Potential of Proposed Gravel Pit to Impact the Source(s) and Quality of Water to Wells and Springs near U.S. Highway 89 and 91 West of Holmes Canyon, and Additional Hazards near the South Edge of Willard, Utah, Box Elder County, North-Central Utah

by

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Executive Summary

Rezoning the Lumberjack property, parcel 02-055-0117, to allow a gravel pit should be denied in light of the following issues:

A. Groundwater and Groundwater Flow
B. Water Quality
C. Earthquake and Landslide Hazards

Information presented in support of the application for the proposed gravel pit is incomplete, and was not certified by an appropriate professional licensed in Utah ("Addressing Groundwater Recharge Concerns – Lumberjack, Professional Statement" hereafter called the Lumberjack report). The information from test borings, referred to in item 2 of that document, should be available to the public if approved by the Utah Division of Water Rights (UDWRights). Neither Will Atkin, UDWRights, nor I could find a request to drill nor any listing of the logs of the test holes in UDWRights files.

A. The logs of those test wells should be made available to further assess the geologic setting of the proposed gravel pit. For example, it is uncertain how far east a thick confining clay layer extends from its known location just west of U.S. Highway 89 and 91, and if its overlying layer connects with the clay-and-gravel layer in well 35 I. (See map and geologic section B-B', Figures 1, 6). This bears on: (1) the depth of cost-effective removal of gravel; (2) places where surface infiltration will impact the perched water table above the thick clay to the west; and (3) places where surface infiltration impinges upon the lower confined aquifer in the east, or on both aquifers.

Due to the heavy winter precipitation this year, overland flow in early March has extended past the mouth of Holmes Canyon to the Brigham-Ogden canal, according to June Summers and Emma Lou Hubbard and the photos that they showed me. Thus, infiltration can persist at least that far to the west, well beyond the area designated "primary recharge area" in Figure 2 of the Lumberjack report. For this reason, the eastern margin of the proposed gravel pit should lie west of that canal.

B. There are several potential impacts on water quality. The Lumberjack report indicated that, "The proposed excavation is not expected to disrupt aquifer recharge in the area." That suggests there will be no application for a new well. Previous court cases established that water diversion and/or wells drilled between Holmes Canyon and U.S. Highway 89 and 91 would impact the established prior rights for wells and springs already there. Any new well in or near the area of the proposed gravel pit or change in use and/or an increase in water extraction from an existing well will be challenged, probably successfully.

Water quality is not addressed in the Lumberjack report. Much water is needed for spraying gravel pits for dust and for washing residue created by a rock crusher that probably will be needed based on boulders recorded in drillers' logs of nearby water wells. Because any water applied at the present surface can readily infiltrate and thereby affect the quality of groundwater at depth, the source(s) of the water used in the pit and its quality need to be described. There is the added hazard of contamination of water during its transport to the site in tankers. Trespassers present additional concerns.

C. The Brigham City segment of the Wasatch fault is overdue for surface rupture (Figures 11, 12). A map showing the proposed gravel-pit boundaries (and access road/s), combined with the logs of the indicated test borings would allow a better estimate of the weight that would be removed (and also indicate where passing lanes and other traffic control will be required, at the bottom of a steep grade, on U.S. Highway 89 and 91). My calculations, based on Figure 2 of the Lumberjack report, suggest the weight of removed material would reach at least ~8 million tons. That would prompt the Earth's surface to rise locally (isostacy), and thereby could trigger an overdue earthquake with resultant ground rupture and/or a landslide. Either could impact the Willard Bay levee, the first by seiche waves or liquefaction, the second by direct impact. The area of the Holmes Canyon alluvial fan has the shortest distance from the mountain front to the levee.

This report has enumerated major issues (A - C) and harmful impacts that could occur as a result of the proposed gravel pit being permitted in the designated area. These major issues should be throughly addressed by the developer in a signed and dated professional report, and afterwards we should be permitted an opportunity for rebuttal before there is further consideration of the request for a rezone to allow the proposed gravel pit.

Background

Mrs. June K. Summers and Mr. Norris J. and Mrs. Emma Lou Summers asked me to evaluate possible impacts of a gravel-extraction pit proposed by the developer on the upper part of the Holmes (aka Robert Holmes) Canyon alluvial fan (Figure 1) a short distance east and uphill of their properties. The property proposed for excavation is a tract belonging to Lumberjack Quarry LLC (02-055-0017) in Box Elder County immediately south of Willard City, Utah. The locations of the pertinent property boundaries are shown on the Box Elder County Web Map, http://gis.boxeldercounty.org/webmap/ (13 March 2013; see Figure 2).

Note: The Utah State Engineer, Division of Water Rights (DWRights), requires that all wells, including test wells, drilled to depths greater than 30 ft must file an application that must be approved prior to drilling, and must thereafter submit drillers' log(s) of any such wells to the UDWRights. There is an unsigned, unstamped document of two pages entitled "Addressing groundwater recharge concerns – Lumberjack, Professional Statement" which indicates that: "Borings while conducting geologic investigation of the alluvial fan did not encounter groundwater in the form of a water table." I could find no record of an application for these borings in the UDWRights website for1/1/2010 through 2/26/2017, nor could a more thorough search by Will

Atkin of UDWRights. Because Figure 2 of the Lumberjack report is a generalized cross section of the proposed area of excavation, this lack of driller's logs of the borings made there has hampered my investigation. Unless approved by another Utah State entity, if those borings exceeded 30 ft, their logs should be available for this study. Otherwise, the developer may not be in compliance with Utah law.

In First District Court, North v. Marsh, No. 11274, 28 April, 1971, Joel E. Fletcher and Frank Haws of Utah State University Water Research Laboratory stated that they introduced fluorescein dye at the mouth of Holmes Canyon, where the stream from that canyon disappeared into the ground near the position of the [main/east strand of the] Wasatch fault zone at the time of their study. They determined that the dye emerged in several springs and wells near U.S, Highway 89 & 91, including the North well (35E in Figures 1, 4, 5, 6).

The Utah State Engineer, dated 19 June 1972, stated: "It has been determined previously in court action, that all the water of Holmes Canyon flows into the alluvial fan and sinks into the ground within a very short distance. There have been dye tests run to indicate this water is feeding numerous wells and springs within the fan and particularly around the base of the alluvial fan....After considerable review of the geology in the Holmes Canyon area, it is felt that the drilling of wells within the fan would certainly cause some interference to the already existing springs and wells."

The Utah Supreme Court further ruled, in North v. Marsh, No. 12929, dated 4 January 1973: "Due to the presence of what is known as the "Wasatch fault" which runs north-south under the west face of the mountains, and to the erosional deposits of rocks and gravel in an alluvial fan at the mouth of the canyon, the waters which flow therefrom sink into the ground within about twenty-five feet of the canyon's mouth. Defendants presented testimony of an expert concerning the placement of 4000 grams of flourascein [sic] dye in the waters in Holmes Canyon; that the dye showed up in the water sources of the plaintiff (except one static well); that in his opinion the waters of the Holmes Canyon supplied plaintiffs' water sources; and the diversion of the surface waters at the mouth of the canyon would diminish the water in plaintiff's sources. We have recognized that such diminution of the quantity of water in established water rights is actionable...."

Note: In early March 2017, heavy runoff from snowmelt in Holmes Canyon extended beyond the main Wasatch fault to the Brigham-Ogden canal based on observations and photographs shown to me by June Summers and Emma Lou Hubbard.

Procedure

To evaluate the area I obtained 21 drillers' logs of water wells in Sections 25 and 35 of T.8 N., R. 2 E., SLBM, and the locations of 7 springs in those two sections and in Section 2, T. 7 N., R. 2 E., SLBM (Figure 1; Table 1). These data were obtained from the Utah Division of Water Rights website, https://www.waterrights.utah.gov/wellinfo/wellsearch.asp. One must search under STR logs to obtain older well logs, and under Selected Related Information/Scanned Documents to find information on proofs of locations and tests and altitudes not recorded by the driller. Altitudes were recorded for only two wells by the drillers, so the 1955 USGS Willard 7.5' topographic map (contour interval 20 ft, supplemental contours 5 ft) was used to approximate the altitude of each remaining well and of each spring.

Two geologic sections, A-A' (Figures 3, 4, 5) and B-B' (Figure 6), were drawn at 3.3x vertical exaggeration to show the types of sediments (particularly confining layers), yields, and recorded positions of the water level (bar-and ball where below ground level; producing intervals shown by black rectangles). The recorded water level allowed an approximation of the static-water level (SWL) to be added to Figure 1 (see Table 1). Twenty additional wells in Sections 14, 22, and 23 of T. 8 N., R. 2 W. and Section 2 of T. 7 N., R. 2 E. were analysed solely for their water levels to assist in generating the contours. The approximate position of the mostly covered main (east) strand of the Wasatch fault (dashed red line in Figure 1) is based on the position shown in Coogan and King (2016) (cf. Doelling and others, 1980; Crittenden and Sorenson, 1985; Davis, 1985; Personius, 1990), adjusted slightly to pass through springs M and N and to lie at sharp flattening of hillslopes.

Annotated aerial views of the Holmes Canyon area were made from my personal collection (Figure 7). Additionally, a literature review was made of the earthquake-recurrence potential (Wong and others, 2016) for this area (Figures 11, 12) in light of Earth's known response to adding weight (subsidence) or removing weight (uplift) (Gilbert, 1890; Crittenden, 1963), especially given the proximity to a major fault at the base of a steep and high landscape (Figure 7). Annotated aerial views of several landslides that predate Lake Bonneville, coincided with it (the catastrophic Bonneville Flood was ~17,400 years ago), and postdate it (Figures 8, 9, 10) are shown to illustrate common and ongoing slope failures and thus potential hazards in the Holmes Canyon area if substantial weight removal during excavation triggers an earthquake and/or landslide.

Figure 1

Figure 1 presented a challenge in contouring the approximate piezometric surface (SWL). Rather than maintaining gently undulating contours more or less parallel to the mountain front (cf. Bjorklund and McGreevy, 1973, 1974), there are at least two deep indentations required (or two areas of closed depressions there). The deep E-W indentation at Willard lies just north of three city wells, 23A, 23E, and 23J (oldest well is 23A, and successively later wells are lettered in sequence). That indentation thus may result from ongoing extraction from those and other nearby wells, e.g., 23B, 23L, and older wells for which there are no logs. There appear to be two large lobes of groundwater north and south of that E-W indentation that extend past U.S. Highway 89 and 91.

The southern indentation is poorly constrained, but required by wells 26J and 35 I, whose SWLs lie slightly below those of wells ~3850 ft and ~1350 ft west, respectively (see Figures 3, 6). As drawn, this indentation trends NNE. A confining layer of clay and cobbles nearly 300 ft thick in well 26J (Figure 3) may extend east to the main fault between canyons, and thereby redirect recharge to the north and south along that fault. The SWL already was low there when well 26J was drilled in 1981 and well 35 I was drilled in 1996.

Goessel (1999) and Oaks (2000) identified two additional strands of the Wasatch fault zone west of the main strand along the mountain face north of Honeyville, Utah. Jensen and King (1999) found a major strand near Utah Highway 38 plus two or three more anastamosing strands between that and the main fault along the mountain front between Brigham City and Honeyville. Schirmer (1985, 1988), Davis (1985), and Coogan and King (2016) identified a second strand along the west side of the bedrock spur at the Pleasant View Salient ~2.5 miles south of Holmes Canyon. The latter strand may extend north to the area of this study as an unidentified fault strand near springs P, R, and S. This could explain why wells 35E, 35G, and 35H are lower in altitude than artesian wells 35C and 35F, but also have a strikingly lower SWL (Figure 5). Lateral impermeability along such a western fault strand may create buildups locally in the piezometric (SWL) surface. There appears to be a lobe that follows the higher southern part of the Holmes Canyon alluvial fan around the area of well 35 I and then trends NW. A smaller westward bulge lies just north of the Pearson Canyon alluvial fan, and may derive from that drainage, and there is yet another bulge around the Pearson Canyon alluvial fan.

The effect of leakage from the Ogden-Brigham canal during irrigation season is unknown. My recollection from field trips that I led across the southern fan remnant and Provo shoreline to the exposed fault surface in the 1970s and 1980s is that the canal has been lined with concrete. If so, leakage probably would be a minor factor except at parted joints or where the concrete may be broken locally by mass wasting.

Geologic Section A-A’

Figure 3 shows the nearly E-W northern part of Section A-A’. Well 26J lies near the seam between alluvial fans at the mouth of an unnamed small canyon in the north and Cook Canyon in the south. Nearly 300 ft of clay and cobbles overlie a water-bearing cobble gravel at least 36 ft thick. Although drillers usually do not distinguish thinly interbedded clays and gravels, the apparent lack of water higher in this bore suggests that the clay and gravel are intermixed, perhaps the result of deposition as debrisflows like those that plagued Willard, Utah, in the 1920s and 1930s (Blackwelder, 1927; Woolley, 1946). Here the muddy deposits may create a seal against the main (east) strand of the Wasatch fault zone and thereby create a local impediment to flow away from the mountains. Perhaps such blockage by clay or impermeability locally along the main strand of the Wasatch fault zone shunts water to the north and south along the fault in this particular area, where it then can exit to the west into gravelly fans with less mud.

The central sector of Section A-A’ is shown in Figure 4. It extends roughly SSE from well 26J to well 35E at Section B-B’. Except for well 26A, which lacks a driller’s notation of water level, all the other wells are artesian. Wells 26A and 26B were deepened, and thus lack data in their upper parts. Salt Lake Formation (Tsl) is identified where gravels are cemented into conglomerate or hardpan, or limestone is noted. Tsl has been folded and faulted since deposition (Goessel and others, 1999; Oaks and others, 1999; Oaks, 2000), and thus typically has a dip and thereby can be distinguished from throughgoing, essentially flat and continuous younger deposits of Quaternary age in the valley. However, near deltas and alluvial fans the deepwater clays rise gradually and pinch out. Here there is thick clay in the central part that thins toward each end as the topography rises, and is overlain in many places by clay with gravel and locally by peat in the north. There is a problem in matching the logs at wells 26C and 26K. The latter is a replacement well, and lies a mere 77 ft SSE of well 26C. All of these artesian wells produce from gravels below the confining clay layer. Well 35E also produces from a thin bed of sand and gravel perched above both the confining clay layer and its overlying layer of clay with gravel (boulders).

Figure 5 shows the southern part of Section A-A'. The clay layer pinches out southward, but the overlying layer of clay with gravel thickens and rises toward well 35G, where a thinner layer of clay with gravel is added above a thin bed of sand and boulders. The higher position of: (1) probable Tsl; (2) a nearsurface layer of clay with gravel; and (3) SWL at wells 35F, 35B, 35C, and 35J, compared with the area of wells 35G and northward, suggests that there may be a western fault strand, downthrown on the west, that passes near springs O, P, and R and well 35H. This possible fault is shown with queries in this part of Section A-A'.

Geologic Section B-B'

This section trends ESE and crosses Section A-A' at well 35E. The persistent clay layer thickens westward whereas the overlying layer of clay with gravel thins or pinches out. The upper clay in well 35D probably represents deposition in deep water during the highstand of Lake Bonneville near 5200 ft and a subsequent stand at the Provo level near 4800 ft following the Bonneville Flood about 17,400 years ago (Janecke and Oaks, 2011a, 2011b). A proposed western strand of the Wasatch fault zone may lie very near U.S. Highway 89 and 91. It is unclear if the layer of clay with gravel in well 35E rises and thins into a similar layer in well 35 I, or if the latter is a separate layer. The slope is about 8°, as shown in the box on the right, where dips are corrected for the 3.3x vertical exaggeration. The SWL in well 35 I appears to be slightly below that westward in well 35E, similar to the SWL in the northern part of Section A-A'.

As in Section A-A', the SWL must rise rapidly eastward from well 35 I toward the main strand of the Wasatch fault. It is unknown if the SWL drops precipitously along that fault from where the intermittent stream in Holmes Canyon reaches the fault, or if it is a steep but even slope westward to that well. However, due to the heavy winter precipitation this year, overland flow in early March has extended past the mouth of Holmes Canyon to the Brigham-Ogden canal (based on oral communication and photos by June Summers and Emma Lou Hubbard). Thus, infiltration can persist at least that far to the west, well beyond the area designated "primary recharge area" in Figure 2 of the Lumberjack report.

Figure 2 of the Lumberjack report exhibits a generalized cross section showing the proposed limits of excavation and three possible deeply buried fault strands west of the main strand of the Wasatch fault zone. This diagram lacks a scale, an indication of vertical exaggeration, and documentation from the test holes drilled. I have assumed no vertical exaggeration, and have scaled distances and depths from their Figure 2 to portray in Section B-B' with its 3.3x vertical exaggeration. The results place the east margin of the pit east of the Ogden-Brigham canal, whereas their generalized diagram shows it beginning just west of a topographic bump which might represent that canal. The base of the pit stays above the layer of brown clay with gravel in well 35 I. I have added their SWL and top of bedrock. The absence of bedrock in well 35 I, which reaches a depth of ~150 ft below the scaled top of their bedrock, shows that detailed drawings like Section B-B', drawn to scale with available data such as the available drillers' logs of water wells (but absent the indicated test borings made at the site), are preferable to generalized diagrams for conveying ground truth.

Discussion

A. Groundwater

Among a number of issues that need resolution is the effect of confining layers on distribution of groundwater. It is uncertain whether or not the thin layer of clay with gravel in well 35 I is continuous with the thicker similar layer in well 35E, nor how far east the underlying gray clay extends. Access to the logs of the drilled test borings might clarify these factors. If the layer of mud and gravel pinches out as it rises into the alluvial fan eastward, infiltration into the eastern, upper part of the proposed gravel pit will affect the deeper water that is produced in wells and any springs to the west producing from below the confining gray clay. A western fault splay near U.S. Highway 89 and 91 may allow water confined below the clay to rise to the surface locally as artesian springs. Water infiltrating into the western, lower part of the proposed gravel pit likely will become perched above the confining clays, and thereby affect the wells and any springs that produce from that perched source.

B. Water quality

The Lumberjack report has no identified author nor a signed and dated stamp by a professional qualified in Utah to create and submit such information. It lists 5 reasons why they do not expect the proposed excavation to "...disrupt aquifer recharge in the area." This includes establishing the eastern pit margin well west of the primary recharge zone, presumably entirely west of the Brigham-Ogden canal.

However, other than the assurance of mitigating overland sediment discharge from the site through settling basins, there is no discussion of maintenance of water quality for those with established water rights to the west. There are numerous possible effects upon the water quality but no indication of how those will be addressed. The following list raises several such issues, but is not exhaustive.

(1) Operations in gravel pits use water for frequent spraying across much of the pit surface when dry to reduce dust. This water will readily soak into the highly permeable gravel in the pit and probably descend rapidly to the deep and/or perched water tables. Given that the Lumberjack report claims that pit operations would not disrupt aquifer recharge in this area, an indication that they do not intend to file for a new well, and that prior court decisions indicate that no new well is likely to

be approved for this site, where will the water come from, and what quality will it have when it is brought to the pit in tankers?

(2) Drillers' logs of water wells in this area commonly record boulders. These will require a rock crusher, which uses water to clean dust and fragments from the crushed material. The typical process is to crush, screen, and wash. The water then is either fed to settling ponds (which could fail even if lined, but usually are intended for infiltration) or passed through a water-cleaning unit. What will be done during the pit operation to ensure that the water thus used in a rock crusher will be treated effectively on site prior to infiltration, or removed from the site? Given that no new well is likely to be approved for this site, where will the water come from, and what quality will it have when it is brought to the pit in tankers?

(3) The channeling of runoff and surface water into detention basins for recharge (see items 3 and 4 of the Lumberjack report) probably will result in rapid downward infiltration of any pit contaminants (see 4 and 5 below). This could degrade water quality for wells and springs to the west.

(4) Numerous trucks that haul the finished rock products (crushed, graded, and washed) will result in oil leaks and possible spills of diesel or other fuels. These are likely to be carried downward to the water table through such permeable materials. Will fuel be stored and dispensed on site? What will be done to minimize leaks and spills, and how will such be treated at the surface if they occur? If a major spill occurs, what procedures will be in place to intercept the materials before they reach the wells and springs to the west? If interceptor wells are put in west of a major spill, they would strikingly decrease the quantity of water (recharge) moving west from the mountains to the wells and springs.

(5) Trespassing in gravel pits after hours of operation is common. We had permission to excavate and study the bedding and faults in a gravel pit at the mouth of Green Canyon just north of Logan, Utah (Janecke and others, 2013). There were so many problems from target shooters and ATVs that we had to contact the North Logan Police Department repeatedly. What safeguards will be put in place to ensure that there is no trespassing after hours that could involve target shooting (lead into the groundwater), ATV usage (oil and fuels spills and human waste), or illegal dumping of fluids (which occurred recently in Millville, Utah, and led to total restriction for the culinary water supply for the entire city)?

C. Earthquake and Landslide Hazards.

The east margin of the proposed gravel pit lies less than ~700 ft west of the main strand of the Wasatch fault. That fault strand, through successive offsets, has resulted in a cumulative vertical displacement of about 6000 ft at the Pleasant View Salient ~2.5 miles south of Holmes Canyon (Schirmer, 1985, his Section A-A'). The Wasatch fault zone (WFZ) is ~220 miles long, and has 10 identified active segments (Machette and others, 1991, 1992; Wong and others, 2016).

These segments "...have ruptured repeatedly and independently in large magnitude ($M \geq 6.75$) earthquakes....At least 22 surface-faulting earthquakes have ruptured the central segments *[Brigham City, Weber, Salt Lake City, Provo, and Nephi]* of the WFZ since about 6000 years ago....inter-event times for the segments range from 700 to 2700 years, and mean recurrence intervals range from 900 to 1500 years, similar to a composite mean recurrence interval for the central WFZ of about 1200 years." (Wong and others, 2016, p. 2). "The probability of one or more earthquakes of M 6.0 or larger in the Wasatch Front area in the next 50 years is 50%....**the probability of one or more earthquakes of M 5.0 or larger in the Wasatch Front region in the next 50 years is 93%.** ***[My emphasis]***...Figure ES-2 [Figure 11] shows the 50-year probabilities for earthquakes of M 6.75 or larger on selected fault segments....probabilities on the Salt Lake, Brigham City, Provo, and Weber segments are 5.8%, 5.6%, 3.9%, and 3.2%, respectively....**earthquakes in the M 5 range can cause significant localized damage in urbanized areas, and the probability of earthquakes of this size occurring in the coming decades is very high."** ***[My emphasis]*** (Wong and others, 2016, p.3).

Figure 12 (Wong and others, 2016, Appendix B, page B-60), based on results from 5 trench sites (one had multiple trenches) shows no evidence of surface faulting along the Brigham City segment in the past ~2400 years. This is twice the average recurrence interval of ~1200 years for the central WFZ. The Brigham City segment, including the main strand just east of the proposed gravel pit, appears overdue compared with other segments in the central WFZ.

The recharge of the confined aquifer south of Willard Canyon may to be mainly through fractures in the Farmington Canyon Complex (see Bryant, 1988, and Hintze and Kowallis, 2009, for a description of these rocks) and in the overlying Geertsen Canyon Quartzite rather than primarily by overland discharge along the canyons, which are shown as intermittent streams. Heavy fracturing is common near faults. Thus, the mountain face here may be susceptible to major failure as landslides.

Gilbert (1890; Crittenden, 1963) showed that shorelines that formed during the Bonneville highstand along the Promontory Range (where Lake Bonneville was ~1000 ft deep) are ~180 ft higher today than those formed simultaneously in very shallow water, e.g., Wendover, Nevada. This indicates that the Earth sinks under added weight (when the shorelines were cut), and rebounds when a weight is removed. This is a process called isostacy, first discovered in the British trigonometric survey of India in the 1800s. In Utah, the relative rebound of the central Bonneville basin, rapid at first and slower now, has averaged ~0.124 inch per year since the Bonneville Flood ~17,400 years ago.

Engineers have long understood this because the areas around all dams begin to sink when the reservoirs behind the dams are first filled. Later, catastrophic failure of a dam can result in subsequent uplift there. Microearthquakes are common near dams when they are filling, analogous to the earthquakes common in Oklahoma today when used-up fracking fluids are injected into fractures deep underground. For these reasons, detailed mapping for potentially active faults is a requisite for large dams. In order to avoid isostatic sinking, large underground parking lots exist under skyscrapers because an excavation is made first, to remove a weight equivalent to or greater than that of the building before it is erected.

The rapid rise of Lake Bonneville in Cache Valley, behind a bedrock barrier at Cutler Narrows (Oaks and others, 2014), compared to a more gradual rise in the main Bonneville basin, is correlated with evidence for four separate, successive episodes of liquefaction of beds that we believe were triggered by earthquakes locally as a result of the accumulating weight of the water (Janecke and others, 2103). Janecke and Oaks (2011a, 2011b) found a misalignment of gullies on the foreset slope of the highstand Bonneville delta across the Riverdale fault NE of Preston, Idaho. That dates the latest fault offset there either just before, during, or just after the Bonneville Flood.

Among numerous examples of landslides in this region, I have selected several from my personal collection of aerial views to illustrate the variety in ages and in scales of landslides in northern Utah. Figure 8 shows the Harrisville (North Ogden), Utah, area slightly SE of Holmes Canyon. Here a post-Bonneville landslide, modified by subsequent overland flow (Coogan and King, 2016, mapped this as an alluvial fan) buried the wave-cut Bonneville highstand shoreline that is ~100 ft high immediately west. A fresh headscarp is apparent in the steep mountain above, on the south flank of Ben Lomond. This deposit extends ~2 miles from the mountain front.

The upper photo in Figure 9 shows three landslides NNW of Cutler Narrows. To the left, a landslide (Biek and others, 2003) obliterates the Provo shoreline, and thus is post-Provo. A landslide closer to the middle (Sprinkel, 1976) is cut by the Provo and Bonneville shorelines, and thus is pre-Bonneville. The landslide in the foreground (Maw, 1968; Oviatt, 1986b) obliterates the Bonneville highstand shoreline, but is impressively cut by the Provo shoreline. It formed as the lake level fell rapidly during the Bonneville Flood. It had sufficient momentum to continue laterally more than a mile from the Provo shoreline under water.

In the lower photo in Figure 9, the larger landslide at Maple Rise along the east face of the Wellsville Mountains has buried the Bonneville and Provo shorelines, and thus is post-Provo (Williams, 1948, 1958, 1962; Dover, 1995). Drillers' logs of water wells show that this landslide is ~25 ft thick near the middle. It extends ~1 mile from the mountain front. The smaller slide is likely the same age. Recurrence intervals of the West Cache fault zone have been studied in trenches and stream gullies by Black (1998), Black and others (1998, 2000), and Solomon (1997, 1999), and are similar to those of the Wasatch Front. Details for the East Cache fault zone are summarized by McCalpin (1989, 1994), and McCalpin and Solomon (2001). Only the central segment has ruptured there in the past 10,000 years, but recurrence intervals there have been similar to those of the Wasatch Front.

The upper photo in Figure 10 shows two very large landslides that have slid down the west face of the Wellsville Mountains in the alcove in the mountain front at Crystal Hot Springs, just north of Honeyville, Utah (Oviatt, 1986a; Goessel, 1999; Goessel and others, 1999; Harty and Lowe, 1999). The large block of Oquirrh Formation across the road east of the springs dips 70° ENE toward the mountain, and has slid there from a position at least 3600 ft higher (the lowest basal contact of Oquirrh outcrops there, near the crest of the Wellsville Mountains. Drillers' logs of water wells show that the base of the landslide in the foreground is 270 ft near its north end and 240 feet near its south end (Oaks, 2000). Detailed gravity measurements by Dr. Ken Cook and his students at the University of Utah, and additional measurements that I have made (Langenheim and others, 2014), show there is bedrock near the surface across this landslide, which extends ~1.5 miles from the mountain front. The Bonneville highstand shoreline is cut across the toes of the two very large slides, so they and the bedrock mass just east of Crystal Hot Springs are older. I have mapped two similar very large landslides along the west face of Temple Peak in the Bear River Range (unpublished), along the Temple Peak fault.

The lower photo in Figure 10 shows a south-facing landslide in the Bear River Range west of Porcupine reservoir. Originally this landslide probably blocked the valley of East Fork Canyon, but did not extend far southward because of the steep valley wall to the south. Subsequently the East Fork River eroded away the southern part of this landslide prior to Lake Bonneville, whose highstand reached into this valley.

There are many additional landslides in northern Utah. Their timing before, during, and after Lake Bonneville correspond to vertical movements of the Earth's crust in response to isostacy and faulting. The frequent runouts of 1 to 2 miles, in places under water, is impressive. Local changes in the weight of the Earth's surface can trigger both earthquakes and landslides.

With information from their drilled test wells, the developer should be able to estimate the weight of the material that they propose to excavate. High-grade metamorphic rock "weighs" ~2.9 g/cc based on density logs of the two Hauser Farms oil wells in Cache Valley (Oaks and others, in prep.). Conversion to English units yields ~181 lbs/cu ft. If the boulder gravels have ~25% pore space, the total is ~136 lb/cu ft. The gravel pit is proposed for an area of 34.73 acres (1,510,755 square feet). If only 75% of the surface area is used for removal, the area would be ~1,133,000 sq ft. That is equivalent to a site ~1065 ft by ~1065 ft. Scaling of the generalized diagram in the Lumberjack report yields an average depth of ~103 ft. The minimum volume to removed would be ~117 million cubic feet, and the weight removed would be ~8 million tons. This is a conservative estimate. Details are provided below. The removal of that much weight (or more), combined with protracted periods of vibration daily from trucks and a rock crusher, could trigger rupture on the main Brigham City segment of the Wasatch fault zone, which appears to be both overdue and high risk (Figures 11, 12). If a landslide results, from faulting or from isostatic adjustments, the steep and high mountain front could collapse and run out a mile or more, perhaps as far as the levee at Willard Bay or beyond. Breaching of the levee along a landslide margin, or destruction of part of the levee via earthquake, by liquefaction or by production of a seiche wave that overtopped the levee, could inundate homes and I-15 in the low area east of the levee. The Holmes Canyon alluvial fan lies at the narrowest distance to the Willard Bay levee, which thereby is the area most susceptible to a landslide runout.

Conclusion

This report has enumerated major issues (A - C) and harmful impacts that could occur as a result of the proposed gravel pit being permitted in the designated area. These major issues should be throughly addressed by the developer in a signed and dated professional report, and afterwards we should be permitted an opportunity for rebuttal before there is further consideration of the request for a rezone to allow the proposed gravel pit.

Yours sincerely,

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Estimated Weight of Rock Products To Be Extracted From Proposed Gravel Pit in Section 35, T. 8 N., R. 2 W. SLBM

Surface Area 34.73 Acres [from Notice of Public Hearing] x 43,500 ft^2 / acre = 1,510,755 ft^2

Exclude ~25% for access road, pit edges, weighing platform, rock crusher, etc. = ~1,133,066 ft^2

This is a conservative extraction area of ~1065 ft x ~1065 ft

Pit cross-section based on generalized section submitted in "Lumberjack Professional Statement"

Used "40" on engineer's triangular scale ruler to determine distances, scaled from 1955 USGS 7.5' Willard topographic map between U.S. Highway 89 and 91 and Wasatch fault:

123 E-W = ~2084 ft
17 vertical = ~ 288 ft
123 x 17 = 2091 vertical area = ~600,192 ft^2
top right to bottom left of rectangle is above pit, so ~50% excluded
triangle on bottom right below pit = (17 x 35) / 2 = 297.5 /2091 = ~14% excluded
total excluded = ~64%; remainder = ~36% x ~288 ft vertical = ~103 ft average depth

~1,133,066 ft^2 x ~103 ft = ~116,700,000 ft^3 of rock material estimated to be removed

Weight ~ 2.9 g / cc based on density logs of metamorphic rocks in two Hauser Farms wells in Cache Valley (range 2.8 to 3.0)

1 gram / cc = 62.428 lbs / ft^3, thus 2.9 g / cc = 181 lbs / ft^3.

Estimate ~25% pore space in alluvial-fan gravels (This is conservative: maximum pore space in perfectly spherical grains of identical size stacked vertically on top of each other ~30%. Finer gravel will fill much of the pore space between larger gravel here, so porosity may be as low as 15% to 20%.)

181 lbs / ft^3 x 0.75 non-pore = ~136 lbs / ft^3

~116,700,000 ft^3 x ~136 lbs / ft^3 = ~15,870,000,000 lbs (almost 16 billion pounds)

~15,870,000,000 lbs / 2000 lbs/ton = ~7,935,000 tons (almost 8 million tons)

Because the numbers are conservative, the weight calculated probably is a minimum.

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Same/Transcontinental Gas Pipe Line Corp, Summers 1958-1960
Research Geologist, Exxon Production Research Co, 1964-1966
Assistant/Associate/Professor of Geology, Utah State University, 1966-1999
Professor Emeritus, 1999-Present
Consulting Geologist, Magellan Petroleum Corp, Central Australia, Summers 1979-1986
Consulting Geologist, Cache Valley area, Classic Geological Studies Corp, 1999-Present

30 refereed publications in journals and books
44 other publications and reports
32 published abstracts
30 years teaching at Utah State University, 10 courses, average load 21.3 quarter hours per year [= 7.1 hrs per qtr]; plus 3 sabbatical leaves
Chair for 18 completed M.S. theses in geology at Utah State University
Committee member for 52 completed M.S. theses in geology at Utah State University
Committee member for 12 completed M.S. theses and Ph.D. dissertations in other departments at Utah State University
Attended 71 professional meetings and field conferences
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Editorial Board for Elsevier's journal, Marine Geology, 1970-1999
11th Recipient of Utah Geological Association's Lehi Hintze Award for outstanding contributions to understanding the geology of Utah, 2013

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