Lake Hennessey and Milliken Reservoir Watershed Study

Hydrology and Water Quality Sampling and Analysis Plan

A Deliverable

to

Napa County and the City of Napa

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Introduction

The recently developed WARMF models for the Lake Hennessey and Milliken Reservoir watersheds will provide a useful tool for understanding and protecting the critical drinking water supply watersheds by informing management decisions. Development of the model is described in the Model Documentation Report for the Lake Hennessey and Milliken Reservoir Watershed Study, Systech Water Resources Inc., February 2019. There is still uncertainty associated with the WARMF simulation results for the Lake Hennessey and Milliken Reservoir models. The cumulative uncertainty is comprised of many individual components but is generally a combination of uncertainty in the water quality input data and uncertainty associated with the model calculations. Model uncertainty can be reduced significantly through calibration of simulation results to measured water quality and quantity data. In the case of the Lake Hennessey and Milliken Reservoir WARMF models, the limited measured data for key water quality parameters in tributaries limits the ability to accurately and precisely calibrate the models to the range of hydrologic conditions that may be present in these watersheds. This document describes a monitoring and analysis plan to gather data to inform and calibrate the WARMF models.

While the focus of this document is on water quality sampling design to facilitate watershed model calibration, there are many additional benefits of monitoring a water resource. Consistent and comparable water-quality monitoring data are needed for describing the status and trends of a water resource, preventing harm to a water resource through early change detection, determining compliance with health standards, predicting the effects of proposed projects or other changes, and documenting regulatory compliance. Regardless of the parameters included in a monitoring plan, it is essential that the plan is executed in a fashion that enables interested parties to use the data to support each of these initiatives. All water sampling and analyses is performed in accordance with EPA requirements for projects involving surface and groundwater monitoring and collection and analysis of water samples using ELAP-certified laboratories.

Recommendations for implementation of a water quality sampling strategy are divided into separate sections below: spatial considerations, temporal considerations, chemical parameters, and additional considerations. The recommendations are designed to provide sufficient information to inform management decisions, identify areas that may impact water quality with respect to drinking water treatment processes, address aesthetic impacts to customers and enforce state and federal drinking water regulations. The recommendations provided are also intended to acquire the data necessary to calibrate the WARMF models so that they can simulate nutrient dynamics with both accuracy and precision, thereby enabling watershed managers to use the models to monitor the state of the watersheds and determine how activities in the watershed will affect the quality of water in the reservoirs. Should there be additional reasons to collect water quality data other than those already stated in the above objective, then changes to the proposed strategy may be required. It is also important to note that the proposed strategy is intended to supplement, not replace, existing water quality monitoring within the watersheds. Data collected as part of this sampling plan should be stored in a publicly available database, along with other sources of water quality and hydrology information. Future efforts to calibrate the WARMF models will rely on all available data, including data collected in conjunction with development or other activities which require monitoring of aquatic resources.

Spatial Considerations

Lake Hennessey Watershed

The majority of locations where tributaries enter each of the lakes, referred to as lake loading sites, are established monitoring locations. In the Lake Hennessey watershed, five locations have been monitored previously (see Figure 1). These sites are labeled H4, H11, H16, H17, and H18 on Figure 1, and are well positioned to accurately account for the majority of flow and chemical constituent load to Lake Hennessey. Two additional lake loading sites are suggested: H5 and H6. If these two sites are added to the sampling network, they will complete the accounting of loading to the Lake. While these sites are important for calibrating the WARMF model, they do not provide information on loading sources within the watersheds.

Water quality in the tributaries upstream of the lake loading sites is currently not monitored. A number of monitoring locations are proposed so that watershed managers and modelers can begin to understand the effects of land use, soils, and other watershed characteristics on hydrology and water quality within the Lake Hennessey watershed. Land use distribution is illustrated in Figure 1 and tabulated in Table 1, and soil map units are displayed in Figure 2. Land use and soil characteristics are typically the dominant drivers of stream hydrology and water quality, so both are used to inform the location of sampling sites. An attempt is made to select sampling locations that delineate areas of uniform land use and/or soil characteristics so that the influence of these characteristics on hydrology and water quality can be directly evaluated. It is important to note that many of the suggested sampling sites are located on private property and permission to access the sites will need to be arranged prior to finalizing the monitoring plan. The plan includes some redundancy in site selection (e.g. multiple sites with similar characteristics) so that if it is not possible to access a site or two, data collected at the remaining sites will be sufficient to define the relationships between watershed characteristics and hydrology/water quality. Once defined, these relationships can be used to improve the accuracy of, and confidence in the calibration of the WARMF models.

Three additional sites are proposed for the Conn Creek watershed: H1, H2, and H3. It is recommended to establish a water quality monitoring site, H1, on Conn Creek at Howell Mountain Road downstream of the town of Angwin. The contributing area upstream of this site (Figure 1) contains the only developed/commercial property in the watershed. Obtaining information on the water quality downstream of these land uses would aid in calibration of simulated hydrologic and chemical processes associated with septic systems, the land discharge from the Pacific Union College wastewater treatment plant, and the developed land use class in general (Table 1 provides a breakdown of land use upstream of each of the proposed sampling locations). H2 is proposed because the contributing area contains many vineyards, and H3 would provide useful information on the response of native vegetation to precipitation.

Four new sites are proposed within the Chiles Creek watershed. One sampling site (H9) should be added on Moore Creek upstream of the confluence with Chiles Creek, and one added on Chiles Creek, just upstream of the confluence with Moore Creek (H10). Adding these two locations would provide additional information for model calibration since Moore Creek is a relatively large watershed comprised predominantly of forest and scrub, while Chiles Creek drains an area with vineyards in the headwaters. Two sites, H7 and H8, are proposed to characterize hydrology and water quality originating from the vineyards located in the Chiles Creek headwaters. These sites are also characterized by different soils than downstream sites, so sampling at these locations will provide additional information on the influence of these soils on hydrology and water quality.

Four new sites are proposed within the Sage Creek watershed. Information on watershed response to different land use classes and soil type could be generated by establishing water quality sampling locations on Sage Creek upstream of the unnamed tributary which drains Fir Canyon (“Fir Canyon Creek”), and on Fir Canyon Creek upstream of the confluence with Sage Creek (sites H14 and H15). These two drainage areas also have very different land use composition, and monitoring both would enable modelers to refine the coefficients associated with the different land use classes. The Sage Creek watershed is somewhat similar in structure to the Chiles Creek watershed, in that intensive vineyard development has occurred in the headwaters. Sites H12 and H13 are proposed to monitor the effects of vineyard development on hydrology and water quality. Similar to sites H7 and H8, sites H12 and H13 drain a soil type that is different from the surrounding catchments.

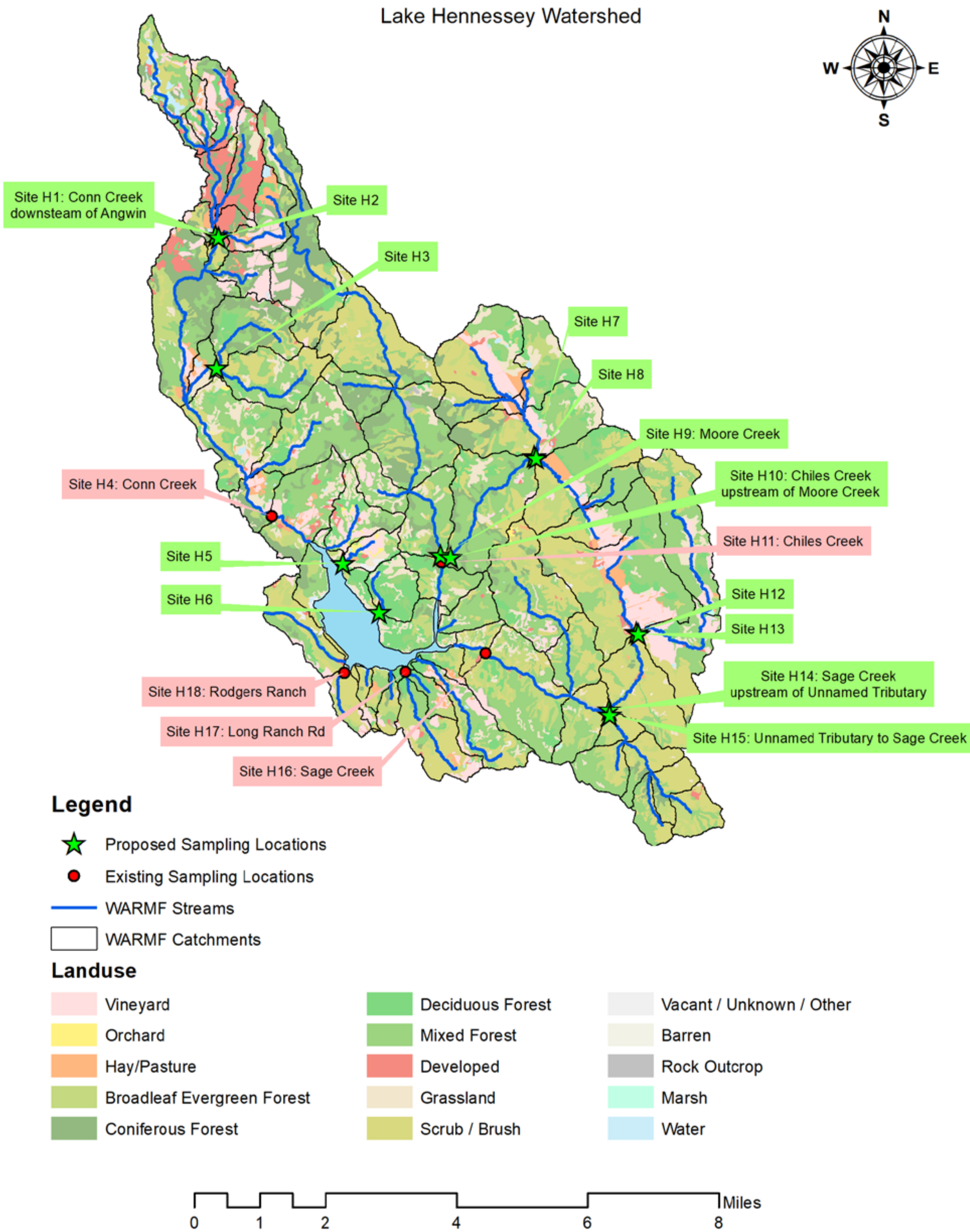

Figure 1 Existing and proposed water quality sampling locations within the Lake Hennessey watershed

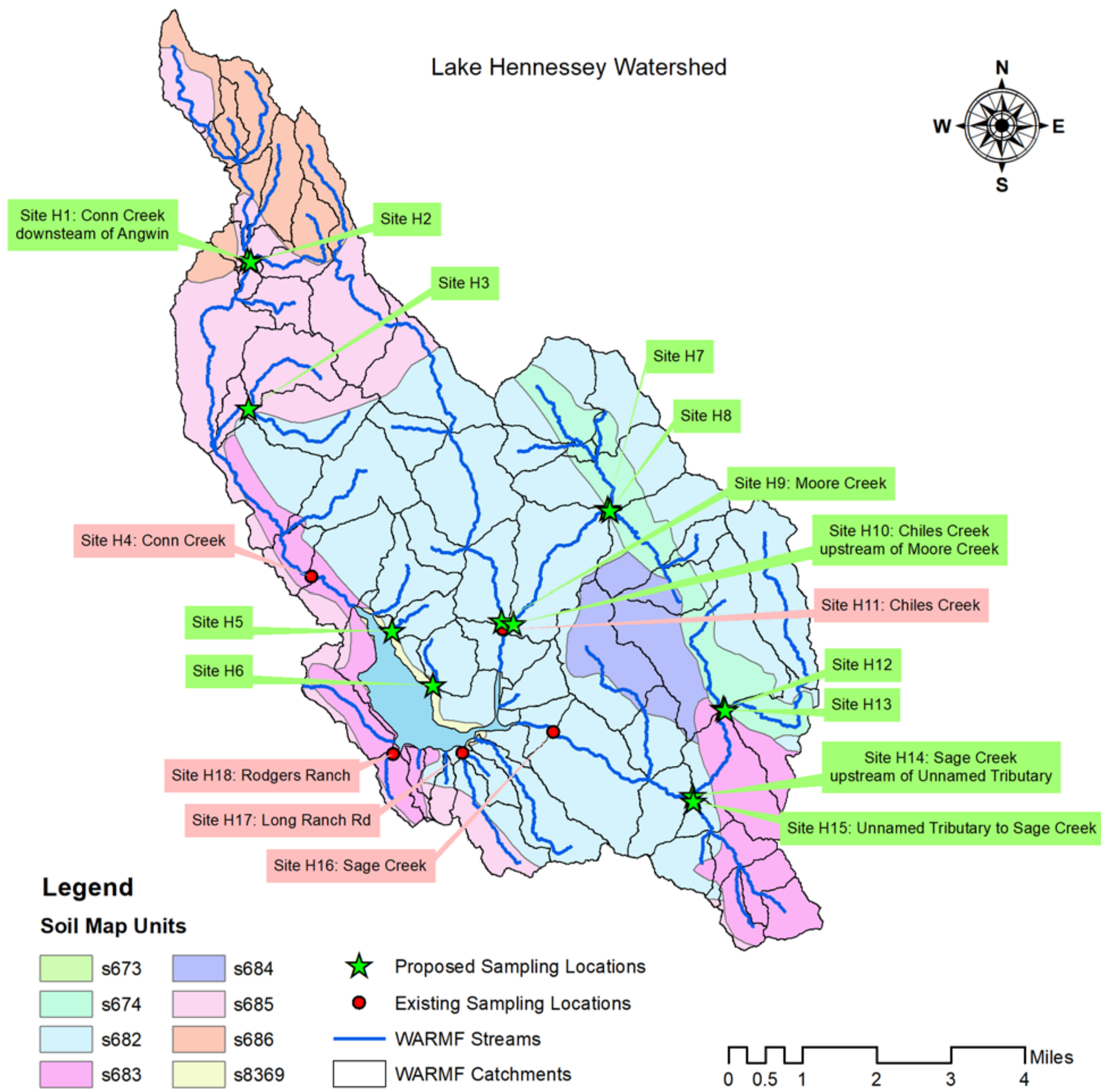

Figure 2 Soil map units located within the Lake Hennessey watershed

Table 1 Drainage area and land use characteristics for Lake Hennessey watersheds upstream of proposed water quality sampling locations

	Watershed Area (Acres)	Forest	Developed	Grassland /Hay /Pasture	Orchard	Scrub/Brush	Vineyard	Water/Marsh	Vacant /Unknown /Other
H1	2,089	39%	26%	8%	0%	8%	15%	4%	0%
H2	476	43%	6%	20%	0%	1%	27%	4%	0%
H3	675	79%	1%	3%	0%	14%	3%	0%	0%
H4	7,872	59%	9%	11%	0%	9%	10%	2%	0%
H5	225	31%	2%	29%	11%	0%	25%	2%	8%
H6	369	76%	0%	23%	0%	1%	0%	0%	0%
H7	2,715	55%	1%	16%	0%	18%	10%	1%	0%
H8	1,521	55%	1%	8%	0%	24%	11%	0%	0%
H9	4,496	68%	0%	8%	0%	21%	3%	0%	1%
H10	5,403	60%	1%	12%	0%	19%	9%	0%	0%
H11	9,929	63%	1%	10%	0%	20%	6%	0%	0%
H12	1,867	55%	2%	7%	0%	20%	15%	1%	0%
H13	1,635	47%	0%	8%	0%	27%	16%	1%	0%
H14	4,338	46%	1%	7%	0%	32%	13%	1%	0%
H15	1,562	53%	1%	1%	0%	45%	0%	0%	0%
H16	8,988	54%	1%	5%	0%	32%	8%	0%	0%
H17	626	41%	2%	3%	0%	39%	14%	0%	0%
H18	234	18%	1%	0%	0%	65%	16%	0%	0%

Milliken Reservoir Watershed

There is very little water quality information available to aid in WARMF model calibration in the Milliken Creek watershed. The two sites that have been established (Site M2: Walt Ranch upstream and Site M3: Walt Ranch downstream) were established to evaluate the effects of a specific contributing area on water quality, but do not provide enough data to accurately calibrate a watershed model. The establishment of additional sites would provide useful information. The location of proposed sites is provided in Figure 3. A site located approximately one quarter mile upstream of where Atlas Peak Road crosses Milliken Creek (site M1) would be useful because the site characterizes a drainage area with extensive longstanding and established vineyard development. The Walt Ranch Upstream site (site M2) is useful coupled with M1 because it will show water quality upstream and downstream of a project prior to and after land use changes are implemented. There is a tributary entering Milliken Creek from the north that drains a forested/grasslands region which has different characteristics than the agricultural portion of the Milliken Creek watershed that is located upstream from this tributary (satellite imagery shows this tributary as an intermittent stream channel, entering Milliken Creek approximately one quarter mile upstream of Atlas Peak Road).

There are four additional sites proposed. Similar to the process employed to select sites in the Lake Hennessey watershed, sites in the Milliken Reservoir watershed were selected to characterize the variability found in both land use (Figure 3) and soils characteristics (Figure 4). These sites are all located downstream of Walt Ranch (site M3), and include:

- Site M4: unnamed tributary to Milliken Creek, selected because the contributing area is representative of natural ground cover (Figure 3, Table 2). Also selected because the soils in the watershed are different from other sampling locations (Figure 4).
- Site M5: unnamed tributary to Milliken Creek, proposed because the creek drains a subbasin that is small but has a high percentage of developed land immediately adjacent to the stream channel (Table 2)
- Site M6: Milliken Creek immediately upstream of the reservoir, proposed because it characterizes the contribution of Milliken Creek discharge and water chemistry to Milliken Reservoir
- Site M7 – Unnamed tributary to Milliken Reservoir, proposed because this is the second largest watershed draining into Milliken Reservoir and is a potentially significant source of discharge and chemical load to the reservoir.

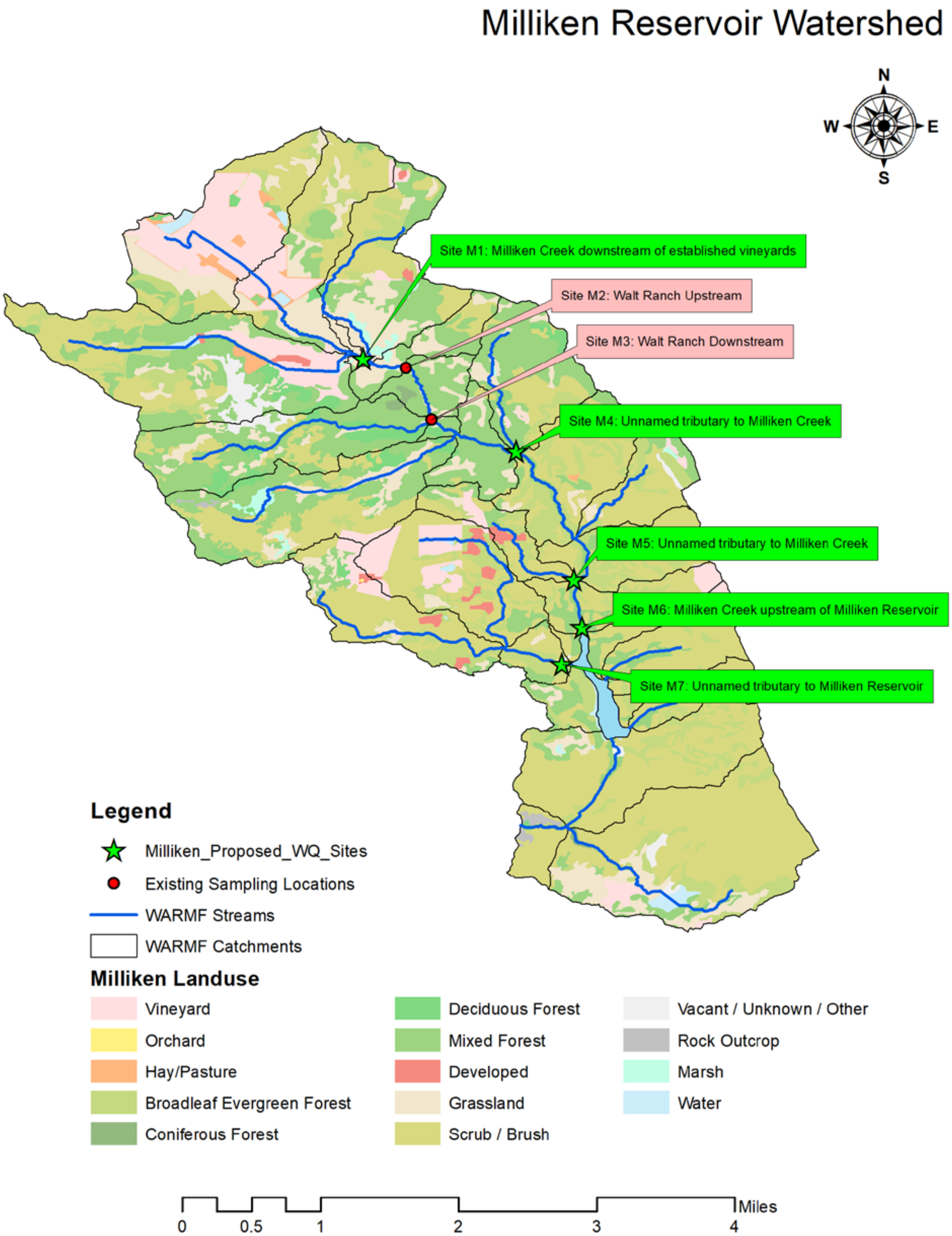

Figure 3 Existing and proposed water quality sampling locations within the Milliken Reservoir watershed

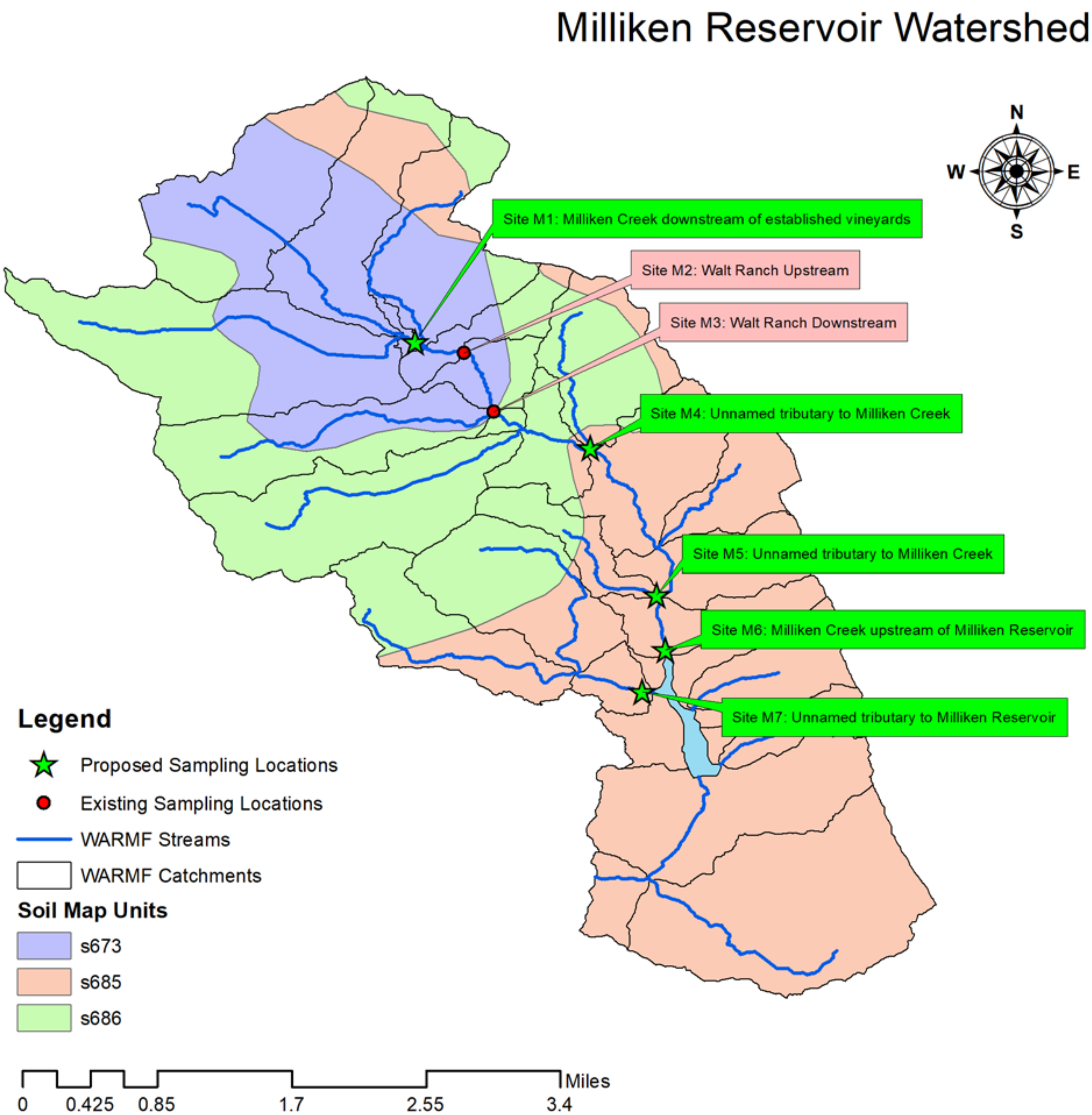

Figure 4 Soil map units located within the Milliken Reservoir watershed

Table 2 Drainage area and land use characteristics for Milliken Reservoir watersheds upstream of proposed water quality sampling locations

	Watershed Area (Acres)	Forest	Developed	Grassland /Hay /Pasture	Scrub/Brush	Vineyard	Water/Marsh	Vacant /Unknown /Other
M1	1,630	30%	1%	16%	26%	23%	2%	3%
M2	2,160	33%	1%	19%	26%	18%	2%	2%
M3	2,271	35%	1%	19%	24%	17%	2%	2%
M4	304	67%	0%	9%	23%	1%	0%	0%
M5	137	36%	7%	3%	45%	9%	0%	0%
M6	4,712	45%	0%	13%	30%	9%	1%	2%
M7	758	28%	4%	5%	47%	15%	1%	0%

Temporal Considerations

A review of existing water quality and hydrology data indicates that the water quality samples that have been collected only represent a relatively narrow segment of the hydrologic conditions that occur in these watersheds. A water quality sampling strategy should be designed to determine the quality of surface waters across the entire range of river discharge experienced in the Lake Hennessey and Milliken Reservoir watersheds. Higher flow conditions are particularly important to monitor since that is when the vast majority of storage water enters Lake Hennessey and Milliken Reservoir. Water quality sampling plans are also designed to address specific questions, and Napa County personnel have indicated that the following are important considerations for sampling design:

- Is the water of acceptable quality for drinking after existing treatment processes (conventional treatment for Lake Hennessey and direct filtration for Milliken Reservoir?)
- Is water quality getting better or worse?
- What is causing the pollution or deterioration of a given lake or stream?

Answers to each of these questions are influenced by the timing of and trends in water quality.

To adequately characterize the quality of water flowing into Lake Hennessey and Milliken Reservoir, samples should be collected at regular intervals throughout the year at each of the locations illustrated in Figure 1 and Figure 3. Ideally, samples would be collected every two weeks during the winter months and through early summer when the creeks are contributing flow to the reservoirs for the first several years (exact length of time is dependent upon data variability) to determine the extent to which concentration of the selected parameters varies with discharge and with season. Additionally, more frequent sampling is likely warranted to capture effects of episodic events such as agricultural fertilizer, pesticide or herbicide application, wildfires, illegal spills or dumping, floods, timber removal, pond draining and agricultural crop harvest. It also provides a better indication of ongoing sources of potential contamination, such as livestock, recreational users, wildlife, and wastewater leach fields.

Storm event sampling should be incorporated into the sampling strategy to characterize the transport of chemical constituents during precipitation events. Collecting samples at regular intervals as streams rise then recede from precipitation events is useful for WARMF model calibration because the chemical signature of water during precipitation events can be used to calibrate overland flow, soil erosion, soil hydrology, and soil pore water chemistry parameters. Storm event sampling could be conducted during a small number of storms (1-3) to start, then expanded if there is significant variability in the data obtained. At a minimum, the proposed sampling locations should include those shown on Figure 2 upstream of Milliken Reservoir and Figure 1 for tributaries that feed Lake Hennessey. The plan includes areas that are already under the influence of land use changes as well as areas, to the extent possible, that are in a natural state. Storm event sampling will be expanded to progress upstream in a sub-basin if results identify water quality concerns.

The most expedient and accurate way to populate and facilitate calibration of the model's water quality predictive capabilities is to sample and analyze sites that represent land use changes. Proposed sample sites recommended based on tributary flow in sub-basins may be physically challenging to access, therefore proposed project sites may be the best to facilitate access to waterways. The City, County and private landowners should work together to facilitate access to sample points, sampling and analyses of water quality data, and use the results to ensure the accuracy and value of the WARMF model.

Chemical Parameters

Table 3 includes a recommended list of core hydrology and water quality parameters that are commonly measured to evaluate waters facing potential degradation. Collection of these data over a period of several years will facilitate improved calibration of the WARMF models for the Lake Hennessey and Milliken Reservoir watersheds.

Table 3 Recommended water quality sampling constituents for the Lake Hennessey and Milliken Reservoir watersheds

Field Measurements	Laboratory Analyses
Stream discharge	Total Kjeldahl nitrogen (organic N + ammonia + ammonium)
Water temperature	Soluble Kjeldahl nitrogen
Air temperature	Nitrate + nitrite
Specific conductance	Ammonia, Ammonium
Dissolved Oxygen	Total phosphorus
pH	Total soluble phosphorus
Turbidity	
	Orthophosphate
	Total organic carbon
	Dissolved organic carbon
	Chlorophyll a
	Total suspended solids
	Total dissolved solids
	Total volatile suspended solids
	Carbonaceous biochemical oxygen demand (CBOD5)
	Sulfate
	Chloride
	Total hardness
	Alkalinity
	Fecal coliform/*E.coli*
	Calcium
	Pesticides and Herbicides (i.e. simazine, di(2-ethylhexylphthalate) (DEHP)

The estimated costs associated with analyzing water quality samples for the constituents listed in Table 3 are provided in Table 5. The estimated cost accounts for laboratory analysis only. The labor costs associated with collection and delivery of samples are not included in this estimate, and can be a significant portion of the overall sampling budget.

Monitoring Priority

This document provides guidance on how to monitor the inflows to Lake Hennessey and Milliken Reservoir to provide a robust set of data for watershed modeling and to provide documentation of degradation of reservoir water quality over time. Given that resources are limited, below in Table 4 are suggested priorities for sampling locations to provide the greatest possible benefit.

Table 4 Prioritized Recommended Water Quality Sampling Sites

	Lake Hennessey Watershed	Milliken Reservoir Watershed
First Priority	• Lake loading sites: H4, H5, H6, H11, H16, H17, H18 • H1 • H2 • H3 • H7 & H8, *or H12 & H13* • H9 & H10, *or H14 & H15*	• M1 • M2 R • M3 R • M4 R • M5 R • M6 • M7 R
Second Priority	• *H7 & H8, or* H12 & H13 • *H9 & H10,* or H14 & H15	

R = Reduced frequency of sampling. Early season, peak storm & late season only.

There is some redundancy built into the proposed sampling strategy. Sampling all locations will provide a very complete dataset, which would be ideal for model calibration. If budget constraints and/or landowner access permission prevent the full implementation of the plan, sites listed as second priority can be omitted as necessary. In the lake Hennessey watershed, lake loading sites should be considered the top priority, followed by site H1, which characterizes hydrology and water quality downstream of Angwin. Sites H2 is valuable because it will represent data gathered before and after proposed land use changes. Site H3 represents soil type similar to that found in the Angwin region however the land is relatively undeveloped. Sites H7 and H8 will provide similar information as sites H12 and H13, so one of these pairs could be omitted if necessary. Sites H9 and H10 are very similar to sites H14 and H15, so again, one of these pairs could be omitted.

In the Milliken Reservoir watershed, site M1 characterizes hydrology and water quality characteristics originating from an area of intense vineyard development. Sites M4, M5, and M7 provide useful information on other land use configurations, and site M6 quantifies hydrology and chemical loading to the lake. These sites are the top priority for sampling. Sites M2 and M3 are valuable because they will represent data gathered before and after proposed land use changes. The sites are being evaluated by the Walt Ranch Project although the list of constituents being analyzed is less extensive than the list defined in this report.

It is recommended that all the constituents listed in Table 3 be sampled together to get a complete analysis of pollutant loading. While stream sampling every two weeks is recommended, more frequent sampling is recommended during the wet season, November – May. This will provide higher resolution data when flow is highly variable and most of the loading is entering the reservoirs. Stream sampling may be done monthly during the dry season or skipped if there is no flow at the sampling sites. Storm event sampling should be done at regular intervals during at least three precipitation events to calibrate the WARMF model simulation of pollutant loading under high flow conditions. ISCO samplers or similar equipment can be used to automatically collect and preserve the samples, which can then be sent off for analysis. Ideally, the storms that are sampled will be at different times of the year, and the program will be expanded to acquire additional data if there is substantial water quality variability between storm events. Reservoir sampling should be conducted throughout the year, as different processes dominate during high flow and low flow regimes (e.g. algae blooms are more likely during low flow, while nutrient concentrations may be higher following precipitation events). As a cost savings measure, the higher cost analyses for pesticides and herbicides could be reduced to monthly instead of every two weeks at the beginning of the program. The analyses can be refined to correspond with data reported to the Agricultural Commissioner such that seasonal application of the fertilizers, pesticides and herbicides take into consideration runoff and the potential for transport whether that is first flush after the dry season, midwinter storms, or spring flows. The monitoring plan should include an adaptive process to evaluate the value of the data collected and refine the locations and frequency of sampling.

Cost of Analyses

Table 5 Estimated Cost of Laboratory Analysis

Laboratory Analyses	Cost (USD/Sample)
Dissolved oxygen	Field measurement
pH	Field measurement
Turbidity	$28.00
Specific conductance	$32.00
Total Kjeldahl nitrogen (organic N + ammonia + ammonium)	$ 50.00
Soluble Kjeldahl nitrogen	$ 50.00
Nitrate + nitrite	$ 50.00
Ammonia, Ammonium	$ 42.00
Total phosphorus	$ 50.00
Total soluble phosphorus	$ 50.00
Orthophosphate	$ 50.00
Total organic carbon	$ 50.00
Dissolved organic carbon	$ 50.00
Total suspended solids	$ 42.00
Total dissolved solids	$ 42.00
Total volatile suspended solids	$ 45.00
Carbonaceous biochemical oxygen demand (CBOD5)	$ 75.00
Sulfate	$ 42.00
Chloride	$ 42.00
Total hardness	$ 35.00
Alkalinity	$ 35.00
Fecal coliform/*E.coli*	$ 60.00
Calcium	$ 42.00
Pesticides and Herbicides	$ 525.00
Total:	$1,487.00

The total expense associated with analysis of one water sample for all parameters listed in Table 5 is $1,487. If all of the proposed water quality sampling locations are sampled (25 sites, 18 in the Lake Hennessey watershed and 7 in the Milliken Reservoir watershed), total analysis cost per sampling event is $37,175. If each site is sampled bimonthly or every two weeks, as originally recommended to quickly populate the model and capture variances in water quality throughout the season, annual expenses for laboratory analysis will be $527,885. Annual costs will be higher when the expenses associated with sample collection and transport are incorporated. This estimate is shown in Table 6, Option A.

In an effort to contain costs and in recognition that the monitoring and analyses program will be adapted (increased or decreased) over time based on the results, a subset for the initial monitoring plan is described in Table 6: Option B. Option B includes monthly monitoring during the winter months at representative 14 sites including H7 & H8 as well as H9 & H10 on Chiles Creek. The representative sites H12 & H13 as well as H14 & H15 have similar variables to the aforementioned sites but are located on Sage Creek so they will be added in the future if warranted based on data-centric plan revisions. The total analysis cost per sampling event is $31,227. Due to the reduced number of sites and frequency (monthly instead of the recommended bimonthly) the total annual cost for Option B is $260,225.

In Milliken watershed, both options allow for reduced monitoring of sites that are between the highest and lowest points in Milliken Creek. Sites M2, M3, M4, M5 and M7 are proposed to start as reduced frequency of monitoring. These samples are located downstream and upstream of full sampling sites, therefore they could be sampled early in the rainy season, within 48 hours of a peak storm and at the end of the rainy season. Depending on the first few years of data, the frequency of these sites may be increased to match the other sampling sites.

Table 6 Estimated Cost of Analyses for a Monitoring Event

Option A: Bi-monthly Analyses during the winter months.

	No. of Sites	Cost of Analysis per Site	Cost per Sampling Event	Frequency of Analyses per Year Bi-Monthly Nov-May	Frequency of Analyses During Storms	Total
Hennessey	18	$1487	$26,766	14	3	$455,022
Milliken	2	$1487	$2,974	14	3	$50,558
Milliken *Reduced*	5	$1487	$7,435	2	1	$22,305
					Subtotal:	**$527,885**

Option B:

	No. of Sites	Cost of Analysis per Site	Cost per Sampling Event	Frequency of Analyses per Year Monthly Nov-May	Frequency of Analyses During Storms	Total
Hennessey	14	$1487	$20,818	7	3	$208,180
Milliken	2	$1487	$2,974	7	3	$29,740
Milliken *Reduced*	5	$1487	$7,435	2	1	$22,305
					Subtotal:	**$260,225**

Due to the expense associated with water quality analysis, the proposed sampling plan should be evaluated under an adaptive management framework. Location and frequency of sampling can and should be adjusted based on review of initial sampling results. For example, if an analyte shows very little variability over a range of hydrologic conditions, the frequency with which that analyte is measured can be decreased. It is also reasonable to consider that not all chemical constituents need to be analyzed at all locations. For example, if there is no potential source of pesticides or herbicides in the watershed upstream of a sampling location, that analyte may be removed from the list of analyses to conduct for that location, or the frequency with which the analyte is measured can be reduced. The analyte can be reincorporated back into the sampling design if conditions in the watershed change.

Additional Considerations

The WARMF watershed models of the Lake Hennessey and Milliken Reservoir watersheds were constructed so that resource managers would have tools at their disposal to evaluate the effects of land management decisions on local water resources. The models are capable of simulating water quality and hydrology in the watersheds upstream of Lake Hennessey and Milliken reservoir. The calibration of these models could be extended in the future to provide the capability to investigate how watershed condition affects water quality in the reservoirs. If resource managers are interested in simulating reservoir processes, the water quality sampling should be expanded to include sampling within the lakes for the same parameters. Lake sampling is time consuming and expensive, so samples can be collected less frequently than river samples. Monthly sampling over several years would yield valuable information. Reservoir simulation would require water quality data collected both at the surface and at depth. Vertical profiles of temperature and dissolved oxygen, which the City has actively collected for over two decades within Lake Hennessey, are key needs to calibrate a model which simulates the stratification of the reservoirs. Because of seasonal taste and/or odor events within Lake Hennessey, the City analyzes surface water samples for algae identification to assist with water treatment operations. To confirm taste and/or odor events in the source water, Geosmin and 2-MIB methyl isoborneol (MIB) sampling is performed monthly. It is also important to consider that reservoirs may be threatened by eutrophication as existing data trends indicate. Source water management is critical for the City to ensure high drinking water quality, manage the aesthetics of the water and to maintain public trust. If the reservoirs become eutrophic in the future, having historical water quality data that illustrates the relationship between the watershed nutrient load and reservoir chlorophyll-a concentrations would be valuable from both a modeling and a regulatory perspective.

Reservoir water quality is largely dependent upon the load of pollutants that enters the reservoir from upstream. The water quality sampling recommendations provide only a portion of the information needed to estimate loading; continuous flow monitoring is also required. Stream gages are operational in the Lake Hennessey watershed, and these gages facilitated hydrology calibration of the WARMF model. However, these gages are designed for measuring base flow and are not accurate at high flow. This situation deserves attention and resources since, from a loading perspective, it is possible for the majority of pollutant load to enter Lake Hennessey during only a handful of extreme events. If improvements to the discharge monitoring are not made it will be more difficult to accurately assess the extent of pollutant loading to the reservoir during these peak events.

In the Milliken Reservoir watershed, accurate flow gages are challenging due to the inconsistent formations and steep channels. There is a gage on Milliken Creek at the reservoir for which data was reported in real-time to napa.onerain.com. This gage only measures depth though – a rating curve, which relates depth to stream discharge, would make the gage much more useful for modeling. The available operations data for Milliken Reservoir includes inflow, reservoir elevation, dam spill, and diversion flow. The data was often inaccurate or incomplete at very high flows and very low flows. To address this issue synthesized total outflow was generated as an input to the WARMF model. Establishing a reliable stream discharge gage on Milliken creek upstream of the reservoir and complete records of discharge from the dam would be extremely helpful for both WARMF hydrology calibration and the quantification of pollutant loads entering and leaving the reservoir.

Recommendations

The goals set out in this effort are to create the WARMF model to understand the status and trends of water quality associated with Lake Hennessey and Milliken Reservoir watersheds, define and predict the spatial and temporal effects of land use changes, and inform land use decisions in the municipal watersheds. To meet these goals and ensure short and long-term protection of water quality in the municipal watersheds, it is recommended that at minimum, the sampling and analyses within the Lake Hennessey and Milliken Watersheds be implemented as defined in Option B. The proposed sample sites must be field-verified to ensure safe and consistent accessibility. City and County staff shall work with adjacent landowners, where applicable to ensure accessibility. Field monitoring instruments that log data real-time shall be considered to gather data for parameters for which the instrumentation is available and feasible. This needs to be considered on a site by site basis since securing and maintaining instruments can be a challenge under high flow conditions. If feasible, the initial costs will be higher, but instrumentation can be less costly in the long term. Currently instruments that log conductivity, turbidity, temperature, pH, nitrate, ammonia and dissolved oxygen are available for purchase. Annual data shall be assessed to determine the effectiveness of the monitoring and analysis program. As data trends are developed, adjustments shall be made to increase or decrease the number of sample sites as well as modify the location and/or frequency of sampling. Over time, the data and calibrated WARMF model will simulate nutrient dynamics with both accuracy and precision, thereby enabling watershed managers to monitor the state of the watersheds and determine how existing and proposed activities in the watershed might affect the quality of water in the reservoirs. This information will inform decisions for land use and associated requirements for land use to ensure drinking water quality protection.