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San Vicente Reservoir Proposed Water Quality Monitoring Program

Prepared for
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1. INTRODUCTION

San Vicente Reservoir (SVR) is located near Lakeside, California, and is used as a source of drinking water supply by the City of San Diego (City), its owner and operator. The reservoir currently has a capacity of about 90,000 acre-feet (see **Figure 1**). It is undergoing an expansion that will raise the dam 117 feet and increase the reservoir's storage capacity to 247,000 acre-feet at the spillway level. The City is considering an option to augment the SVR supply by bringing advanced treated recycled water (*i.e.*, purified water) from an advanced water purification facility to SVR; *i.e.* an Indirect Potable Reuse / Reservoir Augmentation (IPR/RA) project. The purified water would be blended with other water in the reservoir. The current project – the Water Purification Demonstration Project (Demonstration Project) – will not actually put any purified water into the reservoir; rather it will study and model the reservoir augmentation process. A component of the Demonstration Project is the Limnology and Reservoir Detention Study of San Vicente Reservoir (Limnology Study).

As part of the Limnology Study, Flow Science Incorporated (FSI) has developed a numerical three-dimensional water quality model that is used to evaluate hydrodynamic and water quality effects of using purified water to augment SVR. After the model was developed its results were compared to existing field data. The results of this analysis were documented in a Technical Memorandum (TM #1) submitted to the City in 2010 (FSI, 2010). TM #1 has been peer-reviewed by the National Water Research Institute Independent Advisory Panel (IAP) that was assembled for the review of the City's Demonstration Project. After implementing suggestions proposed by the IAP, the model was deemed by IAP to be "an effective and robust tool, for 1) simulating thermoclines and hydrodynamics of the San Vicente Reservoir; 2) assessing biological water quality for nutrients; 3) assessing options for the purified water inlet location" (IAP, 2010).

Upon completion of the SVR model calibration and validation, FSI conducted simulations of purified water delivery to the expanded SVR under various projected future operating conditions using the calibrated and validated model. The simulation results and findings are presented in two separate Technical Memorandums (TM #2 and TM #3). TM #2 summarizes the hydrodynamic aspects of the modeling results and was submitted to the City on November 28, 2011 (FSI, 2011). TM #3 focuses on the water quality aspects of the modeling results and findings, with emphasis on nutrients (phosphorus and nitrogen), dissolved oxygen (DO), and algal productivity, and was submitted to the City on February 24, 2012 (FSI, 2012). Both TM#2 and TM#3 have been peer-reviewed by the IAP.

If SVR is augmented by purified water in the future, the three-dimensional model developed for the Limnology Study is expected to provide a tool for evaluating various reservoir management options, assessing residence time and dilution of the purified water within SVR, determining optimal reservoir operations for maximizing water quality, and minimizing any potential short-circuiting between the inlet and outlet. It is expected that the model will be updated on a yearly basis using new data collected each year. In order to update the model and maintain it as a tool for assessing reservoir water quality and operations, data collection in the reservoir, as well as its inflows and outflows, will be needed. The goal of this document is to provide an outline of an initial reservoir monitoring plan to obtain these necessary data. Another goal of the monitoring plan is to identify monitoring efforts that may be needed to enhance water treatability and address future water quality regulatory issues. It is anticipated that this monitoring plan will be refined based on initial monitoring results and yet to be established regulatory requirements.

This memorandum is organized in four sections. Section 1 is this Introduction. Section 2 identifies the ongoing future data needs that are required to support the goals of the IPR/RA project. Such needs are deemed either "basic" or "optimal". Basic data needs refer to the minimum level of information required to support the goals of the project and future modeling. Optimal data needs define some additional monitoring efforts that may be required to support analysis of future regulatory issues, and to further enhance the water quality modeling ability.

Section 3 of this document identifies some special studies or monitoring efforts that are needed to enhance our understanding of the reservoir. Such studies are typically of short and limited duration. The specific goals of such studies are to clarify various reservoir mixing and water quality processes that can enhance the operational efficiency of the reservoir.

Section 4 of this document identifies data compilation and analysis needs that are necessary to the continuing success of the modeling effort and the understanding of water quality in the reservoir. A key proposed task is the compilation and archiving of all historical and future data (as they become available) into a central repository. After the data are archived, data analysis will be performed to identify various water quality trends. It is also recommended that a yearly data analysis report be issued as part of the future data collection effort.

2. SVR MONITORING PLAN

The SVR monitoring plan will include periodic sampling and measurement of physical, chemical, and biological parameters for inflows, outflows, and at in-reservoir locations. It also includes on-site measurements of meteorological data. Two alternate monitoring plans are proposed to match differing goals, resources, and funding. The "basic" monitoring plan is intended to meet minimum requirements for achieving the monitoring plan goals, while the "optimal" monitoring plan can provide a more comprehensive database to further improve understanding of the reservoir's limnology and enhance the water quality model with additional resources. The "optimal" monitoring plan is essentially an expanded version of the "basic" plan, but involves monitoring at more locations and reservoir depths, as well as more water quality parameters at a higher frequency.

Based on previous experience with modeling and analysis of historical data, the main interest in the spatial variability of water quality is expected to be along a path (i.e., a transect) connecting the location of the purified water discharge into the reservoir and the dam, as well as the path connecting San Vicente Creek (a main stream inflow with additional water transfer from Sutherland reservoir) and the dam. This expected variability was considered in selecting the in-reservoir monitoring stations. **Table 1** provides a list of proposed monitoring stations at the inflow locations, outflow locations, and in the reservoir. A map of these station locations is shown in **Figure 1**. It is noted that many of these stations have been monitored either routinely, or as part of the tracer studies that were performed in 1995 (FSI, 1995).

The selection of monitoring parameters depends on anticipated water quality issues. The important water quality parameters for SVR include metals, DO, nutrients (*i.e.*, phosphorus and nitrogen) and associated biological productivity. Some additional physical, chemical, and biological parameters will also be measured to help with the basic understanding of the reservoir. Meteorological data are needed as they are important drivers for the water quality model.

The monitoring plan is divided into four categories: inflow monitoring, outflow monitoring, in-reservoir monitoring, and meteorological monitoring. The "optimal" and "basic" plans are proposed for each category and are discussed in greater detail in the following sections.

Table 1. SVR Monitoring Sites

Site #	Abbreviation	Type	Location	Notes
1	BAR	Inflow Station	Barona Creek	
2	SNC	Inflow Station	San Vicente Creek	Includes the water transfer from Sutherland
3	KIM	Inflow Station	Kimball Creek	Also known as West Fork San Vicente Creek
4	TOL	Inflow Station	Toll Road Creek	
5	AQA	Inflow Station	Aqueduct Creek	Aqueduct Creek is a natural water course. It is not to be confused with the First San Diego Aqueduct, which conveys imported water.
6	AQW	Inflow Station	The First San Diego Aqueduct	The imported water through the First San Diego Aqueduct
7	PWI	Inflow Station	Purified Water Inflow	Optional, can be replaced by using flow rate and water quality measured at the APWF effluent
8	SVPL	Outflow Station	Dam outflow	San Vicente Pipeline #1 downstream of dam
9	SVA	In-reservoir Station	Lat: 32.9129 Lon: -116.0250	Near the Dam, the original Station A currently sampled by the city
10	SVC	In-reservoir Station	Lat: 32.9225 Lon: -116.9221	Main body of the reservoir to the west of Lowell Island
11	SVG	In-reservoir Station	Lat: 32.9295 Lon: -116.9071	Main body of the reservoir to the east of Lowell Island
12	SVH	In-reservoir Station	Lat: 32.9400 Lon: -116.9097	In Kimball Arm and near the largest surface stream inflow, San Vicente Creek
13	SVN	In-reservoir Station	Lat: 32.9201 Lon: -116.9131	Near the Design Purified Water Inlet Location
14	SVWX East	Meteorological Station	On the east side of Lowell Island	Meteorology Station
15	SVWX West	Meteorological Station	On the west side of Lowell Island	Meteorology Station

2.1 INFLOW MONITORING

There are five surface streams that flow into SVR: Barona Creek, San Vicente Creek, Kimball Creek, Toll Road Creek, and Aqueduct Creek (Aqueduct Creek is different from the imported water inflow through the First San Diego Aqueduct). In addition, the imported water flows into SVR through the First San Diego Aqueduct (**Figure 1**). The water transfer from Sutherland Reservoir enters SVR through San Vicente Creek. Monitoring these inflows for water quantity and quality will be required in order to provide important input data for future modeling and water and nutrient loading calculations.

The list of suggested inflow monitoring parameters, locations, and monitoring frequency is provided in **Table 2** for the "basic" monitoring plan. Field measurements for parameters such as temperature and DO should be done *in situ* using a sonde (such as a YSI or Hydrolab profiler). For parameters that require laboratory analysis (such as nutrients, please refer to **Table 2**), discrete grab samples are required. Such samples would then be preserved and transferred to a laboratory for analysis. The purpose for monitoring certain parameters, listed in the table for reference, includes the need for model input, model verification, or water treatability. In the "basic" monitoring plan, the *in situ* measurements at the First San Diego Aqueduct (AQW) and San Vicente Creek (SNC) are suggested to be done continuously *i.e.*, daily or hourly results because the flows at these sites are more or less continuous and there is a man-made structure to locate autonomous monitoring equipment. The other four inflows (BAR, KIM, TOL, and AQA) have highly variable flows and are located in steep rocky natural channels. It is not possible to deploy autonomous monitoring equipment at these sites and each monitoring event is necessarily a stand-alone visit. It is suggested that monitoring be done monthly at these four creek inflows. For parameters that require laboratory analysis, monthly grab sampling is suggested for all inflow sites. This sampling frequency provides a modest resolution of the water quality's temporal variation in the inflows with relatively less resources required and a lower cost.

During wet-weather events (*i.e.*, storms), both flow and nutrient loadings may be large and highly variable. Thus, both flows and nutrient levels in the inflow need to be monitored during representative wet-weather events to characterize flow and nutrient loadings. A study of available historic precipitation data shows that there are a total of 8 days with daily precipitation greater than 0.5 inch between 10/26/2004 and 1/1/2008, a period of on-site precipitation data available to the authors, and they account for 10% of the total number of days with precipitation during this period. For the monitoring plan, it is suggested that a wet-weather event be defined as an event with expected daily precipitation greater than 0.5 inch. On average, it can be expected to have about two forecasted wet-weather events per year. It is suggested for the "basic" monitoring plan that up to two wet-weather events per year be monitored on an hourly basis. The specific parameters required to be monitored during wet-weather events for the "basic" monitoring plan are listed in **Table 2**. An alternative to the hourly sampling of the inflows during wet-weather events is to use a flow-weighted composite sampling method. This involves using an autosampler to capture representative flow-weighted composite samples during wet-weather events. Details on this method can be found in Paulsen *et al*. (2011).

Table 2. Inflow Monitoring – Basic Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Flow	cfs	±0.5	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
Temperature	^{o}C	±0.10	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
Dissolved Oxygen [DO]	mg/L	±0.20	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
pH	N/A	±0.20	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
Oxidation-Reduction Potential [ORP]	mV	±20	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
Electrical Conductivity [EC]	mS/cm	±0.5%	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
Specific Conductance	mS/cm	±0.01	6 Locations[2]	Daily or monthly[1,3]	In-situ	Model Input
Total Dissolved Solids [TDS]	mg/L	±1	6 Locations[2]	Daily[1] or monthly[1,3]	In-situ	Model Input
Total Nitrogen [TN]	mg/L	0.05	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
Total Phosphorus [TP]	mg/L	0.01	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
Nitrate [NO_3]	mg/L	0.05	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
Nitrite [NO_2]	mg/L	0.05	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
Ammonia [NH_4]	mg/L	0.02	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
Orthophosphate [PO_4]	mg/L	0.01	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
SRP	mg/L	0.01	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
TOC	mg/L	0.01	6 Locations[2]	Monthly[1]	Grab Sample	Model Input
Iron [Fe]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Sodium [Na]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Potassium [K]	mg/L	0.1	6 Locations[2]	Monthly	Grab Sample	Treatability
Manganese [Mn]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Calcium [Ca]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Magnesium [Mg]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Carbonate [CO_3]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Bicarbonate [HCO_3]	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Alkalinity	mg/L	0.01	6 Locations[2]	Monthly	Grab Sample	Treatability
Sulfate [SO_4]	mg/L	0.1	6 Locations[2]	Monthly	Grab Sample	Treatability
Chloride [Cl]	mg/L	0.1	6 Locations[2]	Monthly	Grab Sample	Treatability
TDS	mg/L	10	6 Locations[2]	Monthly	Grab Sample	Model Input
Chlorophyll *a*	µg/L	1	6 Locations[2]	Monthly	Grab Sample	Model Input
Phycocyanin	µg/L	1	6 Locations[2]	Monthly	Grab Sample	Treatability

Notes: 1. Hourly sampling and measurements for up to two wet-weather events (*i.e.*, daily precipitation greater than 0.5 inch) per year.
2. BAR, SNC, KIM, TOL, AQA, AQW.
3. Daily at SNC and AQW; monthly at BAR, KIM, TOL, and AQA

Table 3 lists the "optimal" monitoring plan for the inflows. The main difference between the "basic" and "optimal" monitoring plan is that the "optimal" monitoring plan suggests increasing monitoring frequency for all of the parameters that require laboratory analysis from monthly to twice monthly and to increase stand-alone monitoring visits to the four creeks [BAR, KIM, TOL, and AQA] from monthly to twice per month. This will improve resolution of water quality temporal variation in the inflows. In addition, the "optimal" monitoring plan suggests monitoring all *in situ* parameters and parameters that require laboratory analysis on an hourly basis for all wet-weather events (*i.e.*, daily precipitation greater than 0.5 inch).

Table 3. Inflow Monitoring – Optimal Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Flow	cfs	±0.5	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
Temperature	°C	±0.10	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Dissolved Oxygen [DO]	mg/L	±0.20	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
pH	N/A	±0.20	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
Oxidation-Reduction Potential [ORP]	mV	±20	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
Electrical Conductivity [EC]	mS/cm	±0.5%	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
Specific Conductance	mS/cm	±0.01	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
Total Dissolved Solids [TDS]	mg/L	±1	7 Locations[2]	Daily or twice per month[1,3]	In-situ	Model Input
Total Nitrogen [TN]	mg/L	0.05	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
Total Phosphorus [TP]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
Nitrate [NO_3]	mg/L	0.05	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
Nitrite [NO_2]	mg/L	0.05	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
Ammonia [NH4]	mg/L	0.02	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
Orthophosphate [PO_4]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
SRP	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
TOC	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Model Input
Iron [Fe]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Sodium [Na]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Potassium [K]	mg/L	0.1	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Manganese [Mn]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Calcium [Ca]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Magnesium [Mg]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Carbonate [CO3]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Bicarbonate [HCO3]	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Alkalinity	mg/L	0.01	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Sulfate [SO4]	mg/L	0.1	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
Chloride [Cl]	mg/L	0.1	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability
TDS	mg/L	10	7 Locations[2]	Twice per month[1]	Grab Sample	Model Verification
Chlorophyll *a*	µg/L	1	7 Locations[2]	Twice per month[1]	Grab Sample	Model Verification
Phycocyanin	µg/L	1	7 Locations[2]	Twice per month[1]	Grab Sample	Treatability

Notes:
1. Hourly sampling and measurements for all wet-weather events (i.e., daily precipitation greater than 0.5 inch) at BAR, SNC, KIM, TOL and AQA.
2. BAR, SNC, KIM, TOL, AQA, AQW, PWI.
3. Daily at SNC, AQW and PWI; monthly at BAR, KIM, TOL, and AQA

2.2 OUTFLOW MONITORING

The only outflow from SVR is the water withdrawn through the intake structure at the dam. Keeping an accurate record of port opening history and monitoring daily outflow rate is essential for modeling accuracy. Water temperature is relatively easy to measure and can be used to verify the accuracy of port opening records. Thus, the open ports, water temperature, and outflow rates are suggested to be monitored for the "basic" monitoring plan (**Table 4**). For the "optimal" monitoring plan, a list of water quality parameters (**Table 5**) is suggested to be monitored to enhance the modeling effort and provide information for the reservoir operation management and water treatability for downstream water treatment plant.

Table 4. Outflow Monitoring – Basic Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Open Ports			SVPL		In-situ	Model Input
Temperature	^{o}C	±0.10	SVPL	Daily	In-situ	Model Verification
Flow	cfs	±0.5	SVPL	Daily	In-situ	Model Input

Table 5. Outflow Monitoring – Optimal Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Open Ports			SVPL		In-situ	Model Input
Temperature	^{o}C	±0.10	SVPL	Daily	In-situ	Model Verification
Dissolved Oxygen [DO]	mg/L	±0.20	SVPL	Daily	In-situ	Model Verification
pH	N/A	±0.20	SVPL	Daily	In-situ	Model Verification
Oxidation-Reduction Potential [ORP]	mV	±20	SVPL	Daily	In-situ	Model Verification
Electrical Conductivity [EC]	mS/cm	±0.5%	SVPL	Daily	In-situ	Model Verification
Specific Conductance	mS/cm	±0.01	SVPL	Daily	In-situ	Model Verification
Total Dissolved Solids [TDS]	mg/L	±1	SVPL	Daily	In-situ	Model Verification
Flow	cfs	±0.5	SVPL	Daily	In-situ	Model Verification
Total Nitrogen [TN]	mg/L	0.05	SVPL	Twice per month	Grab Sample	Model Verification
Total Phosphorus [TP]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Model Verification
Nitrate [NO_3]	mg/L	0.05	SVPL	Twice per month	Grab Sample	Model Verification
Nitrite [NO_2]	mg/L	0.05	SVPL	Twice per month	Grab Sample	Model Verification
Ammonia [NH4]	mg/L	0.02	SVPL	Twice per month	Grab Sample	Model Verification
Orthophosphate [PO_4]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Model Verification

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
SRP	mg/L	0.01	SVPL	Twice per month	Grab Sample	Model Verification
TOC	mg/L	0.01	SVPL	Twice per month	Grab Sample	Model Verification
Iron [Fe]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Sodium [Na]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Potassium [K]	mg/L	0.1	SVPL	Twice per month	Grab Sample	Treatability
Manganese [Mn]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Calcium [Ca]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Magnesium [Mg]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Carbonate [CO3]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Bicarbonate [HCO3]	mg/L	0.01	SVPL	Twice per month	Grab Sample	Treatability
Alkalinity	mg/L	0.01	SVPL	Twice per month	Grab Sample	Model Treatability
Sulfate [SO4]	mg/L	0.1	SVPL	Twice per month	Grab Sample	Treatability
Chloride [Cl]	mg/L	0.1	SVPL	Twice per month	Grab Sample	Treatability
TDS	mg/L	10	SVPL	Twice per month	Grab Sample	Model Verification
Chlorophyll *a*	µg/L	1	SVPL	Twice per month	Grab Sample	Model Verification
Phycocyanin	µg/L	1	SVPL	Twice per month	Grab Sample	Treatability

2.3 IN-RESERVOIR MONITORING

The "basic" monitoring plan suggests measuring water temperature, pH, DO, ORP, EC, specific conductance, and TDS profiles every one meter vertically in the top 30 meters, then every five meters to the bottom using a sonde (**Table 6**). This will provide adequate resolution across the thermocline. Chlorophyll *a* and phycocyanin only need to be measured using top five meter composite samples. For other grab sample parameters to be analyzed in the laboratory, the "basic" monitoring plan suggests that they be measured at the surface and bottom, as well as at the elevations of all the submerged intake tower ports. It is also suggested that the above mentioned parameters be monitored on a monthly frequency at two in-reservoir monitoring stations: SVA and SVN. These locations are recommended because they correspond to locations close to the outlet and purified water inlet, respectively.

The "optimal" monitoring plan will increase the monitoring frequency from monthly to twice monthly (**Table 7**), providing a more detailed view of the in-reservoir water quality. It also suggests monitoring these parameters at five in-reservoir stations so a more detailed spatial view of the reservoir can be developed and compared to the model. Grab sample parameters that require laboratory analysis are suggested to be monitored at the surface, bottom, and every 10 meters in between, to provide better vertical spatial resolution. The "optimal" monitoring plan also proposes to measure the cell count and biomass of different algal species in the reservoir to study the dominant algal species within the reservoir. It is suggested that a fluorometer be attached to the sonde to measure *in vivo* chlorophyll *a* profiles to provide information on the vertical distribution of algae. Note that the fluorometer should be calibrated and verified before and during the deployment following the protocol from the manufacturer.

Table 6. In-reservoir Monitoring – Basic Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose	Sampling Depth
Depth	m	±0.01	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Temperature	^oC	±0.10	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Dissolved Oxygen [DO]	mg/L	±0.20	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
pH	N/A	±0.20	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Oxidation-Reduction Potential [ORP]	mV	±20	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Electrical Conductivity [EC]	mS/cm	±0.5%	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Specific Conductance	mS/cm	±0.01	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Total Dissolved Solids [TDS]	mg/L	±1	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Chlorophyll *a* using profiling fluorometer	µg/L	1	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Phycocyanin using profiling fluorometer	µg/L	1	SVA, SVN	Monthly	In-situ	Model Verification	Multiple[1]
Secchi Depth	m		SVA, SVN	Monthly	In-situ	Model Verification	

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose	Sampling Depth
Total Nitrogen [TN]	mg/L	0.05	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Total Phosphorus [P]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Nitrate [NO_3]	mg/L	0.05	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Nitrite [NO_2]	mg/L	0.05	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Ammonia [NH4]	mg/L	0.02	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Orthophosphate [PO_4]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
SRP	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
TOC	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Iron [Fe]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Sodium [Na]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Potassium [K]	mg/L	0.1	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Manganese [Mn]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Calcium [Ca]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Magnesium [Mg]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Carbonate [CO3]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Bicarbonate [HCO3]	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Alkalinity	mg/L	0.01	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Sulfate [SO4]	mg/L	0.1	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
Chloride [Cl]	mg/L	0.1	SVA, SVN	Monthly	Grab Sample	Treatability	Multiple[2]
TDS	mg/L	10	SVA, SVN	Monthly	Grab Sample	Model Verification	Multiple[2]
Chlorophyll *a*	µg/L	1	SVA, SVN	Monthly	Grab Sample/	Model Verification	Top 5 m composite
Phycocyanin	µg/L	1	SVA, SVN	Monthly	Grab Sample	Treatability	Top 5 m composite

Notes:
1. Sample every one meter in the top 30 meter water and every five meters for the rest water column.
2. Sample at Surface, Bottom, and at the elevations of all the submerged intake tower ports.

Table 7. In-reservoir Monitoring – Optimal Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose	Sampling Depth
Depth	m	±0.01	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Temperature	°C	±0.10	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Dissolved Oxygen [DO]	mg/L	±0.20	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
pH	N/A	±0.20	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Oxidation-Reduction Potential [ORP]	mV	±20	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Electrical Conductivity [EC]	mS/cm	±0.5%	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Specific Conductance	mS/cm	±0.01	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Total Dissolved Solids [TDS]	mg/L	±1	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Chlorophyll *a* using profiling fluorometer	µg/L	1	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Phycocyanin using profiling fluorometer	µg/L	1	5 Locations[3]	Twice per month	In-situ	Model Verification	Multiple[1]
Secchi Depth	m		5 Locations[3]	Twice per month	In-situ	Model Verification	
Total Nitrogen [TN]	mg/L	0.05	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Total Phosphorus [TP]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Nitrate [NO_3]	mg/L	0.05	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Nitrite [NO_2]	mg/L	0.05	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Ammonia [NH4]	mg/L	0.02	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Orthophosphate [PO_4]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
SRP	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
TOC	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Iron [Fe]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Sodium [Na]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose	Sampling Depth
Potassium [K]	mg/L	0.1	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Manganese [Mn]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Calcium [Ca]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Magnesium [Mg]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Carbonate [CO3]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Bicarbonate [HCO3]	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Alkalinity	mg/L	0.01	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Sulfate [SO4]	mg/L	0.1	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
Chloride [Cl]	mg/L	0.1	5 Locations[3]	Twice per month	Grab Sample	Treatability	Multiple[2]
TDS	mg/L	10	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Multiple[2]
Chlorophyll *a*	µg/L	1	5 Locations[3]	Twice per month	Grab Sample	Model Verification	Top 5 m composite
Phycocyanin	µg/L	1	5 Locations[3]	Twice per month	Grab Sample	Treatability	Top 5 m composite
Algae Species Cell count and Biomass			5 Locations[3]	Twice per month	Grab Sample	Model Verification	Top 5 m composite

Notes: 1. Sample every one meter in the top 30 meter water and every five meters for the rest water column.
2. Sample at Surface, Bottom, and every 10 meters in between.
3. SVA, SVC, SVG, SVH and SVN.

2.4 METEOROLOGICAL MONITORING

Monitoring meteorological data is commonly done by instruments that automatically measure and record the data at a pre-defined frequency. There is no difference between the "basic" and "optimal" plans for meteorological monitoring. Two meteorological stations are proposed for SVR: one on the east side of Lowell Island and the other on the west side of Lowell Island. This arrangement is suggested in order to capture the wind variation on the windward and leeward sides of the island. It is expected that the western station will provide more representative wind data when the wind is blowing from the west, and similarly when the wind is predominantly from the east.

Table 8. Meteorological Data – Basic and Optimal Plan

Parameter	Units	Preferred Detection Limit	Location	Frequency	Parameter Type	Purpose
Air Temperature	^oC	±0.10	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Barometric Pressure	mBar	±0.10	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Relative Humidity	%	±3%	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Wind Velocity	m/s	±3%	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Wind Direction	deg true	±3%	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Precipitation	Mm	±4%	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Solar Irradiance	w/m^2	±5%	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input
Photosynthetically active radiation	$Umol/s/\ m^2$	±5%	SVWX East, SVWX West	every 15 minutes	In-situ	Model Input

3. SPECIAL STUDIES

Section 2 discussed the ongoing data needs to help support the modeling effort, water treatability, and analysis of potential regulatory issues. In this section, we identify some short-term investigations that can enhance our understanding of various reservoir processes.

3.1 SUTHERLAND RESERVOIR WATER QUALITY

In Section 2, routine monitoring of San Vicente Creek, which transports water from Sutherland Reservoir into SVR, is discussed and outlined. Aside from routine monitoring of the creek, it is suggested that a special study be conducted to better identify the water quality in Sutherland Reservoir. In this study, monthly water quality samples will be performed for a period of 12 months. The parameters to be measured would include vertical profiles using a sonde (temperature, DO, pH, ORP, EC, specific conductance, and TDS). Furthermore, samples at three different elevations (surface, bottom, and at the outlet level) should be collected and analyzed for the parameters listed as "grab sample" in **Table 2** on monthly basis.; except that Chlorophyll *a* and Phycocyanin only need to be sampled in the top 5 m. The goal of such a study is to understand the reservoir's water quality over a yearly cycle, and to identify whether water transfer timing can be optimized to maximize water quality in SVR.

3.2 ALGAL DYNAMICS STUDIES

Laboratory and in-lake studies can provide valuable information for modeling algal dynamics. In particular, the in-situ determinations of nutrient uptake rates by algae, as well as the rate of algal growth, are important for accurate modeling of algal dynamics (Tietjen, 2011). It is suggested that a one-time study of algal growth dynamics be conducted to determine the main relationships between nutrient uptake and algal growth in the reservoir.

3.3 SEDIMENT OXYGEN DEMAND AND NUTRIENT RELEASE

Sediment oxygen demand is an important feature in determining water quality in SVR. As the sediments utilize oxygen in the hypolimnetic waters, the DO eventually gets depleted. After DO depletion, various nutrients are released from the sediments, and may contribute a significant source for subsequent algal growth. As a result, the determination of sediment oxygen demand as well as sediment nutrient release rates is important. Such a study was completed in the 1990s (Buetel, 2001, and Buetel, *et al*, 2007), but a similar follow up study is recommended after the reservoir expansion.

3.4 TRACER STUDIES OF PURIFIED WATER

If required for demonstration purposes, tracer studies can be conducted to demonstrate the fate, mixing, and dilution of the purified water inflow. These studies will be similar to the 1995 tracer studies that were performed wherein a tracer is injected in the inflow for a short duration (approximately 24 hours). The concentration of the tracer within the lake at various stations and depths would then be measured. From the results, the dilution of the tracer can be computed, as well as the residence time distribution. At least two such studies are envisioned: one during the stratified season (late spring or summer), and another during the winter turnover period, when the purified water is expected to rapidly mix within the reservoir.

4. DATA COMPILATION AND ANALYSIS

The purpose of this task is to gather all historical and future data, compile it into a database, and analyze the data with the purpose of discerning any trends. The following tasks are envisioned.

4.1 ANALYSIS OF PRE IPR/RA PROJECT DATA

This task assesses all water quality data gathered before the IPR/RA project is operational. As part of this task, all pertinent historical water quality data will be gathered and compiled in a suitable database. The database format should allow for easy manipulation of the data. After the database is established, it is recommended that a detailed data analysis be performed to include:

- An analysis of historical trends for all available inflow and in-reservoir water quality parameters, including temperature, TDS, nutrients, DO, and chlorophyll *a*. There should be a review of data integrity to include a data set clean up, if needed. Various data trends should be identified and examined. The analysis should include plotting parameters of concern and producing summary charts and tables that will help assess the reservoir water quality.
- A statistical analysis of various data to determine seasonal, yearly, and multi-year data trends. Identify any relationships between inflow and in-reservoir water quality trends. Determine the range of variation and identify the maximum, minimum and standard deviation of various water quality parameters, such as DO, chlorophyll *a*, Secchi depth, and temperature.
- A determination whether the statistics can indicate a shift in the reservoir's water quality between the old and expanded reservoir.
- Construction of a water and nutrient budget (phosphorus and nitrogen) on a yearly basis.
- Preparation of an extensive data analysis report.

4.2 YEARLY ANALYSIS OF POST IPR/RA PROJECT DATA

This task assesses water quality data gathered subsequent to the IPR/RA project becoming operational. It is suggested that, if the IPR/RA project is implemented in SVR, the various water quality data obtained under Sections 2 and 3 be appended to the data set on a yearly (or shorter time frame) basis. The data should be reviewed and any data integrity issues identified and corrected. On a yearly basis, it is expected that the following tasks would be performed.

- Analysis of all available inflow and in-reservoir water quality parameters, including temperature, TDS, nutrients, DO, and chlorophyll *a*. There should be a review of data integrity to include clean up of the data set if needed. Data trends should be identified and examined. The analysis should include plotting various water quality parameters and the production of summary charts and tables that will help assess the reservoir water quality.
- A statistical analysis of available data and a comparison of the particular year to the historical reservoir trend. Identify any relationships between inflow and in-reservoir water quality trends. Determine the range of variation and identify the maximum, minimum and standard deviation of various water quality parameters, such as DO, chlorophyll *a*, Secchi depth, temperature etc.
- A determination if statistics can indicate a shift in the reservoir's water quality between pre and post IPR/RA project.
- Construction of a yearly water and nutrient budget (phosphorus and nitrogen).
- A comparison of data to model predictions.
- A determination if model or data adjustments are needed to improve our reservoir understanding.

The expected layout of the table of contents of a typical yearly report would be as follows:

1. Introduction and purpose of monitoring
2. Summary of measured data
3. Overall assessment of data quality
4. Actions needed to correct or clean up data set
5. Detailed presentation of the data set (figures, tables, etc.)
6. Trend analysis of data set
7. Nutrient and water budget
8. Statistical parameters obtained from data set
9. Comparison of current data to data from previous years
10. Detailed comparison to model predictions
11. Recommendations for changes in future monitoring or modeling
12. Conclusions

5. REFERENCES

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FIGURES

Map of San Vicente Reservoir Monitoring Stations

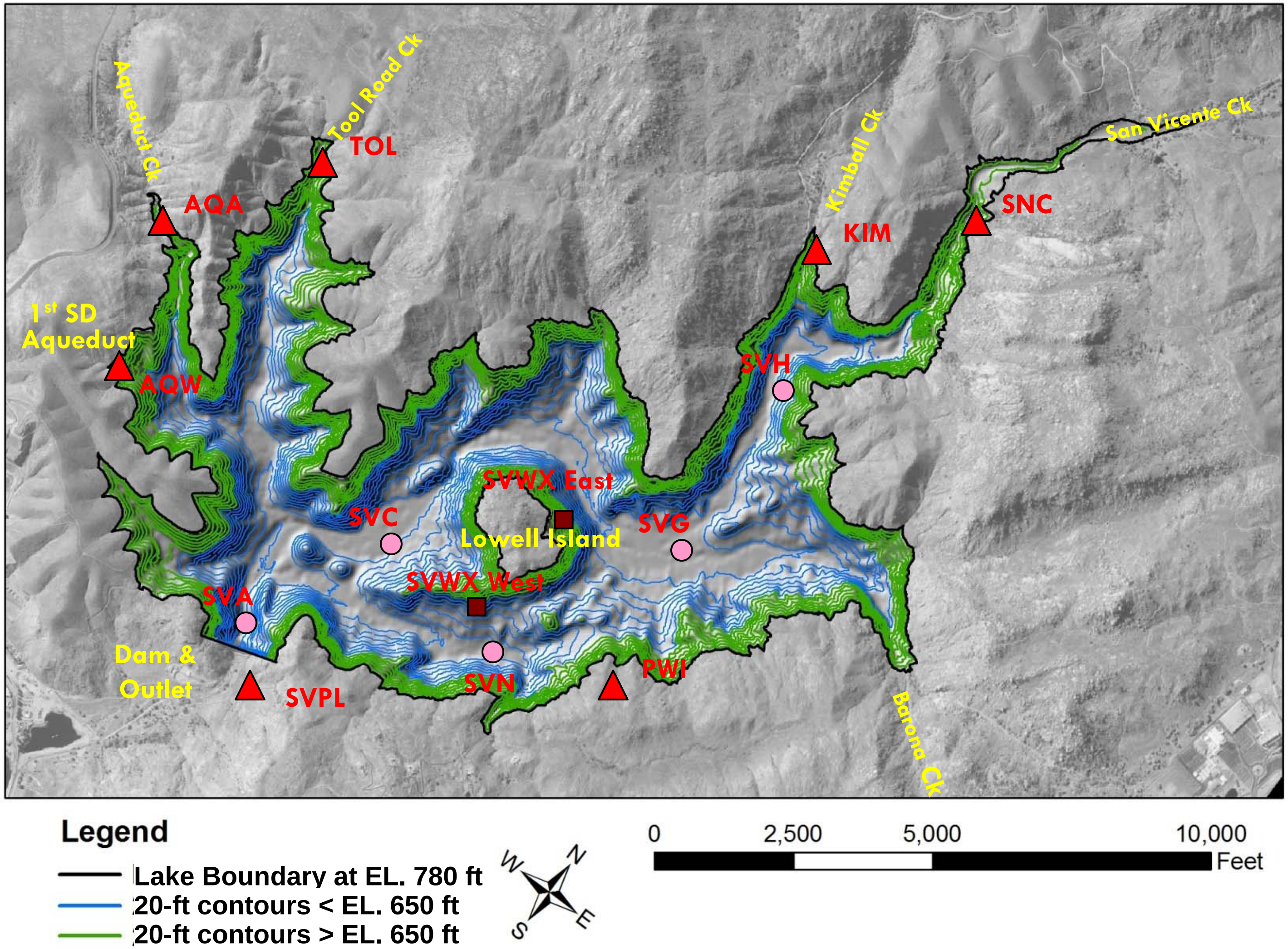

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Figure 1

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