D R A F T TECHNICAL MEMORANDUM

Geochemistry Evaluation for the City of Malibu Legacy Park Area Injection Well Project

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SUMMARY

Based upon recently-obtained data, the injection of highly treated wastewater into one or more of the proposed wells in the City of Malibu Legacy Park area appears technically feasible from a geochemical perspective provided the wells are operated properly.. Proper operation of the wells from a geochemical perspective involves injecting the wastewater at a disinfection level of at least one milligram per liter chlorine to minimize bacterial growth during injection. Disinfection will also be needed if any well is idled for more than a few days in order to prevent the creation of a biofilm within the well, particularly the well screens.

1.0 Introduction

Analytical data for water samples obtained from three wells in the City of Malibu Legacy Park area (Table 4.1), along with treated wastewater from a small local wastewater treatment plant, are used as the basis for this geochemical evaluation of potential problems involved with injecting wastewater into the local groundwater basin. Primary concerns involve the compatibility of local groundwater with the wastewater, and the tendency for precipitating minerals that might lead to well or aquifer plugging. Potential chemical reactions between injected water and the aquifer mineralogy is also a potential concern. Aquifer characteristics available for this evaluation included lithologic descriptions of the aquifer sediments during the drilling of three test wells, and petrologic and mineralogical data from select samples from the test wells documented in a report by Mineralogy, Inc.

The following sections describe physical characteristics of the aquifer as they related to geochemical issues, the chemistry of native groundwater and treated wastewater , description of mixing results for injection water and groundwater, and finally a summary of potential geochemical reactions with the aquifer mineralogy. All samples for metals and metalloids were analyzed on samples filtered in the filed using a 0.45 micron filter, which provides conventionally defined dissolved concentrations of these constituents.

2.0 Physical Characteristics of the Aquifer

Three test wells were recently completed in the Civic Center Gravels to assess local groundwater conditions. As reported in the core logs, these wells are screened in unconsolidated gravels and sands with variably distributed clay beds. The screened section of well MW01 contains only one relatively thin silt bed and one relatively thin clay bed within multiple thick gravel and sand beds. The silt bed is located in the upper part of the well screen section, and the clay bed in the lower third of the screened interval. Conversely, in well MW02, multiple relatively thick silts and clays are present in the upper half of the screened interval. Two gravels occur in the uppermost part of the well while sands thicken with depth. A relatively thick sand unit is present in the lower third of the screened interval. The well MW03 lithologic sequence closely resembles that of MW01, but with no silt beds. In addition, the multiple thin clays are variably dispersed within the sand and gravel beds throughout the screened depth interval of MW03. Relatively thick gravel deposits occur in the lower third of the screened interval in this well.

The gravels and sands found in all three test wells are comprised of uncemented, easily disaggregated, poorly sorted, subangular lithic grains with minor amounts of clays variably coating grains and periodically occurring as mudstone grains. The Mineralogy Inc. report suggests that the clay could also be pore filling, probably where sands and gravels are in contact. The report indicates an overall lack of cementing and pore-filling clay suggesting a porous and permeable aquifer.

Wood fragments are reported in a dark gray sand at 74-80 foot depth interval in MW02 and, particularly, in both clays and sands at multiple depth intervals of MW03. However, no wood fragments are reported for MW01 sediments. Wood fragments tend to form localized reduced zones in aquifer sediments, frequently resulting in the precipitation of pyrite within the wood fragments. If wood fragments are sufficiently abundant they can create reducing zones in the aquifer. The variable brown (generally oxidizing) and gray to dark gray (generally reducing) color of the aquifer sediments indicate a mixture of oxidizing and reducing conditions with neither condition dominating the aquifer sediments. This can mean either the aquifer is tending toward oxidizing or reducing conditions. However, results of water quality sampling that are discussed later indicate that local groundwater in all three areas is under oxidizing conditions. This indicates that the primary water-producing depth intervals of all three wells are under oxidizing conditions.

The Mineralogy Inc. report indicates that the mineralogy of the Civic Center Gravels is relatively simple and consistent between the three wells. Based on x-ray diffraction results of grab samples, the plagioclase feldspar andesine ($(Na, Ca)Al\ Si_3O_8$) is nearly equal in abundance to quartz (SiO_2), averaging about 37 and 35 percent of the samples, respectively.   The swelling clay montmorillonite ($(Ca,Na)_{0.3}(Al,Mg)_2Si_4O_{10}(OH)_2 \cdot nH_2O$)) is the third most abundant mineral, averaging 15 percent. The potash feldspar microcline ($KAlSi_3O_8$) averages 9 percent and the pyroxene mineral augite ($(Ca, Na)(Mg, Fe, Al, Ti)(Si, Al)_2O_6$) averages 3 percent. The clay illite, an essentially non-swelling clay with the formula $KAl_2(Si_3AlO_{10})(OH)_2$, averages about one percent. Trace amounts of hornblende (calcium, iron, magnesium aluminosilicate), chlorite (iron, magnesium aluminosilicate) and kaolinite (aluminosilicate) are present.

The combination of the dominance of feldspars over quartz and lack of carbonates makes this aquifer unique. Adding wood fragments further increases the degree of rarity. Quartz typically dominates other minerals in almost all alluvial aquifers and almost all aquifers contain calcite or dolomite as a cement or

in particulate form. Feldspars, particularly plagioclase feldspars like andesine, are relatively soluble and therefore contribute to the total dissolved solids in the groundwater within relatively short distances from recharge sources.

Most of the andesine grains show dissolution pitting and are the primary source of montmorillonite clay. The cation exchange capacity (CEC) of the clays is relatively low at about 15 milliequivalents per 100 gram of sediment, which is about equal to the abundance of montmorillonite as indicated in the x-ray diffraction results. Lab results indicate that calcium is the dominate cation in exchange positions on the clays, ranging from 50 to 60 percent of the total. The remaining exchange positions are taken by magnesium (about 30 percent), sodium (about 15 percent), and potassium (3 to 6 percent).

The above results are important because a calcium- and magnesium-rich CEC clay, such as that present in samples obtained from the three test wells, forms a relatively stable blanket-like structure that coats aquifer particles. Sodium-rich CEC clays, on the other hand, would form a relatively unstable ribbon-like structure that tears off and migrates into the pore throats of the aquifer thereby reducing the permeability. Sodium-dominant injection water could also potentially present a problem by exchanging sodium for calcium and destabilizing the clay by forming the ribbon-like structure that can tear off and move to a pore throat. However, the Sodium Absorption Ration (SAR), which is a measure of the tendency for dissolved sodium in irrigation waters to adversely affect soil clays due to ion exchange, is relatively low, which is favorable. Therefore, the clay minerals in the aquifer mineral are likely to remain stable.

Major element chemistry reflects the mineralogy of the aquifer sediments with silica dominating the chemistry, ranging between 64 and 67 percent of the samples analyzed, followed by aluminum oxide, which ranges between 11 and 14 percent. Calcium and iron oxide represent about 5 percent of the samples, magnesium oxide about 4 percent, and sodium oxide about 3 percent. All other major elements are less than one percent. Sulfur is generally less than its detection limit of 0.05 percent, but the MW03 sediments contain about this concentration probably reflecting dispersed very fine-grained iron-sulfide.

About half of the trace elements and metals are less than their respective detection limits of 10 or 20 parts per million (ppm). These include arsenic and lead. With the exception of strontium and cobalt, the other detected elements are generally immobile. The respective concentrations of the detected elements is sufficiently low under the groundwater and injection water chemistries described in the following sections that they are unlikely to be mobilized, and even if mobilized they would likely either be sorbed to the aquifer skeleton or dispersed into undetectable concentrations in the groundwater. Only strontium may be present in the groundwater at a concentration of probably no more than a few milligrams per liter (mg/L). Strontium is neither a health nor an aesthetic problem element.

3.0 Groundwater Chemistry

There are similarities between groundwater from these three wells but also some significant differences for wells completed in the same aquifer in such close proximity. The similarity in water chemistry is shown by a trilinear diagram (Figure 1) derived from the analytical data listed on Table 1. The groundwaters all cluster in a group in the upper diamond part of the trilinear diagram typically used to differentiate groundwaters. This part of the diagram would suggest little difference in the major ion

chemistry. However, significant differences do occur in the lower right triangle of the negative ion percentages (bicarbonate, sulfate and chloride). The primary differences are in the sulfate-bicarbonate percentages and this involves groundwater from MW02 versus similar percentages for MW01 and MW03. The most significant difference is between these groundwaters and the injection water, the primary focus of this evaluation.

Correcting the transcription error for alkalinity in the analytical data for the December 19th sampling of MW01 (discussed further below), the mass balance error is exceptionally low with all analyses less and usually significantly less than 7 percent. In other words, on a mass balance basis, the analytical data are of excellent quality.

Groundwater from all three wells has a near neutral pH, high silica, low iron, relatively low manganese concentrations and consistently very low trace elements including metals and metalloids concentrations. For example, the metalloid arsenic is below its detection limit in all the groundwater samples. The elevated silica concentration ranging between 29 milligrams per liter (mg/L) in MW01, and 42 mg/L in MW03 probably reflects the dissolution of the andesine plagioclase feldspar dominant mineral in the aquifer mineralogy. However, there are significantly different sulfate concentrations between wells. The groundwater chemistry from each of the three wells is described individually in the following sections.

Although time-series water quality sampling of field parameters (conductivity, temperature, and oxidation-reduction potential) were obtained during the pumping tests using a flow-through cell during the pumping tests at each well, the data appear to have been adversely affected by temperature fluctuations during the day and possible by direct solar heating. Therefore, field water quality parameters are discussed in general terms.

3.1 Chemistry of Groundwater at MW01

Well MW01 was sampled for laboratory analysis of water quality on December 19th and 21st, 2011 during the constant rate pumping test. Field parameters were collected during the the pumping test as well as on March 8th, 2012. Groundwater temperatures during the pumping test ranged from 17 degrees Celsius (°C) to 19.3 °C. Conductivity measurements range from 2,570 to 1,910 microsiemens per centimeter (µS), the pH from 6.83 to 7.3, and the oxidation reduction potential (ORP) from plus 35 to minus 22 millivolts (mv) (Table 1). Converting the ORP readings to Eh (by adding 240 mv to correct the reference electrode to a hydrogen reference electrode) provides an Eh range of between about plus 218 and plus 275 mv, this represents oxidizing conditions that are typical for a shallow alluvial groundwater.

Based on laboratory results, the bulk chemistry of the groundwater sample from MW01 is a sodium-magnesium-calcium-sulfate water chemistry type with a TDS of 1,600 mg/L (Table 4.1). The total dissolved solids sum (TDSS) calculated by adding up the reported concentrations of the ions ranges between 1,620 and 1,660 mg/L. These differences are not considered significant. The TDS is above the aesthetic drinking water standard of 500 mg/L.

With respect to major ion chemistry, the percent alkalinity tends to decrease with increasing percent TDSS, while at the same time the percent sodium, sulfate and chloride slightly increases. The native groundwater from MW01 exceeds the current aesthetic drinking water concentration for sulfate of 250

mg/L. The major ion chemistry is consistent with a minor seawater component. There is clearly an error in the posted alkalinity concentration of 64 mg/L as calcium carbonate in the December 19th, 2011 analytical data. To maintain proper ion balance, and to be more consistent with subsequent samples, the alkalinity is more likely closer to about 390 mg/L as calcium carbonate. Detected trace elements, iron, manganese and zinc tend to decrease with pumping time.

No wood fragments are reported in the lithologic description of the alluvial sediments from this well. However, wood fragments are variably reported in the description of the alluvial sediments of wells MW02 and, particularly, MW03. Wood fragments are therefore present in sediments near the MW01 well location. The increase in some minor and trace ion concentrations would also be consistent with the accumulation of selective parameter concentrations when the well is idle from finer-grained parts of the aquifer containing wood fragments in surrounding alluvial sediments. The wood fragments likely contain fine-grained iron-sulfide (pyrite) that slowly oxidizes in the oxidized groundwater. Pyrite typically contains manganese and zinc as impurities. When the pyrite oxidizes it releases sulfate and the more soluble metals, manganese, zinc and other metals and metalloids it contains as impurities (for example, copper, nickel chromium and vanadium). The iron becomes oxidized to iron oxyhydroxide and coats aquifer particles forming an adsorption media that can remove and retain most of the copper, nickel, arsenic, chromium and vanadium from the groundwater. The wood fragments apparently occur in the vicinity of this well location but are not evenly dispersed throughout the aquifer and therefore their contribution as part of the bulk flow reflects this variable and limited distribution of dissolution products from this source when the well is pumped.

With the exception of manganese, all of the other metals and metalloids are significantly less than their respective drinking water standards and most are beneath their respective very low detection limits. Manganese ranges between 0.048 mg/L, slightly less than the current aesthetic drinking water concentration of 0.050 mg/L to a still low concentration of 0.084 mg/L. Since the manganese concentration decreased to less than the drinking water concentration under a constant pumping rate it has a limited source and may well not be above the drinking water concentration in the water injected into the aquifer at this well location.

It would be useful to include the total organic carbon (TOC) of the groundwater from this and the other two wells prior to injecting the highly treated waste water. Laboratory results for wastewater (discussed later) indicates 9.5 mg/L dissolved organic carbon, and it would be useful to be able to separate the native groundwater TOC from that of the injection water. The slow oxidation of the surrounding wood fragments likely contributes sufficient TOC to be detected in the groundwaters. The wood fragments are also probably responsible for the very low total phosphorus concentration of 0.068 mg/L and may also contribute a small amount of nitrogen to the nitrate as nitrogen concentration of 1.7 to 1.8 mg/L. This nitrate nitrogen is well below the current drinking water standard of 10 mg/L.

Both the total Kjeldahl nitrogen (TKN) and ammonia nitrogen concentrations are less than their respective detection limits. TKN is the sum of ammonia nitrogen and organic nitrogen. The organic nitrogen concentration is proportionately produced by the microbe population present in the aquifer. Since both the TKN and ammonia nitrogen are less than their respective detection limits, the organic nitrogen is probably also less than detection. This means that the microbial population is also very low in the bulk aquifer sediments. However, the equilibrium dissolved carbon dioxide estimated by

thermodynamic equilibrium modeling (discussed below) indicates that microbes are probably present within the surrounding aquifer sediments and utilizing the wood fragments for their metabolism. This is supported by the very low total phosphorus concentration but orthophosphate concentrations less than its detection limit. The difference between these two represents the organic form of phosphorus and indicates a very low organic phosphorus concentration in the groundwater probably produced by microbes. The organic phosphorus slowly converts to orthophosphate but the calcium concentration is sufficiently high that it would likely be rapidly precipitated as a member of the apatite group of minerals.

3.1.1 Thermodynamic Equilibrium

Thermodynamic equilibrium modeling of groundwater from MW01 estimates equilibrium with respect to cristobalite (silica), plagioclase feldspar, calcite (calcium-carbonate), dolomite (calcium- magnesium-carbonate), magnesite (magnesium-carbonate) and swelling smectite clay. Most of this suite is consistent with and reflects the mineralogy identified by Mineralogy Inc. in their report. X-ray diffraction has a detection limit of a few percent so there may well be trace amounts of the carbonates in the aquifer sediments.

Since the dissolved carbon dioxide is part of the alkalinity determined in the laboratory, its estimated concentration trend generally mimics the alkalinity concentration and it does in the MW01 groundwater. The estimated equilibrium dissolved carbon dioxide decreases from an elevated 49 mg/L on the 19th to a still elevated but significantly lower 25 mg/L on the 21st sampling during the constant rate pumping test. Groundwater from alluvial aquifers typically contain less than about 10 mg/L dissolved carbon dioxide therefore the dissolved carbon dioxide is considerably elevated in this groundwater. This level supports the presence of a microbial population producing carbon dioxide in this alluvial aquifer.

The total amount of dissolved carbon dioxide in the groundwater may be higher than these equilibrium concentrations. If so, pumped groundwater may initially be slightly cloudy from the creation of very tiny carbon dioxide bubbles which dissipate rather quickly. When this is the case, the water clears within a short time as the bubbles are expelled from the water. The creation of the very tiny carbon dioxide bubbles results from the decrease in pressure from the alluvial aquifer plus the pumping pressure to that of the atmospheric pressure. If this does not occur then the total carbon dioxide gas in the produced groundwater is about equal to the estimated equilibrium dissolved carbon dioxide.

3.2 Chemistry of Groundwater at MW02

Field measurements indicated a groundwater temperature of between about 18°C and 20°C, conductivity between about 2,300 and 2,400 µS, and pH between about 7.3 and 7.5. The ORP was relatively consistent between minus 40 mv to minus 57 mv, which is equivalent to an Eh of between plus 183 to plus 200 during the pump test. As in groundwater from MW-01, the groundwater from MW02 is well oxidized.

Based on results of the laboratory samples, the groundwater from MW02 is a sodium-calcium-sulfate chloride water chemistry type with the lowest TDS of the three wells ranging between 1,500 and 1,600 mg/L. The TDS exceeds the aesthetic drinking water standard of 500 mg/L.

Magnesium, sulfate, chloride and fluoride increased slightly during the pumping test while calcium decreased slightly. Sodium remained constant and but the alkalinity variably ranged between 310 and 340 mg/L. These differences are sufficiently low that they will not affect the estimate of compatibility with the injection water. Even though the sulfate concentrations in groundwater from this well are the lowest of the three wells they exceed the aesthetic drinking water standard of 250 mg/L.

Dissolved iron is less than its detection limit of 0.05 mg/L as would be expected for an oxidized water with a near neutral pH. The minimum solubility for dissolved iron occurs within the near neutral pH of this groundwater. On the other hand, the dissolved manganese concentration ranges between 0.66 and 0.77 mg/L and appear to be slightly decreasing with pumping time. The dissolved manganese concentrations in groundwater from this well are the highest of the three wells and are more than an order of magnitude higher than the aesthetic drinking water standard of 0.05 mg/L. Unlike iron that precipitates within minutes at this near neutral pH, the dissolved manganese remains in solution for days to weeks because of its slow precipitation kinetics.

With the exception of selenium, the metals and metalloids concentrations in this groundwater are similar to less than those of groundwater from MW01. Selenium concentrations are very low but range between non-detect and 0.026 mg/L. Selenium concentrations appear to decrease with pumping time. These concentrations are less than to significantly less than the drinking water standard of 0.05 mg/L.

Both the TKN and ammonia nitrogen concentrations are less than their detection limits. Nitrate nitrogen ranges between a very low 0.18 and 0.34 mg/L. The total phosphorus of 0.11 mg/L is almost twice that of groundwater from MW01. However, similar to MW01, the orthophosphate is less than its detection limit. This means that the phosphorus is present as organic phosphorus. This higher organic phosphorus probably reflects the presence of wood fragments in the alluvial sediments of this well and the lack of wood fragments within the drilled alluvial sediments of MW01. A TOC or DOC determination on this groundwater would be useful to assess the microbial conditions. Even so, the nitrogen speciation suggests that the microbial population is very low and probably restricted to the wood fragments.

3.2.1 Thermodynamic Equilibrium

The thermodynamic equilibrium modeling results are very similar to those of groundwater from MW01 with the exception that it is in equilibrium with the manganese carbonate mineral rhodochrosite. The thermodynamic equilibrium modeling of groundwater from MW02 estimates equilibrium with respect to cristobalite (silica), plagioclase feldspar, calcite (calcium-carbonate), dolomite (calcium- magnesium-carbonate), magnesite (magnesium-carbonate), rhodochrosite, and swelling smectite clay. Most of this suite is consistent with and reflects the mineralogy identified by Mineralogy Inc. in their report. X-ray diffraction has a detection limit of a few percent so there may well be trace amounts of the carbonates in the aquifer sediments.

The estimated equilibrium dissolved carbon dioxide is also elevated in this groundwater, ranging between 21 and 31 mg/L. This concentration is toward the low end of groundwater from MW01. Coupled with the presence of wood fragments in the alluvial sediments at this well location, lower sulfate concentration and higher manganese and total phosphorus concentrations of this groundwater, the wood fragments have been and are undergoing more active oxidation at and near this well location than in the alluvial sediments nearer MW01.

3.3 Chemistry of Groundwater at MW03

Field data indicate a groundwater temperature between 15.5 to 20.8 °C at this well, a pH of about 7.1, conductivity of about 3,540 to 3,620 µS, and an ORP of minus 51 to minus 102 mv (Eh between about plus 140 and plus 190 mv). These values of Eh indicate an oxidized groundwater.

One sample for laboratory analysis of water quality was obtained from this well for one laboratory sample near the end of the constant rate pump test. Results indicate an unusual magnesium-sodium-sulfate water chemistry type with a TDS of 2,700 mg/L, the highest TDS of all three wells. The TDSS with a concentration of 2,680 mg/L is essentially the same as the TDS. With the exception of the minor and trace ions, all the major ions are considerably higher in groundwater from MW03 than the other wells.

The water chemistry and TDS suggest that this groundwater from this well location is more affected by seawater than the other wells. However, the alluvial sediments associated with this well location also contain the highest occurrence of reported wood fragments as well. This occurrence is probably responsible for the lower Eh and the significantly higher alkalinity and sulfate than the other wells.

Dissolved iron is less than its detection limit of 0.05 mg/l reflecting the oxidized nature of the groundwater and its near-neutral pH. The manganese concentration of 0.66 mg/l is the same as the last sample of groundwater from MW02 and considerably higher than the manganese concentrations of MW01. This manganese concentration is over an order of magnitude higher than the aesthetic drinking water standard of 0.05 mg/L.

All nutrient parameters are less than their detection limits. These parameters include TKN, ammonia nitrogen, nitrate nitrogen, total phosphorus and orthophosphate. Neither TOC nor DOC concentrations are available but should be considered in any future analytical schedule.

Almost all of the remaining minor and trace metals and metalloids are generally below their detection limits. Selenium, one of the few detected in this group, with a concentration of 0.019 mg/L approaches the lowest selenium concentration of groundwater from MW02. This selenium concentration is significantly lower than the current drinking water standard of 0.05 mg/l.

3.3.1 Thermodynamic Equilibrium

The thermodynamic equilibrium modeling results indicate essentially the same conditions as that of MW02, indicating thermodynamic equilibrium with cristobalite (silica), plagioclase feldspar, calcite (calcium-carbonate), dolomite (calcium- magnesium-carbonate), magnesite (magnesium-carbonate), rhodochrosite (manganese carbonate), and swelling smectite clay. Most of this suite is consistent with and reflects the mineralogy identified by Mineralogy Inc. in their report. X-ray diffraction has a detection limit of a few percent so there may well be trace amounts of the carbonates in the aquifer sediments.

The estimated equilibrium dissolved carbon dioxide is quite elevated in this groundwater, ranging between 67 and 98 mg/L. This is about twice to three times higher than those of groundwater from the other two wells. This level of carbon dioxide would almost certainly be related to microbial activity but, given the non-detect concentrations of the nutrient parameters, their activity would appear to be restricted

to the wood fragments and not be present in the bulk of the aquifer sediments. With this much estimated dissolved carbon dioxide, a groundwater recovered from the well location may well initially appear slightly murky due to the formation of very tiny carbon dioxide gas bubbles. The water would relatively rapidly clear as the gas escapes from the water surface.

4.0 Injection Water Chemistry

The injection water is represented by a sample of highly treated wastewater from a small local wastewater treatment plant collected on March 8th, 2012. It had a temperature of 20.6 °C, a conductivity of 738 µS, a slightly less than neutral pH of 6.88, and an ORP of plus 112 mv. Converting the ORP to Eh, the Eh is about plus 352 mv. This Eh is essentially the equivalent to a typical surface water stream.

The injection water is a sodium-chloride-bicarbonate-sulfate water chemistry type with a TDS of 450 mg/L and a slightly higher TDSS of 507 mg/L. TDS is less than the drinking water standard of 500 mg/L but the TDSS is slightly above this standard. Furthermore, the sulfate concentration of 119 mg/L is less than its drinking water standard of 250 mg/L. The total suspended solids of 10 mg/L is expected to be significantly reduced in the actual injection water prior to injection.

Sodium represents exactly 50 percent of the cations while calcium and magnesium sum to 45 percent. Therefore, ion exchange on the clays would likely be slow since sodium has only a plus one valence while both calcium and magnesium have a plus two valence – therefore essentially double the exchange charge basis. Competition for exchange sites on the clays is likely to tend toward a stable calcium and magnesium concentration on exchange sites. Therefore, the clays will tend to remain stable.

Almost all water quality parameter concentrations are lower in the injection water than in the native groundwater from the three wells. Potassium, zinc and both the nitrogen series and orthophosphate have higher concentrations in the injection water than in groundwater from other wells. Potassium tends to form a pillar connecting clay layers when it is exchanged onto a clay so this higher concentration will tend to aid in the stability of the clays. Although higher in the injection water, the zinc concentration of 0.0372 mg/L is still significantly less than the drinking water standard of 5 mg/L. All of the other analyzed metals, including both iron and manganese, are either also less than or near their respective detection limits. Except for zinc all are also significantly less than their respective concentrations in the native groundwater from the wells. For example, the manganese concentration is less than 0.02 mg/L and is therefore less than its drinking water standard.

The TKN concentration of 11 mg/L is less than the ammonia nitrogen concentration of 13 mg/L. This indicates that the wastewater is highly treated but since TKN is the sum of the ammonia nitrogen and organic nitrogen at least one of the values is incorrect. Perhaps the treatment/analytical techniques release or form more ammonia nitrogen than the TKN method determined. The nitrate nitrogen concentration of 6.5 mg/L is well within the drinking water standard of 10 mg/L. The orthophosphate as phosphorus concentration of 3 mg/L is likely mostly complexed with calcium and or magnesium and also likely to be precipitated in the aquifer matrix. It would be useful to determine the total phosphorus in future analytical schedules to be able to assess the nutrient potential for microbial activity in the aquifer. The

dissolved organic carbon (DOC) of 9.5 mg/L is elevated since groundwater in most alluvial aquifers contain less than about 2 mg/L DOC.

The combination of elevated ammonia nitrogen, DOC and probably both total phosphorus and orthophosphate provides a nutrient input that is likely to promote microbial activity within the aquifer. At an extreme, the groundwater and the aquifer could become reduced. This redox condition itself is not necessarily a problem but with time under reducing conditions the groundwater is likely be become a sodium-bicarbonate water chemistry type with elevated pH. This transition would promote the formation and precipitation of clay particularly since plagioclase feldspar is a dominant mineral in the aquifer. However, this condition will occur at a distance from the injection well and is not likely to present a problem for the injection well.

If the injection well is to be idled for more than a few days after injection of the treated wastewater has started then a chlorine residual (or equivalent disinfectant) of at least one mg/L is strongly recommended in the last day or so of injected water. This level of disinfection would be beneficial as a common practice to minimize bacterial activity in the injection well during its idle time. If the injection well is suddenly idled for some unplanned circumstance leading to a few idle days, a sufficient amount of disinfectant should be introduced into the well to minimize bacterial growth. Given the nutrient level of the injection water microbial growth would be expected and within a few days resulting in the growth of a biofilm within the well that would likely eventually lead to a reduction of specific capacity at the well. Once initialized, bacterial activity in a well is very difficult to control.

All four individual disinfection byproducts are less than their respective detection limits.   The total organic halides (TOX) is also a very low 0.062 mg/L.

4.1 Thermodynamic equilibrium

The injection groundwater is only in equilibrium with respect to cristobalite, plagioclase feldspar and a swelling smectite clay.   All the carbonate minerals are significantly undersaturated. In other words, the injection water would tend to dissolve carbonate minerals present in the aquifer mineralogy rather than precipitate them. The equilibrium dissolved carbon dioxide is an elevated 25 mg/L. This is similar to the lower levels present in the native groundwater.

5.0 Mixing between Injection Water and Native Groundwater

One of the major concerns for any injection project is the potential for precipitation of minerals where the injection water mixes with the native groundwater. However, based on data provided for this study, a 50:50 mixture of injection water with native groundwater results in dilution of almost all native groundwater concentrations. Thermodynamic modeling estimates that the degree of undersaturation of the carbonate minerals in the injection water is sufficiently high that mixtures of the two waters only result in equilibrium conditions or conditions near equilibrium but slightly undersaturated. In other words, given this injection water chemistry as representative of actual future injection water chemistry, the modeling estimates that there are apparently no minerals in the database of about 650 that would precipitate creating a measurable problem when the water is injected.

The sodium adsorption ratio (SAR) was developed to determine if the dissolved sodium concentration in an irrigation water would result in adversely affecting the soil clays by ion exchange was calculated for the injection water. The injection water sample for this study has a SAR value of 3. SAR values less than 10 are considered acceptable. Therefore, the clay minerals in the aquifer mineral are likely to remain stable.

6.0 Potential Reactions between Injection Water Chemistry and Aquifer Mineralogy

Given the available injection water and native groundwater chemistry, thermodynamic equilibrium modeling results estimate that there are no apparent adverse chemical reactions that would occur between the injection water chemistry and the aquifer mineralogy that would likely have an adverse impact. Abiotic chemical reactions between the injection water and the aquifer mineralogy are likely to progress at a rate similar to that of the existing native groundwater system that occur from recharge to the individual well locations.