REPORT

SUPPLEMENTAL GEOLOGIC HAZARDS RECONNAISSANCE

CEDAR COVE SUBDIVISION LOT 12

2670 EAST BYBEE DRIVE

OGDEN, WEBER COUNTY, UTAH

Prepared for

Corey Combe
2181 East Combe Road
Ogden, UT 84403

October 2, 2017

Prepared by

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October 2, 2017

Corey Combe
2181 East Combe Road
Ogden, UT 84403

SUBJECT: Supplemental Geologic Hazards Reconnaissance
Cedar Cove Subdivision Lot 12
2670 East Bybee Drive
Ogden, Weber County, Utah

Dear Mr. Combe:

This report presents results of a supplemental engineering geology and geologic hazards review and reconnaissance conducted by Western GeoLogic, LLC (Western GeoLogic) for Lot 12 in the Cedar Cove Subdivision in unincorporated Weber County, Utah, Utah (Figure 1 – Project Location). The Project consists of a 1.27-acre parcel identified as Weber County Assessor's parcel number 07-723-0012. The Project is on west- to south-facing slopes overlooking the Weber River about 3,600 feet west of Broad Hollow at the western base of the Wasatch Range, and is in the NE¼ Section 26, Township 5 North, Range 1 West (Salt Lake Base Line and Meridian). Elevation of the site ranges between about 4,660 and 4,750 feet above sea level. It is our understanding that the property is currently planned for development of one residential home in the western part of the parcel.

PURPOSE AND SCOPE

The purpose and scope of this investigation is to identify and interpret surficial geologic conditions at the site to identify potential risk from geologic hazards to the Project. This investigation is intended to: (1) provide preliminary geologic information and assessment of geologic conditions at the site; (2) identify potential geologic hazards that may be present and qualitatively assess their 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. Such recommendations could require further multi-disciplinary evaluations, and/or may need design criteria that are beyond our professional scope. No hazard-specific evaluations or subsurface exploration were conducted for this report or within the scope of our study.

The following services were performed in accordance with the above stated purpose and scope:

- A site reconnaissance conducted by an experienced certified engineering geologist to assess the site setting and look for adverse geologic conditions;

- Review of readily-available geologic maps, reports, and air photos; and
- Evaluation of available data and preparation of this report, which presents the results of our study.

The engineering geology section of this report has been prepared in accordance with Bowman and Lund (2016) and current generally accepted professional engineering geologic principles and practice in Utah, and meets specifications provided in Chapter 27 of the Weber County Land Use Code within the above stated scope. We do not include discussion of radon hazard potential, as recommended in Bowman and Lund (2016), because radon gas poses an environmental health hazard and indoor levels are heavily influenced by several post-construction, non-geologic factors. The hazard from radon should be evaluated by long-term testing following construction.

PREVIOUS STUDIES

A prior geologic hazards reconnaissance report was prepared for the Project by Western GeoLogic in September 2007 (Western GeoLogic, 2007). Our prior report identified earthquake ground shaking, surface fault rupture, liquefaction, and landslides as geologic hazards posing a potential risk to the site. With regard to these hazards, we recommended a design-level geotechnical engineering study be conducted prior to construction to address soil foundation conditions, evaluate the potential for liquefaction and shallow groundwater as needed, and evaluate stability of slopes at the site. Western GeoLogic (2007) further identified the site as being in an area of "Moderate" radon hazard potential, but this hazard is no longer addressed in our reports as noted above.

Western GeoLogic (2007) was incorporated as an appendix to a geotechnical engineering evaluation prepared for the Project by Earthtec Testing & Engineering (ETE, 2007). ETE's (2007) report discusses and provides recommendations regarding General Site Grading, Structural Fill and Compaction, Backfill, Excavation, and Permanent Cut and Fill Slopes (Section 8.0); Slope Stability (Section 10.0); Seismic Design and Liquefaction (Section 11.0); Foundation Design and Settlement (Section 12.0); Lateral Earth Pressures (Section 13.0); Floor Slabs (Section 14.0); and Surface Drainage (Section 15.0). ETE (2007) hand augered one test hole at the Project to a depth of 10 feet and encountered only poorly graded sand with silt; one soil sample was obtained at a depth of 5.0 feet for lab analysis (as reported in Table 1 and Section 8.0). No groundwater was encountered in the test hole to the explored depth. ETE (2007) also conducted a slope stability evaluation for the site that found static and pseudo-static factors of safety of 1.585 and 1.258 (respectively), as discussed in Section 10.0.

Portions of this report have been excerpted from Western GeoLogic (2007) for clarity and consistency, and appended where needed for site-specific discussions.

HYDROLOGY

The U.S. Geological Survey (USGS) topographic map of the Ogden Quadrangle (Figure 1) shows no surface-water impoundments, springs, or active drainages at the property. No springs, seeps, or wetland areas were also observed at the Project or in the vicinity in 2007 or in our field reconnaissance. Slopes at the site appeared very dry in both 2007 and currently. The nearest spring on Figure 1 is Hamre Spring about 1,250 feet northeast of the site.

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 west and then south into the Weber River floodplain.

Elevation of the shallow aquifer varies somewhat based on seasonal and climatic fluctuations. No evidence of groundwater was observed in the slopes at the site, and depth to groundwater is unknown but is likely greater than 30 feet. No groundwater was also encountered in ETE's (2007) test hole to a depth of 10 feet. However, groundwater levels may vary annually from climatic fluctuations, and also seasonally from snowmelt runoff and man-made sources such as landscape irrigation. Seasonal variations would be typical for an alpine environment. Perched conditions may also be found above less-permeable, fine-grained lacustrine sediments underlying the site that could cause locally shallower groundwater levels.

GEOLOGY

Surficial Geology

The site is located about 3,600 feet west of the mouth of Broad Hollow at the western base of the Wasatch Range, a major north-south trending mountain range marking the eastern boundary of the Basin and Range physiographic province (Stokes; 1977, 1986). Surficial geology of the site is mapped by Coogan and King (2016; Figure 2) as mainly younger Quaternary landslide deposits (unit Qmsy). The hatched scarp on Figure 2 north of the site marks an embayment in the deltaic sediments characteristic of a prehistoric earthflow. Such failures are commonly found in the downcut slopes bordering the Weber River floodplain in the area.

Coogan and King (2016) describe surficial geologic units in the site area on Figure 2 as follows:

> ***Qh, Qh?*** - *Human disturbances (Historical).* Mapped disturbances obscure original deposits or rocks by cover or removal; only larger disturbances that pre-date the 1984 aerial photographs used to map the Ogden 30 x 60- minute quadrangle are shown; includes engineered fill, particularly along Interstate Highways 80 and 84, the Union Pacific Railroad, and larger dams, as well as aggregate operations, gravel pits, sewage-treatment

facilities, cement plant quarries and operations, brick plant and clay pit, Defense Depot Ogden (Browning U.S. Army Reserve Center), gas and oil field operations (for example drill pads) including gas plants, and low dams along several creeks, including a breached dam on Yellow Creek.

Qaf, Qafy, Qaf3, Qaf3?, Qaf4, Qaf4?, Qaf5 - *Alluvial-fan deposits (Holocene and Pleistocene).* Mostly sand, silt, and gravel that is poorly bedded and poorly sorted and that is not close to late Pleistocene Lake Bonneville and is geographically in the Huff Creek and upper Bear River drainages; variably consolidated; includes debris flows, particularly in drainages and at drainage mouths (fan heads); generally less than 60 feet (18 m) thick. Qaf with no suffix used where age uncertain or for composite fans where portions of fans with multiple ages cannot be shown separately at map scale; toes of some fans have been removed by human disturbances, so their age cannot be determined.

Where possible, subdivided into relative ages, indicated by letter and number suffixes (like Qa and Qat suffixes) and relative ages only apply to the local drainage, with unit Qafy being the lowest (youngest) fans and unit 3 may or may not post-date Lake Bonneville. Relative ages of these fans are partly based on heights above present drainages at drainage-eroded edge of fan. The relative age is queried where the age is uncertain, generally due to the height not fitting into the typical order of surfaces. The various deposits listed, Qafy and Qaf3 through Qaf5, are 20 to 140 feet (6-40 m) above and west of Saleratus Creek, and also above Yellow Creek and the Bear River. Qafy fans are active, impinge on present-day floodplains, divert active streams, and overlie low terraces.

Qal, Qal1, Qal2, Qal2? - *Stream alluvium and flood-plain deposits (Holocene and uppermost Pleistocene).* Sand, silt, clay, and gravel in channels, flood plains, and terraces typically less than 16 feet (5 m) above river and stream level; moderately sorted; unconsolidated; along the same drainage Qal2 is lower than Qat2 and has likely been subject to flooding, at least prior to dam building; present in broad plains along the Bear, Ogden, and Weber Rivers and larger tributaries like Deep, Cottonwood, East Canyon, Lost, and Saleratus Creeks, along Box Elder, Heiners, and Yellow Creeks, and in narrower plains of larger tributary streams; locally includes muddy, organic overbank and oxbow lake deposits; composition depends on source area, so in back valleys typically contains many quartzite cobbles recycled from the Wasatch Formation; mostly Holocene, but deposited after regression of Lake Bonneville from the late Pleistocene Provo shoreline; width in Morgan Valley is combined flood plain of Weber River and East Canyon and Deep Creeks; 6 to 20 feet (2-6 m) thick and possibly as much as 50 feet (15 m) along Weber River and thinner in the Kaysville quadrangle; greater thicknesses (>50 feet [15 m]) are reported in Morgan Valley (Utah Division of Water Rights, well drilling database), but likely include Lake Bonneville and older Pleistocene deposits.

Suffixes 1 and 2 indicate ages where they can be separated, with 1 including active channels and 2 including low terraces 10 to 20 feet (3-6 m) above the Weber and Ogden Rivers, and the South Fork Ogden River that may have been in the flood plain prior to damming of these waterways. Qal2 queried in low terraces above Bear River, Saleratus Creek, and Dry Creek where deposits may not be in the flood plain.

Qac - *Alluvium and colluvium (Holocene and Pleistocene).* Unsorted to variably sorted gravel, sand, silt, and clay in variable proportions; includes stream and fan alluvium, colluvium, and, locally, mass-movement deposits too small to show at map scale; typically mapped along smaller drainages that lack flat bottoms; more extensive east of Henefer where Wasatch Formation (Tw) strata easily weather to debris that "chokes" drainages; 6 to 20 feet (2-6 m) thick. Some deposits are "perched" on benches 80 feet (25 m) and more above present-day drainages like Left Fork Heiners Creek (Heiners Creek quadrangle) and Harris Canyon (Henefer quadrangle). In the Devils Slide quadrangle, some deposits are "perched" on benches about 60 to 130 feet (18-40 m) above Quarry Cottonwood Canyon indicating the alluvium is at least partly Lake Bonneville age and older (see Qab and Qao in tables 1 and 2).

Qat2, Qat3 - *Stream-terrace alluvium (Holocene and Pleistocene).* Sand, silt, clay, and gravel in terraces inset into late Pleistocene Weber River delta above Weber River flood plain; moderately to well-sorted, pebble and cobble gravel and gravelly sand with subangular to rounded clasts; unconsolidated to weakly consolidated; upper surfaces slope gently downstream; locally includes thin and small mass-movement and alluvial-fan deposits; subdivided into relative ages, indicated by number suffixes, with 2 being the lowest/youngest terraces and 3 divided by a scarp on the map into an upper and lower terrace; terraces 20 to 50 feet (6-16 m) above the Weber River; exposed thickness less than 20 to 50 feet (6-16 m) (after Yonkee and Lowe, 2004). These terraces do not fit into table 1 or 2 because they post-date the regression of Lake Bonneville from the Provo shoreline and appear to be graded to lake levels below the Gilbert shoreline.

Qms, Qms?, Qmsy, Qmsy?, Qmso, Qmso? - *Landslide deposits (Holocene and upper and middle? Pleistocene).* Poorly sorted clay- to boulder sized material; includes slides, slumps, and locally flows and floods; generally characterized by hummocky topography, main and internal scarps, and chaotic bedding in displaced blocks; composition depends on local sources; morphology becomes more subdued with time and amount of water in material during emplacement; Qms may be in contact with Qms when landslides are different/distinct; thickness highly variable, up to about 20 to 30 feet (6-9 m) for small slides, and 80 to 100 feet (25-30 m) thick for larger landslides. Qmsy and Qmso queried where relative age uncertain; Qms queried where classification uncertain. Numerous landslides are too small to show at map scale and more detailed maps shown in the index to geologic mapping should be examined.

Qms without a suffix is mapped where the age is uncertain (though likely Holocene and/or late Pleistocene), where portions of slide complexes have different ages but cannot be shown separately at map scale, or where boundaries between slides of different ages are not distinct. Estimated time of emplacement is indicated by relative-age letter suffixes with: Qmsy mapped where landslides deflect streams or failures are in Lake Bonneville deposits, and scarps are variably vegetated; Qmso typically mapped where deposits are "perched" above present drainages, rumpled morphology typical of mass movements has been diminished, and/or younger surficial deposits cover or cut Qmso. Lower perched Qmso deposits are at Qao heights above drainages (95 ka and older) and the higher perched deposits may correlate with high level alluvium (QTa_) (likely older than 780 ka) (see table 1). Suffixes y and o indicate probable Holocene and Pleistocene ages, respectively, with all Qmso likely emplaced before Lake Bonneville transgression. These older deposits are as unstable as other slides, and are easily reactivated with the addition of water, be it irrigation or septic tank drain fields.

Qmc - *Landslide and colluvial deposits, undivided (Holocene and Pleistocene).* Poorly sorted to unsorted clay- to boulder-sized material; mapped where landslide deposits are difficult to distinguish from colluvium (slopewash and soil creep) and where mapping separate, small, intermingled areas of landslide and colluvial deposits is not possible at map scale; locally includes talus and debris flow and flood deposits; typically mapped where landslides are thin ("shallow"); also mapped where the blocky or rumpled morphology that is characteristic of landslides has been diminished ("smoothed") by slopewash and soil creep; composition depends on local sources; 6 to 40 feet (2-12 m) thick. These deposits are as unstable as other landslide units (Qms, Qmsy, Qmso).

Qct - *Colluvium and talus, undivided (Holocene and Pleistocene).* Unsorted clay- to boulder-sized angular debris (scree) at the base of and on steep, typically partly vegetated slopes; shown mostly on steep slopes of resistant bedrock units; 6 to 30 feet (2-9 m) thick.

Qlf, Qlf?, Qlfb, Qlfb? - *Fine-grained lacustrine deposits (Holocene and upper Pleistocene).* Mostly silt, clay, and fine-grained sand deposited near- and off-shore in Lake Bonneville; typically mapped as Qlf below the Provo shoreline (P) because older transgressive (Qlfb) deposits are indistinguishable from younger regressive deposits; mapped as Qlfb above the Provo shoreline because these deposits can only be related to the Bonneville shoreline (B) and transgression; grades upslope with more sand into Qls or Qlsp; typically eroded from shallow Norwood Formation in Ogden and Morgan Valleys and at least 12 feet (4 m) thick near Mountain Green. Qlf and Qlfb queried where grain size is uncertain.

In the Kaysville quadrangle, Qlf deposits that are below the Gilbert (G) shoreline are at least partly the same age as this shoreline (Holocene-latest Pleistocene) and post-date late Pleistocene Lake Bonneville. Qlf deposits below the Holocene (H) highstand shoreline are Holocene. Both ages of deposits are generally less than 15 feet (5 m) thick.

Deeper water fine-grained deposits overlie older shoreline and delta gravels (Qlf/Qdlb) at the mouths of several drainages along the Weber River. These gravels were deposited above the Provo shoreline during transgression of Lake Bonneville to the Bonneville shoreline (see unit Qdlb).

Qadp, Qadp? - *Provo-shoreline and regressive alluvial and deltaic deposits (upper Pleistocene).* Cobbly gravel, sand, silt, and clay deposited above (subaerial) and in Lake Bonneville (subaqueous); typically mapped where shorelines are obscure, so that line cannot be drawn between alluvial fan and delta; mapped below/near the Provo shoreline and related to the Provo and slightly lower regressional shorelines; deposits prominent east of Brigham City, at mouth of North Ogden Canyon, and on bench north of the Weber River; deposited as delta foreset beds with original dips of 30 to 35 degrees that allow separation from mixed lacustrine deposits (Qdlp); deltaic deposits at least 40 feet (12 m) thick and contain subrounded to well-rounded pebble and cobble gravel in a matrix of sand and silt with interbeds of sand and silt; capped by gently dipping alluvial-fan and stream topset beds that are less than 16 feet (5 m) thick, are poorly to moderately sorted, silty to sandy, subangular to well-rounded pebble and cobble gravel, and contain subangular to angular clasts in a matrix of sand and silt with interbeds of sand and silt (see units lpd and alp of Personius, 1990).

East of Brigham City at the mouth of Box Elder Canyon these deposits have been extensively excavated for sand and gravel. King estimates these deposits are about 200 feet (60 m) thick (from topographic contours) south of the mouth of Box Elder Creek, while Smith and Jol (1992) implied they are 400 feet (120 m) thick to the west of the Ogden map area.

The Provo shoreline fan-delta sediments were eroded from Bonneville-shoreline lacustrine and alluvial deposits, contain 20 to 70 percent rounded recycled Lake Bonneville clasts (Personius, 1990), and were redeposited during and soon after the Bonneville flood, which occurred during the drop of Lake Bonneville to the Provo shoreline. The Qadp unit probably includes Provo-stillstand deltaic deposits, sub-Provo-stillstand (regressional) alluvial-fan and lacustrine-deltaic deposits that contain abundant reworked materials from the Provo-shoreline delta, and locally overlying alluvial-fan deposits. Personius (1990) noted that deposits at the mouth of Box Elder Canyon are a fan-delta. A fan-delta is built when an alluvial fan enters a lake or ocean, and includes both the fan and the delta.

Qlg, Qlg?, Qlgp, Qlgb, Qlgb? *- Lake Bonneville gravel and sand (upper Pleistocene).* Mostly interbedded pebble and cobble gravel and sand deposited along beaches and slightly offshore; varies from clast supported to only rare gravel clasts in a matrix of sand and silt; grades downslope and, locally, laterally into finer grained deposits (Qls, Qlsp, Qlsb); mapped as Qlg downslope from topographic slope break of Provo and regressive beaches (Qlgp) because gravel and sand may be related to Lake Bonneville transgression on this gentler slope; also mapped as Qlg where Provo shoreline not distinct or relationships to shorelines uncertain; Qlg and Qlgb queried where grain size or unit identification uncertain; up to about 100 feet (30 m) thick in gravel pits but less than 20 feet (6 m) thick on most valley slopes. Constructional landforms (beach ridges, bars, and spits) and transgressive (t) shorelines limited in Ogden map area.

Qlgp is mapped in beaches near and below the erosional bench at the Provo shoreline (P); gravel typically subrounded to rounded, but locally along bedrock mountain fronts marked by a carbonate-cemented, poorly sorted, angular pebble to boulder gravel in a sandy matrix.

Qlgb is mapped in beaches mostly just downslope from Bonneville shoreline (B), typically an eroded bench, and above Provo shoreline; deposited during transgression to and occupation of the Bonneville shoreline; clasts typically subrounded to rounded but contains subangular to angular clasts on steep bedrock mountain fronts; mountain front Bonneville shoreline benches covered by locally mappable (> 6 feet [2 m] thick) colluvium and talus (Qmt, Qc, Qct).

Xfcb, Xfcb? - Biotite-rich schist (Paleoproterozoic). Medium-gray to dark-brown, strongly foliated, biotite-rich schist with widespread garnet and sillimanite; displays alternating biotite-rich and quartz-feldspar-rich bands that are rotated into complex fold patterns; cut by garnet-bearing pegmatite dikes; also contains some thin layers of amphibolite, quartz-rich gneiss, and granitic gneiss; gradational contacts with migmatitic gneiss.

Citations, tables, and/or figures referenced above are not provided herein, but are in Coogan and King (2016).

Seismotectonic Setting

The property is located west of the western 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 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). North of the Weber River, the WFZ forms a complex zone of multiple west- and east-dipping fault traces. The nearest faults in this zone are two east-dipping antithetic traces about 475 to 600 feet east of the property. The main west-dipping fault trace is located about 800 feet east of the site. Several paleoseismic studies have been conducted on the Weber segment to evaluate its Holocene earthquake history. Nelson and others (2006) report finding evidence for four large-magnitude earthquakes 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) indicate that 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.

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.

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).

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 (Oviatt, 2015). Approximately 30,000 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, around 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. Headward erosion of the Snake River-Bonneville basin drainage divide then 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). The Project is located below the elevation for the lake highstand, which is mapped on Figure 2 about 2,400 feet east of the Project (blue line and B). The Provo shoreline is not mapped in the area, but roughly corresponds to the terrace crest north of the site (Figure 1, 4,800-foot elevation contour).

Following the Bonneville flood, the lake stabilized and formed a lower shoreline referred to as the Provo shoreline between about 16,500 and 15,000 years ago. 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. Drainages that fed Lake Bonneville began downcutting through stranded deltaic complexes and near-shore deposits as the lake receded from the Provo shoreline. Great Salt Lake then experienced a brief transgression around 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 September 29, 2017, Mr. Bill D. Black of Western GeoLogic conducted a supplemental reconnaissance of the property. Weather at the time of the site reconnaissance was clear and sunny with temperatures in the low 60's (°F). A photographic record of the site reconnaissance is provided in the Appendix. The site is on west- to south-facing slopes overlooking the Weber River floodplain about 0.8 miles northwest of the mouth of Weber Canyon. Native vegetation at the site is sparse and generally consists of low grasses with scattered oak brush and cedar trees.

The site straddles a low ridge on the north and east sides of Bybee Drive that is mantled by sandy surficial sediments displaying small dunes. The western part of the property along Bybee Drive (the proposed home area) is nearly flat, but slopes steepen eastward to around an overall steepness of about 2:1 to 3:1 (horizontal to vertical). Interbedded gravelly sand and silt deltaic lenses were evident in the south-facing slopes in the eastern part of the site. Western GeoLogic (2007) reports hand excavating one 3.5-foot-deep test pit at the slope base east of Bybee Drive in the area of the proposed home. This test pit reportedly exposed poorly to well-bedded sands resembling the nearby bedded deltaic sediments. ETE's (2007) test hole reportedly also exposed similar sediments. No surficial evidence for recent or ongoing slope instability, debris flows, seeps, springs, active drainages, surface faults, or other geologic hazards was observed at the site.

Except for several homes to the north, west, and south developed after 2007, and evidence for a recent wildfire that burned much of the amphitheater north of the Project, no other differing conditions were observed or noted in our reconnaissance from those previously reported. The wildfire reportedly occurred in September 2017 and engulfed over 600 acres, including several homes in the area.

Air Photo Observations

High-resolution orthophotography from 2012 (Figure 3A) and 0.5-meter bare earth DEM LIDAR from 2013-2014 (Figure 3B) were reviewed to obtain information about the geomorphology of the Project area. The site is below the crest of a south-facing terrace on slopes that have been impacted by a prehistoric flow failure; the Project straddles the south flank of this failure (Figures 3A-B). This area has old river terraces that are part of a discontinuous landslide complex along the Weber delta from Weber Canyon to Washington Terrace (unit Qmsy, Figure 2). The river terraces are remnants of the former Weber River floodplain stranded by downcutting through the Weber delta after the retreat of Pleistocene Lake Bonneville. The deltaic sediments forming the terraces have experienced instability from a variety of causes in both prehistoric and historic time. However, undeformed, sub-horizontal deltaic beds were observed in the eastern part of the site during our reconnaissance, and are evident on Figures 3A-B further north and east. Undeformed deltaic sands were also observed in Western GeoLogic's (2007) hand-excavated test pit. All the above evidence suggests the site is in a zone of depletion where the deltaic sediments failed and flowed downslope to a lower accumulation (depositional) zone further west and southwest.

No other evidence of geologic hazards was observed on the air photos at the site or in the area.

GEOLOGIC HAZARDS

Assessment of potential geologic hazards and the resulting risks imposed is critical in determining the suitability of the site for development. Table 1 below shows a summary of the geologic hazards reviewed at the site, as well as a relative (qualitative) assessment of risk to the Project for each hazard. A "high" hazard rating (H) indicates a hazard is present at the site (whether currently or in the geologic past) that is likely to pose significant risk and/or may require further study or mitigation techniques. A "moderate" hazard rating (M) indicates a hazard that poses an equivocal risk. Moderate-risk hazards may also require further studies or mitigation. A "low" hazard rating (L) indicates the hazard is not present, poses little or no risk, and/or is not likely to significantly impact the Project. Low-risk hazards typically require no additional studies or mitigation. We note that these hazard ratings represent a conservative assessment for the entire site and risk may vary in some areas. Careful selection of development areas can minimize risk by avoiding known hazard areas.

Table 1. *Geologic hazards summary.*

Hazard	H	M	L	...Hazard Rating
Earthquake Ground Shaking	X			
Surface Fault Rupture		X		
Liquefaction and Lateral-spread Ground Failure			X	
Tectonic Deformation		X		
Seismic Seiche and Storm Surge			X	
Stream Flooding			X	
Shallow Groundwater			X	
Landslides and Slope Failures		X		
Debris Flows and Floods			X	
Rock Fall			X	
Problem Soil			X	

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). Based on 2015 IBC provisions, a site class of D (stiff soil), and a risk category of II, USGS calculated uniform-hazard and deterministic ground motion values with a 2% chance of exceedance in 50 years are as follows:

Table 2. *Seismic hazards summary.*
(Site Location: 41.1430 ° N, -111.9125 ° W)

S_S	*1.266 g*
S_1	*0.479 g*
S_{MS} (F_a x S_S)	*1.266 g*
S_{M1} (F_v x S_1)	*0.728 g*
S_{DS} (2/3 x S_{MS})	*0.844 g*
S_{D1} (2/3 x S_{M1})	*0.486 g*
Site Coefficient, F_a	*= 1.000*
Site Coefficient, F_v	*= 1.521*

Given the above information, earthquake ground shaking poses a high risk to the site. Based on IRC design codes, ETE (2007; Section 11.2) recommends using a design acceleration of 1.18g, based on an S_S of 1.77 and Fa site coefficient of 1.0. This recommended value is significantly higher than that currently recommended in the 2015 IBC (S_{DS} of 0.844g above).

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 a large singular rupture or several smaller ruptures in a broad zone. Ground displacement from surface fault rupture can cause significant damage or even collapse to structures located on an active fault.

The nearest mapped faults to the site are two discontinuous, east-dipping antithetic traces of the Weber section of WFZ about 475 to 600 feet east of the Project on Figure 2. No evidence of surface faulting such as fault scarps or lineaments was evident at the property or on air photos, but at this distance the eastern roughly 25 feet of the site would be in the Surface Fault Rupture Special Study Zone on Weber County hazard maps. Based on this, the risk from surface faulting is rated as moderate. Given that the proposed home location is in the western part of the lot, no further evaluation following guidelines in Bowman and Lund (2016) appears needed.

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.

Loose, sandy sediments were observed in the slopes at the site that could be susceptible to liquefaction. However, liquefaction potential is also dependent on groundwater depth, which is likely greater than 30 feet deep. Based on the above, the existing hazard from liquefaction at the site is rated as low. Weber County GIS mapping shows the site is in a low to moderate liquefaction hazard zone (zone 4). Given that the site was on the margin of a prehistoric earthflow possibly from a liquefaction-induced failure, conducive soil conditions were present, and perched groundwater could also be present, Western GeoLogic (2007) recommended liquefaction hazards be addressed in the Project geotechnical engineering report. However, ETE (2007) did not address this hazard, presumably because no perched groundwater was encountered in their shallow test hole and their stability analyses indicated that slopes had satisfactory global factors of safety.

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 active normal faults. Western GeoLogic (2007) indicated the site is about 500 feet west of the WFZ, and at this distance the property could experience a few degrees of seismic tilting. Based on this, the risk from tectonic deformation is rated as moderate. However, tectonic subsidence is not typically a life-safety issue or considered for single-family residential structures.

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 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 are mapped crossing the site or were observed during our reconnaissance. Given the above, we rate the risk from stream flooding as low. However, Western GeoLogic (2007) noted sheet and rill flow could pose a seasonal concern. Surface drainage is discussed in Section 15.0 of ETE's (2007) report.

Shallow Groundwater

No springs are shown on the topographic map for the Ogden quadrangle at the site, and no springs, seeps, or wetland areas were observed in our reconnaissance. Groundwater at the site is likely greater than 30 feet deep, although perched conditions above less-permeable sediments may be beneath the site. Groundwater depth can also 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. Western GeoLogic (2007) did not anticipate shallow groundwater would pose a significant concern to the proposed development, and no groundwater was encountered in ETE's (2007) test hole to an explored depth of 10 feet.

Landslides 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.

The site straddles the eastern margin of a prehistoric earthflow. Lineaments from bedded lacustrine deltaic sediments are evident in slopes east and north of the site (Figures 3A-B), and bedded deltaic sediments were also observed by Western GeoLogic (2007) in a hand-excavated test pit in the area of the proposed home. The surficial and air photo evidence suggest that the site is in a zone of depletion where sediments failed and moved downslope to the southwest to a lower (depositional) accumulation zone. No evidence for recent or ongoing slope instability was observed in 2007 or during our supplemental reconnaissance.

Based on the above, Western GeoLogic (2007) rated the risk from landslides in the western part of the site as high, but indicated the eastern part would have a lower hazard. The hazard is therefore rated as moderate. Western GeoLogic (2007) recommended a geotechnical engineering slope-stability evaluation be conducted prior to building, which is addressed in Section 10.0 of ETE's (2007) report. ETE (2007) indicated their analyses showed suitable global factors of safety, but recommended an engineered retaining structure be employed if the proposed home would be closer than 20 feet to the slope toe.

Debris Flows

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 deposits or drainages, and no evidence of debris-flow features was observed in 2007 or in our supplemental reconnaissance. Based on the above, the hazard from debris flows at the site is rated as low.

Rock Fall

No bedrock outcrops were observed at the site or in higher slopes that could present a source area for rock fall clasts. Based on the above, we rate the hazard from rock falls as low.

Swelling and Collapsible Soils

Soil conditions and specific recommendations for site grading, subgrade preparation, and footing and foundation design are provided in ETE (2007).

CONCLUSIONS AND RECOMMENDATIONS

The only geologic hazard posing a high relative risk to the site is earthquake ground shaking. The risk from surface fault rupture, tectonic deformation, and landslides is rated as moderate. Western GeoLogic (2007) identified earthquake ground shaking, surface fault rupture, liquefaction, and landslides as geologic hazards posing a potential risk, and recommended a design-level geotechnical engineering study be conducted prior to construction to address soil foundation conditions, evaluate the potential for liquefaction and shallow groundwater as needed, and evaluate stability of slopes at the site. These recommendations appear to have been addressed in ETE (2007), except with regard to liquefaction. We note that the risk from this hazard varies with the presence of shallow groundwater, which was not observed by ETE (2007).

Development at the site should follow ETE's (2007) recommendations. 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. We further recommend Western GeoLogic (2007), ETE (2007), this report, and all future geologic and geotechnical reports regarding the property be made available to architects, building contractors, and in the event of a future property sale, real estate agents and potential buyers.

This 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 site-specific observations and 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; its 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 environmental professional 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

LICENSED PROFESSIONAL GEOLOGIST
10-2-2017
BILL DUANE BLACK
NO. 5224898-2250
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Reviewed by:

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5251804
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Craig V. Nelson, P.G.
Principal Engineering Geologist

ATTACHMENTS

Figure 1. Location Map (8.5"x11")
Figure 2. Geologic Map (8.5"x11")
Figure 3A. 2012 Air Photo (8.5"x11")
Figure 3B. LIDAR Image (8.5"x11")
Appendix. Photographic Record of Site Reconnaissance

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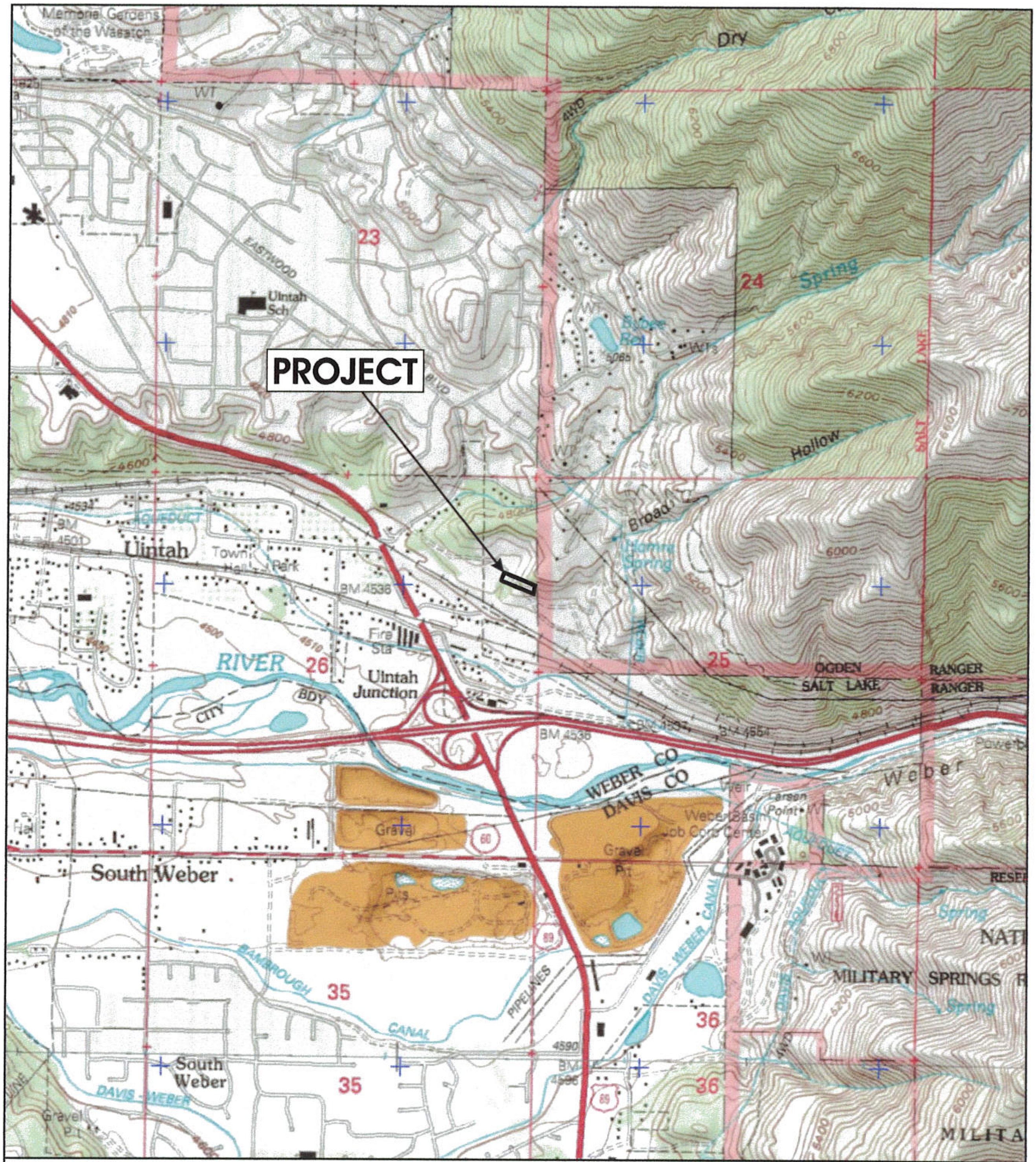


Source: U.S. Geological Survey 7.5 Minute Series Topographic Maps, Utah - Ogden, 1998;
Project location NE1/4, Section 26, T5N, R1W (SLBM); 41.1430° N, -111.9125° W.

LOCATION MAP

SUPPLEMENTAL GEOLOGIC HAZARDS RECONNAISSANCE

Cedar Cove Subdivision Lot 12
2670 East Bybee Drive
Ogden, Weber County, Utah

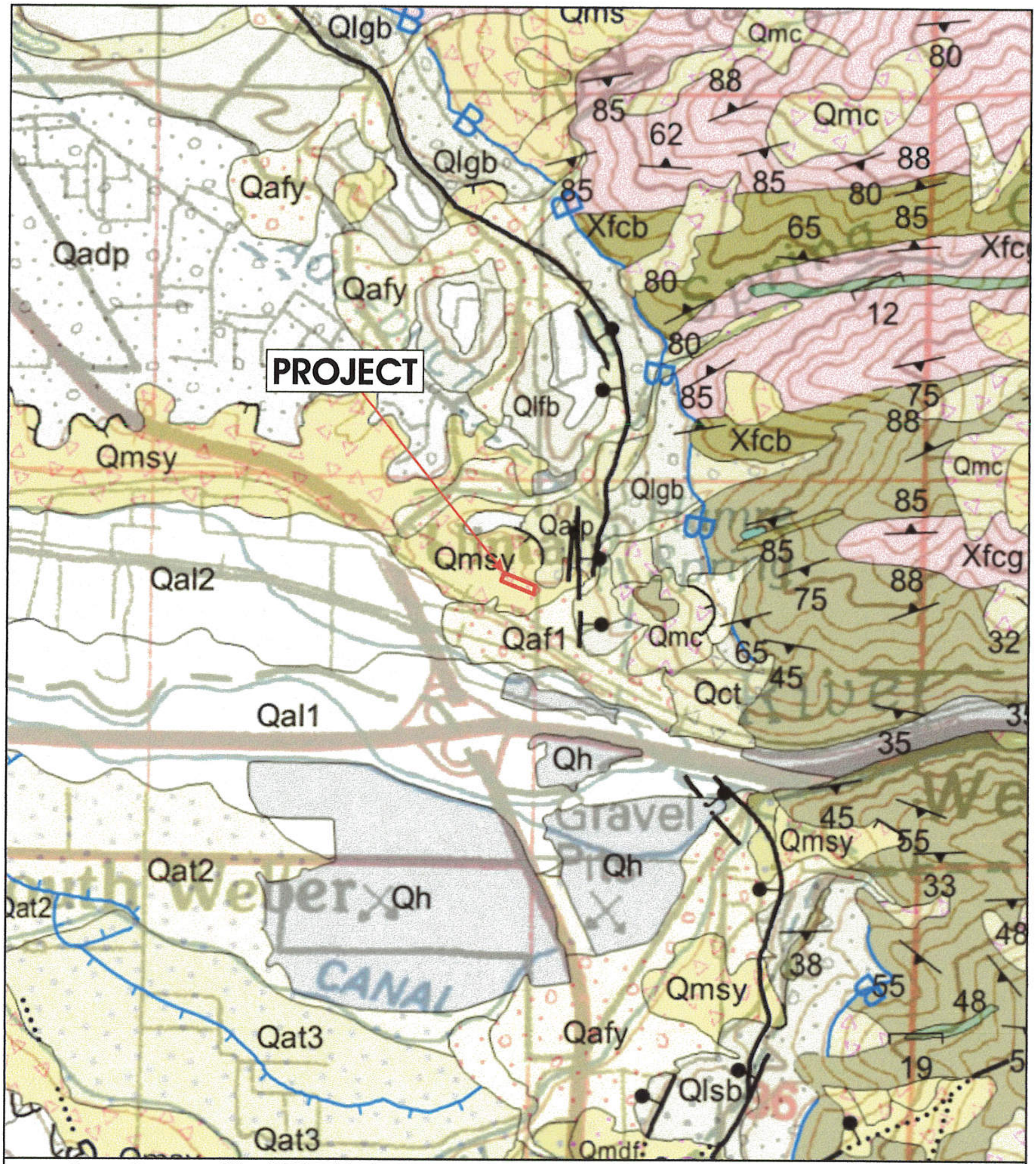
FIGURE 1

N
W E
S

0 1000 2000 feet

Scale 1:24,000
(1 inch = 2000 feet)

WESTERN GEOLOGIC



Source: Coogan and King (2016); original map scale 1:100,000. See text for explanation of nearby surficial geologic units.

N
W E
S

0 1000 2000 feet

Scale 1:24,000
(1 inch = 2000 feet)

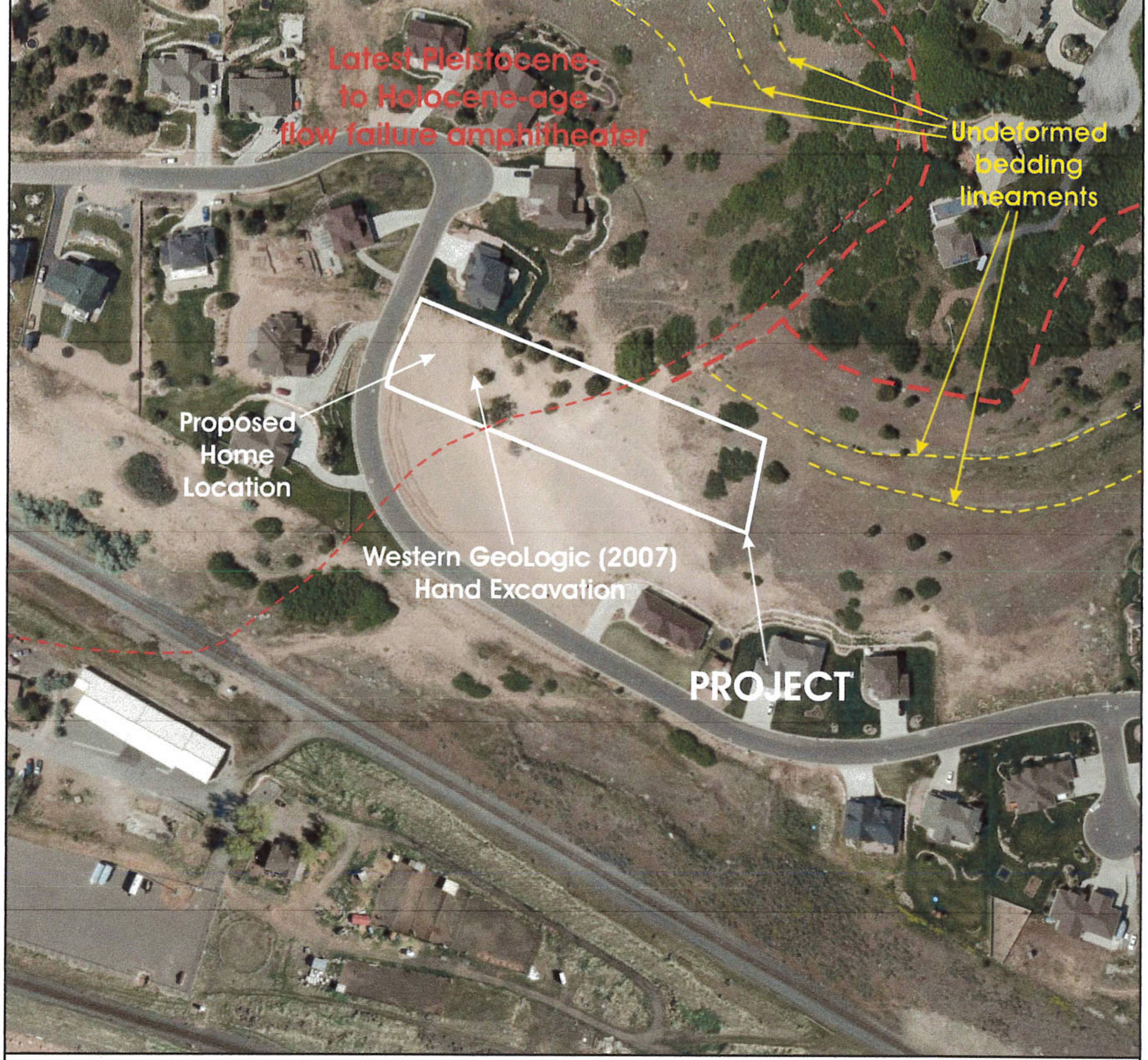
WESTERN GEOLOGIC

GEOLOGIC MAP

SUPPLEMENTAL GEOLOGIC HAZARDS RECONNAISSANCE

Cedar Cove Subdivision Lot 12
2670 East Bybee Drive
Ogden, Weber County, Utah

FIGURE 2



Source: Utah AGRC, High Resolution Orthophoto, 0.5-foot resolution, 2012.

Scale 1:2,400
(1 inch = 200 feet)

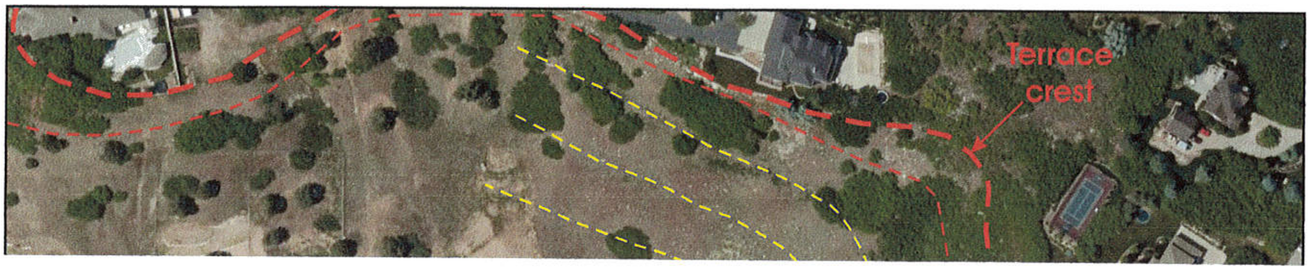
WESTERN GEOLOGIC

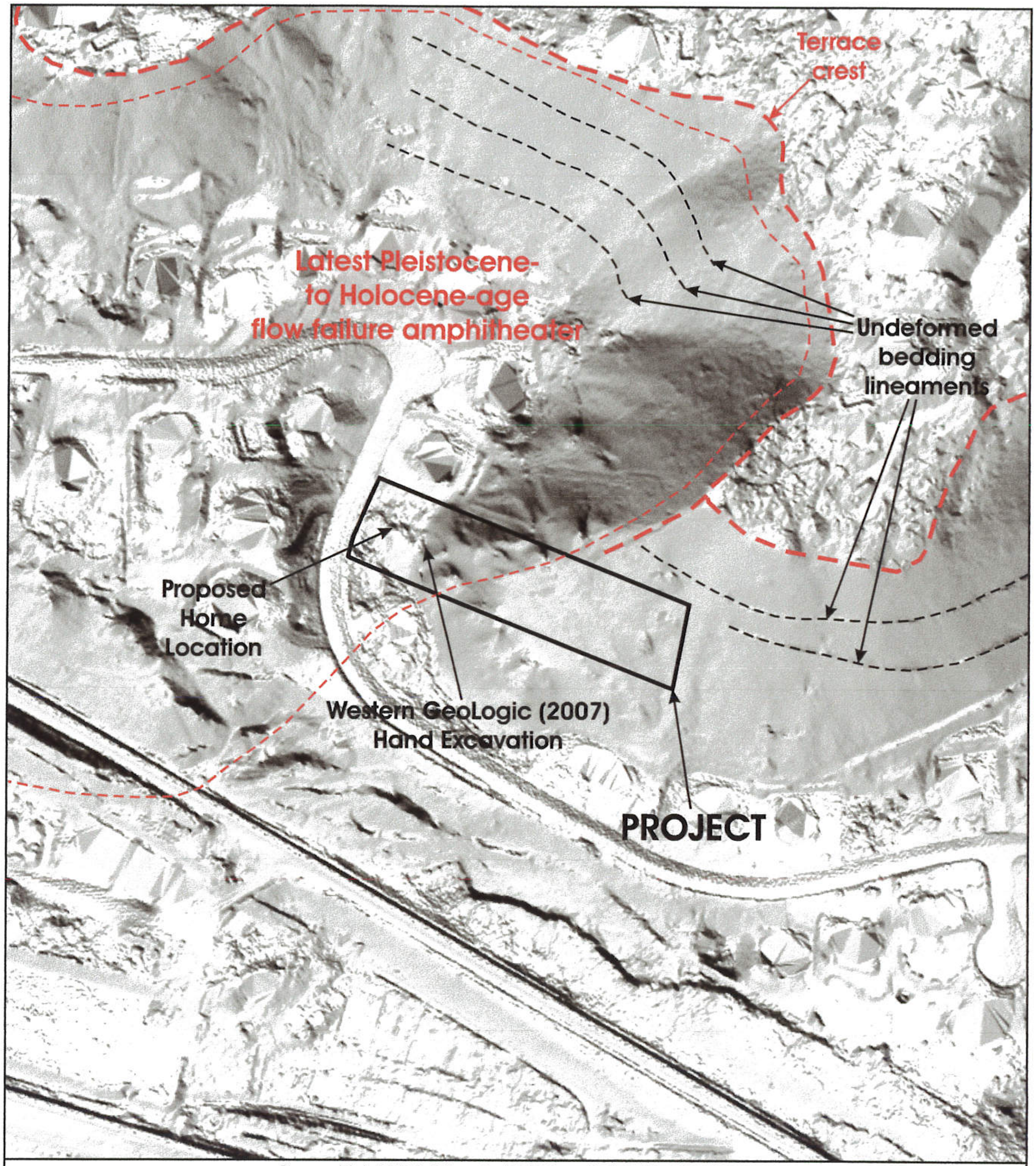
2012 AIR PHOTO

SUPPLEMENTAL GEOLOGIC HAZARDS RECONNAISSANCE

Cedar Cove Subdivision Lot 12
2670 East Bybee Drive
Ogden, Weber County, Utah

FIGURE 3A


Terrace crest



Source: Utah AGRC, 0.5-meter LIDAR Bare Earth DEM, 2013/2014.

Scale 1:2,400
(1 inch = 200 feet)

WESTERN GEOLOGIC

LIDAR IMAGE

SUPPLEMENTAL GEOLOGIC HAZARDS RECONNAISSANCE

Cedar Cove Subdivision Lot 12
2670 East Bybee Drive
Ogden, Weber County, Utah

FIGURE 3B

Photographic Record of Site Reconnaissance
Cedar Cove Subdivision Lot 12 - 2670 East Bybee Drive
Ogden, Weber County, Utah

Photo 1. View north across proposed home area toward amphitheater

Photo 2. Typical surficial soils

Photographic Record of Site Reconnaissance
Lot 25 Elkhorn Subdivision Phase 2 - 3529 North Elkridge Trail
Eden, Weber County, Utah

Photo 3. View north toward burned area

Photo 4. Bedded lacustrine deltaic sediment exposed on slope in east part of site.

Photographic Record of Site Reconnaissance
Lot 25 Elkhorn Subdivision Phase 2 - 3529 North Elkridge Trail
Eden, Weber County, Utah

Photo 5. View east toward Weber Canyon

Photo 6. View west of western part of site and adjacent home