APPENDIX H

THE WELLS OF LOREN AND BETTY DODDS AND DAN SHANTZ AND PARTICLE TRANSPORT ANALYSIS IN GROUNDWATER

Once you eliminate the impossible, whatever remains, no matter how improbable, must be the truth. - Arthur Conan Doyle

Background

One of the central concerns of this study stems from reports of two wells contaminated by sediment that were alleged to have been directly related to the digging of the South Pond. The pond was reportedly dug with a drag-line in 1978 and excavated to a depth of 45 feet below the water surface (Dodds, 2002/Attachment H-1; Dodds and Dodds, 2003/Attachment H-2). The following year, attempts to mine gravel with a hydraulic suction device on a barge ended when the barge tipped and sank.

The sedimentation events in the two wells are described in a 2003 affidavit by Betty and Loren Dodds (Dodds and Dodds (2003)/Attachment H-2):

> In the mid-1970s Mike Stephens, a local contractor, discovered a vein of high grade gravel in the south west corner of the pit. He kept digging in this area until he reached the water table. He brought in a dredging machine and kept digging until he created the "pond" which is at the center of this current controversy. In 2 1/2 - 3 weeks, we began to notice a film of sediments in the toilets and bathtubs. At this time it became obvious that there was a connection between gravel mining operations in the pit and the cloudiness and sedimentation in our water.
>
> The pump in neighbor Dan Shantz' well seized up and burned out. The pump as well as the hot water heater had to be replaced.
>
> Stephens' gravel mining permit expired in the fall and the dredging stopped. Our water began to clear up and within 5-6 weeks was no longer cloudy.

After the sedimentation event of the 1970s, Betty Dodds reported (in 2002) that the water has been "clear ever since" (oral commun., 12/13/02). Dodds, Loren and Betty (2002/Attachment H-3) also reported that they "had no problems with the well until 1978 when Mike Stephens...continued to mine gravel to a depth 45 feet below our water table".

The Dodds well was drilled in 1965 and the Dodds had lived on Summers Place and used the well since May 1966. The well was classified as a Class A public water-supply well in 1977 by ADEC because it served four homes. The well was reclassified as a Class C public water supply source in 1989. Class C wells are no longer regulated by ADEC.

Loren Dodds reported that " ... the year after Mike Stephans lost his equipment in the bottom of the pond, another operator tried to do hydraulic mining of the gravel in the bottom of the pond but the rocks were too big to come up" (Munter, 2003/Attachment H-4).

The two events of well sedimentation in 1978 are corroborated by letters written by Phyllis Backhaus (Attachment H-5), Karla Dodds Korman (Attachment H-6), and Dan Shantz (Attachment H-7).

These observations by people who witnessed them at the time of the events have never been doubted or refuted in any of the voluminous reviews of Sand Lake area groundwater resources.

The Dodds's and Shantz's wells are approximately 160 feet apart. The Dodds's well is interpreted to tap the upper zone at an elevation -92 feet MOA72 and the Shantz 1973 well is interpreted to tap the zone at an elevation of -52 ft MOA72. These wells are shown in Cross Section B-B' (Figure 8). A second well was drilled for the Shantz property in 2019, is similar to the 1973 well, and is also shown on Figure 8.

Numerous professionals have been made aware of these observations and tried to provide explanations for what happened or didn't happen, considering that transport of sediment through an aquifer for a distance of 840 feet or more from the pond to the Dodds's and Shantz's wells seems improbable, at best.

TERRASAT, Inc., the consultant for the developer of the pits in 2003 and 2004, dismissed the claims, asserting that the Dodds's water source was protected because "the confining unit is present across the proposed Kincaid Estates Subdivision and significant mixing of water between the upper water table aquifer and deeper aquifers is not occurring (TERRASAT, Inc., 2004a)

The Alaska Department of Environmental Conservation (ADEC, 2003) investigated the Sand Lake gravel pits area and found that "Class C public water system wells to the south and to the west of the proposed Kincaid Estates Subdivision fully penetrate a confining layer and draw water from the confined aquifer that is below, and is interpreted to be not connected to, the shallow overlying unconfined aquifer, or water table aquifer."

An independent review by the University of Alaska Anchorage in 2004 (Munk and others, 2004), concluded that: "There are several viable explanations regarding the occurrence of sediment/turbidity in wells near the southern pond near the site. We do not believe that this occurrence alone proves that the wells are hydraulically connected to the pond." These other potentially viable explanations are discussed in detail later in this Appendix.

Another independent study by the University of Alaska Fairbanks and review of the Dodds's assertion about the connection between the pond and their well (concluded that "It is our strong opinion that this is not physically possible" (Kane and others, 2008). Kane and others (2008) showed contamination of the Dodds and other wells by tritium from recent (subsequent to 1952) groundwater recharge from atmospheric sources. Kane and others (2008) do not provide an explanation of how tritium could be present in the Dodds' well water in the context of the conclusions by ADEC (2003) and TERRASAT Inc. (2004a) that the aquifer was protected by a confining unit.

The Municipality of Anchorage (as reported by Munk and others, 2004), concluded in their "Findings of Fact" that: "The Board found based upon geological information presented there does not appear to be the connectivity between the pond aquifer and the deeper aquifer from which the Dodds' well draws water. "

During the summer of 2004, large portions of the former gravel pit area were re-graded and the land surface re-contoured in preparation for residential development. This resulted in large areas of exposed soils where earthwork had been conducted. In late September 2004, a major rainstorm resulted in the flow of large quantities of sediment-laden water into the South Pond (See Photo H-1) resulting in the pond water becoming highly turbid and "reddish brown" (Watson Company, 2004; Attachment H-8). Sometime between October 9 and October 21, 2004, the Dodds filter became dirty with the "same reddish brown color" as the water in the pond. (Watson Company, 2004; Attachment H-8).

Photo H-1. Flow of turbid water towards South Pond, September 2004.

A few weeks after the late September storm, Betty Dodds came to a public meeting with two filters from their well-water filtration system that were heavily coated with fine sediment that appeared to be of a similar distinctive color as the sediment-laden pond water. Betty and Loren Dodds reported that this was highly unusual. These events are corroborated by SACC (2004), which states that "Betty Dodds well filters have heavy sedimentation that began approximately 3 weeks after the heavy rains of September."

The 2004 events were not included in the report by Munk and others (2004) because the discovery of clogged sediment filters in the Dodds' water system occurred after the release date of the report, October 6, 2004.

More recently, the Municipality of Anchorage (2019) has reported that "Some residents are concerned that this discharge (from a stormwater overflow structure into the South Pond) could adversely impact the water quality of the pond." This is rather an understatement of resident's concerns regarding their drinking water sources and the historical facts leading to those concerns. The Municipality seems to have acknowledged the relationship between the South Pond and drinking water supplies in the 1970's by initially refused to issue a mining permit for the following season (Dodds and Dodds, 2003). Only when the developer agreed to install a filtering system on the Dodds's water system was a permit issued.

Scope of investigation, approaches, and goals

This appendix provides a review of technical literature regarding particle transport in aquifers and applies the findings of this project to investigate and evaluate the Dodds's and Shantz's well histories. The findings of prior reviews of the matter are also reviewed and evaluated.

The approach taken in this review follows the concepts and principles of abductive reasoning, Occam's razor, falsifiability, and the method of multiple working hypotheses.

Abductive reasoning:

> starts with an observation or set of observations and then seeks to find the simplest and most likely conclusion from the observations. This process, unlike deductive reasoning, yields a plausible conclusion but does not positively verify it. Abductive conclusions are thus qualified as having a remnant of uncertainty or doubt, which is expressed in retreat terms such as "best available" or "most likely".
> (https://en.wikipedia.org/wiki/Abductive_reasoning)

Occam's razor:

> ...the preference for simplicity in the scientific method is based on the falsifiability criterion. For each accepted explanation of a phenomenon, there may be an extremely large, perhaps even incomprehensible, number of possible and more complex alternatives. Since failing explanations can always be burdened with *ad hoc* hypotheses to prevent them from being falsified, simpler theories are preferable to more complex ones because they are more testable. (https://en.wikipedia.org/wiki/Occam%27s_razor)

Falsifiability is further explained by:

> In the philosophy of science, falsifiability or refutability is the capacity for a statement, theory or hypothesis to be contradicted by evidence. For example, the statement "All swans

are white" is falsifiable because one can observe that black swans exist. (https://en.wikipedia.org/wiki/Falsifiability)

In this case, many possible explanations for the observations have been proposed. Each will be examined to determine how well it explains the observed facts using the method of multiple working hypotheses (originally from Chamberlin (1890;1897), as found at http://www.sortie-nd.org/lme/Statistical%20Papers/Chamberlain_1997.pdf) This method was long ago recognized as superior to earlier methods such as the method of a ruling theory or of a single working hypothesis. Any credible explanation for what happened (or did not happen) must be able to reasonably explain all of the observations. If it does not explain the observed facts or if it is burdened with excessive *ad hoc* hypotheses it is rejected.

Some investigators have dwelt on whether or not "proof" exists to substantiate the Dodds' claims. Having such "proof", perhaps in the form of a controlled modern experiment to attempt to duplicate circumstances that occurred in the 1970s would be useful, however it would be difficult to perform as a result of many practical considerations. Proof, in the rigorous scientific sense, is not possible with the existing information and is not considered necessary for the purposes of this study. Rather, the goal of this work is to provide a useful framework for resource managers and the public to better understand the plausibility and likelihood of what happened. Then, reasonable aquifer protection measures can be formulated and implemented and water users can be provided with some assurance that the quality of well water is reasonably protected for future use as a drinking water source or alternate water sources can be procured.

If concerns and aquifer protection measures are not resolved and a divergence of opinion remains, then the prospect of conducting an experiment to try to duplicate particulate transport through the aquifer or at least to conduct a dissolved tracer experiment in order to definitively prove aquifer connections or lack thereof is feasible and should not be ruled out. Three possible tracers that should be considered are: 1) introduction of a large quantity of suspended sediment in the South Pond; 2) fluorescein dye; and 3) an ionic tracer such as sodium bromide.

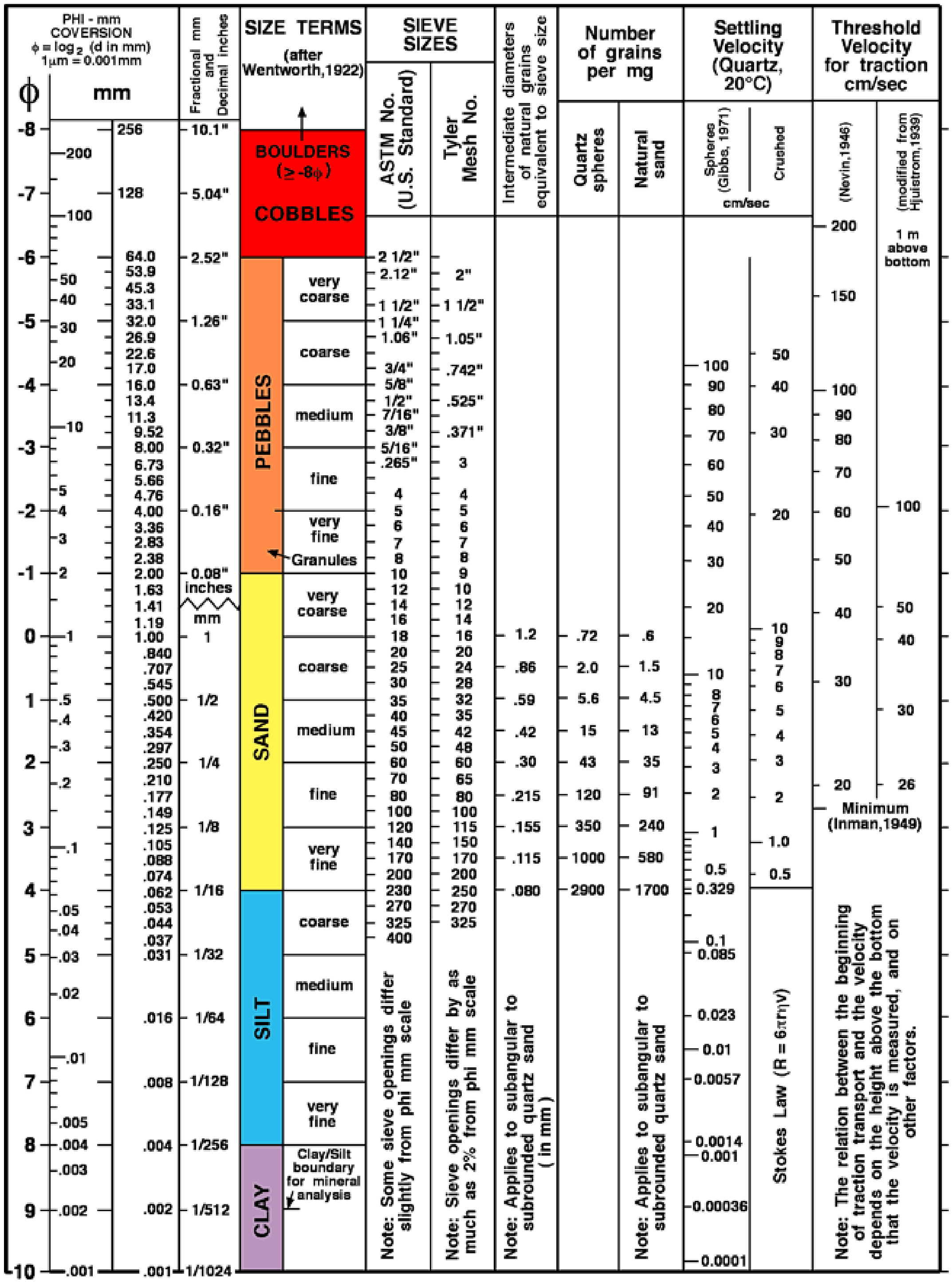
Particle transport in aquifers

Concepts and Processes. As early as 1986 is was known that, "transport of suspended particulate matter is widely recognized to occur in subsurface environments" (McDowell-Boyer and others, 1986). Abundant literature describes the transport of particulate matter in aquifers because of the importance of understanding pathogenic organism transport in aquifers, solid-phase contaminant transport, biorestoration of contaminated groundwater and other processes (Bradford and others, 2002). Much of the literature focuses on colloid-sized material, generally defined as less than 10 microns in diameter. One micron is one one-thousandth of a millimeter. A variety of inorganic, organic, and microbiological colloids exist in natural subsurface systems including silicate clays, iron and aluminum oxides, mineral precipitates, humic materials, microemulsions of non-aqueous phase liquids, viruses, and bacteria (Bradford and others, 2002)

Colloid particles vary widely in concentration, composition, structure, and size depending on the spatial and temporal variability of physical, chemical, and microbiological characteristics. The concentration of natural colloids in groundwaters typically ranges from 10^8 to 10^{17} particles L^{-1} (Kim, 1991).

The affidavit of Dodds and Dodds (2003) refers to a "film of sediments" and to "cloudiness and sedimentation" of water. These observations are consistent with particle sizes in water in the size range of clay and silt. Using the common geological classification of Wentworth (1922) silt particles are between 0.004 mm up to 0.0625 mm in diameter, or 4 to 62.5 microns and clay particles are from 1 to 4 microns. Colloid-sized particles, therefore, are generally in the range of clay to fine to very-fine silt.

Figure H-1 is a summary of particle size classification based on Wentworth (1922).



Source: U.S. Geological Survey Open-File Report 2006-1195 (Williams and others, 2006)
http://pubs.usgs.gov/of/2006/1195/htmldocs/nomenclature.htm

Figure H-1. Wentworth scale.

Some documents in the record refer to silt and sand being transported to the Dodds's and Shantz's wells (see, for example Shantz (2002)/Attachment H-7). Scientific or engineering reviewers have commented on the difficulty of transporting sand-sized material through aquifers. This review minimizes the significance of reports of sand-sized particle transport because:

- reports of particle sizes by non-professionals are inherently inexact;
- the real issue is the plausibility of transport of silt and clay sized material from the South Pond, because if this actually occurred, it has the clear effect of demonstrating the vulnerability of local wells to recurring contamination from the South Pond;
- one of the key documents of this discussion is the Dodds and Dodds (2003) affidavit, which never mentions "sand"; and
- this review will show that even the transport of fine sand through an aquifer is possible.

Bradford and others (2006) provides an overview of particle transport theory in porous media that is summarized here. Three mechanisms for colloid deposition from water containing colloids flowing through porous media are commonly recognized: attachment, mechanical filtration, and straining.

Attachment. Attachment is the process whereby solid particles in the fluid become attached to aquifer particles surrounded by water containing the colloids. In this case the pore sizes are considerably larger than the colloids and the colloids are transported to the solid grains of the aquifer through the fluid. Attachment for colloids is controlled by complex forces of gravity, buoyancy, fluid drag, electrical repulsion or attraction, and London-van der Waals interaction.

Mechanical filtration. Mechanical filtration refers to the retention of colloids, particles, and/or aggregates at soil surfaces that are too large to pass through soil pores resulting in the formation of a filter cake.

Straining. Similar to mechanical filtration, straining of colloids occurs in saturated aquifer pores and depends on the ratio of the colloid and pore size. Straining only occurs in a fraction of the soil pore space near grain-to-grain contacts or when grain roughness prevents particulates that are too large from fitting through the inter-granular openings. Similar to attachment, strained colloids experience forces due to gravity and buoyancy, fluid drag, electrical double-layer repulsion (or attraction), and London—van der Waals interaction.

It is common knowledge that sand filters are used in the water treatment process for removal of sediment and water purification and are used extensively in the water industry throughout the world (https://en.wikipedia.org/wiki/Sand_filter). We also know that there are limits to the filtering ability of porous media. For example, many Alaskans are familiar with the cloudiness and turbidity of rivers that have glacial sources and that carry large amounts of glacial silt, such as the Copper River, the Matanuska River, and the Susitna River, among many others. Common knowledge would tell us that if a sample of that water were poured through a column of ordinary glass marbles, the water coming out would likely be indistinguishable from the water going in and that no significant filtering or clogging would have occurred. Furthermore, this would not likely depend on the length of the column, be it 1 foot, 10 feet, 100 feet, or even 1000 feet. There must be some relationship, therefore, between the size of particles in the turbid water and the grain size or pore size of the porous medium. This topic has been rigorously investigated for many decades.

Sakthivadivel (1966, 1969) developed relationships between the effective diameter of small particles in water and soil grain size distribution characteristics to predict mass removal by straining. Sakthivadivel (1966, 1969) reported that straining was significant when the suspended particle diameter was greater than 5% of the median grain diameter of the porous medium (Bradford and others, 2002), but straining was not effective at smaller suspended particle diameters.

Matthess and Pekdeger [1985] generalized this rule to porous media made up of a distribution of grain sizes and presented theoretical criteria suggesting that the ratio of the colloid to median grain diameter needs to be greater than 18% for straining to occur in uniform sand, although increasing the sand gradation (i.e. a non-uniform sand) would lower this threshold. Recent experimental observations, however, suggests that straining occurs for much lower ratios of the colloid to median grain diameters (Bradford and others, 2006).

Applying these concepts to the South Pond area, Well KE-22 (Appendix A) reported a 35-ft thick aquifer interval comprised of:

> "Gravel with sand (GP): dark gray with olive, about 50% fine to coarse angular to rounded gravel; about 50% fine to coarse angular sand; no odor, Gravel to 1 inch. Coal chunks up to 3/4 inch." (TERRASAT, Inc., 2005).

The borehole was logged using the Unified Soil Classification (USC) system, which is slightly different than the Wentworth system. The size criteria distinguishing sand from gravel is 4.75 mm under the USC system, compared to 2 mm using the Wentworth system. Assuming that the median grain diameter of the material was 4.75 mm, a 5% threshold would be 0.24 mm (240 microns). This means that significant straining would occur for particle sizes larger than this size, which is near the upper size limit for a fine-grained sand. Very-fine-grained sand down to 62.5 microns would be well below this threshold. This indicates that it would be possible and plausible for sediment in the clay and silt size range (1 to 62. 5 microns) to flow through such material and that it would even be possible for fine- to very-fine-grained sand to pass through such material.

Another way of trying to understand the transport of particles through aquifers is to examine pore sizes or pore throat sizes in the porous medium. Figure H-2 is a diagram that visually compares the size ranges of typical pore sizes in different porous media (silt pore size = 0.4-12 microns, sand pore size = 12-400 microns, and gravel pore size >400 microns) with the sizes of pathogenic organisms. Clay and silt particles, between 1 and 10 microns in diameter, although not shown in the chart, are similar in size to bacteria and protozoa and are smaller than pores in sand and gravel deposits with large pores by up to three orders of magnitude (factor of 1000).

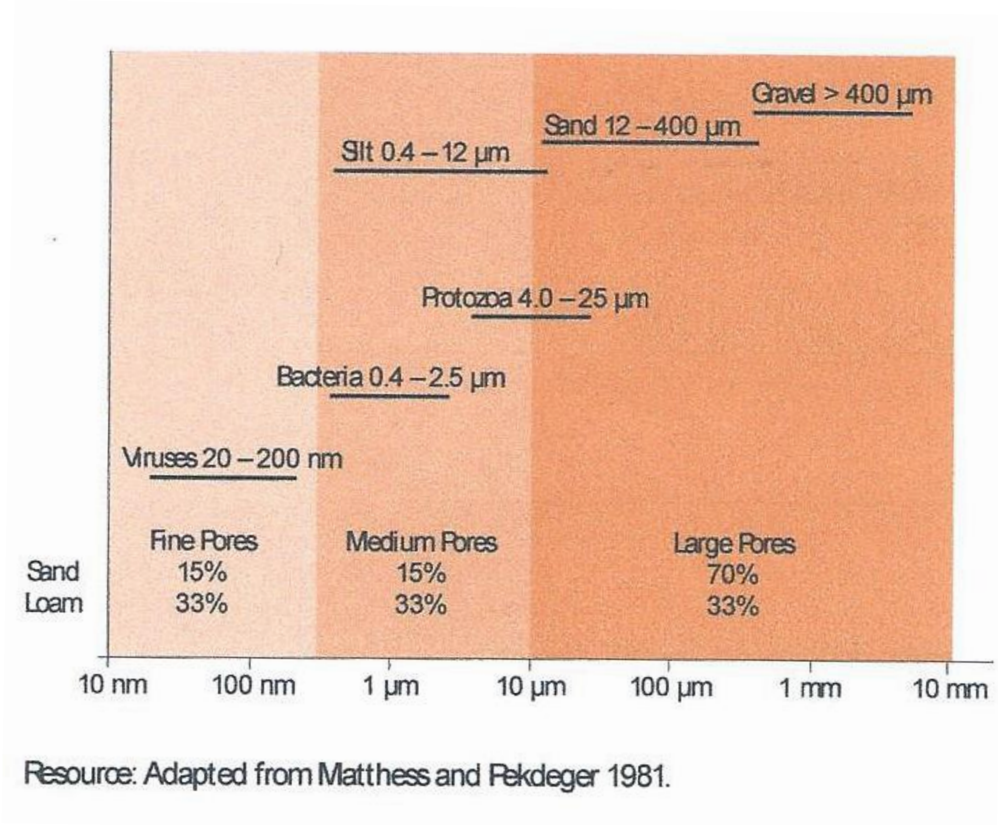


Figure H-2. Comparison of particle sizes to pore sizes. Size range of pathogens compared to aquifer matrix characteristics (at the top pore size ranges of silt, sand and gravel are shown) (from Krauss and Griebler, 2011).

Similarly, Vance (1994) summarizes pore entrance sizes as follows:

- fine to coarse grained silts pore entrance size ranges from 0.7 to 7 microns;
- fine to coarse grained sands from 24 to 240 microns; and
- fine to coarse grained gravels 720 to 7,200 microns.

Clearly, clay and fine silt particles are much smaller than pore entrance sizes of sands and gravels and would readily enter and flow through the pores.

Field studies

It is important to evaluate whether field studies corroborate the general concepts identified above. Figure H-3 show the results of a literature survey of documented travel distances of different types of pathogens in different types of aquifers. The results show that in porous aquifers, microbes and viruses may travel long distances of several hundred meters (Figure H-3).

These studies show that the transport of viruses and bacteria in sand and gravel aquifers for hundreds of meters is well documented.

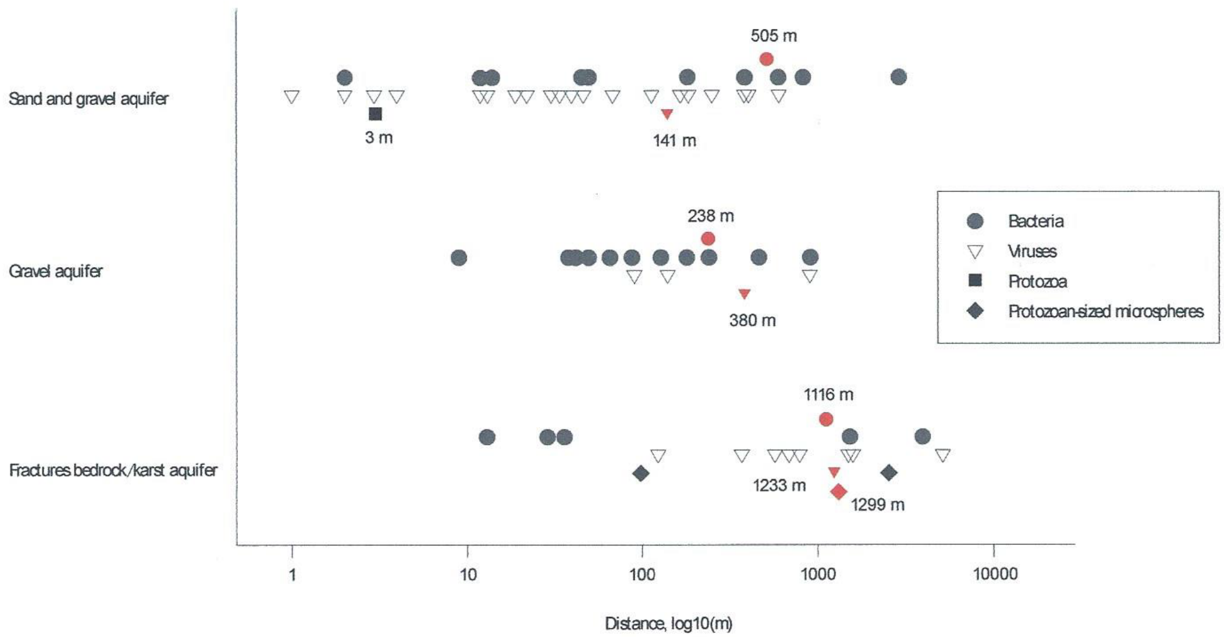


Figure H-3. Transport distance of pathogens in different aquifer matrices. Average travel distances are shown by red symbols. Data collected from the literature. (From Krauss and Griebler, 2011).

A study in Wyoming by the U.S. Geological Survey (Spangler and Susong, 2006) demonstrates an example of groundwater and suspended sediment (turbidity) flow through highly-permeable talus deposits towards a spring. The spring had been discharging silty water to a small lake. A fluorescein dye tracer was inserted into the groundwater flow system 1.45 miles upgradient of the lake and the tracer turned the lake water tell-tale green about one day later. This work demonstrated an average linear groundwater velocity of about 8000 ft/day at the site. The high permeability within this aquifer was also indicated by the large variation of springflow in response to snowmelt runoff and precipitation, and by the high concentration of suspended sediment (turbidity) in the water discharging into the spring-fed lake.

Application of the information summarized above to the South Pond area, it is reasonable to conclude that transport of clay- and silt-sized suspended sediment particles through a permeable sand and gravel aquifer material is plausible. A key requirement for evaluating potential flow of suspended sediment to local wells is the existence of a geological pathway to allow groundwater to flow between the South Pond and local wells.

Geological pathway analysis

An important part of this analysis is the geological framework and whether or not a continuous pathway of permeable deposits may exist between the South Pond and local wells. Figures 11 and 11a show the configuration of the top of the upper zone of the Anchorage confined aquifer system. This surface confirms the finding of Ulery and Updike (1983) that there is considerable relief on this surface. Additional relief is provided by the inclusion of the non-cohesive facies of the Bootlegger Formation in the definition of the upper zone (see discussion in main report). Several wells define the top of upper zone in this area. In particular, six wells listed in Appendix A and shown in Figure 11 show that there is an upward slope of the top of the upper zone from the Dodds's and Shantz's wells eastwards towards the South Pond. The wells, from west to east are (using the Well_ID in Appendix A):

- SH2-6(13)-2019 (Shantz 2019 well)
- SH2-6(13) (Shantz 1973 well)
- SH2-6(4A) (Dodds well)
- SH2-5C
- SH2-5B
- KE-22

The trend of slope and the data from Well KE-22 indicate the presence of an area where the upper zone is near sea level at the location of the South Pond. This means that the excavations for sand and gravel resources in the South Pond could have extended into the upper zone. As previously described, the reported depth of the pond when dug was about 45 feet. A depth of 45 feet would mean that the bottom of the pond is approximately the same elevation as the top of the sand and gravel zone noted in the well log for well KE-22. Mapping in this project shows that KE-22 and the Dodds's and Shantz's wells all tap the upper zone of the Anchorage confined aquifer system. In the western part of the South Pond, the upper zone of the Anchorage confined aquifer system is inferred to be unconfined (see Figure 11).

If the confining unit above the upper layer is not continuous, then a hydraulic connection may exist between the pond and the high-permeability sediments encountered by KE-22 and local water wells. Examination of Cross Section B-B' (Figure 8) shows that the confining unit noted in the well log for Well KE-22 is thin and very close to the bottom of the South Pond, suggesting that a gap in the confining unit may be present. Numerous studies have shown that sedimentary layers (such as the confining unit noted in the log of well KE-22 between depths of 50 ft and 75 ft) in this part of the former Sand Lake gravel pits tend to be discontinuous. Also, it seems unlikely that the excavation work that occurred to create the South Pond would have occurred if there was an extensive or thick confining unit present at that location.

This project assigns the base of the Bootlegger Formation at the Well KE-22 well site to an elevation below the bottom of the KE-22 well. The gravel and sand sediments in the bottom 35 feet of that borehole are assigned to the noncohesive facies of the Bootlegger, consistent with Updike and Ulery (1986), who commented that "aggregate is mined in the Sand Lake area from the coarse facies of the fan delta and the re-transported channel deposits in the marginal segments of the delta".

In natural lakes in glaciated terrains, it is common for fine-grained lake sediments that have accumulated since end of the most recent glacial age (more than 10,000 years ago) to impede groundwater-lake interactions. In this case, since the South Pond was formed only recently and because Loren Dodds reported (Munter, 2003) that hydraulic dredging encountered rocks too large to hydraulically lift, it is likely that the water in the pond is in direct contact with sands and gravels at the bottom of the pond. If these materials are part of the same formation as encountered by Well KE-22, which is located very close to the pond, then there is a direct geological pathway for pond water to enter the upper zone of the aquifer. This geological pathway is also indicated in a cross section by Munk and others (2010) (see Figures H-4 and H-5).

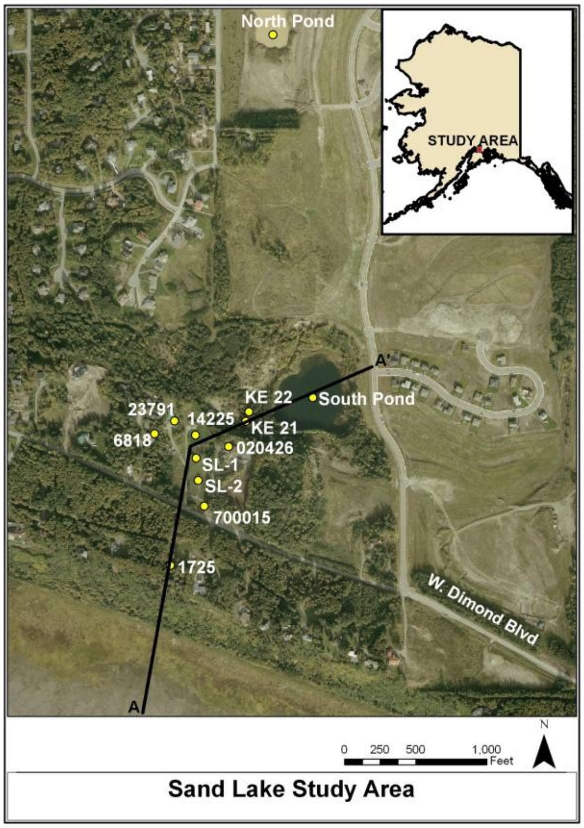


Figure H-4. Aerial photograph of the Munk and others, (2010) study area in southwest Anchorage showing the line of cross-section A-A' in Figure H-5.

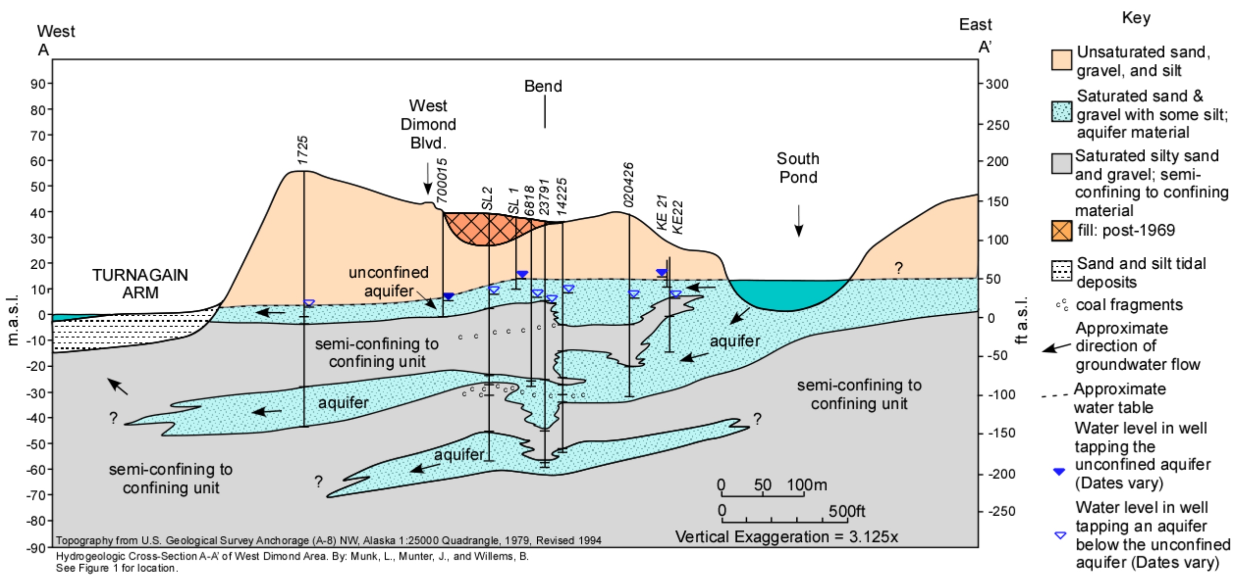


Figure H-5. Hydrogeologic cross section from Munk and others (2010). Note that the Dodds's well is denoted as well 6818.

Aquifer test results

The aquifer test conducted on pumped well SL-6D and described in Appendix F resulted in drawdown responses being observed in four wells located 1000 to 2000 feet away demonstrating aquifer interconnectedness in the area of the South Pond. This interconnectedness included the relatively shallow aquifer tapped by well KE-22 (upper zone top elevation -7 ft NAV83) and the relatively deep aquifer tapped by well SL-2 (middle zone top elevation -185 ft NAV83). This test further substantiates the concept that confining layers in this area should not be considered as continuous confining layers that effectively separate aquifers. The hydraulic conductivity of the upper zone is estimated to be approximately 300 ft/day in the vicinity of the pumped well based on an analysis of the aquifer test data (Appendix F).

Analysis of water-quality data

The Dodds's well and the South Pond have been sampled for a variety of constituents during this investigation (see Appendix B) and the Dodds's well was also sampled by Kane and others (2008) for many of the same parameters plus tritium. The Shantz well has not been sampled. The quality of water at the pond and from the Dodds's well is not a close match. The Dodd's well exhibited higher TDS, salinity, alkalinity, chloride, sulfate, calcium, magnesium, and iron, along with a few other parameters. The South Pond sample had higher dissolved oxygen, pH, temperature, potassium, and fluoride, among a few other parameters. Kane and others (2008) also found tritium concentrations of 6.59 TU from the Dodds's water sample, well above natural background levels. The lack of a close match of the water quality data could be interpreted in several different ways:

- that the two different waters are not connected;
- that the chemistry of the water changes as it moves through the groundwater flow system, essentially the dissolved oxygen would tend to be utilized in chemical reactions and minerals in the aquifer would tend to dissolve. The pond water would change to become more like the Dodd's well water quality. The short flow path between the South Pond and the Dodds's well, however, suggests that this might not be a major factor;
- there could be mixing between the pond water and ambient groundwater and the geochemical signature of the pond water would essentially be absorbed into a larger volume of groundwater.

With the data available, there is not a distinctive geochemical signature in the pond water sample to make a definitive determination. Thus, the common dissolved ion, nutrient, and trace metal analyses are concluded to be in-determinant in assessing potential connections between the South Pond and the Dodds's well. The tritium data are indicative of recharge to the aquifer sampled sometime subsequent to the beginning of atmospheric nuclear testing in the early 1950's. This would be the expected finding if water does travel from the South Pond to the Dodds's well. See further analysis of the tritium data in the main body of the report.

Quantitative flow rate analysis

Freeze and Cherry (1979) describes how average linear velocity of groundwater is related to tracer studies where the bulk mass of groundwater moves a "short but significant" distance along a flowpath. Average linear velocity is defined as the ratio of travel distance to travel time. Using, the Dodds's estimate of 2.5-3 weeks (assume 19 days) and a distance of 840 feet from the well to the closest edge of the pond, then the average linear velocity of the leading edge of the plume of sediment from the pond would have travelled at an average linear velocity of 44 feet/day.

Freeze and Cherry (1979) also derive an equation for average linear velocity that can be calculated from hydrogeologic parameters that are measurable in the field.

Using Darcy's Law, the following equation for average linear velocity is derived:

$v=KI/n$

Where:

v= average linear velocity
K= hydraulic conductivity
I=hydraulic gradient
n= average effective porosity

Hydraulic conductivity (K). Using the transmissivity T determined by the aquifer test at Well 6D and an aquifer thickness of 73 feet determined from the well log, a value of hydraulic conductivity of 300 ft/day is determined. Using the data from the TERRASAT Inc., (2004e) test of the Anchorage Asphalt well, 1940 ft^2/day, and an aquifer thickness of 6 feet (from the well log, Well AA, Appendix A) , a value of hydraulic conductivity of 320 ft/day is calculated. Dearborn (1983 and Attachment E-1 of Appendix E) calculated a value of 1500 ft^2/day from a test of the same well. This equates to a value of hydraulic conductivity of 300 ft/day. Freeze and Cherry (1979) estimate that a value of hydraulic conductivity characteristic of aquifer materials midway between a "clean sand" and a "gravel", is 0.001 m/s, or 280 ft/day. Thus, a value for hydraulic conductivity for the upper zone for this analysis is assumed to be approximately 300 ft/day.

Hydraulic gradient (I). Another necessary condition for the transport of particulate matter from the South Pond into local wells is the existence of a groundwater gradient from the pond to the Dodds's and Shantz's wells.

The elevation of the water surface at the pond is approximately 39 ft MOA72. Figures 9 and 9a show the approximate configuration of the water table near the South Pond. The maps show that groundwater is inferred to flow into the pond from the east side. The water table gradient is relatively flat on the west side. The water table at the pond (approximately 39 ft MOA72) is about 18 feet higher than the potentiometric surface of the upper zone at Well KE-22, which indicates a downward component of the groundwater flow gradient from the pond into the upper zone in this area.

The difference in water levels between the South Pond and Well KE-22 is relatively large and could potentially contraindicate a direct hydraulic pathway from the pond to the Well KE-22. However, Well KE-22 was drilled with air-rotary methods and 6-inch steel casing. There are no indications of any perforations or screen in the casing, and it likely taps into the aquifer only through the open end of the casing at a depth of 120 feet below land surface, or -52 ft MOA72. This is deep enough that the actual flowpath from the pond to the Dodds's and Shantz's wells may occur at a higher elevation where the difference in water levels between that higher part of the aquifer and the South Pond is not as great. Table xx shows that the vertical gradient at the KE-21/KE-22 location is the strongest one identified in the study area. Together with the location of this area near the coast, this means that there are ample possibilities for sand and gravel layers between the bottom of the pond and the bottom of well KE-22 to have intermediate values of head and a smoother gradient between the Dodds's well and the South Pond.

Three water-level measurements have been made in the Dodds's well subsequent to the drilling of the well in 1965 (see Appendix A). The water level in the completed well was not reported at the time of drilling. The calculated average water-level elevation is 17.2 ft MOA72. This elevation is below the pond surface elevation by about 22 feet and is also below the water levels in surrounding wells. These data indicates that the Dodds's well data are consistent with an interpretation that the well taps a permeable part of the aquifer that provides a favorable flow path and hydraulic gradient to the west from the South Pond towards the Dodds's and Shantz's wells. The calculated average hydraulic gradient between the pond and the Dodds's well is approximately 0.026 ft/ft.

Examining the potentiometric surface map (Figure 14), shows the presence of a valley-like low in the surface extending from the South Pond southwestward towards Turnagain Arm, potentially indicating a zone are of higher hydraulic conductivity along this alignment. Such a high permeability structure, if it exists could concentrate flow in the direction towards the Dodds's and Shantz's wells and onward towards the coast.

Average effective porosity (n). Fettter (1988) provides estimates of porosity of "well-sorted sand or gravel" to be in the range 25%-50% and "sand and gravel, mixed" to be in the range of 20%-35%. For the Darcy analysis described above, the parameter of interest is effective porosity, which is the total porosity minus the percentage of porosity that does not contribute to flow. In sand and gravel deposits, the percentage of porosity that does not contribute to flow could be a small number, but in any case, effective porosity is always less than or equal to total porosity. Using these concepts and typical literature values, the effective porosity could be estimated to average approximately 0.3.

Recent research has introduced the concept of mobile porosity to replace effective porosity in equation 1 (Enviro-wiki, 2021) (https://www.enviro.wiki/index.php?title=Groundwater_Flow_and_Solute_Transport). This work comes from tracer tests where dissolved solutes were observed to migrate more rapidly through aquifers than could be explained by typical reported values of effective porosity. A typical value for mobile porosity for glacial outwash sediments of 0.145 is provided.

Considering the uncertainty involved in estimating effective or mobile porosity, both values described above are used to calculate a range of average linear flow velocities.

Inserting parameter values into the equation 1:

v_1=((300 ft/day) x (0.026 ft/ft))/0.3 = 26 feet/day.

v_2=((300 ft/day) x (0.026 ft/ft))/0.145 = 54 feet/day.

Using a distance of 840 feet and the velocity, v_1 (above), an estimated arrival time to the Dodds' well of 32 days is calculated. This is somewhat longer than the 17.5 to 21 days reported by the Dodds.

Similarly, the travel time using v_2 provides an estimated arrival time to the Dodds's well of 16 days, which is slightly shorter than the 17.5 to 21 days reported by the Dodds.

Thus, this study calculates a range of estimated travel times from the pond to the Dodds's well of 16 to 32 days, which brackets the number of days that it reportedly took for the sediment to travel from the pond to the well and, considering the typical uncertainty inherent in Darcy's Law calculations, constitutes a good match to the observed facts using independently collected field data in the near vicinity.

The sand and gravel in the aquifer was likely deposited by flowing streams of water from nearby glacial sources. This depositional environment almost certainly resulted in stratification, with different layers of sands and gravels within the overall deposit. Many studies have shown that stratification causes "fingering" whereby an advancing plume does not all travel at the same velocity, but the leading edge of the plume can arrive sooner than the plume average or peak concentration. This is known as longitudinal dispersion.

After mining ended in the fall, the Dodds' also report that the water "within 5-6 weeks was no longer cloudy". This somewhat longer time for the water to clear up could also reflect longitudinal dispersion at the tail of the contaminant plume.

Thus, the available information about available geological pathways, aquifer parameters, hydraulic gradients, and standard textbook groundwater transport analysis is supportive of the Dodds' allegation of a connection between their well and the South Pond and sediment transport from the pond to their well shortly after the pond was dug.

Conclusion of particulate transport analysis

Transport of sediment from the South Pond to the Dodds's and Shantz's wells is concluded to be plausible as a result of:

- literature studies showing the transport of sediment in the silt and clay size range through aquifers is well documented and perhaps even transport of material up to fine sand is possible;
- observed time-limited sediment-producing events in the Dodds's well during the only two known times of high turbidity events in pond water in 1978 and again in 2004;
- corroboration of sediment in the nearby Shantz's well at the same time as the 1978 event in a well that taps the same aquifer zone;
- the absence of sediment producing events at other times between 1965 and summer of 1978 and between late fall of 1978 and fall of 2004 when there was no pond or the pond water was clear;
- favorable visual color analysis of pond water and the Dodds's well filters during the 2004 event;
- Municipality of Anchorage action apparently based on their understanding that a connection existed between the South Pond and the Dodds's well right after the 1978 event;
- favorable geological pathway analysis including a likely breach or natural absence of aquifer confining layers beneath the South Pond.
- aquifer testing has shown the presence of hydraulic connections between wells tapping different zones of the Anchorage confined aquifer system in widely spaced wells up to 2000 feet apart.
- elevated levels of tritium have been found in the Dodds's well, which means that at least some of the water from the well is hydrologically recent - i.e. recharged subsequent to the early 1950's;
- favorable standard groundwater transport travel-time analysis using Darcy's Law:
    - a. measured groundwater hydraulic gradients;
    - b. measured aquifer hydraulic conductivities; and
    - c. estimated effective aquifer porosity.

Evaluation of Prior Studies

The conclusions of prior evaluations are still widely accepted - i.e that the Dodds' story "is not physically possible" (Kane and others, 2008) or that the source of sediment in the water supplies of Shantz and Dodds wells came from the aquifer in close vicinity of the well bores (Munk and others, 2004), or that:

> Professional geologic research of the Bootlegger Cove Formation and of the Anchorage area groundwater flow regime suggests that the Class C public water system wells to the

> south and to the west of the proposed Kincaid Estates Subdivision fully penetrate a confining layer and draw water from the confined aquifer system that is below, and is interpreted to be not connected to, the shallow overlying unconfined aquifer, or water-table aquifer (ADEC, 2003).

This is important because of on-going work related to a recent storm-water overflow structure built in 2016 that has twice (in 2016 and 2017) discharged urban stormwater runoff into the pond. The Municipality of Anchorage passed a $2.1 million bond issue intended to reroute stormwater runoff to discharge elsewhere, however the funds available have been determined to be insufficient (Municipality of Anchorage, 2019). The Municipality has recently decided to proceed with a bioswale alternative (Tsu, 2021) that will be designed to discharge stormwater into the hydrologic basin occupied by the South Pond, with an indeterminant frequency of discharging stormwater directly into the pond. The design for this project has not yet been completed and construction is scheduled for 2022.

For these reasons, it is important to thoroughly evaluate prior analyses of the Dodds' and Shantz' observations in the context of new data collected and evaluated during this investigation. Prior evaluations included language that much about the hydrogeology of the Sand Lake area was uncertain at the time of their investigations as a result of the complexity of the geology and the paucity of data. Many of these uncertainties have now been resolved and provide new insights into the hydrogeology of the South Pond and surrounding area.

Other reviews of the hydrogeology provided by various documents by TERRASAT, Inc. and J. A. Munter Consulting, Inc. are referenced and included in the review by Munk and others (2004) and are not reviewed separately here.

Kane and others (2008) study

The bulk of efforts in the study by Kane and others (2008) were devoted to sampling 68 wells and surface water bodies throughout the Sand Lake area and analyzing and presenting the results in the context of the geologic framework of the area. This work is a material advancement of our knowledge of groundwater conditions in the area.

Kane and others (2008), however, did not correctly depict the detailed geological stratigraphy of the area around the South Pond. They made no use or mention of the well log of KE-22 and did not show the inferred continuity of permeable sand and gravel deposits from KE-22 (near the pond) to the Dodds/Shantz well area and appear not to have used the information from Well KE-22 in their analysis. They report not being able to obtain permission to access monitoring wells or the ponds on the Kincaid property. The log of KE-22 penetrated a 35-foot thick layer of gravel and sand, which is key to defining the stratigraphic relationships immediately downgradient of the pond (see Munk and others (2010) (Figure 2)/Figure H-5). None of Kane and others (2008) hydrogeologic cross sections, for example, go through the pond.

The conclusion by Kane and others (2008) that:

"It is our strong opinion that this is not physically possible"

is reportedly based on four factors:

1. "It is several hundred feet from the pond to the well";

   Analysis: This factor is not a strong or conclusive argument. Numerous studies have shown that colloidal-sized particles can travel similar distances through sand and gravel aquifers as shown in Figures H-2 and H-3. Also, Spangler and Susong's (2006) study of a turbid spring-fed lake also indicates that silt transport through aquifers is physically possible, perhaps even for considerable distances.

2. "The subsurface material is clean sand and gravel with scattered layers of fine materials, excellent for filtering out any suspended mater in groundwater";

   Analysis: Flow from the pond to the Dodds's and Shantz's well is predominantly horizontal and most flow would be expected to be through permeable and stratified sands and gravels, not through "scattered layers of fine material". If such layers were present in the flow path, they would likely be discontinuous and flow would tend to go around them. As seen in Figure H-5 and Figure 8 of this report, there is no documented continuous layer of fine material that would substantially block or filter groundwater flow. This item is concluded to not be a significant factor in the analysis.

3. "the hydraulic gradient is quite low here and therefore the velocity of the groundwater would be low, even in the relatively porous sands and gravels. Again, excellent conditions for filtering out any suspended matter."

   Analysis: The hydraulic gradient is simply not "low" by the standards of sand and gravel aquifers. For example, the gradient between KE-22 and the Dodds well, at about 0.026 or 140 feet/mile, can be compared to the gradient in the Tanana/Chena floodplain of 3 feet/mile (Glass and others, 1996). Average linear velocity calculations provided in this appendix show that aquifer hydraulic gradient parameters are: 1) appropriate and suitable for the travel time described by the Dodds' affidavit; 2) are not low; and 3) therefore should not be characterized as providing "excellent conditions for filtering out any suspended matter". This purported factor is simply incorrect.

4. The sample of water from the Dodds well contained no detectable nitrate but was very high in iron and the sample contained tritium, indicating the water is post-1952 in recharge age. The isotopic signature of the water indicated recharge from snowmelt, as did most of the other groundwater samples in the study.

> **Analysis:** The iron and nitrate data are not indicative of the absence of flow from the South Pond. The logic by which this statement pertains to potential sediment transport is not clear. The isotope results are similarly inconclusive or irrelevant to the situation. The noted high tritium level indicates relatively recent recharge, such as from the South Pond, and does not support the opinion expressed by the authors; rather, it supports the case for recent groundwater flow from the South Pond to the Dodds's well.

Of the four factors provided above, therefore, none of them are concluded to provide any significant support for the authors' opinions about the transport of sediment through the aquifer.

Perhaps more importantly, however, Kane and others, (2008) do not provide any theory, hypothesis, or any plausible alternative that would explain the Dodds's and others observations. They did not consider the large body of literature related to the transport of particulate matter through groundwater systems. They also did not provide a hydrogeologic analysis of groundwater flow using available well logs or water-level information. They did not explain the timing of the onset and cessation of the observed sediment in the 1970s, the occurrence of sediment in two neighboring wells at the same time, or the recurrence of the event after the heavy rains of 2004. All of these observations were left a mystery. Yet there has been no dispute that the Dodds accurately described the sediments and timing of the sedimentation event in their well water in the 1970s. Kane and others (2008), in summary, spent very little effort analyzing this situation and we are left simply with the authors' poorly supported opinion about what they thought could not happen and no theory or hypothesis about what actually happened. Thus, this opinion is rejected until and unless a credible theory or explanation about what did happen is provided.

Munk and others (2004) study

Munk and others, (2004) concluded that "the sediment in these wells (the Dodds's and Shantz's wells) is likely mobilized in an annular space very near the well opening".

This has been interpreted by many people as somewhat equivalent to the conclusion of the UAF study. This is too simplistic a summary of UAA's findings. UAA understood and made extensive comments about the paucity of data and geologic complexity that made it very difficult to really understand the hydrogeology of this area.

Here is a sampling:

> No concerted effort to study the groundwater system in the Sand Lake area has been made and data is lacking in order to understand the system at the site of the proposed subdivision. Therefore, many questions remain about the geology and hydrogeology of the area. This has a significant impact on ideas regarding the protection of the aquifers at the proposed Kincaid Estates Subdivision. Ideas about groundwater flow, chemical transport in the subsurface, and the concentrations of those chemicals have (been) based

on an unclear understanding of the geologic and hydrogeologic system. Therefore, we identified specific aspects of geology, hydrogeology, and geochemistry that are not well understood and indicate where those aspects have significant impact on conclusions made in previous reports. (p.73).

The discontinuous character of low permeability units both above and below the water table makes favorable conditions for perched groundwater and for lenses of confined aquifer material in addition to laterally extensive aquifers. The strength of the connections between aquifers cannot be determined from the available water level data and lithologic information. Aquifers that appear to be separated by many feet of low-permeability sediments might actually be connected at some distance from the borehole location where sediments may be coarser grained. This is indicative of stratigraphic units deposited as part of a glacial deltaic and glacial fluvial system where there is a lot of grain size variability both vertically and horizontally. The cohesive facies identified by Ulery and Updike (1983) and used in the conceptual hydrologic model of Barnwell et al. (1972) as the continuous confining layer is likely discontinuous in the geologic transition zone of Sand Lake area. Additional borings and hydraulic testing are necessary to determine the continuity of the confining layer underlying the proposed subdivision. (p.73-74).

The incidence of silt and sand alone in the private wells downgradient of the pond does not indicate a greater potential for these wells to be contaminated by activity at the pond. However, no measurements of the aquifer materials have been made to indicate whether or not there is a connection between the pond and the aquifer in which the wells are completed in. (p. 75).

It is also our opinion that currently, the data that would satisfactorily answer the question about the hydraulic connection between the upper and lower aquifer has not been collected. (p. 75).

Current information about the aquifer and hydrogeologic processes indicates there is not a greater potential for these wells to be contaminated by activity at the pond. However, no measurements of the aquifer materials have been made to indicate whether or not there is a connection between the pond and the aquifer in which the wells are completed. It is apparent from drillers' well logs that these wells are completed in aquifers containing many intervals of loose and reportedly heaving sands. The sediment in these wells is likely mobilized in an annular space very near the well opening. (p. vii).

There is insufficient evidence available to support the conclusion that the water table aquifer is not hydraulically connected to the deeper aquifers.

> - Comprehensive cross sections developed for this study do not indicate that there is a continuous confining layer across the site.
> - The available water quality data did not lead us to conclude that the lower aquifer water does not commingle with the upper aquifer water.
> - There are several viable explanations regarding the occurrence of sediment/turbidity in wells near the southern pond near the site. We do not believe that this occurrence alone proves that the wells are hydraulically connected to the pond. (p.ix).
>
> This review shows that there is little evidence to prove or disprove the relation between the incidence of turbidity and an elevated susceptibility of these wells to surface contamination. Likewise, there is little evidence to prove or disprove the nature of the hydraulic connection between the pond and the wells. (p. 52)
>
> The only information we have at this point is that sediment/turbidity increased in well 6818 during excavation in the southern pond. The lack of any other evidence at the site poses limitations in trying to determine exactly why this happened. (p. 55)

In summary, it is clear from the extracts above that Munk and others (2004) found that data were lacking to provide a definitive conclusion of what actually happened when the pond was dug. Because of these uncertainties, Munk and others stated:

> "Therefore, we can only speculate about what actually occurred." (p.56).

This is arguably the most important finding of their work - that determination of the truth about what actually happened was not possible at the time.

In this study, all possible explanations ("multiple working hypotheses") of what happened as discussed by Munk and others (2004) and documents referenced therein are described below. The potential applicability of these explanations to the events and observations that have been documented as part of this study is assessed using the approaches described above on pages 4-5 of this Appendix.

This review of the UAA study findings, however, starts with identification of a significant error. The authors describe a well denoted as "Well 12" as the well owned by Dan Shantz, who reported sediment in his well at about the same time as the Dodds. Unfortunately, the well log used in the analysis for the Dan Shantz well by UAA was the wrong well log and in the wrong location. Well 12 was completed October 3, 1983, by Jay Williams Drilling on Lot 15 of Seaview Heights Subdivision, Block 2, Lot 6 (Lot 6 was a large lot divided into many smaller lots). This was five years after the digging of the pond in 1978. A review of the Municipality's On-Site files shows that David Remme owned that lot (Lot 15) in the early 1980's when the property was developed, and there is no record of ownership by Dan Shantz. Also according to On-Site files, Dan Shantz owned Seaview Heights Block 2, Lot 6 (Lot 13) in 2019 when a new well was drilled as part of the approval for a new septic system. The original well for Lot 13 was drilled in 1973 by M-W Drilling, Inc., for Waldo Remme, who appears to have developed the lot. A new well was drilled in 2019 for Dan Shantz, apparently because the 1973 well was inadvertently drilled on Lot 12 (this was recently discovered during a septic system upgrade). The letter from Dan Shantz (see Attachment H-7) confirms that Dan Shantz lived at Lot 13, not Lot 15. The existence of the 1973 well log appears to have been unknown to both UAA and TERRASAT, Inc. investigators (TERRASAT, Inc., 2003). Up until recently, the log was not in the State WELTS system (the system did not exist prior to about 1981 or 1982). The 1973 well, however, was entered into the U. S. Geological Survey's Ground Water Site Inventory (GWSI) system in 1980.

It makes sense that the 1973 well was the one that experienced sediment in 1978 because, aside from the fact that it existed then, it is located right across the street from the Dodds's well and it appears to tap the same zone (the upper zone) of the Anchorage confined aquifer system. The new well drill in 2019 generally confirms the sequence of sediments noted in the 1973 well and also in the Dodds' well. All three wells are shown on Cross Section B-B' (Figure 8).

The new-found existence of the 1973 Dan Shantz well log lends considerable information to the analysis of what happened in 1978. The Dodds's well and the Shantz's well are about 160 feet apart and apparently had similar experiences of sediment in their water at about the same time. The Shantz well logs and Dan Shantz observations lend considerable substantiation to the observations and reports of what happened at the Dodds's well.

Munk and others concluded that sediment was “likely mobilized in an annular space very near the well opening” and provide several possible theories as to how or why that could occur. Identified possibilities include:

- sediment movement from nearby the well openings from:
    - increased usage or an increase in pump size;

  Analysis: The Dodds's well had been in use serving four homes for many years. There was no reported increase of usage or increase in pump size or evidence of anything of this nature. Even if there were, this effect would be extremely unlikely to last for the many weeks reported by the Dodds and Dodds (2003) and even more unlikely to have been experienced by both the Dodds's and Shantz's wells. This also does not explain the reoccurrence of sediment after the 2004 rains. This possible explanation is therefore rejected.

    - back surging of water into the aquifer materials past failing check valves;

  Analysis: Again, there is no evidence or indication that this occurred in either well much less in both wells at the same time or that the effect would be other than temporary rather than lasting for weeks and only for weeks, or would also have occurred in 2004. If the Dodds' well had been worked on shortly before the first sedimentation event, both Loren and Betty Dodds would have known about it and would have been very likely to have reported it in their detailed affidavit and their numerous communications about the event. This possible explanation is also rejected.

- loosening or sloughing of aquifer materials into void space around the well;

Analysis: This possible explanation does not state why such loosening or sloughing would occur. First, there is unlikely to be any void spaces larger than aquifer pores. The aquifer materials are un-cemented and un-lithified and generally are not thought to stand open after a well is constructed. The well drilling industry has been drilling wells in the Sand Lake area since at least the late 1940's and the technical know-how to construct a well to prevent the intrusion of large amounts of sediment was well established even in 1965. While some homeowners sometimes experience a slow influx of sediment that periodically plugs sink aerators or screens in appliance water lines, the kind of sediment influx that starts suddenly and coats tubs and toilets as described or causes pumps or water heaters to fail (only a few years after they were installed) is extremely unlikely. This possible explanation, again does not explain why it started, why it stopped, why it affected two wells at the same time, and why sediment reappeared in 2004. This possible explanation is also rejected.

- barometric pressure changes in artesian wells;

Analysis: Water level changes in artesian wells caused by barometric pressure changes are limited to a few tenths of a foot of water column height and occur many times per year. Wells normally experience a much greater fluctuation in pressure when pumps turn on and off, usually many times per day. This possible explanation also does not explain why sediment started appearing in the two wells after lengthy service without sediment, why the sedimentation stopped after mining ceased, even though barometric pressure changes have continued to occur, or why sediment reappeared in 2004. This possible explanation is also rejected.

- Movement of sediment down an unsealed annular space (Gaber, 1998);

Analysis: Wells such as the Dodds's and Shantz's wells in Anchorage are usually drilled by means of cable tool or air-rotary methods using a bit that is smaller in diameter than the well casing and shoe. Casing is usually made of 6-inch-inside-diameter steel and a drive shoe is welded to the bottom of the well casing. The drive shoe is stout enough to prevent the casing from deforming while being driven through gravelly or coarser sediments. After the hole is advance a few feet beyond the end of the casing and shoe, the casing is pounded down with a casing hammer and the process is repeated. Drilling usually stops when a permeable sand and gravel aquifer is encountered that yields water and "clears up" relatively quickly, forming a natural gravel pack in the open bottom of the well. During this drilling process, an oversized hole is not created. Unsealed annular spaces as described by Gaber (1998) are most commonly attributed to holes that are drilled with drilling mud and are larger than the casing diameter. Casing is installed in these well after the entire borehole is drilled. This is a common well drilling technique in the Midwestern U.S., where the Gaber (1998) reference originates, but is almost unheard of in Anchorage. There is no evidence that any of the wells in the study area of this report were drilled with drilling mud. The sediments in the area of the South Pond/Dodds/Shantz wells area are generally deformable enough that they would be expected to press against the well casing as a result of earth overburden pressures and close off any significant void space that might have formed during drilling either by cable-tool or air-rotary methods.

Gaber (1998) describes several possible means of repairing wells that have flow down an unsealed annulus, but makes no mention of the problem fixing itself after a few weeks. This possible explanation also does not explain why two nearby wells might have the same problem at the same time, or why the problem would suddenly recur 26 years later, in 2004. This possible explanation is also rejected.

- Vibrations from earthquake, tides, vehicle traffic, explosions.

Analysis: Munk and others (2004) note that these events can cause groundwater level fluctuations in confined aquifers. Earthquakes, in particular, are known to also cause turbid water in wells and earthquakes are relatively common in the Anchorage area. These effects are typically short-lived, however, and would not be expected to last for many weeks. If an earthquake had occurred near the onset of sedimentation in the Dodds or Shantz wells, however, it is highly likely that it would have been reported. This is really only a hypothetical possibility, however, since no analysis has been conducted to correlate an earthquake with the onset of sedimentation, or explain why it seemed to occur in two wells, but was not reported in other wells. This possible explanation also fails to explain why sediment recurred in 2004. This possible explanation is also rejected.

- Vibrations from earth-moving activity associated with sand and gravel mining.

Analysis: Munk and others (2004) noted that this explanation is unlikely because of continued detection of turbidity after mining ceased. This possible explanation is also rejected.

- Perforated well casing;

  Analysis: The well logs of both the Dodds's and Shantz's wells do not give any indication that either well was perforated. This possible explanation is also rejected.

- Collapse/erosion of clay/silt 3 feet above aquifer;
  Analysis: See the analysis above related to unsealed annular space. This possible explanation is also rejected.

- Increased water usage or pumping rate;

  Analysis: There is no data to suggest that the water usage increased or pumping rate increased at the time of onset of the sedimentation in both wells. As a Class A well, the Dodds well had been operating at a higher flow rate for many years compared to a single family domestic well. This possible explanation also does not explain why sediment started appearing in the two wells after lengthy service without sediment, why the sedimentation stopped after mining ceased, or why sediment reappeared in 2004. This possible explanation is also rejected.

To summarize, all of these possibilities are speculative and not supported by any on-site data. None of the theories provide any real possibility of explaining:

- the unusual timing of the onset of the sedimentation 2 1/2 - 3 weeks after the pond was dug;
- the cessation of cloudiness after mining was complete for the season;
- the occurrence of sedimentation in two wells more than 100 feet apart tapping the same aquifer zone when neither well reported any prior problems;
- the repeated occurrence of a sedimentation event in 2004 after an intervening period of 26 years without sedimentation problems.

In particular, Munk and others, (2004):

1) did not consider the true well log for the Shantz well;

2) did not consider the 2004 sedimentation event (the event happened after their report was written);

3) provided no explanation for the specific timing of the appearance of sediment in wells only a few weeks after the pond became turbid;

4) provided no explanation for the specific timing of the disappearance of sediment in wells only a few weeks after mining ceased;

5) provided no explanation for the absence of sediment in the well during the 1965-2003 history of use of the well except shortly after gravel mining in the pond;

6) did not consider the tritium findings from Kane and others, (2008) indicating that the Dodds's water was relatively recently recharged to the aquifer;

7) did not consider the results of test well KE-22 (see attached), which had not been drilled at the time of their study (it was drilled in 2005);

8) did not consider literature documenting the processes and results of field studies related to fine particulate matter transport in aquifers; and

9) did not consider the results of test drilling, geophysical studies, aquifer testing, stratigraphic mapping, synoptic water level surveys and potentiometric and water table surface mapping, and hydrograph analysis conducted during this current study.

Thus, the contribution of Munk and others, (2004) relative to the potential contamination of the Dodds's and Shantz's well from the South Pond is best characterized in their own words as:

> It is also our opinion that currently, the data that would satisfactorily answer the question about the hydraulic connection between the upper and lower aquifer has not been collected. (p. 75).

and

> This review shows that there is little evidence to prove or disprove the relation between the incidence of turbidity and an elevated susceptibility of these wells to surface contamination. Likewise, there is little evidence to prove or disprove the nature of the hydraulic connection between the pond and the wells. (p. 52)

In other words, Munk and others (2004) work regarding the contamination of the Dodds and Shantz wells in 1978 was indeterminant.

Munk and others also considered particle suspension dynamics and the improbability of the transport of sediment larger than colloids:

> ... particles larger than the colloidal (suspended) fraction would require turbulent flow conditions in order to be transported. This is because the force of water needs to be at least as high as the inertial forces of the particle (Komar, 1976). When flow in aquifers is turbulent, Darcy’s law does not apply to groundwater flow (Bear, 1972; Fetter, 2003). Conceptually, it seems unlikely that groundwater would flow turbulently from the pond to well 6818 for approximately 860 ft laterally and approximately 137 ft vertically along any path. This turbulent flow would have to be unimpeded along its entire flowpath through well 6818 and beyond, otherwise the groundwater flow would essentially back up, causing it to slow down and lose turbulence.

A review of Komar (1976) shows that the work was developed and pertains to open-water conditions, not flow through a porous media. Munk and others also evaluated work by TERRASAT, Inc. (2004d):

> TERRASAT, Inc. (2004d) presents calculations of particle settling to explain how sediments as large as fine-grained sand cannot be transported through aquifer pores. Even though conceptually, this is a good argument, there are problems with applying these calculations to groundwater transport. First of all, the equations used are not formulated for calculating particle motion through porous media. These equations were designed to calculate the velocity of a spherical particle in open water where the particle is free to fall through the water column. In porous media, the physical contact of the sediment with the media, the tortuosity of the flow path, physical constriction at the pore throats and any number of other factors make the straightforward particle settling calculations non-descriptive of conditions in the aquifer. The second problem with the explanation that particle settling prohibits sediment movement through aquifers is that sediment movement (at least in the colloidal form) within this aquifer did occur, as evidenced by the continued turbidity in the wells.

The limitations described above that are applied to the analysis of TERRASAT, Inc. (2004d) also apply to the work of Komar (1976) and the analysis of Munk and others (2004). The result of these analyses seems to be that there is general concurrence that colloid-sized particulate transport through aquifers is hydraulically feasible, and that as the particle sizes get larger, and flow paths get longer, transport of particles becomes more unlikely. But this is a very complex process and absolute statements about what sizes of particles can or cannot be transported through aquifers between colloid size through fine-sand size are all ill-supported by current hydraulic theory. All of this is rendered relatively moot, however, as the focus of this work is on whether colloid-size particles travelled from the South Pond through the aquifer to the Dodds's and Shantz's wells, as alleged by residents.

ADEC (2003) study

One of the principle conclusions fo the ADEC (2003) study is provided above on page H-20 of this appendix. Munk and others, (2004) also provided a thorough review of that study and found that:

> Therefore, the appropriate data do not exist to make conclusions about the connection or lack thereof between the upper and lower parts of the aquifer system in the area or for the site of the proposed subdivision which has extremely limited data available to address this problem.

Similarly, this study finds that the ADEC (2003) study lacked sufficient data and rigorous analysis to provide reliable conclusions about the connections or lack thereof between the shallow and deep aquifer. For example, a large part of their geological analysis was based on well logs from just nine widely spaced public water-supply wells in their regulatory system, rather than the hundreds of single family wells in the study area. Also, the ADEC (2003) findings are contraindicated by the presence of tritium in the Dodds's well, which would not be expected if the well tapped a confined aquifer that was truly "not connected to" (ADEC 2003) the shallow aquifer and the South Pond.

Munk and others (2010) Study

Munk and others (2010) concluded:

> "...that the shallow and mid-depth aquifers (tapped by the Dodds and other wells) appear to be susceptible to surface contamination and that efforts to avoid or minimize future contamination of these aquifers are warranted."

This conclusion has been confirmed and expanded upon by this project.

Summary and Conclusions

All data reviewed during this investigation indicates that the Dodds and Dodds (2003) claim that the excavation of the South Pond in 1978 directly cause turbid water to flow through the aquifer and into their well and household plumbing system is plausible and is the most likely explanation for what happened. All alternate explanations or opinions by other investigators have been examined and rejected for multiple reasons. No other viable working hypotheses are available to explain the observed facts:

- The Dodds well reportedly pumped unusual amounts of sediment 2.5-3 weeks after digging into aquifer during late 1970s;
- the well operated normally without excessive sediment for about 13 years prior to the pond being dug and afterwards until 2004;
- The well experienced a repeat episode of sediment influx after soil disturbance, a major rainstorm, storm runoff into the South Pond, and contamination of the pond waters with high levels of turbidity in 2004;
- A second well (the Shantz's well) near the Dodds's well that taps the same aquifer zone also reported sediment at the same time, causing a fairly new (less than 5 years old) well pump to burn out and a hot water heater to fail;
- Tritium was found in the Dodds's well water, which is indicative of water derived from atmospheric sources of tritium that only occurred subsequent to 1952;
- A geological pathway for groundwater flow from the bottom of the South Pond to the Dodds and Shantz wells has been identified:
    - "large rocks" were found in the bottom of the South Pond;
    - steep banks are found in the formerly mined and un-reclaimed pit;
    - The south Pond has a reported depth to 40-45 feet into the aquifer;
    - There is known discontinuity of confining layers in the near vicinity;

- A 35+-ft thick aquifer of 50/50 mix of gravel/sand was found next to South Pond
- local aquifer mapping and a cross section shows that the top of the aquifer zone is interpreted to be continuous from the pond to the Dodds's and Shantz's wells;

- a literature review shows that the transport of fine particulate matter (at least up through the size of fine silt) through aquifers has been documented in field settings, confirmed by laboratory studies, and is widely recognized by groundwater professionals;
- Aquifer testing shows connections between aquifers over distances up to 2000 feet.
- Local area synoptic mapping of the water table and potentiometric surface show groundwater flow directions and gradients suitable for groundwater flow towards the Dodds's and Shantz's wells;
- Darcy's law calculations using study-area field-derived aquifer parameters closely matches the reported time frame of sediment arrival at the Dodds's well both in 1978 and 2004 and is consistent with the timing of the clearing up of the well water after the turbidity subsided;
- A systematic review of the hypotheses, speculations, and opinions of prior investigators resulted in the rejection of all of them for their inability to explain the observed events. They were all hampered by a dearth of data (and a mis-identification of a key well log) to understand local groundwater flow systems compared to what is available through this investigation.

Thus, there is no explanation or even any viable working hypothesis for what happened for the observed facts other than the simplest of all explanations: that the story of sediment transport as reported by Dodds and Dodds (2003) is true.

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