

Sand Lake Area Groundwater: Geochemistry and Aquifer Connectivity



A report to:

Anchorage Waterways Council

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Executive Summary

Unresolved concerns by local well owners about redevelopment of the Sand Lake Gravel Pits and potential contamination of local aquifers has prompted an additional study of hydrogeologic conditions and groundwater quality near the old gravel pits. Two test wells were drilled and sampled for stratigraphic information, and completed as monitoring wells in two of the three aquifers identified at the site. Water samples obtained from the two wells found differences in nitrates, arsenic, and tritium, although the major and trace ion geochemistry of the samples were more or less similar. A hydrogeologic cross section suggests that the “shallow” and “middle” aquifers may be connected in the vicinity of the gravel pit, potentially explaining why wells tapping the “shallow” and “middle” aquifers both contain tritium, although the log of a well tapping the “middle” aquifer suggests that water is derived from beneath a thick confining layer. Tritium in aquifers is attributed to water that has been recharged since the beginning of atmospheric testing of thermonuclear weapons in 1952. Water-level data indicate that there is a downward vertical gradient from the shallow aquifer towards deeper aquifers at the site, but that the quantity of flow is uncertain.

All volatile organic compounds and semi-volatile organic compounds were below their standard detection limits for both wells sampled. The deeper well sampled exceeded the USEPA maximum contaminant level for arsenic, while the shallow well exceeded the maximum contaminant level for nitrates. The arsenic is considered to be naturally occurring and consistent with values previously analyzed in the area. The nitrate concentrations are higher than values found in other well in the area and are likely attributable to local conditions that are not well understood. Shallow groundwater in the vicinity of the test drilling site is concluded to be susceptible to surface contamination and efforts to avoid or minimize future contamination of these aquifers are warranted.

Acknowledgements

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Introduction

Background

Redevelopment of the former Sand Lake Gravel Pit into residential housing (over 500 planned new homes) and two school sites has sparked increasing concerns among neighboring users of private wells over potential changes in water quality from the development. Surrounding neighborhoods are developed with on-site wells and septic systems serving mostly single-family homes. Past sand and gravel mining in the gravel

pit has resulted in the creation of two deep excavations that contain water, at least one of which (the South Pond) is directly connected to the adjacent water table aquifer (Figures 1 and 2).

Excavation and roiling of the pond in the 1970's and storm- and regrading-derived turbidity in the pond in 2004 are reported by residents to have closely preceded observations of sediment production from a well downgradient (westward) of the pond. These observations have heightened local concerns that activity in the former gravel pit may adversely affect well water quality in the vicinity of the pits.

Wells in the Sand Lake area tap a complex glacial stratigraphy of sands, silts, and gravels. Prior studies have provided mixed conclusions about the protection of wells by confining units. ADEC (2003) interpreted that continuous confining units are widely present in the area and that all wells in the area are adequately protected, while UAA (Munk et al., 2004) found that aquifers and confining units are highly irregular and frequently cannot be correlated from well to well. Kane et al (2008) found that there is a "complex hydrogeologic setting that makes it difficult to accurately delineate groundwater flow and can result in large differences in flow direction, rate, and head differences over short vertical distances." This lack of conformity by different investigators has further increased confusion and concern of residents.

UAF also found that some wells in the Sand Lake area contained tritium at post-1952 concentrations (Kane et al., 2008), including four wells ranging in depth from 250 to 300 ft. These data suggest that at least some wells in the Sand Lake area pump groundwater that is less than 60 years old and may be vulnerable to changes in the quality of water recharged to the aquifer on a multi-decadal or shorter timescale, contrary to earlier ADEC (2003) suggestions.

Study Objectives and Scope

The present study seeks to:

1. develop a better understanding of groundwater conditions in the West Dimond area downgradient of the South Pond by test drilling and sampling groundwater from multiple depths;
2. interpret the geologic findings at the test drilling locations along with data from surrounding well logs and surface exposures to understand boundaries, potential interconnections, and recharge-discharge relationships of aquifers; and
3. utilize groundwater geochemistry from the test wells to determine baseline water-quality characteristics, especially targeting water from different geologic strata, and investigate whether the water quality and geochemistry data are useful for interpreting aquifer interconnections via water quality "fingerprints".
4. evaluate seasonal changes in groundwater quality and geochemistry.

5. initiate a potential long-term groundwater monitoring station to detect potential changes in groundwater conditions over time.

These objectives have been pursued through the drilling and development of two monitoring/test wells on a private parcel in the West Dimond area of Anchorage. Each well was sampled twice, during February and again in April, 2009, with samples submitted for laboratory analyses. Local hydrogeologic relationships are presented in a cross section extending from the South Pond to the nearby Turnagain Arm incorporating the test well sites and publicly-available driller's logs of nearby wells. Chemical analyses of water samples are presented and discussed.

Local Hydrogeology

Extensive summaries of the geology and hydrogeology of southwest Anchorage have been presented elsewhere and are not repeated here (Ulery and Updike (1983), Munk et al. (2004), Moran and Galloway (2006), and Dearborn and Freethey (1974), among others).

In brief, sedimentation associated with multiple glaciations of the area has left behind a complex assemblage of nonlithified glacial, glaciofluvial, and glaciomarine sediments. No water wells in the study area are reported to penetrate lithified rock formations. Detailed cross sections by Munk and others (2004) showed that aquifers and confining units in many areas could not be confidently correlated from well to well because of the complex glacial stratigraphy.

Groundwater flow systems in the area are not well defined as a result of the complex stratigraphy and limitations imposed by 1) the absence of synchronous and reliable non-pumping water-level measurements and 2) accurate elevation measurements on wellheads. Maps by Munk and others (2004) and Kane and others (2008) show, in the West Dimond area, a general direction of groundwater flow to the southwest towards Turnagain Arm.

Methods

Test Well Installation and Development

Two test wells were drilled at locations shown in Figure 1 using air rotary drilling. The wells were cased with 6-in. steel casing and completed with open ends and developed with a natural gravel pack. Each well was constructed to Municipality of Anchorage standards for domestic water wells, including the installation of grout by the dry driven grout method. Well drilling observation and geologic sample logging was performed on-site during all active drilling by a geologic technician and periodically inspected and overseen by an Alaska-licensed professional geologist.

After initial air-lift development, submersible pumps were installed in each well in order to purge the wells until clear water was produced and to perform preliminary yield testing of the wells.

Appendix A contains the driller's logs of both wells as well as more detailed geologic logs of the wells.

Elevation Data

Elevation data collected with survey-grade GPS systems for selected points in the study area are provided in Appendix B.

Cross Section

Appendix C contains copies of well logs used for the preparation of a hydrogeologic cross section. The line of section and well locations are shown in Figure 1, and elevation control for selected sites was determined as described above and from the U.S. Geological Survey 1:25000 scale topographic map of the area.

Field and Laboratory Methods

In situ measurements of static groundwater level were made with an electric water-level indicator prior to purging the well and sampling the groundwater. Other field measurements taken during each sampling event included pH, dissolved oxygen, specific conductance, and temperature. Alkalinity and Fe^{2+} were also measured at the time of sampling using a portable titrating kit and colorimeter, respectively, following standard methods outlined in Munk et al. (in press) and modified USGS methods from Koterba et al. (1995).

Water samples were collected in cleaned high density polyethylene (HDPE) bottles for dissolved elemental concentrations, anions, and stable isotope analyses. The sample bottles were rinsed on site with the sample water three times prior to collection of the sample. The water samples for dissolved element analysis were filtered using a 0.45 μm membrane and were preserved using ultrapure nitric acid, and brought to pH less than 2.0. Another filtered but unacidified 60 mL sample was collected for anions analysis. The unfiltered water sample for stable (hydrogen and oxygen) isotope analysis was collected in a 15 mL HDPE bottle. A duplicate sample for major and trace element and anion analysis was collected during the first round of sampling in February 2009. All samples were stored at 4°C from the time of collection until time of analysis at UAA's Applied Science Engineering Technology (ASET) Laboratory. Inductively Coupled Plasma Mass Spectrometry (ICP-MS) was used for elemental concentration determination and Ion Chromatography (IC) for anion concentrations. Hydrogen and oxygen isotopes were analyzed, specifically: ^1H and ^2H (deuterium) and oxygen ^{16}O and ^{18}O , by stable isotope mass spectrometry in the Stable Isotope facility at UAA.

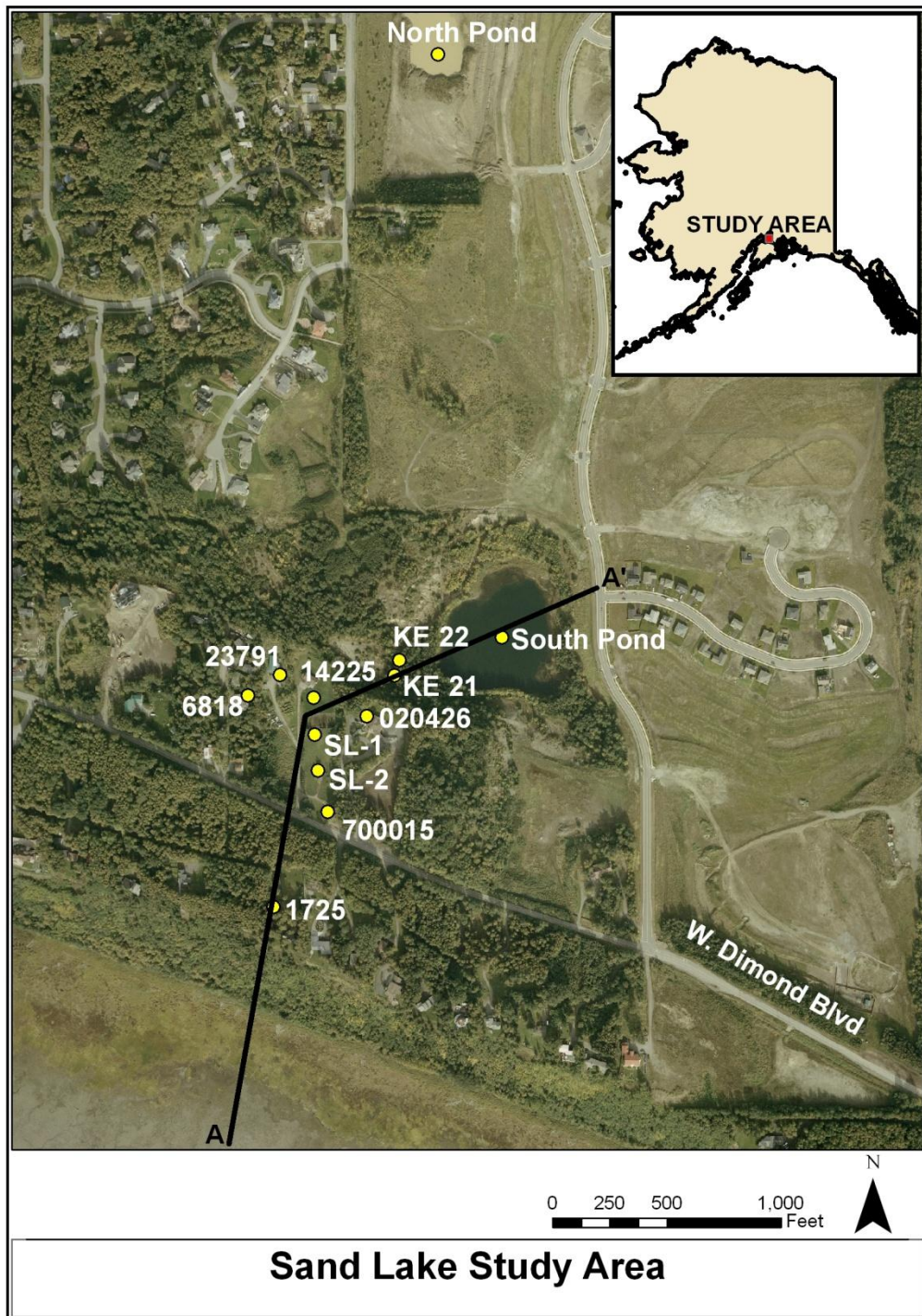


Figure 1. Aerial photograph of the study area in southwest Anchorage showing locations of wells, surface water elevation measurement sites used in this study, and the line of cross-section A-A' in Figure 2.

During the February sampling one water sample from each of SL-1 and SL-2 wells was collected in a clean, rinsed 500mL HDPE bottle with no head space and sent to the University of Waterloo Environmental Isotope Lab in Ontario, Canada, for tritium isotope analyses.

Water samples for volatile organic compounds (VOCs) and semi-volatile organic compounds were collected in clean glass containers provided by SGS labs Anchorage, AK. Samples were collected according to SGS protocols and stored on ice at 4°C and delivered to the SGS lab in Anchorage, Alaska. Chain of custody procedures for SGS labs was followed.

The duplicate major and trace element sample from the February sampling round indicates that the percent differences between the duplicate and the primary samples are less than or equal to 5% (Appendix D, Table 3) indicating very high quality of the data. Additionally, all calibration check verification standards and blanks that were run with the samples for multi-element analysis by ICP-MS indicate acceptable recoveries and below detection results, respectively.

Results and Discussion

Hydrogeology and Stratigraphy

Test drilling confirmed the presence of multiple aquifers in the area. Well SL-1 was completed to a depth of 90 ft below land surface in the shallowest waterbearing zone at the site. After penetrating through near-surface fill and peat, the borehole encountered predominantly sand until encountering saturated conditions at a depth of approximately 80 ft, tapping into a water table aquifer. The final static water level in the well was 81 ft below land surface. The well was pumped for 21 hours at a rate of 9 gallons per minute with a submersible pump in order to fully develop the well.

Test drilling of the second well, SL-2, southwest of SL-1, showed the presence of the water table sand and gravel aquifer extending to a depth of approximately 125 ft. The aquifer is underlain by predominantly fine- to very-fine-grained sand with estimated 30 to 40% silt. A second aquifer was encountered in well SL-2 at a depth interval of 210 to 217 ft below land surface. This aquifer produced water that could have been developed into a water well, however, it was decided to keep drilling to investigate deeper aquifers. A third aquifer was encountered at a depth of 310 ft producing a relatively strong estimated yield of 30-40 gpm with airlift pumping. The well was completed with an open end at a depth of 317 ft. Notable in the log of the well were two distinct intervals where abundant detrital coal fragments were encountered.

A Grundfos submersible pump was used to test pump and develop the well to produce clear water.

Water level data collected from the two test wells and converted to a common datum, show that the water level in the deeper well has consistently remained approximately 18 ft below the water level in the water table aquifer tapped by SL-1. This indicates that there is a downward potential for groundwater flow between the two aquifers, and that

the deeper aquifer has the potential of being recharged by the shallower aquifer. The quantity of flow between the aquifers is unknown.

The broader context of potential aquifer boundaries and relationships is presented by cross-section A-A' (Figure 2). Cross Section A-A' shows that the water table aquifer found in the test wells was also encountered by other wells in the area and by the South Pond excavation. The survey data show that the water table gradient from the area of the pond towards well SL-1 is approximately 0.007 ft/ft, which is within the range of water table gradients reported by Dearborn and Freethey (1974) for southwest Anchorage. Thus, groundwater in the vicinity of the South Pond can be expected to flow towards the southwest in the water table sand and gravel aquifer relatively unimpeded by any known geological boundaries. Since well 100015 was reportedly deepened after initial drilling, well SL-1 and well KE-21 (both monitoring wells) are now the only two known wells currently tapping the water table aquifer in the close vicinity of the line of cross section.

The cross section illustrates that the coal fragments identified at two different horizons during test drilling for this project were also noted in the driller's logs of wells 23791 (shallow) and 14225 (deep) suggesting some stratigraphic continuity of deposits in this area. Other well logs that do not denote the occurrence of coal does not necessarily indicate that coal was not encountered, only that the driller did not make note of it.

The mid-depth aquifer shown in the cross section is tapped by several wells in the area. Well SL-2 drilled through this aquifer to reach the deeper aquifer. The cross section provides an interpretation that postulates that the middle aquifer may be hydraulically connected to the shallow aquifer beneath the South Pond. This connection is supported by the finding of Kane and others (2008) that water from well 6818 contained elevated tritium concentrations (6.59 Tritium Units), indicative of the influence of atmospheric nuclear testing. The owner of this well reported that there was silt production in the well during 1) the summer that the pond was excavated and 2) following a major rain event in the fall of 2004 after a summer of grading activity in the Sand Lake Gravel Pit and 3) the sudden influx of turbid stormwater runoff into the pond.

All well data consistently show that there is a downward hydraulic gradient between the shallow and middle aquifers, showing the potential for groundwater flow from the shallow aquifer to the middle aquifer, however the quantity of flow is unknown.

A deeper aquifer is tapped by three wells in the area. The recharge-discharge relationship between the mid-depth and deep aquifers is not clear because of the lack of surveyed elevation control and time-synchronous water-level data from the private wells in the area. A comparison of data between SL-1 and SL-2, however shows that there is a significant downward gradient between the shallow and deeper aquifers. The deep aquifer did not produce any detectable tritium, indicating that that aquifer appears not be directly connected to recent atmospheric circulation. The potential relative isolation of this deeper aquifer is depicted in figure 2.

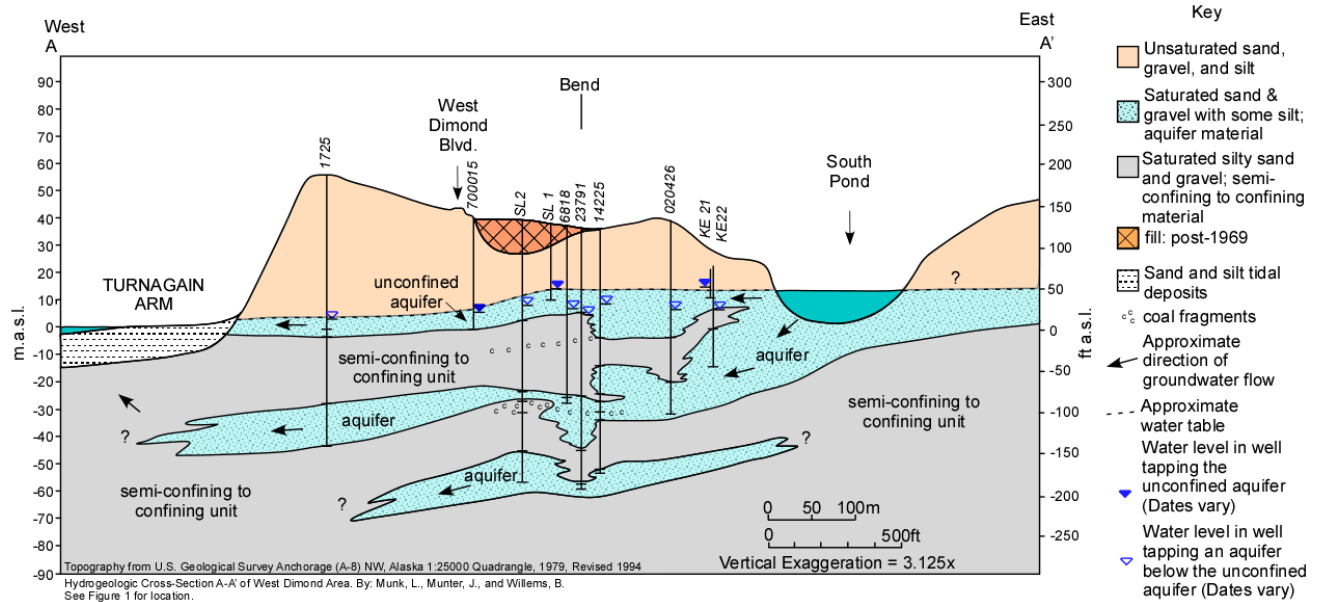


Figure 2. Hydrostratigraphic Cross section A-A'.

Groundwater Quality and Geochemistry

Static water level (measured from the top of the well casing down) is illustrated in Figure 3. Static water level measurements for SL-1 were 83.80 ft in February and 83.85 ft in April and for SL-2 the measurements were 107.30 ft and 106.92 ft, respectively. The field water quality measurements included pH, temperature, specific conductivity, and dissolved oxygen which are illustrated in Figure 4 and listed in Table 1, Appendix D. These water quality parameters were measured in February and April 2009 at both SL-1 and SL-2. pH measurements from SL-1 were 5.91 and 5.97 and 7.53 and 7.91 for SL-2. Temperature of the groundwater from SL-1 was 5.50 °C in February and 6.60 °C in April and for SL-2 was 3.70 °C and 3.70 °C, respectively. Specific conductivity was higher in SL-1 at 487 $\mu\text{S}/\text{cm}$ in February and 462 $\mu\text{S}/\text{cm}$ in April as compared to 283 $\mu\text{S}/\text{cm}$ in February and 284 $\mu\text{S}/\text{cm}$ in April for SL-2. Dissolved oxygen in SL-1 was .92 mg/L in February and .83 mg/L in April and 5.89 mg/L and 2.03 mg/L for SL-2, respectively.

Water levels in the two wells are different as SL-1 taps a more shallow part of the aquifer than SL-2 (Figure 2), with very little change in water level for SL-1 between sampling times. SL-2 however, shows an increase of 0.38 ft from February to April. The field water quality measurements indicate that the groundwater in both SL-1 and SL-2 differs significantly in pH (more acidic in SL-1) and dissolved oxygen content (much less in SL-1). It is possible that the high organic content of the fill material encountered in SL-1 has caused this lower pH and dissolved oxygen level. The presence of organics can result in a lower pH due to the release of organic acids as well as decreased dissolved oxygen as the organic material decays and consumes available oxygen. Specific conductance is also higher in SL-1 vs. SL-2 which can be an indicator of more

dissolved constituents in SL-1 as compared to SL-2 groundwater. Temperature is slightly lower in SL-2 as compared to SL-1 likely because the groundwater from SL-2 is being extracted from a deeper part of the aquifer, however, these temperatures are consistent with groundwater temperatures measured by Munk et al., (in press) and Kane et al., (2008).

A piper plot illustrating the overall groundwater composition in terms of major cations and anions is provided in Figure 5. This plot indicates that the groundwater from SL-1 and SL-2 is classified as Ca-Mg-HCO₃ which is consistent with other studies of groundwater in Anchorage (Munk et al., in press). The piper plot also indicates that the water in both wells is relatively similar in terms of major cation and anion classification and does not vary much between sampling events with the exception that the water has relatively more HCO₃ in the April sampling event which is likely the result of increased infiltration due to the start of break-up in April, 2009.

Other anion results including NO₃⁻ are included in table 2. It is worth noting that the NO₃⁻ concentrations in SL-1 were 34.0 mg/L and 19.0 mg/L in February and April, respectively. Groundwater from SL-2 had NO₃⁻ that was below analytical detection during both sampling rounds. The USEPA drinking water standard for nitrate is 10 mg/L. The cause for the higher nitrate concentrations in SL-1 is not certain, however, SL-1 is approximately 90 feet deep and therefore draws water from a more shallow part of the aquifer system. In general, shallow aquifers are more susceptible to contamination from near-surface sources, which could be contributing the NO₃⁻ to the groundwater. In any case, the high concentration of NO₃⁻ is also consistent with the lower dissolved oxygen as described above and higher overall Fe²⁺ measured in SL-1 (see results and discussion below). The nitrate values detected are significant higher than any of the values reported by Kane and others (2008) (maximum value 7.65 mg/L) and is unlikely to be naturally-occurring. Further testing of this groundwater for NO₃⁻ is highly recommended and warranted as there may be an unknown source of contamination in the vicinity.

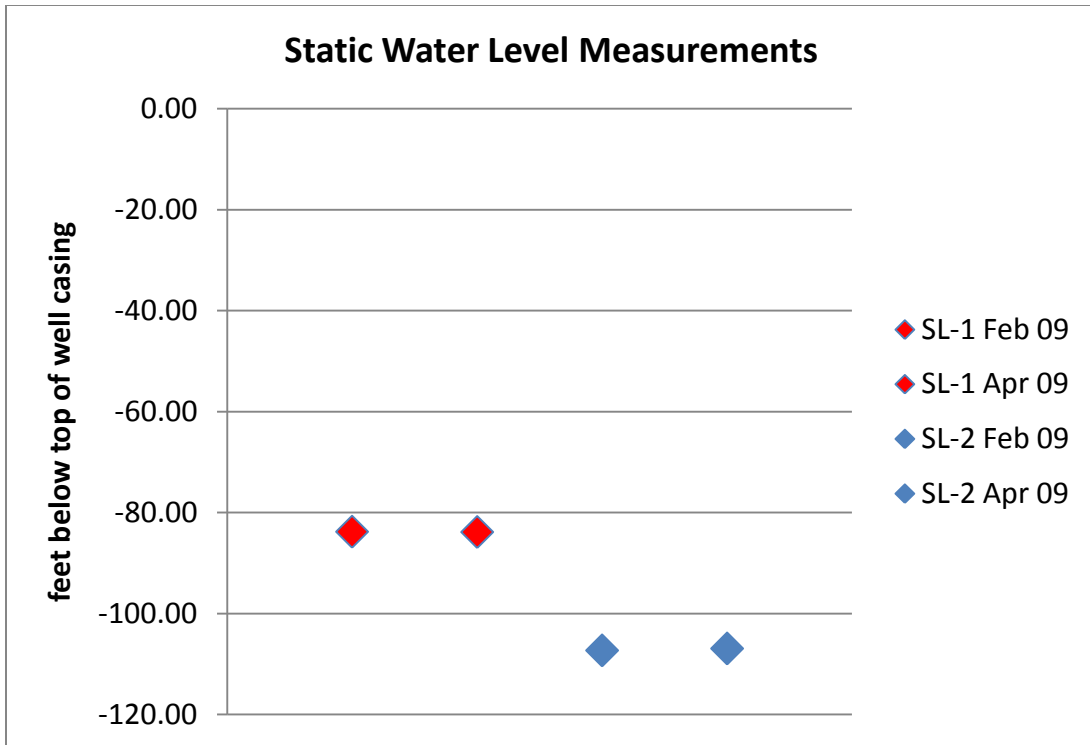


Figure 3. Static water levels in SL-1 and SL-2. Please note the static water level is feet below surface of the well casing.

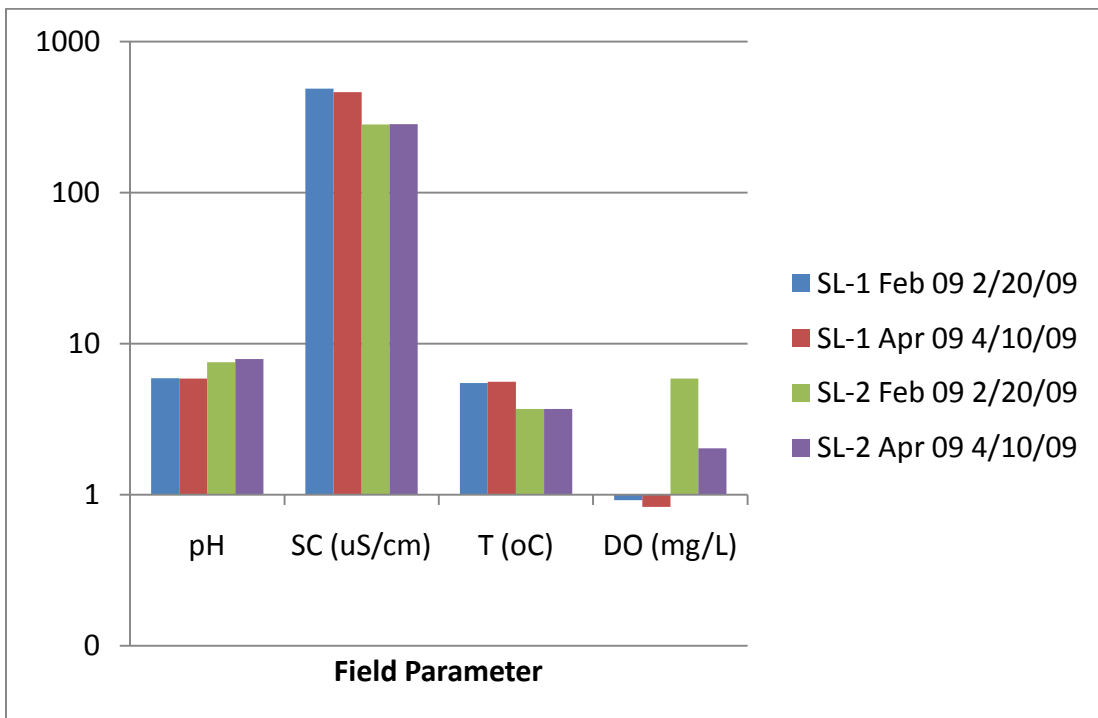


Figure 4. Field water quality measurements for SL-1 and SL-2.

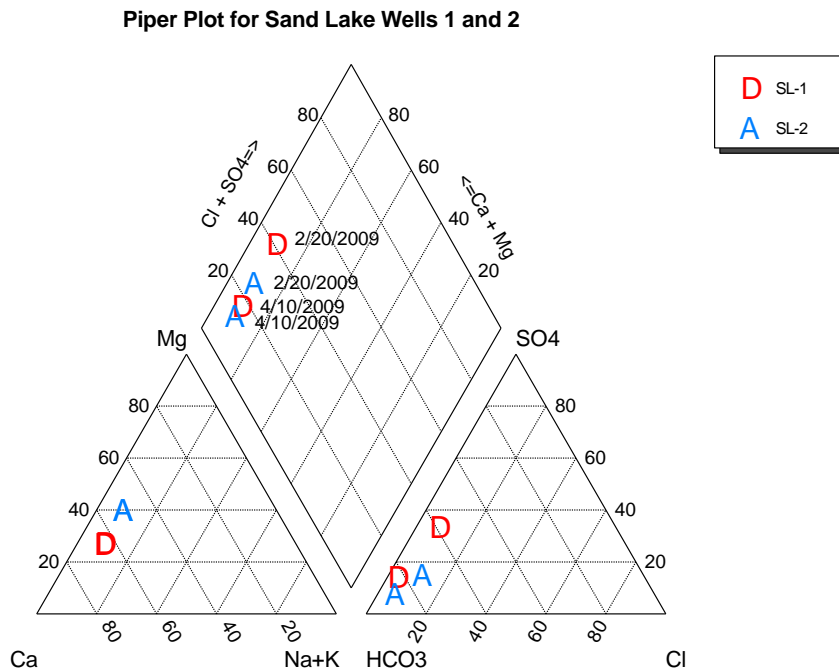


Figure 5. Piper plot indicating the Ca-Mg-HCO₃ character of the groundwater sampled in SL-1 and SL-2.

Iron and manganese are two elements that are very sensitive to changes in pH and the amount of dissolved oxygen as compared to major elements which are generally geochemically conservative in most groundwater environments. Figure 6 illustrates the dissolved iron and manganese concentrations for SL-1 and SL-2 for both sampling times. SL-1 has concentrations of dissolved Fe and Mn that are an order of magnitude higher than the dissolved concentrations in groundwater samples from SL-2. Lower pH and lower dissolved oxygen combined with elevated NO₃⁻ in the groundwater from SL-1 also correspond to higher dissolved Fe and Mn in that water. This is compared to the deeper water in SL-2 which has higher pH and higher dissolved oxygen and no detectable NO₃⁻. Iron and manganese are favored to precipitate as solid oxyhydroxides from aqueous solution in the presence of abundant dissolved oxygen (Faure, 1998). The net effect of this geochemical process is to reduce the amount of dissolved concentrations of both elements in solution. This is likely the dominant process responsible for the iron and manganese concentrations being up to an order of magnitude lower in SL-2 as compared to SL-1. Furthermore, the measurements of Fe (II) (Table 1, Appendix D) made in the field indicate that there is more reduced Fe

present in SL-1 as compared to SL-2 groundwater during both sampling events. The more reduced form of Fe, which is Fe (II), will be higher when less dissolved oxygen is in the system (Faure, 1998). In addition, the high NO_3^- in SL-1 is contributing to overall iron reduction.

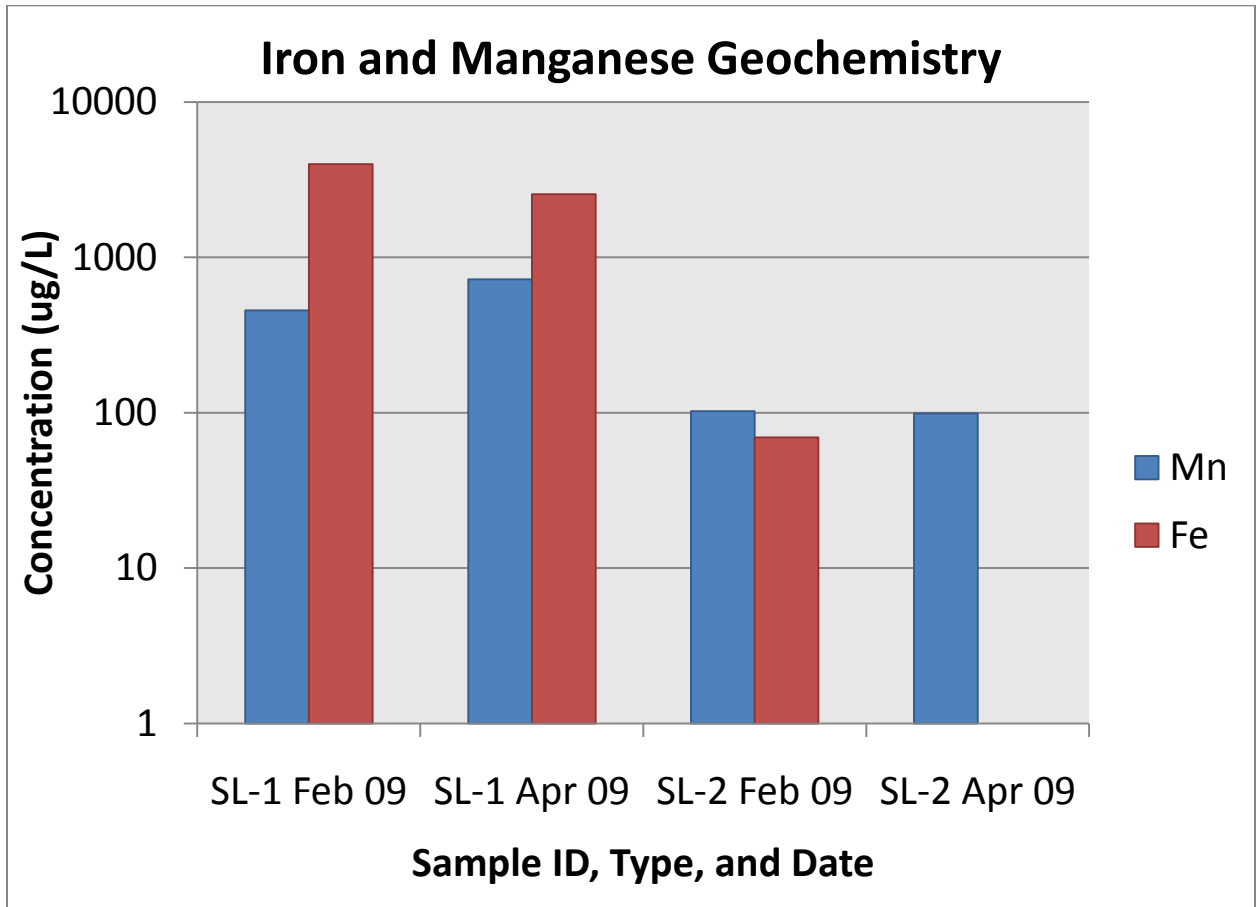


Figure 6. Dissolved Fe and Mn concentrations in SL-1 and SL-2.

Trace element geochemistry can also aid in understanding groundwater composition and to decipher differences and similarities in the water collected from different parts of an aquifer. Figure 7 illustrates the trace element concentrations of cobalt, nickel, copper, zinc, arsenic, selenium, and molybdenum. These are the most common measureable trace elements in the Anchorage groundwater (Munk et al., in press and current study). For the most part, the cation trace elements including Co, Cu, and Zn are of low concentration (<5 $\mu\text{g/L}$) and do not vary much from SL-1 to SL-2 or based on sampling time. However, the groundwater from SL-1 did have elevated nickel during the February sampling event, but without a longer term data set it is not possible to conclude what may have caused the potentially anomalous concentration of nickel. Additionally, the arsenic concentrations in groundwater from SL-2 are above the EPA

maximum contaminant level (MCL) of 10 µg/L but below the detection limit (<1 µg/L) in groundwater from SL-1. The elevated As in SL-2 is a potential health hazard to those consuming untreated drinking water from the aquifer.

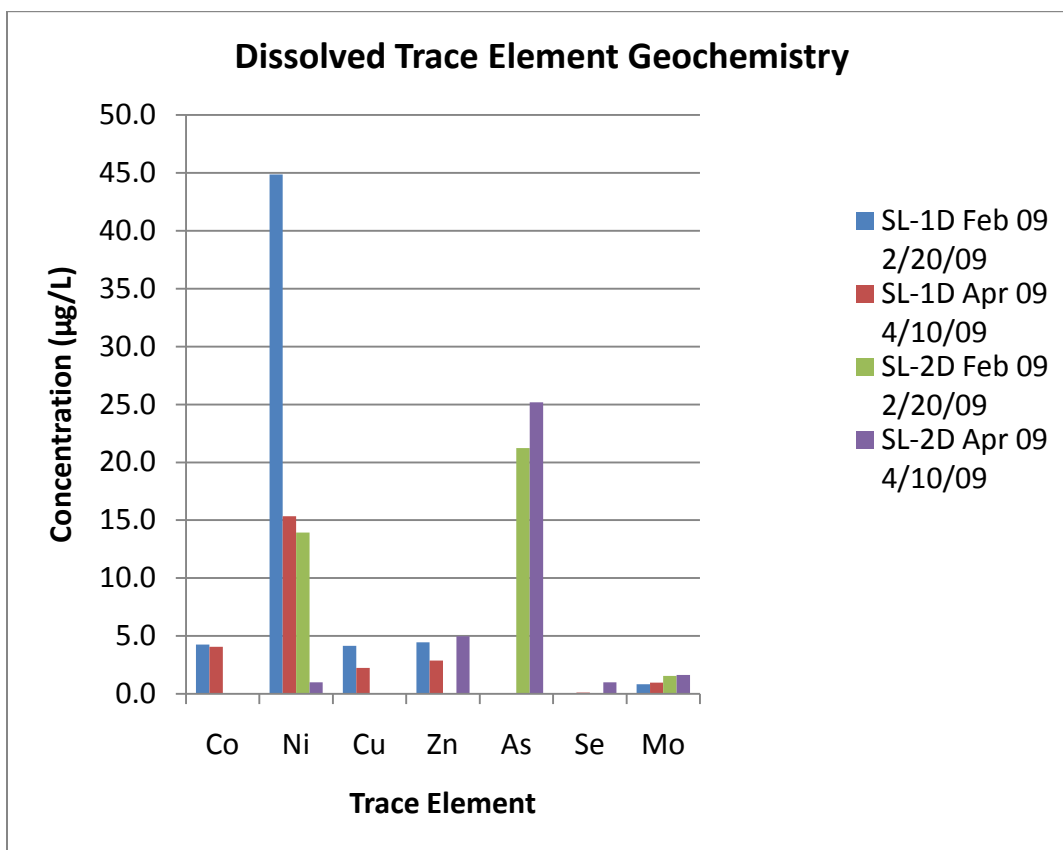


Figure 7. Trace element concentrations. Note the elevated concentration of arsenic in SL-2.

The hydrogen and oxygen isotopic composition of groundwater is the result of mixing of recharge sources (rain, snow, etc.) as well as water-rock interactions that occur in the aquifer (Faure and Mensing, 2005 and references within). The isotopic composition of meteoric water varies on a seasonal basis and as a function of source and path of air masses brought in during storms. Essentially, temperature is the controlling factor on the relative isotopic composition of meteoric water in that colder temperatures result in larger fractionation factors which cause the resulting precipitation to be more depleted in the heavier isotope of oxygen (^{18}O) and hydrogen (^2H or D) than precipitation falling during warmer temperatures. For example snow falling in winter will have less ^{18}O and ^2H than rain falling in the summer. Therefore, any variable affecting the temperature of an air mass can cause changes in the isotopic composition of the resulting precipitation, including altitude and latitude. Because geologic materials (rocks and minerals) contain higher amounts of ^{18}O , water that interacts with these materials, for example in an aquifer, will undergo isotopic exchange with the rocks and minerals and therefore will have a larger $\delta^{18}\text{O}$ signature (Faure and Mensing, 2005).

The stable isotopic composition of the groundwater collected from SL-1 and SL-2 monitoring wells indicates that this water is very similar in isotopic composition between wells and during both sampling events with only minor variations of 1-3‰ (per mil) (Figure 8). This indicates that the source(s) of the water to the aquifer is similar and that the geologic material in the shallow and the upper parts of the aquifer is also likely similar. Additionally, these values are consistent with the range of values from Kane et al. (2008) (see comparison in Figure 8) with a slight variation likely due to differences in sampling times and years. The data from Kane et al. (2008) also indicate an overall enrichment in $\delta^{18}\text{O}$ likely reflecting the water-rock interactions in the aquifer. Overall the data for the monitoring wells falls slightly to the right of the Meteoric Water Line (MWL) and the Local Meteoric Water Line (LMWL) which was developed for the Anchorage and Matanuska-Susitna Valley by Sjoström et al. (2006). The MWL represents a trend line that all meteoric water plots along in terms of its hydrogen and oxygen isotopic composition. Therefore, a deviation from that line may indicate that there are other processes affecting the isotopic composition of the water. The data for the two monitoring wells indicate a slight enrichment in ^{18}O which is likely due to water-rock interactions. Standard Mean Ocean Water (SMOW) represents water with no fractionation effects and therefore has average $\delta^{18}\text{O}$ and δD values equal to zero.

Another isotope of hydrogen that can be useful in determining the relative age of groundwater is tritium (^3H) which naturally occurs in extremely low concentrations but has been added to the atmosphere from detonation of thermonuclear bombs. This tritium then becomes part of water that is stored in aquifers. Because we know that the largest amount of tritium was added to the atmosphere between 1952-1963, it is possible to use that time frame as a relative cutoff of water stored in aquifers that is older versus younger than that time (ie. relative dating). Tritium was analyzed in the February samples from SL-1 and SL-2. The results are shown in Table 4 and indicate that the deeper well (SL-2) has a value below the detection limit of 0.8 TU and the shallower well (SL-1) has a value of 4.3 TU indicating that at least a portion of the water in the shallow well was recharged subsequent to 1952 and is younger than the water in the deeper well. These data are within the concentration range reported by Kane et al. (2008) for a much larger set of data for groundwater tritium in the Sand Lake area.

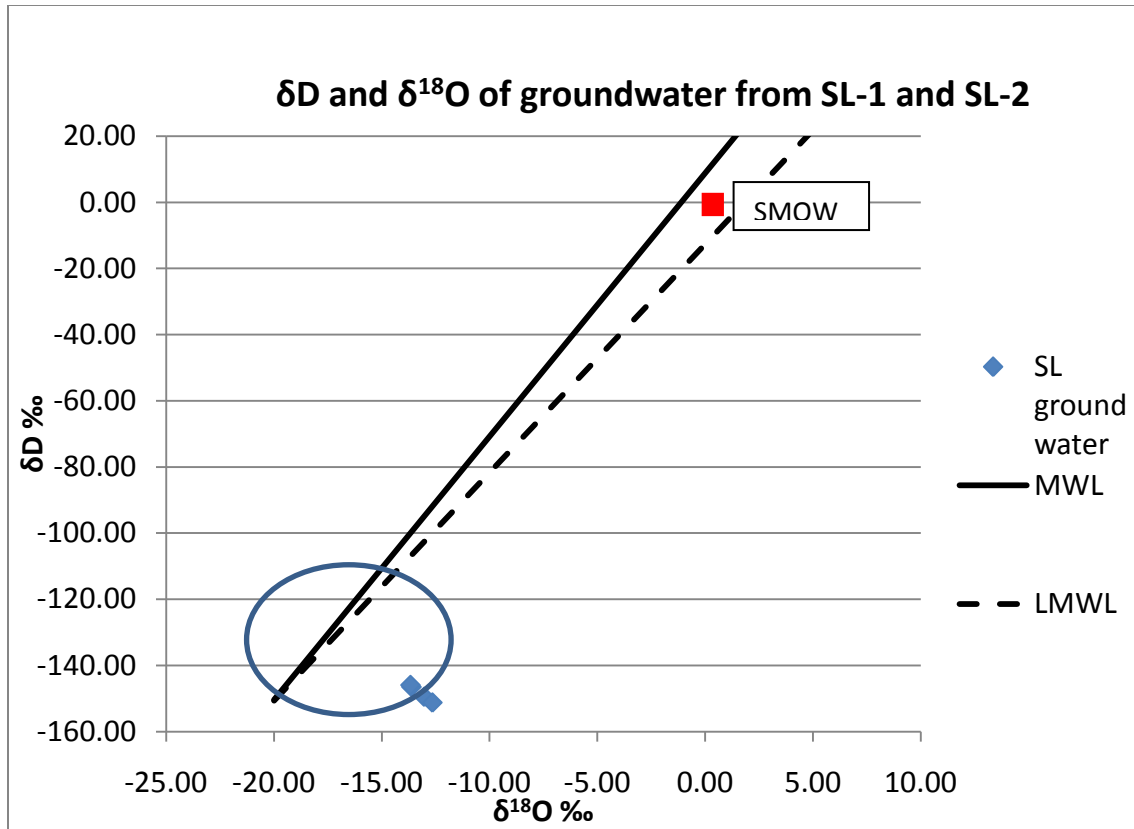


Figure 8. $\delta^{18}\text{O}$ (oxygen) and δD (hydrogen) isotopic ratios of groundwater from SL-1 and SL-2 monitoring wells. MWL = Meteoric Water Line (global) and LMWL = Local Meteoric Water Line based on precipitation data from Anchorage and the Matanuska-Susitna Valley area (Sjostrom et al., 2006). Blue oval represents the general area of data points from Kane et al. (2008), SMOW = Standard Mean Ocean Water.

Volatile Organic Compounds and Semi-Volatile Organic Compounds

All volatile organic compounds and semi-volatile organic compounds were below their standard detection limits as reported by SGS labs Anchorage, Alaska (Appendix E).

Conclusions

Test drilling, water quality analyses, and a hydrogeologic cross section have shown that the South Pond in the former Sand Lake Gravel Pit and its associated aquifer is connected to a shallow aquifer downgradient of the pond and groundwater can be expected to flow relatively unimpeded by geological boundaries towards the test well sites. The shallow aquifer is also hypothesized to potentially provide recharge to a mid-depth aquifer downgradient of the pond. A deeper aquifer at the site may be more hydrogeologically separated.

The shallow aquifer is also shown to contain elevated tritium, indicative of receiving atmospheric recharge subsequent to the beginning of atmospheric testing of nuclear explosives in 1952. The mid-depth aquifer has previously been shown to also contain tritium at similar concentrations, further supporting a relatively direct aquifer connection between the two aquifers. The deeper aquifer in the area does not contain measurable tritium and may be locally separated from the shallow and mid-depth aquifer.

Water quality and chemistry data show that there are some differences in water chemistry between the shallow and deep aquifers particularly in terms of pH, dissolved oxygen, nitrates, iron and manganese concentrations, and some trace elements, most notably arsenic. Except for nitrates, the variations are within the range of a more comprehensive study of the Sand Lake area aquifers by Kane et al., (2008). The data set for this study and the variations in the results are small enough that “fingerprinting” of different water types to demonstrate separation of aquifers is inconclusive. Additionally, no major seasonal differences in water chemistry were detected; however, only two sampling events were possible for this study. Results from a more comprehensive seasonal groundwater study in Anchorage by Munk et al., (in press) indicate that over a five month period (based on monthly sampling) there are significant changes in the overall water quality and composition in the Anchorage aquifer, particularly with respect to the mobility of arsenic.

Water quality data also show that waters from both wells meet maximum contaminant levels for the parameters measured, except that water from the deep aquifer exceeded the maximum contaminant level for arsenic and water from the shallow aquifer exceeded the maximum contaminant level for nitrates. These maximum contaminant levels are applicable to public water systems and are also set by the US Environmental Protection Agency and the World Health Organization. Kane and others (2008) found that most wells in the Sand Lake area also exceed the MCL for naturally-occurring arsenic. This is a very significant environmental problem that may be affecting the health of those drinking the untreated groundwater.

The source of nitrates in well SL-1 is not known, but the levels found are significantly above what is typically considered natural background concentrations in Anchorage (typically more than 2 or 3 mg/L nitrates is considered man-caused). The presence of these nitrates, along with the presence of tritium, shows that the shallow and mid-depth aquifers appear to be susceptible to surface contamination and that efforts to avoid or minimize future contamination of these aquifers are warranted.

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Appendix A: Test Well Logs

Appendix B: Survey Data

Appendix C: Logs used for Cross Section

Appendix D: Field Data and Inorganic Geochemistry Data Tables

Table 1. Field data measurements for Sand Lake Area Monitoring Wells

Sample ID	Date	SWL (ft below top of casing)	pH	SC ($\mu\text{S}/\text{cm}$)	T ($^{\circ}\text{C}$)	DO (mg/L)	Alk (mg/L) as HCO_3^-	Fe (II) (mg/L)
SL-1	2/20/09	83.80	5.91	487	5.50	0.92	104	>3.30
SL-1	4/10/09	83.85	5.87	462	5.6	0.83	220	1.75
SL-2	2/20/09	107.30	7.53	283	3.70	5.89	51	0.00
SL-2	4/10/09	106.92	7.91	284	3.7	2.03	128	0.07

Table 2. Anion data for Sand Lake Area Monitoring Wells

Sample ID	Date	F^-	Cl^-	SO_4^{2-}	NO_3^-	$\text{P}_2\text{O}_4^{2-}$
SL-1	2/20/2009	bd	8.4	46.6	34.0	nd
SL-1	4/10/2009	bd	6.1	29.6	19.0	nd
SL-2	2/20/2009	bd	5	8.2	nd	nd
SL-2a	2/20/2009	bd	5.1	7.9	nd	nd
SL-2	4/10/2009	bd	5.8	8.9	nd	nd

nd = not detected (below detection limit)
all units are in mg/L

Table 3. Major and trace element data for Sand Lake Area Monitoring Wells

Element	units	LOD	SL-1	SL-2	SL-2a	% Diff between SL-2 and SL-2a	SL-1	SL-2
			2/20/2009	2/20/2009	2/20/2009		4/10/2009	4/10/2009
Be	$\mu\text{g}/\text{L}$	0.0					<LOD	<LOD
Na	$\mu\text{g}/\text{L}$	51.2	16696.5	10591.8	10926.6	3.2	16701.6	10849.5
Mg	$\mu\text{g}/\text{L}$	49.5	26446.0	25197.5	26012.0	3.2	25469.9	25492.0
Al	$\mu\text{g}/\text{L}$	0.9	5.9	<LOD	<LOD	NA	1.5	<LOD
K	$\mu\text{g}/\text{L}$	147.9	1375.5	1939.0	1951.8	0.7	1350.5	1983.3
Ca	$\mu\text{g}/\text{L}$	114.5	103114.1	52720.0	55525.4	5.3	98452.1	53146.4
V	$\mu\text{g}/\text{L}$	0.6	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Cr	$\mu\text{g}/\text{L}$	1.3	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Mn	$\mu\text{g}/\text{L}$	0.8	456.6	102.2	103.5	1.3	721.7	99.0
Fe	$\mu\text{g}/\text{L}$	68.8	3990.6	69.5	<LOD	NA	2548.9	<LOD
Co	$\mu\text{g}/\text{L}$	0.7	4.3	<LOD	<LOD	NA	4.1	<LOD
Ni	$\mu\text{g}/\text{L}$	0.9	44.9	13.9	14.2	2.0	15.3	1.0
Cu	$\mu\text{g}/\text{L}$	1.2	4.1	<LOD	<LOD	NA	2.2	<LOD

Element	units	LOD	SL-1	SL-2	SL-2a	% Diff between SL-2 and SL-2a	SL-1	SL-2
Zn	µg/L	1.2	4.5	<LOD	<LOD	NA	2.9	5.0
As	µg/L	0.7	<LOD	21.2	21.3	0.2	<LOD	25.2
Se	µg/L	0.9	<LOD	<LOD	<LOD	NA	0.1	1.0
Mo	µg/L	0.5	0.8	1.6	1.6	1.3	1.0	1.6
Ag	µg/L	0.6	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Cd	µg/L	0.9	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Sb	µg/L	0.7	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Ba	µg/L	0.5	55.6	51.9	52.5	1.2	53.9	53.0
Tl	µg/L	0.7	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Pb	µg/L	0.5	<LOD	<LOD	<LOD	NA	<LOD	<LOD
Th	µg/L	0.8	<LOD	<LOD	<LOD	NA	<LOD	<LOD
U	µg/L	0.6	<LOD	<LOD	<LOD	NA	<LOD	<LOD

<LOD = below the limit of detection

NA= not applicable

Sample	Date	Tritium	$\delta^{18}\text{O}$ (‰)	δD (‰)
SL-1	2/20/2009	4.3	-13.03	-149.47
SL-1	4/10/2009		-12.65	-151.21
SL-2	2/20/2009	<0.8	-13.62	-146.49
SL-2	4/10/2009		-13.67	-145.90

Tritium is reported in Tritium Units (TU)

1TU = 3.221 Picocuries/L

1TU = 0.11919 Becquerels/L

Appendix E: SGS VOC and Semi-VOC Data