November 13, 2009

Mr. Jay Yahne, P.E.
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Layton, UT 84041-0983

SUBJECT: Geologic Hazards Reconnaissance
South Weber Reservoir #4
South Weber and Layton, Davis County, Utah

Dear Mr. Yahne:

This report presents results of a reconnaissance-level engineering geology and geologic hazards review and assessment conducted by Western GeoLogic, LLC (Western GeoLogic) for a proposed South Weber City municipal water tank and water line west of U.S. Highway 89 and north of State Highway 193 in Davis County, Utah (Figure 1 – Project Location). The site straddles the terrace and north-facing slopes overlooking the Weber River floodplain east of the Wasatch Range front and south of Weber Canyon, and is in the Section 3, Township 4 North, Range 1 West and Section 34, Township 5 North, Range 1 West (Salt Lake Base Line and Meridian). Elevation of the Project ranges between about 4,860 to 4,600 feet above sea level.

PURPOSE AND SCOPE

The purpose and scope of this investigation is to identify and interpret surficial geologic conditions at the site and identify potential risk from geologic hazards to the project. This investigation was conducted at a reconnaissance level and is intended to: (1) provide a preliminary assessment of geologic conditions at the site; (2) identify and qualitatively evaluate potential geologic hazards that may be present and pose a significant risk to the intended site use; and (3) provide recommendations for additional site- and hazard-specific studies or mitigation measures, as may be needed based on our findings. The scope of the study does not include any hazard-specific evaluations (such as landslide studies), although additional studies may be recommended based on our findings.

The following services were performed in accordance with the above:

- A site reconnaissance conducted by an experienced certified engineering geologist to assess the site setting and look for evidence of adverse geologic conditions;
- Review of readily available geologic maps, reports, and aerial photography; and
• Evaluation of available data and preparation of this report, which presents the results of our study.

The engineering geology section of this report was prepared in general accordance with the Guidelines for Preparing Engineering Geologic reports in Utah (Utah Section of the Association of Engineering Geologists, 1986).

HYDROLOGY

The U.S. Geological Survey (USGS) topographic map of the Kaysville Quadrangle shows no natural springs or surface-water drainages in the Project immediate vicinity, although two rectangular retention basins are near the south and north Project ends (Figure 1). The Davis-Weber Canal also flows westward slightly north of the northern Project end (Figure 1). No seeps or springs were also observed in our site reconnaissance.

The subsurface hydrology in the area is dominated by the East Shore aquifer system. This aquifer system is comprised of a shallow, unconfined water table zone, and the deeper, often confined, Sunset and Delta aquifers (Feth and others, 1966). The depth to the shallow unconfined aquifer varies somewhat depending on topography and climatic and seasonal fluctuations. It is influenced by seepage from irrigation systems, and infiltration from precipitation and urban runoff. The Sunset aquifer (typical depth 250-400 feet) and Delta aquifer (typical depth 500-700 feet) provide water that generally meets the standards for public drinking water supply. Based on topography the regional groundwater flow is expected to be to the north into the Weber River floodplain.

Elevation of the shallow aquifer varies somewhat based on seasonal and climatic fluctuations. Perched groundwater conditions are possible at the site above less permeable, fine-grained lacustrine layers commonly found in the area. Depth to groundwater at the site is uncertain, but is likely greater than 50 feet.

GEOLOGY

Seismotectonic Setting
The property is located west of the base of the Wasatch Range. The Wasatch Range is a major north-south trending mountain range marking the eastern boundary of the Basin and Range physiographic province (Stokes, 1977, 1986). The Basin and Range province is characterized by a series of generally north-trending elongate mountain ranges, separated by predominately alluvial and lacustrine sediment-filled valleys and typically bounded on one or both sides by major normal faults (Stewart, 1978). The boundary between the Basin and Range and Middle Rocky Mountains provinces is the prominent, west-facing escarpment along the Wasatch fault zone (WFZ) at the base of the Wasatch Range. Late Cenozoic normal faulting, a characteristic of the Basin and Range, began between about 17 and 10 million years ago in the Nevada (Stewart, 1980) and Utah (Anderson, 1989) portions of the province. The faulting is a result of a roughly east-west directed, regional extensional stress regime that has continued to the present (Zoback and Zoback, 1989; Zoback, 1989).
The WFZ is one of the longest and most active normal-slip faults in the world, and extends for 213 miles along the western base of the Wasatch Range from southeastern Idaho to north-central Utah (Machette and others, 1992). The fault zone generally trends north-south and, at the surface, can form a zone of deformation up to several hundred feet wide containing many subparallel west-dipping main faults and east-dipping antithetic faults. Previous studies divided the fault zone into 10 segments, each of which rupture independently and are capable of generating large-magnitude surface-faulting earthquakes (Machette and others, 1992). The central five segments of the fault (Brigham City, Weber, Salt Lake, Provo, and Nephi) have each produced two or more surface-faulting earthquakes in the past 6,000 years (Black and others, 2003). The Project is in the Weber segment portion of the fault. The nearest mapped trace of the Weber segment of the WFZ is 1.3 miles to the east (Solomon, 2007), and no active faults are mapped at the site.

The Weber segment of the WFZ extends for about 35 miles from the southern edge of the Plain View salient near North Ogden to the northern edge of the Salt Lake salient near North Salt Lake (Machette and others, 1992). Previous paleoseismic studies indicate four large-magnitude surface-faulting earthquakes have occurred on the Weber segment since mid-Holocene time. Nelson and others (2006) report finding evidence for four events at the Garner Canyon and East Ogden sites, including what they infer was a partial segment rupture (with 1.6 feet of displacement) around 500 years ago. This partial segment rupture was not evident at the Kaysville site of McCalpin and others (1994), although chronologic intervals for the remaining three earthquakes were similar. DuRoss and others (2009) report paleoseismic data from the 2007 Rice Creek site support a preferred scenario of six surface-faulting earthquakes in Holocene time, with four events since about 5,400 years ago, and confirm Nelson and others’ (2006) partial segment rupture timing. Lund (2005) indicates preferred earthquake timing for the last four surface-faulting earthquakes on the Weber segment is: (1) an event Z between 200 to 800 years ago (partial segment rupture) and/or between 500 and 1,400 years ago (complete segment rupture), (2) an event Y between 2,300 and 3,700 years ago, (3) an event X between 3,800 and 5,200 years ago, and (4) an event W between 5,400 and 6,800 years ago. The consensus preferred recurrence interval for the Weber segment, as determined by the Utah Quaternary Fault Working Group, is 1,400 years for the past four surface-faulting earthquakes (Lund, 2005).

The site is also in the central portion of the Intermountain Seismic Belt (ISB), a generally north-south trending zone of historical seismicity along the eastern margin of the Basin and Range province extending from northern Arizona to northwestern Montana (Sbar and others, 1972; Smith and Sbar, 1974). At least 16 earthquakes of magnitude 6.0 or greater have occurred within the ISB since 1850; the largest of these earthquakes was a $M_S$ 7.5 event in 1959 near Hebgen Lake, Montana. However, none of these earthquakes occurred along the Wasatch fault or other known late Quaternary faults (Arabasz and others, 1992; Smith and Arabasz, 1991). The closest of these events was the 1934 Hansel Valley ($M_S$ 6.6) event north of the Great Salt Lake.
Unconsolidated Deposits
The site is located within the Wasatch Front Valley System, a deep sediment-filled, structural basin flanked by two uplifted range blocks; the Wasatch Range to the east, and the Lakeside Mountains to the west. The Project is below the highest Bonneville shoreline of Lake Bonneville, but crosses the Provo shoreline level in its north part. Surficial geology at the site was mapped by Solomon (2007) as historical to middle Holocene landslide deposits, middle Holocene to upper Pleistocene landslide deposits, upper Pleistocene alluvium, and Pleistocene deltaic sediments deposited by the Weber River during the Bonneville stage of former Lake Bonneville (units Qms1, Qms2, Qafp, and Qldb, respectively; Figure 2). Solomon (2007) describes surficial units in the site vicinity on Figure 2, from youngest to oldest in age, as follows:

Qmf -- Debris-flow deposits (upper Holocene). Very poorly sorted, subangular, cobble-to boulder-size gravel in a matrix of silt, sand, and minor clay; unsorted and unstratified; deposits characterized by rubbly surface, debris-flow levees, and alluvial channels; mapped near the mouth of Corbett Canyon in the northeast part of the quadrangle. Many debris flows occurred in 1983 following a period of unusually heavy precipitation and rapid spring snowmelt, but their deposits cannot be differentiated at map scale from landslide deposits at canyon mouths and most are mapped here as younger landslide deposits (Qmsy); other debris flows are too small to map and are included in units Qaf1, Qafy, Qalz, and Qal. Maximum thickness about 20 feet (6 m).

Qms1 -- Landslide deposits, unit 1 (Historical to Middle Holocene). Very poorly sorted clay, silt, sand, and minor gravel; grain size and texture varies with the nature of the deposits in the source area; unit 1 landslides occur in bluffs bordering the Weber River flood plain and north of Kaysville along steep bluffs incised by drainages following regression of Lake Bonneville; characterized by moderately fresh scarps and hummocky topography, with freshest scarps in areas of historical movement. Most unit 1 landslides along the Weber River originate in sandy Lake Bonneville deltaic deposits, form gently sloping alluvial-fan shaped deposits overlying unit 2 landslide deposits on river terraces that fringe the bluffs, and apparently result from flow failure, perhaps liquefaction induced, of the bluff face; one landslide along the Weber River, the Cedar Bench landslide, is an earth slide resulting from fill failure on the slope bordering an irrigation pond (Solomon, 1999). Landslides along other drainages are found at and slightly below the gradational contact between overlying Lake Bonneville sand and silt and underlying silt and clay and are the result of a combination of rotational and translational earth slides; parts of several of these landslides have been historically reactivated, resulting in damage to roads and houses. Thickness of the deposits is highly variable.

Qaf1 – Modern (level 1) alluvial-fan deposits (upper Holocene). Poorly to moderately sorted, weakly to non-stratified, silt- to boulder-size sediment deposited principally by debris flows and debris floods at the mouths of mountain-front canyons; upper parts characterized by abundant boulders and debris-flow levees that radiate away from the fan apex; small, finer grained alluvial-fan deposits are found on gentle slopes in the northern part of the quadrangle, deposited by shallow, dispersive flows; equivalent to the younger part of Qaf but differentiated where deposits can be mapped separately; commonly
overlies lacustrine and older alluvial-fan deposits; debris-flow and debris-flood hazards are highest on modern alluvial fans, their undivided equivalents within younger alluvial fans (Qafy), and debris-flow deposits (Qmf); less than 30 feet (9 m) thick.

**Qms2 – Landslide deposits, unit 2 (middle Holocene to Upper Pleistocene).** Very poorly sorted clay, silt, sand, and minor gravel; grain size and texture varies with the nature of the Lake Bonneville deltaic deposits in the source area; unit 2 landslides are found in steep bluffs bordering the Weber River flood plain and extend on to the adjacent stream terrace; the landslide deposits are rounded, heavily vegetated, and incised by alcoves formed from unit 1 landslides, suggesting that unit 2 deposits predate unit 1 deposits; unit 1 and unit 2 landslide deposits along the bluffs in the Kaysville quadrangle are the southeastern extension of the South Weber landslide complex mapped by Pashley and Wiggins (1972); thickness of the deposits is highly variable.

**Qaf2 – Level 2 alluvial-fan deposits (middle Holocene to upper Pleistocene).** Commonly poorly sorted sand, silt, clay, and minor pebbles deposited in the southwest part of the quadrangle, where stream flow from major drainages lost confinement and dispersed on a gently sloping plain near the Great Salt Lake shore; also found as poorly to moderately sorted, silt- to boulder-size sediment at the mouths of minor drainages along the mountain front, mostly south of Bair Canyon; deposited by debris flows and debris floods graded to or slightly above modern stream level; equivalent to older part of Qafy, but differentiated where deposits can be mapped separately; commonly overlies or incised into lacustrine deposits; probably less than 30 feet (9 m) thick.

**Qafy – Younger alluvial-fan deposits, undivided (Holocene to upper Pleistocene).** Poorly to moderately sorted, weakly to non-stratified, silt- to boulder-size sediment deposited principally by debris flows, debris floods, and streams; equivalent to modern and level 2 alluvial-fan deposits (Qaf1, and Qaf2.) that are undifferentiated because units are complexly overlapping or too small to show separately; also mapped where the age of Holocene alluvial-fan deposits is uncertain; upper parts of fans are locally deeply incised; occurs near canyon mouths along the mountain front; probably less than 40 feet (12 m) thick.

**Qac – Alluvial and colluvial deposits, undifferentiated (Holocene to upper Pleistocene).** Poorly to moderately sorted, generally poorly stratified, clay- to boulder-size, locally derived sediment deposited in drainages along the Wasatch Range front by fluvial, rockfall, slopewash, and creep processes; generally less than 30 feet (9 m) thick.

**Qlf – Lacustrine silt and clay deposits (Holocene to Upper Pleistocene).** Poorly sorted silt, clay, and minor sand deposited in deep and (or) quiet water of Lake Bonneville and, below the Gilbert shoreline of Great Salt Lake; commonly calcareous; typically laminated or thin bedded; ostracodes locally common; grades upslope into lacustrine sand, silt, and deltaic deposits; mapped on gentle slopes below the Provo shoreline where deposits cannot be correlated with a specific phase of the Bonneville lake cycle; etched by the Gilbert shoreline, minor shorelines above the Gilbert shoreline from the regressive phase of Lake Bonneville, and faint shorelines below the Gilbert shoreline from the post-
Gilbert recession of Great Salt Lake; a small part of the earlier Stansbury shoreline from
the transgressive phase of Lake Bonneville is mapped in Qlf on the east edge of
Kaysville, extending to the southeast into lacustrine sand and silt (Qlsbp); generally less
than 15 feet (5 m) thick.

_Qafp_ – Alluvial-fan deposits related to the Provo (regressive) phase of the Bonneville
lake cycle (upper Pleistocene). Poorly to moderately sorted, silt- to cobble-size
sediment, with local boulders, deposited principally by debris flows whose surfaces are
graded to the Provo shoreline at the mouth of Bair Canyon; incised by active streams;
probably less than about 40 feet (12 m) thick.

_Qldb_ – Deltaic deposits related to the Bonneville (transgressive) phase of the
Bonneville lake cycle (upper Pleistocene). Moderately to well-sorted, moderately to
well-rounded, sand, silty sand, gravelly sand, silt and clay; silt and clay content increases
downward and westward; thin to thick bedded; partly cemented with calcium carbonate
and locally overlain by a thin veneer of eolian sand. Mapped at two locations on the
Weber River delta: (1) between the Provo and Bonneville shorelines in the north-central
part of the quadrangle, east of Hill Air Force Base, incised by linear channels; the
channels (Qafp/Qldb) probably record scour into the delta during the rapid drawdown of
the lake as it fell from the Bonneville shoreline to the Provo shoreline when the lake’s
threshold in Idaho failed (O’Conner, 1993); and (2) below the Provo shoreline if the
northwest part of the quadrangle, between Layton and Clearfield, the eastward extension
deltaic deposits on the south flank of a ridge on the border between the adjacent
Clearfield and Roy quadrangles interpreted by Sack (2005a, 2005b) as a landscape
component created during the transgressive phase of Lake Bonneville. Maximum
thickness about 70 feet (20 m).

_Qlsb_ – Lacustrine sand and silt related to the Bonneville (transgressive) phase
of the Bonneville lake cycle (Upper Pleistocene). Fine- to coarse-grained
lacustrine sand interbedded with gravelly sand and silty sand deposited between
the Bonneville and Provo shorelines; grades laterally northward to sandy deltaic
Lake Bonneville deposits (Qldb); typically thick bedded and well sorted;
gastropods locally common; deposited in relatively shallow water as beaches
and, at the mouths of larger canyons, deltas that no longer retain distinctive
morphology; mapped near the base of the Wasatch Range north of Bair Canyon;
as much as 50 feet (15 m) thick.

_Qlgb_ – Lacustrine gravel and sand related to the Bonneville (transgressive)
phase of the Bonneville Lake cycle (upper Pleistocene). Moderately to well-
sorted, moderately to well-rounded, clast-supported, pebble to cobble gravel
interbedded with lesser amounts of pebbly sand and clean sand, deposited
between the Bonneville and Provo shorelines; thin to thick bedded; gastropods
locally common in sandy lenses; locally partly cemented with calcium carbonate;
typically forms a bench along the Bonneville shoreline near the base of the
Wasatch Range; locally as much as 200 feet (60 m) thick.
Lake Bonneville History
Lakes occupied nearly 100 basins in the western United States during late-Quaternary time, the largest of which was Lake Bonneville in northwestern Utah. The Bonneville basin consists of several topographically closed basins created by regional extension in the Basin and Range (Gwynn, 1980; Miller, 1990), and has been an area of internal drainage for much of the past 15 million years. Lake Bonneville consisted of numerous topographically closed basins, including the Salt Lake and Cache Valleys (Oviatt and others, 1992). Sediments from Lake Bonneville comprise some of the unconsolidated deposits in the site vicinity.

Timing of events related to the transgression and regression of Lake Bonneville is indicated by calendar age estimates of significant radiocarbon dates in the Bonneville Basin (Donald Currey, University of Utah; written communication to the Utah Geological Survey, 1996; and verbal communication to the Utah Quaternary Fault Parameters Working Group, 2004). Approximately 32,500 years ago, Lake Bonneville began a slow transgression (rise) to its highest level of 5,160 to 5,200 feet above mean sea level. The lake rise eventually slowed as water levels approached an external basin threshold in northern Cache Valley at Red Rock Pass near Zenda, Idaho. Lake Bonneville reached the Red Rock Pass threshold and occupied its highest shoreline, termed the Bonneville beach, after about 18,000 years ago. During the transgression and highstand, major drainages that emanate from within the Wasatch Range (such as the Weber River) formed large deltaic complexes in the lake at their canyon mouths. The lake remained at its highest level until 16,500 years ago, when headward erosion of the Snake River-Bonneville basin drainage divide caused a catastrophic incision of the threshold and the lake level lowered by roughly 360 feet in fewer than two months (Jarrett and Malde, 1987; O’Conner, 1993). Following the Bonneville flood, the lake stabilized and formed a lower shoreline referred to as the Provo shoreline. The drainages feeding the lake also began downcutting through stranded deltaic complexes. Climatic factors then caused the lake to regress rapidly from the Provo shoreline, and by about 13,000 years ago the lake had eventually dropped below historic levels of Great Salt Lake. Oviatt and others (1992) deem this low stage the end of the Bonneville lake cycle. Great Salt Lake experienced a brief transgression between 12,800 and 11,600 years ago to the Gilbert level at about 4,250 feet before receding to and remaining within about 20 feet of its historic average level (Lund, 1990).

SITE CHARACTERIZATION

Empirical Observations

On October 26, 2009 Mr. Bill D. Black of Western GeoLogic conducted a brief site reconnaissance of the Project and surrounding area. Weather at the time of the site reconnaissance was sunny to partly cloudy with temperatures in the 50’s (°F). The water tank and southern water line are on a terrace top (upper terrace) of the Weber Delta about 2.3 miles southwest of the mouth of Weber Canyon which stair-steps downward and northward to the
margin of the Weber River floodplain. The northern water line extends northwestward from the water tank across the upper terrace crest, then northeastward across a mid-level terrace, and then eastward and northeastward across steep slopes bordering the mid-level terrace. These latter slopes are in a complex area of multiple, overlapping, Holocene landslides that extends westward and northwestward several miles from U.S. Highway 89. The upper and mid-level terraces are in lacustrine deltaic sediments deposited by the Weber River in Lake Bonneville. The terrace top (upper terrace) has generally locally dissected, rolling to gentle, slopes that dip to the southwest and are bordered northeast of the water tank by a prominent, steep, west-, north, and east-facing terrace scarp. A mid-level terrace is at the base of this terrace scarp that is bordered on the north by a second, north- to northeast-facing, steep slope area in which the landslide complex occurs. The cover photo for this report illustrates this stair-stepped area, showing (from left to right) the upper terrace (with cell phone tower), terrace scarp, mid-level terrace, and steep slopes in the landslide complex.

Native vegetation in the Project area consists mainly of grasses and scattered sage brush in the upper terrace; with grasses, sage brush, and scattered to dense oak brush in the mid-level terrace and adjoining slopes. No seeps or springs were observed in the Project area, and no evidence of ongoing slope instability or fresh landslides were observed in our reconnaissance. No bedrock outcrops, active drainages, or geomorphic landforms related to surface faulting or debris flows were also observed.

**Air Photo Observations**

U.S. Geological Survey digital orthophoto aerial photography (1997 and 2006; 1-meter and 0.3-meter resolution, respectively) and 1937 black and white stereo aerial photography (frames 10-AAK3-12 and 13, scale 1:20,000) were reviewed to obtain information about the geomorphology of the Project area. Figure 3 shows the 2006 air photo of the water tank site and northern Project part. The water tank is on the upper terrace of the Weber Delta, which stair-steps downward to the northeast due to downcutting after the Bonneville flood. The upper terrace is bounded by a steep terrace scarp northeast of the water tank; a mid-level terrace associated with the Provo stage of Lake Bonneville is at the base of this scarp (Figure 3). This mid-level terrace is in turn bounded on the north by a second steep slope area produced by downcutting following lake retreat from the Provo level. These latter slopes are marginally stable and in a complex area of Holocene landsliding (Figure 3). The water line extending from the water tank skirts westward around the terrace scarp, crosses the mid-level terrace, and then proceeds eastward and northeastward between several prominent landslide scarps into the landslide complex, including crossing a younger Holocene landslide deposit (Figure 3). No other geologic hazards were observed on the air photos in the Project area.

**GEOLOGIC HAZARDS**

Assessment of potential geologic hazards and the resulting risks imposed is critical in determining the suitability of the site for development. A discussion and analysis of geologic hazards follows.
Earthquake Ground Shaking

Ground shaking refers to the ground surface acceleration caused by seismic waves generated during an earthquake. Strong ground motion is likely to present a significant risk during moderate to large earthquakes located within a 60 mile radius of the project area (Boore and others, 1993). Seismic sources include mapped active faults, as well as a random or “floating” earthquake source on faults not evident at the surface. Mapped active faults within this distance include: the East and West Cache fault zones; the Brigham City, Weber, Salt Lake, and Provo segments of the Wasatch fault zone; the East Great Salt Lake fault zone; the Morgan Fault; the West Valley fault zone; the Oquirrh fault zone; and the Bear River fault zone (Black and others, 2003).

The extent of property damage and loss of life due to ground shaking depends on factors such as: (1) proximity of the earthquake and strength of seismic waves at the surface (horizontal motions are the most damaging); (2) amplitude, duration, and frequency of ground motions; (3) nature of foundation materials; and (4) building design (Costa and Baker, 1981). Peak ground, 0.2 second spectral, and 1.0 second spectral accelerations (percent of gravity, %g) at the site with 10% and 2% probabilities of exceedance in 50 years are estimated in Frankel and others (2002) as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>10% PE in 50yr</th>
<th>2% PE in 50yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>PGA</td>
<td>19.73</td>
<td>59.80</td>
</tr>
<tr>
<td>0.2 sec SA</td>
<td>48.07</td>
<td>136.98</td>
</tr>
<tr>
<td>1.0 sec SA</td>
<td>17.17</td>
<td>57.13</td>
</tr>
</tbody>
</table>

Given the above information, earthquake ground shaking is a risk to the Project. The hazard from earthquake ground shaking can be adequately mitigated by prudent design and construction of the water tank and infrastructure in accordance with appropriate codes and design requirements.

Surface Fault Rupture

Movement along faults at depth generates earthquakes. During earthquakes larger than Richter magnitude 6.5, ruptures along normal faults in the intermountain region generally propagate to the surface (Smith and Arabasz, 1991) as one side of the fault is uplifted and the other side down dropped. The resulting fault scarp has a near-vertical slope. The surface rupture may be expressed as either a large, singular scarp, or several smaller ruptures comprising a fault zone. Ground displacement from surface fault rupture can cause significant damage or even collapse to structures located across a rupture zone.

No active faults are mapped at the site, and no evidence for surface faulting was observed on air photos or during our reconnaissance. Solomon (2007) indicates the nearest active (Holocene) fault to the site is the Weber section of the Wasatch fault zone roughly 1.3 miles to the east. Based on the above, the risk from surface faulting is rated as low.
Liquefaction and Lateral-spread Ground Failure
Liquefaction occurs when saturated, loose, cohesionless, soils lose their support capabilities during a seismic event because of the development of excessive pore pressure. Earthquake-induced liquefaction can present a significant risk to structures from bearing-capacity failures to structural footings and foundations, and can damage structures and roadway embankments by triggering lateral spread landslides. Earthquakes of Richter magnitude 5 are generally regarded as the lower threshold for liquefaction. Liquefaction potential at the site is a combination of expected seismic (earthquake ground shaking) accelerations, groundwater conditions, and presence of susceptible soils.

Liquefiable sands are mapped in the site vicinity and were observed at the surface during our reconnaissance. However, liquefaction potential is also dependant on groundwater depth, which is likely greater than 30 feet. Liquefaction is not common where groundwater depths exceed 30 feet. Given the above, we rate the existing risk from liquefaction as low. However, flow failures from the steep slopes may be generated during a large magnitude earthquake if both perched groundwater and susceptible sandy soils are present during a threshold earthquake. Such failures would be a component of the landslide hazard at the site discussed below.

Tectonic Deformation
Tectonic deformation refers to subsidence from warping, lowering, and tilting of a valley floor that accompanies surface-faulting earthquakes on normal faults. Large-scale tectonic subsidence may accompany earthquakes along large normal faults (Lund, 1990). Tectonic subsidence is believed to mainly impact those areas immediately adjacent to the downthrown side of a normal fault. The nearest active fault to the site is the main trace of the Weber segment of the Wasatch fault zone about 1.3 miles to the east. At this distance, it is possible the site will experience a low degree of eastward seismic tilting. Such tilting may have some impact on the water tank and water lines, particularly with regard to alteration of flow gradients and patterns to and from the water tank.

Seismic Seiche and Storm Surge
Earthquake-induced seiche presents a risk to structures within the wave-oscillation zone along the edges of large bodies of water, such as the Great Salt Lake. Given the elevation of the subject property and distance from large bodies of water, the risk to the subject property from seismic seiches is rated as very low.

Stream Flooding
Stream flooding may be caused by direct precipitation, melting snow, or a combination of both. In much of Utah, floods are most common in April through June during spring snowmelt. High flows may be sustained from a few days to several weeks, and the potential for flooding depends on a variety of factors such as surface hydrology, site grading and drainage, and runoff. No active drainages cross the site or were evident during our reconnaissance, and based on this the hazard from stream flooding should be low. However, site hydrology and runoff should be addressed by the civil engineering design for the development.
Shallow Groundwater
No springs are shown on the topographic map for the Kaysville quadrangle at the site and no springs or seeps were observed during our site reconnaissance. Depth to groundwater at the site is unknown, but is likely greater than 50 feet. Groundwater depth can fluctuate based on seasonal and climatic variations in up-gradient runoff infiltration, and may decrease as water is added from sources such as landscape irrigation. Local perched groundwater zones may also be present above less-permeable lake sediments. We do not anticipate that shallow groundwater will pose a significant constraint to the site.

Landslide and Slope Failures
Slope stability hazards such as landslides, slumps, and other mass movements can develop along moderate to steep slopes where a slope has been disturbed, the head of a slope loaded, or where increased groundwater pore pressures result in driving forces within the slope exceeding restraining forces. Slopes exhibiting prior failures, and also deposits from large landslides, are particularly vulnerable to instability and reactivation.

Figures 2 and 3 show that the northern water line extending from the water tank crosses a prehistoric landslide complex. This prehistoric slide complex consists of numerous, overlapping, slumps and earthflows, including an area of younger Holocene landslide deposits. Several prominent scarps mark landslide source areas in the steep slopes below the crest of the mid-level terrace. The landslides were possibly produced by a build up of pore-water pressure in the slopes from perched groundwater levels in the underlying deltaic sediments. These failures were likely either rapid, liquefied earthflows that originated as a rotational slump in the steep slopes, similar to the 425 East South Weber landslide that occurred in February of 2005 (Giraud, 2005), or slow-moving translational slides that lacked sufficient water to fully mobilize. Flow failure deposits may extend hundreds of feet beyond slope base, and the depositional distances from the scarps on Figure 3 suggest past slides in the Project area were likely such flows. Understanding the exact failure mechanism is difficult without subsurface data (such as from trenching). Liquefaction flow failures, which are a third type of failure common in the area, may also occur from the steep slopes if both perched groundwater and susceptible sandy soils are present during a threshold earthquake. Such failures in the area are typically marked by large, teardrop amphitheaters, such as those to the east of the Project.

Given all of the above, we rate the risk from landsliding to the Project as high. Although the water tank and southern water line are in geologic deposits that have not been affected by landsliding in the past, the proposed routs of the northern water line crosses landslide deposits to reach planned service areas in South Weber. It is possible, in the absence of careful engineering, that a water line located in the landslide area could suffer damage or failure should landslide movement reoccur. Slope movement could also cause leakage that might exacerbate slope instability. A catastrophic failure could cause considerable damage from flooding and sedimentation to the down slope residential areas. Based on this risk, we recommend that a site-specific geotechnical engineering evaluation be performed prior to building to evaluate stability of the steep slopes along the northern part of the water line route and provide needed data for proper design of the water tank and ancillary utilities. Recommendations for reducing the risk from landsliding should be provided if factors of safety are determined to be unsuitable, and design features such as leak detection sensors and automatic cut-off valves should be
deployed to reduce risk from leakage or failure. Care should also be taken that site grading does not destabilize slopes in this area without prior geotechnical analysis and grading plans, and that proper drainage is maintained.

The slope stability analysis will require a detailed cross section based on site-specific geologic and subsurface data, including stratigraphy, soil strengths, and inferred or known groundwater depth. No geologic cross sections were created for this reconnaissance-level report, but could be provided once subsurface data is available and profile locations for the stability analyses have been selected. An important part of the stability evaluation will be to identify past failure mechanisms and model potential future failure modes. Failure mechanisms can often be inferred, but only confidently identified by subsurface data obtained from trenching or drilling.

Debris Flows and Floods
Debris flow hazards are typically associated with unconsolidated alluvial fan deposits at the mouths of large range-front drainages, such as those along the Wasatch Front. The site is not in any mapped alluvial fan deposits, and no evidence of debris-flow channels, levees, or other debris-flow features was observed at the property. Given this evidence, the hazard from debris flows at the site is rated as low.

Rock Fall
The water tank and water lines are not in close proximity to any bedrock outcrops that may provide a source for rock falls. No bedrock is mapped in the Project area, and no large boulders were observed at the surface that could pose a hazard. Based on the above, the hazard from rock falls is rated as low.

Snow Avalanche
A hazard from snow avalanches may exist due to proximity of the site to mountainous areas with south-, west- and north-facing slope aspects. Based on the distance of the site from the mountain front, the risk from snow avalanche is very low.

Radon
Radon comes from the natural (radioactive) breakdown of uranium in soil, rock, and water and can seep into homes through cracks in floor slabs or other openings. Radon only poses an indoor-air health hazard, and therefore is not a risk for a water tank.

Swelling and Collapsible Soils
Surficial soils that contain certain clays can swell or collapse when wet. No evidence of potential swelling and collapsible soils was observed at the site. Sediments at the site appear to consist mainly of sand with lesser silt and gravel. However, a geotechnical engineering evaluation should be performed during the subdivision approval process to address soil conditions and provide specific recommendations for site grading, subgrade preparation, and footing and foundation design.

Volcanic Eruption
No active volcanoes, vents, or fissures are mapped in the region. Based on this, no volcanic hazard likely exists at the site and the risk to the project is very low.
CONCLUSIONS AND RECOMMENDATIONS

The Project is in an upper terrace from deposition by the Weber River during the highstand of Pleistocene Lake Bonneville, and extends downslope to a mid-level terrace associated with the Provo level. This mid-level terrace is bounded by steep slopes formed by downcutting of the Weber River since Lake Bonneville retreated. The water tank and southern water line are in stable slopes areas underlain by lacustrine deltaic sediments, but the northern water line must cross a prehistoric landslide complex to reach planned service areas in South Weber. The Project is also in an area of potentially strong ground shaking from seismic sources such as the Wasatch fault zone. Given the above, principal geologic hazards to the Project would be landslides and earthquake ground shaking. The following recommendations are provided to address these hazards:

- A design-level geotechnical engineering study should be conducted prior to construction to:
  1. Address soil conditions at the Project for use in foundation design, site grading, and drainage;
  2. Provide recommendations regarding tank and infrastructure design to reduce risk from seismic acceleration; and
  3. Evaluate stability of steep slopes along the water line route in the northern part of the Project, including providing recommendations for reducing the risk from landsliding if factors of safety are unsuitable. Design measures such as leak detection sensors and automatic cut-off valves should be employed for the tank to reduce risk from leakage or failure. Further detailed mapping and subsurface data, such as from drilling or trenching, may be needed in landslide areas crossed by the water line to provide the geologic information needed for the slope stability analysis and to determine past slope failure mechanisms.

Availability of Report
This report, and all prior and subsequent reports and reviews, should be made available to architects, building contractors, and in the event of a future property sale, real estate agents and potential buyers. The report should be referenced for information on technical data only as interpreted from observations and not as a warranty of conditions throughout the site. The report should be submitted in its entirety, or referenced appropriately, as part of any document submittal to a government agency responsible for planning decisions or geologic review. Incomplete submittals void the professional seals and signatures we provide herein. Although this report and the data herein are the property of the client, the report format is the intellectual property of Western Geologic and should not be copied, used, or modified without express permission of the authors.
LIMITATIONS

This investigation was performed at the request of the Client using the methods and procedures consistent with good commercial and customary practice designed to conform to acceptable industry standards. The analysis and recommendations submitted in this report are based upon the data obtained from compilation of known geologic information. This information and the conclusions of this report should not be interpolated to adjacent properties without additional site-specific information. In the event that any changes are later made in the location of the proposed site, the conclusions and recommendations contained in this report shall not be considered valid unless the changes are reviewed and conclusions of this report modified or approved in writing by the engineering geologist.

This report has been prepared by the staff of Western GeoLogic for the Client under the professional supervision of the principal and/or senior staff whose seal(s) and signatures appear hereon. Neither Western GeoLogic, nor any staff member assigned to this investigation has any interest or contemplated interest, financial or otherwise, in the subject or surrounding properties, or in any entity which owns, leases, or occupies the subject or surrounding properties or which may be responsible for environmental issues identified during the course of this investigation, and has no personal bias with respect to the parties involved.

The information contained in this report has received appropriate technical review and approval. The conclusions represent professional judgment and are founded upon the findings of the investigations identified in the report and the interpretation of such data based on our experience and expertise according to the existing standard of care. No other warranty or limitation exists, either expressed or implied.

The investigation was prepared in accordance with the approved scope of work outlined in our proposal for the use and benefit of the Client; it’s successors, and assignees. It is based, in part, upon documents, writings, and information owned, possessed, or secured by the Client. Neither this report, nor any information contained herein shall be used or relied upon for any purpose by any other person or entity without the express written permission of the Client. This report is not for the use or benefit of, nor may it be relied upon by any other person or entity, for any purpose without the advance written consent of Western GeoLogic.

In expressing the opinions stated in this report, Western GeoLogic has exercised the degree of skill and care ordinarily exercised by a reasonable prudent professional geologist in the same community and in the same time frame given the same or similar facts and circumstances. Documentation and data provided by the Client, designated representatives of the Client or other interested third parties, or from the public domain, and referred to in the preparation of this assessment, have been used and referenced with the understanding that Western GeoLogic assumes no responsibility or liability for their accuracy.
The independent conclusions represent our professional judgment based on information and data available to us during the course of this assignment. Factual information regarding operations, conditions, and test data provided by the Client or their representative has been assumed to be correct and complete. The conclusions presented are based on the data provided, observations, and conditions that existed at the time of the field exploration.

It has been a pleasure working with you on this project. Should you have any questions please call.

Sincerely,
Western GeoLogic, LLC

Bill. D. Black, P.G.
Associate Engineering Geologist

Reviewed by:
Craig V Nelson, P.G., C.E.G.
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ATTACHMENTS

- Figure 1. Location Map
- Figure 2. Geologic Map
- Figure 3. Air Photo, North Area
REFERENCES


Solomon, B.J., 2007, Surficial geologic map of part of the Kaysville Quadrangle, Davis County, Utah: Utah Geological Survey Map 224, scale 1:24,000.


FIGURE 1

LOCATION MAP

GEOLOGIC HAZARDS RECONNAISSANCE
South Weber Reservoir #4
South Weber and Layton, Davis County, Utah

FIGURE 2
GEOLOGIC MAP

Source: Solomon (2007); see text for description of nearby geologic units.

PROJECT

GEOLOGIC MAP
GEOLOGIC HAZARDS RECONNAISSANCE
South Weber Reservoir #4
South Weber and Layton, Davis County, Utah

FIGURE 2
FIGURE 3
AIR PHOTO, NORTH AREA

Source: U.S. Geological Survey orthophoto, August 2006, 0.3m resolution.
Landslide mapping modified from Solomon (2007).

GEOLOGIC HAZARDS RECONNAISSANCE
South Weber Reservoir #4
South Weber and Layton, Davis County, Utah

FIGURE 3