normal probability plot

Figure 8 represents the same probability analysis graphed on a logarithmic x-axis scale. A minimum dilution of 100 is equivalent to a logarithm of minimum dilution value of 2.0. The minimum dilution values don't form a straight line in Figure 8, indicating the minimum dilution does not come from a Log-Normal distribution.

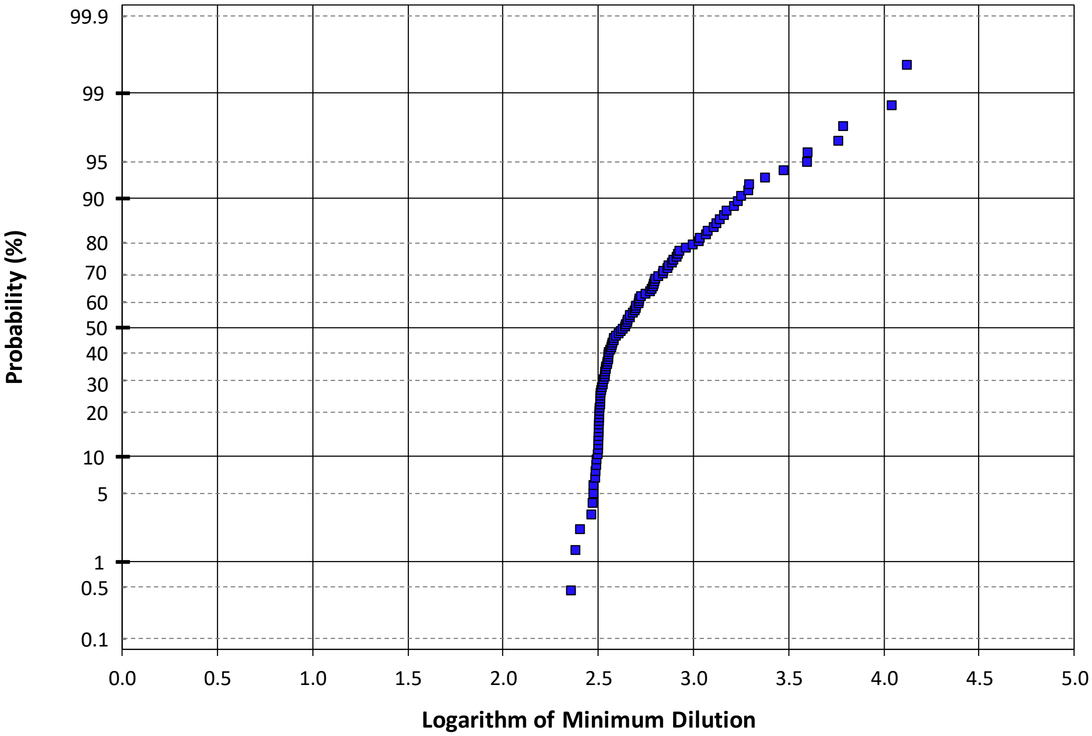


Figure 8. Logarithm of minimum dilution normal probability plot

Other goodness of fit tests were then conducted to verify whether the minimum dilution values or logarithm of minimum dilution values fit a suite of commonly used probability distributions including Normal, Beta, Gamma, General Extreme Value, Pearson, Exponential, and Rayleigh distributions. With a 95% significance level, the tests indicate that the minimum dilution values or their logarithm values do NOT come from any of these distributions. This is expected given that the distinct seasonal variation of the purified water inflow rate and the decreasing water levels in the reservoir throughout the simulation period can affect the values of minimum dilution.

However, a close visual examination of Figure 8 indicates that two linear fits can be developed for the higher logarithm values of minimum dilution between 2.6 – 4.5 and for the medium values between 2.5 – 2.6, respectively. The lowest three dilution values fall outside of these two linear fits and could be considered as potential outliers from the rest of the data samples. A modified Thompson tau outlier test method was then used to confirm that the lowest three minimum dilution values can be considered as outliers from the rest of data at a 95% significance level. If we assume that the lowest three minimum dilution vales can form an outlier group, a linear relationship can be developed for the outlier group and the value of minimum dilution at a 99.9% confidence interval can then be extrapolated from this linear relationship in the probability plot (Figure 9). It should be noted that using the linear relationship for the outlier group is justified since the outlier group consists of a small number of data points and a more sophisticated relationship is not possible. In addition, a linear relationship represents a normal distribution for the outlier group, a reasonable assumption without knowing the actual distribution of the outlier group.

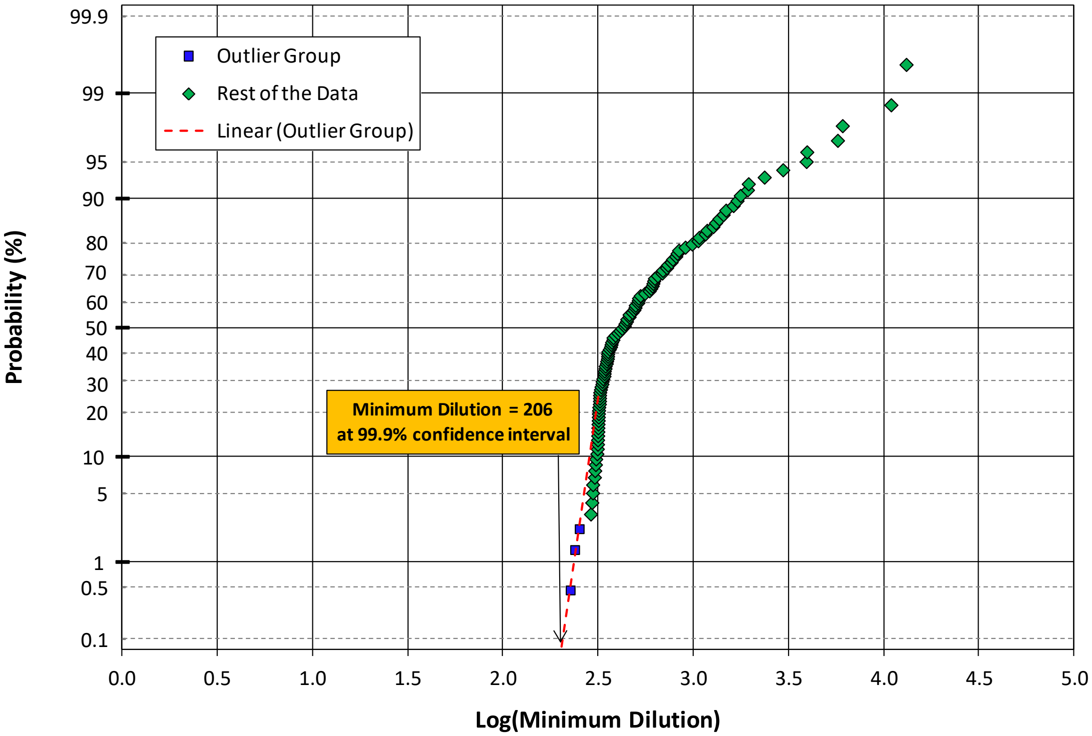


Figure 9. Logarithm of minimum dilution normal probability plot extrapolated for 99.9% confidence (Flow Science 2018)

The extrapolated data suggests a 99.9% confidence interval occurring at a logarithm of minimum dilution value of 2.31, equivalent to a minimum dilution value of 206 for the Boundary Scenario. Therefore, with the inclusion of a diffuser, the Boundary Scenario is able to maintain a dilution above 100:1 greater than 99.9% of the time.

5 Conclusion and Next Steps

The modeling results indicate that the inclusion of a diffuser allows the Project to maintain a dilution above 100 beyond a 99.9% probability. This should allow the JPA to continue planning and designing the project to meet the minimum required pathogenic microorganism control of 12/10/10 for viruses, *Giardia*, and *Cryptosporidium*.

To improve understanding of reservoir conditions, it is recommended that a new weather station be installed at a location that is more representative of the wind conditions experienced at the reservoir. A comparison of the weather data sets from the new weather station and the current weather station is also recommended to identify the difference between the data sets. A full-scale tracer test within the LVR needs to be performed to validate the hydrodynamic model calibration and will provide further confidence to the JPA that no additional treatment should be required. The IAP will need to convene to review the tracer test plan and it is recommended to include a review of these new modeling results as part of that meeting to get the IAP's comments on the most recent modeling results.

6 References

Flow Science Incorporated (2017). "Las Virgenes Reservoir Purified Water Augmentation Analysis – Hydrodynamic Modeling." Report for *Las Virgenes-Triunfo Joint Power Authority."* January 26.

NWRI Independent Advisory Panel for Las Virgenes-Triunfo Pure Water Project (2018). "Findings and Recommendations from the Panel Meeting held May 4, 2018." Report for the *Las Virgenes Municipal Water District*. June 26.

Institute for Hydromechanics (2017). "Environmental planning, prediction and management of brine discharges from desalination plants." Report for the *Middle East Desalination Research Center*. December.