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TECHNICAL MEMORANDUM

TO: Tessa Brinkman – Rise Grass Valley Inc. 4091-19
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DATE: 24 February 2020

SUBJECT: Desktop Study of Cemented Paste Backfill

INTRODUCTION

Rise Grass Valley Inc. (Rise) owns the Idaho-Maryland Mine (IMM), a past producing gold mine that was shut down during World War II. Rise is currently working with regulators to permit the restart of operations at the IMM. Rise has tasked Itasca Denver, Inc. (Itasca) with conducting a desktop study of cemented paste backfill (CPB) use and its potential impacts on water quality, and site-specific considerations for IMM.

CEMENTED PASTE BACKFILL OVERVIEW

Backfill methods are typically employed in mining to improve geotechnical stability by backfilling mined stopes (voids) and allow the recovery of the ore body to be maximized. CPB has several important advantages over surface disposal and other methods of mine backfilling, such as hydraulic and uncemented fills, as discussed in the following section.

CPB typically consists of tailings mixed with cement and water, although other additives or mined materials are sometimes included. The relative proportions of these components and the particle-size distributions are selected such that the mixture is dense, viscous, and does not segregate into separate liquid and solid fractions when it is transported (Verburg 2001). Typically, this requires a solids content of approximately 70% to 85% and a significant fine particle-size fraction (e.g., Potvin et al. 2005 and Zhao et al. 2019). CPB is generally formulated on the surface and delivered by pumping to where it is needed within the mine.

BENEFITS OF TAILINGS DISPOSAL BY CPB

The proper use of CPB has been documented to provide a variety of benefits relative to other tailings disposal methods such as hydraulic fill and uncemented fills (e.g., Levens et al. 1996;

Verburg 2001; MEND 2006; Schafer 2016). Some of the most significant benefits include the following:

- The introduction of neutralizing potential from the cement binder material, which can offset acid generation from sulfidic tailings materials and mine wall rock,
- The reduction of surface impacts and the total surface footprint relative to surface tailings storage facilities,
- Enhanced strength relative to uncemented backfill or conventional hydraulic fill (with or without cement),
- The reduction of the porosity and permeability of the tailings material relative to hydraulic fill, uncemented fill or no fill,
- The reduction in solute loading from the CPB relative to hydraulic fill or uncemented fill because solute transport in the low permeability CPB is limited by diffusion,
- Maximized recovery and reuse of process water, and
- Elimination of bleed water from placed backfill because of the non-draining nature of CPB.

Properly prepared CPB uses some water for cement hydration and retains the remaining water within its matrix. Being non-draining, CPB does not separate during transport or curing, does not generate high pressure on bulkheads, and does not create underground mine water handling related problems (Potvin et al. 2005).

Importantly, CPB typically reduces the mobility of chemical constituents and has additional neutralization capacity compared to uncemented tailings. During the cement hydration process, calcium silicate hydrates form, and subsequently fill pore space, which creates adherence between particles. The associated reduction in porosity and permeability results in increased retention of water and reduced permeability to air (Levens et al. 1996; Schafer 2014). The lower air permeability results in lower rates of sulfide oxidation. Because sulfide oxidation is the primary source of acidity from mined materials, lower rates of sulfide oxidation result in reduced releases of acidity and other solutes, such as metals, which tend to be much more soluble under acidic conditions (Levens et al. 1996). Additionally, sulfide oxidation and solute release reactions occur on the surface interface of minerals, so the reduction of mineral surface areas that are exposed to air and water also helps to reduce solute releases compared to unamended tailings. Previous geochemical testing on CPB samples from Leeville Mine in northern Nevada showed that metal release from intact CPB samples was controlled by diffusion, a much slower mechanism for solute transport than advection (Schafer 2014).

POTENTIAL WATER-QUALITY ISSUES WITH CPB

There are some potential water-quality related issues with CPB if it is not implemented correctly. Negative water-quality impacts from CPB are generally related to the specific composition of the tailings materials used in the CPB and/or to CPB that does not set properly or is not strong enough

to remain intact in the mine environment. A variety of site-specific factors can affect the ability of CPB to set and its long-term strength. For example, insufficient binder content, excessive water content, or water with high sulfate concentrations (e.g., from high-sulfide tailings) can decrease CPB strength or inhibit proper setting. If CPB does not set properly, it may be less effective at reducing the mobility of chemical constituents, and there is the potential for the binder material to be leached from the CPB mixture. Additionally, high sulfide-content tailings that are acid generating and have elevated metals concentrations can result in metals leaching from CPB and can degrade CPB strength.

Because cements and grouts are alkaline in nature, some studies have noted that the potential exists for these materials to preferentially leach from CPB and cause elevated pH values in groundwater and/or release constituents from the cement or other additives (MEND 2006). This could potentially increase the mobility of some constituents relative to circumneutral conditions. However, the exterior portion of CPB material typically undergoes carbonation reactions that adsorb atmospheric carbon dioxide to form calcite and replace calcium-silicate hydrates (Schafer 2014). The release of alkalinity and other constituents from CPB is generally limited by diffusion because of the low permeability of the CPB and the accumulation of these less reactive minerals on the outer CPB surface. For these reasons, leach tests for diffusive release that utilize intact CPB, rather than crushed samples, provide the most realistic measure of the release of alkalinity and other constituents from CPB (Schafer 2016). These tests typically indicate that cured CPB is not likely to result in notably elevated downgradient groundwater pH values.

The presence of chromium in cement has been identified as a potential water-quality concern related to the use of CPB (Hamberg et al. 2018). Hexavalent chromium (Cr[VI]) is an oxidized form of chromium that is more soluble and mobile in the environment than reduced forms of chromium. Notably less Cr(VI) leaches from cured cement than from unhydrated cement; Estokova et al. (2018) demonstrated that less than 0.5% of total chromium leached from a range of cured cement composites compared to 0.8% to 1.8% of total chromium from the Portland cement binder itself. Thus, selecting a supplier with low Cr(VI) content cement and ensuring the CPB is not inundated before it sets can minimize the potential for issues with Cr(VI) leaching.

IMM CPB PLAN

Itasca understands that Rise is evaluating the engineering and economic aspects associated with key factors of their ultimate CPB mixture. Rise has indicated that they plan to use a mixture that contains 15% water by weight and to use tailings with a particle-size distribution that is similar to the one used historically at the IMM, in which approximately 11% of the material passed a 44-micron screen. At this time, the cemented backfill material to be used in the IMM is anticipated to have rheological and hydrological characteristics that are suitable for typical use as CPB.

The process Rise plans for handling mined material and processing ore is outlined in Figure 1. The mined material will be separated into ore and waste rock. The ore will be crushed and then will undergo gravity separation to remove particulate gold. The gravity separation will yield fine-

grained ore material called cleaner concentrate, intermediate grain size tailings called middlings or cleaner tailings, and tailings of a larger grain size called rougher tailings (Figure 1). The cleaner tailings and rougher tailings then both undergo bulk sulfide flotation. The bulk sulfide flotation process is designed to separate the gold and associated sulfides from the rest of the tailing materials. The bulk sulfide flotation yields rougher concentrate and flotation tailings (Figure 1). The cleaner concentrate and rougher concentrate are both shipped offsite for further processing and gold recovery. The CPB used in the IMM will be composed of flotation tailings (tailings that have had ore concentrate, sulfide, and trace metals removed by flotation), Portland cement as the binder material, and water. The final formulation of the CPB, including the precise binder amount, binder source, and water content, will ultimately be defined based on rheology and strength characterization testing. This testing program will ensure that the IMM CPB is formulated to set properly and will have sufficient strength for the intended applications within the mine. Rise does not plan to use waste rock, concentrate, or other binders/additives in the IMM CPB.

IMM METALLURGICAL AND GEOCHEMICAL TESTING

Rise conducted tests of metallurgical processes on aliquots of a large bulk 47-kilogram composite sample of mineralized drill core from 72 intervals in nine different boreholes (McClelland Laboratories, Inc. [MLI] 2020). That metallurgical testing generated sample materials that were representative of the IMM flotation tailings that are proposed for use in the IMM CPB. Environmental testing was conducted on the resulting representative flotation tailings samples generated from the metallurgical testing.

The metallurgical tests included gravity separation and bulk sulfide flotation procedures, designed to simulate the processes Rise plans to use on their ore (Figure 1). Gravity separation procedures were conducted on three aliquots (G-1 to G-3, Table 1) of the larger bulk ore sample to evaluate the effects of the particle size on gold recovery.

Bulk sulfide flotation procedures were conducted on the combined cleaner tailings and rougher tailings from the gravity separation procedures. Four flotation samples were prepared from those gravity separation tailings, listed in Table 1. The samples F-2, F-3, F-4 represented the particle sizes used in the gravity separation procedures. A portion of the gravity tailings sample G-1 was further ground to create an additional flotation test sample with a smaller particle size, referred to as sample F-1. Each of the flotation samples was subjected to the proposed flotation recovery process, which yields flotation tailings and rougher concentrate (Figure 1).

Sulfide sulfur was analyzed for the unprocessed bulk composite material as well as the flotation tailings generated from each of the four flotation procedures. As listed in Table 1, the unprocessed sample contained 1.6% sulfide sulfur, whereas the flotation tailings samples contained approximately 0.06 to 0.12% sulfide sulfur; the sulfide sulfur recovery was approximately 93 to 96%. Thus, only a trace amount of sulfide sulfur remains in the flotation tailings, effectively eliminating potential water quality issues associated with the use of high-

sulfide tailings in CPB. The gold recovery from the combined gravity separation and flotation procedures was high, ranging from 95 to 98% (Table 1), indicating that the ore processing procedures were effective. Both the sulfide sulfur and gold recovery increased with decreasing particle size over the range used in the flotation procedures.

Additional environmental testing was conducted by ACZ Laboratories (ACZ) on the flotation tailings samples. Modified acid-base accounting (ABA) analysis including paste pH, detailed sulfur speciation, and a titration-based estimate of the sample acid-neutralization potential (ANP) was conducted on each flotation tailings sample (ACZ 2020). As listed in Table 2, the ABA analysis showed that all four samples were net acid-neutralizing, with low acid-generation potential (AGP) due to low sulfur contents and elevated ANP values of approximately 200 tons calcium carbonate equivalents per kiloton (t CaCO₃/kt).

The solid-phase composition of each of the four flotation tailings samples was also analyzed using a strong-acid digestion (EPA 1996) conducted by ACZ. This method is not intended to be a total digestion; however, it is a very strong acid digestion that will dissolve almost all elements that could potentially become environmentally available (EPA 1996). The results of the solid-phase composition analyses are listed in Table 3 (ACZ 2019). The solid-phase concentrations are similar to (less than ten times) the average crustal abundance for elements such as antimony, arsenic, cadmium, copper, nickel, thallium, vanadium, and zinc, which are commonly associated with low-sulfide gold mineralization, further indicating that the flotation process effectively removed trace metals associated with the sulfide minerals. Molybdenum was the only trace metal that was detected at an average concentration in the flotation tailings that was more than ten times the average crustal abundance.

A waste extraction test modified to use deionized water as the lixiviant (WET-DI) was also conducted on each of the four flotation tailings samples. The results are listed in Table 4. The primary maximum contaminant levels (MCLs) for drinking water in California are also listed in Table 4. As shown in Table 4, the WET-DI concentrations are less than the primary MCLs for all flotation tailings samples. Although molybdenum was somewhat elevated in the solid-phase composition of the tailings relative to the average crustal abundance, molybdenum did not leach from the tailings in the WET-DI tests. All of the flotation tailings leachate samples had molybdenum concentrations that were below the detection limit of 0.02 milligrams per liter (mg/L).

Based on the testing results described herein, IMM flotation tailings have low sulfide content, are net acid-neutralizing, have solid-phase metals contents that are comparable to the average crustal abundances, and have leachate concentrations from WET-DI tests that meet all California primary MCLs. Thus, it is likely that the CPB used in the IMM will have very low solute release rates and will be generally environmentally benign. Because of the low sulfide content of the flotation tailings, IMM CPB is anticipated to have good long-term strength as long as sufficient binder material is used. The proposed strength characterization testing will provide the necessary

information regarding the required amount of binder. Additionally, the CPB will be placed while the mine is dewatered, so the CPB will cure before it is inundated by groundwater.

If the IMM ore-processing methods change substantially, additional geochemical testing of flotation tailings may be necessary to confirm that these results are still applicable. Additionally, Rise plans to conduct geochemical testing using the final CPB formulation once a specific Portland cement source has been selected, in order to confirm that no constituents (e.g., pH values or chromium) release at levels of concern from the final selected CPB formulation as a result of the binder composition or the interaction between the binder and the tailings material.

CONCLUSIONS

Based on the discussion provided above, the use of CPB is an environmentally favorable disposal alternative for tailings because, when used properly, it significantly limits solute release, and reduces the surface footprint of the mine and associated environmental impacts. However, it is clear from case studies and theoretical behavior of CPB that there are a variety of site-specific factors that could affect the potential for water-quality impacts. Some important factors to consider in designing and using CPB include the following:

- Selecting an appropriate amount and type of binder material through geochemical and geotechnical testing, paying particular attention to the strength of the cured CPB;
- Geochemical testing of both the tailings that will be used in the CPB and the intact, cured CPB material itself;
- Preventing inundation of CPB before it is cured;
- Preventing contact of CPB with acidic water (especially before it is cured); and
- Minimizing the amount of contact time of cured CPB with atmospheric oxygen.

Each of these factors described above are addressed by Rise's proposed CPB plan and available characterization testing. Based on the currently available site-specific information, Itasca anticipates that the CPB mixture developed using flotation tailings from the IMM will be relatively inert due to the low sulfide and metals content of the flotation tailings.

Itasca understands that Rise plans to complete more extensive strength, rheological, and geochemical testing on their ultimate CPB mixture at a later stage in the IMM project. Prior to placement of CPB in the mine, engineering evaluation of the proper cement to tailings ratios will be conducted, and batch testing of those mixtures will be performed to determine the actual concentrations of constituents that may be present in any leachate from the CPB.

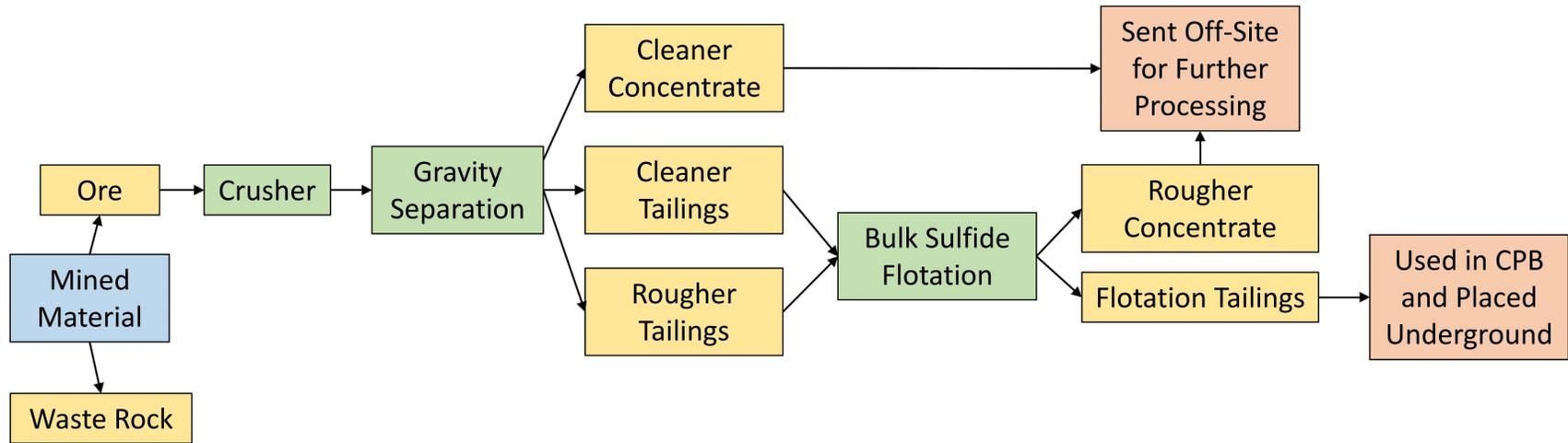
Based on the available data, the use at IMM of the CPB composed of flotation tailings, Portland cement, and water is anticipated to optimize water quality relative to surface tailings disposal, other fill methods (e.g., hydraulic fill or sand fill), and no backfill. The CPB will contribute

additional net neutralization potential to the backfilled areas and is not anticipated to negatively affect groundwater as a result of solute leaching because of the low metals content, low sulfide content, and net-neutralizing character of the IMM CPB materials.

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- Attachments: Figure 1 – Flow Chart Illustrating Ore Processing
Table 1 – Bulk Composite and Flotation Tailings Sulfide Content and Recovery
Table 2 – Acid-Base Accounting Results for Flotation Tailings
Table 3 – Solid-Phase Composition of Flotation Tailings
Table 4 – WET-DI Leachate Concentrations for Flotation Tailings



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Flow Chart Illustrating Ore Processing

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FIGURE NO.
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TABLE 1
Bulk Composite and Flotation Tailings Sulfide Content and Recovery

Material		Particle Size ¹	Sulfide Sulfur ² (%S)	Sulfide Sulfur Recovery (%)	Total Gold Recovery (%)
Gravity Separation Sample	Flotation Test Sample				
Bulk Composite Ore Sample		--	1.60	--	--
G-1	F-1	80%-75 μ m (gravity tailings from 80%-180 μ m that were re-ground)	0.06	96.3	97.9
	F-2	80%-180 μ m ³	0.06	96.2	97.2
G-2	F-3	80%-300 μ m ³	0.12	92.9	94.8
G-3	F-4	80%-212 μ m ³	0.10	93.9	96.0

Notes:

1. A particle size of 80%-75 μ m indicates that 80% of the sample passes a 75 micrometer filter.
2. The sulfide sulfur content listed in this table was measured as part of gold and silver assay. The sulfide sulfur for the flotation test samples refers to the sulfide sulfur content of the flotation tailings.
3. Sample subject to short polish grind prior to flotation test to create fresh sulfide mineral surfaces before the bulk sulfide flotation procedure (MLI 2019), and therefore approximated the particle size distributions from the gravity separation process.

TABLE 2

Acid-Base Accounting Results for Flotation Tailings

Sample	Paste pH	Total Sulfur	Hot Water Extractable	HCl Extractable	HNO ₃ Extractable	Residual Sulfur	AGP ²	ANP ³	Net Neutralization Potential (ANP - AGP)	Neutralization Potential Ratio (ANP/AGP)
Units	su	%S				t CaCO ₃ /kt			unitless	
F-1 ¹	8.6	0.04	<0.01	<0.01	0.04	<0.01	1.25	199	198	159
F-2 ¹	8.3	0.05	0.01	<0.01	0.01	<0.01	1.56	194	192	124
F-3	8.9	0.06	<0.01	<0.01	0.06	<0.01	1.88	204	202	109
F-4	8.7	0.06	0.01	<0.01	0.05	<0.01	1.88	189	187	101

Notes:

1. Additional ABA testing was conducted on these samples by MLI, as reported in MLI (2019).
2. AGP calculated based on total sulfur content (i.e., %S x 31.25).
3. ANP determined by titration as per Nevada Modified Sobek ABA procedure (i.e., NDEP 2015).

TABLE 3
Solid-Phase Composition of Flotation Tailings

Parameter (mg/kg)	Units	Average Crustal Abundance ¹	F-1 ²	F-2 ²	F-3	F-4
Aluminum	mg/kg	83,600	16,100	16,300	16,300	16,300
Antimony	mg/kg	0.2	0.2	<0.2	<0.2	<0.2
Arsenic	mg/kg	1.8	1.7	1.4	2.0	1.2
Barium	mg/kg	390	18.4	16.6	17.9	17.6
Beryllium	mg/kg	2	0.23	0.22	0.22	0.22
Boron	mg/kg	9	<2	<2	<2	<2
Cadmium	mg/kg	0.16	0.61	0.62	0.62	0.59
Chromium	mg/kg	122	73	75	88	88
Cobalt	mg/kg	29	13	13	13	13
Copper	mg/kg	68	86	86	87	84
Iron	mg/kg	62,200	35,500	36,000	35,200	35,200
Lead	mg/kg	13	11.8	9.34	10.2	8.88
Manganese	mg/kg	1,060	1000	1010	990	994
Molybdenum	mg/kg	1.2	22	33	42	37
Nickel	mg/kg	99	31.1	31.5	30.3	29.9
Selenium	mg/kg	0.05	0.11	0.12	0.13	0.11
Silver	mg/kg	0.08	0.23	0.21	0.23	0.2
Thallium	mg/kg	0.72	<0.05	<0.05	<0.05	<0.05
Vanadium	mg/kg	136	72.0	73.2	73.4	73.0
Zinc	mg/kg	76	65	63	63	63
Mercury by Direct Combustion AA	ng/g	86	39.9	45.1	41.9	71.3

Notes:

1. Source: Price (1997).
2. Additional solid-phase chemical composition extractions and analysis were performed by Western Environmental Testing Laboratory and are provided in MLI (2019). Quality control results indicate consistently lower practical quantitation limits in the ACZ analyses, suggesting more reliable measurements. Thus, the ACZ analyses are presented here.

TABLE 4

WET-DI Leachate Concentrations for Flotation Tailings

Parameter	Units	California Primary MCLs ¹	California Secondary MCLs ⁴	F-1	F-2	F-3	F-4
Aluminum	mg/L	1	0.2	0.17	0.18	0.26	0.28
Antimony	mg/L	0.006		0.0015	0.0015	0.0031	0.0020
Arsenic	mg/L	0.01		0.0018	0.0013	0.0019	0.0014
Barium	mg/L	1		<0.007	<0.007	<0.007	<0.007
Beryllium	mg/L	0.004		<0.00008	<0.00008	<0.00008	<0.00008
Boron	mg/L			<0.02	<0.02	<0.02	<0.02
Cadmium	mg/L	0.005		<0.00005	<0.00005	<0.00005	<0.00005
Calcium	mg/L			9.0	8.5	7.5	8.3
Chloride	mg/L		500 ⁵	1.7	1.9	2.8	2.5
Chromium	mg/L	0.05		<0.01	<0.01	<0.01	<0.01
Cobalt	mg/L			<0.01	<0.01	<0.01	<0.01
Conductivity at 25°C	umhos/cm		1,600 ⁵	105	100	115	118
Copper	mg/L	1.3 ²	1.0	<0.01	0.01	0.02	0.09
Fluoride	mg/L	2		<0.1	<0.1	<0.1	<0.1
Hardness as CaCO ₃	mg/L			38	36	33	36
Iron	mg/L		0.3	<0.03	<0.03	<0.03	<0.03
Lead	mg/L	0.015 ²		<0.0001	<0.0001	<0.0001	<0.0001
Magnesium	mg/L			3.8	3.5	3.5	3.8
Manganese	mg/L		0.05	<0.01	<0.01	<0.01	<0.01
Mercury	mg/L	0.002		<0.0002	<0.0002	<0.0002	<0.0002
Molybdenum	mg/L			<0.02	<0.02	<0.02	<0.02
Nickel	mg/L	0.1		<0.008	<0.008	<0.008	<0.008
Nitrate	mg/L	45 ³		0.03	0.05	0.22	0.19
Nitrate/Nitrite as N	mg/L	10		0.06	0.08	0.28	0.24
Nitrite as N	mg/L	1		0.03	0.03	0.06	0.05
Potassium	mg/L			3.8	4.2	7.8	7.4
Residue, Filterable (TDS) @180C	mg/L		1,000 ⁵	64	72	78	78
Selenium	mg/L	0.05		0.0003	0.0002	0.0003	0.0003
Silver	mg/L		0.1	0.0001	<0.0001	<0.0001	<0.0001
Sodium	mg/L			3.7	3.6	5.1	4.7
Sulfate	mg/L		500 ⁵	8.4	6.3	8.5	8.7
Thallium	mg/L	0.002		<0.0001	<0.0001	0.0003	0.0001
Vanadium	mg/L			0.008	0.010	0.018	0.014
Zinc	mg/L		5.0	<0.01	<0.01	<0.01	<0.01
Bicarbonate as CaCO ₃	mg/L			40.7	40.2	43.5	44.6
Carbonate as CaCO ₃	mg/L			4.5	3.2	2.6	3.1
Hydroxide as CaCO ₃	mg/L			<2	<2	<2	<2
pH	su		6.5 - 8.5 ⁶	9.4	9.3	9.3	9.3
Total Alkalinity	mg/L			45.2	43.4	46.1	47.7

Notes:

1. California primary MCLs listed as per California Waterboard (2018a). Additional types of standards exist such as secondary MCLs and public health goals.
2. Action levels for copper and lead as per California Waterboard (2019).
3. Concentration is in units of mg/L nitrate as NO₃.
4. Secondary MCLs listed as per California Waterboard (2018b).
5. Upper bound of secondary MCL range (California Waterboard 2018b).
6. U.S. EPA secondary MCL (EPA 2020).