REPORT

GEOLOGIC HAZARDS RECONNAISSANCE

LIBERTY CREEK INVESTMENTS LAND

ABOUT 3800 NORTH 2900 EAST

LIBERTY, WEBER COUNTY, UTAH

Prepared for

Cecil Satterthwaite
4015 East River Drive
Liberty, Utah 84310

July 20, 2019

Prepared by

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Cecil Satterthwaite
4015 East River Drive
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SUBJECT: Geologic Hazards Reconnaissance
Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

Dear Mr. Satterthwaite:

This report presents results of a reconnaissance-level engineering geology and geologic hazards review and evaluation conducted by Western Geologic & Environmental LLC (Western Geologic) for the Liberty Creek Investments Land in Liberty, Utah (Figure 1 – Project Location). The Project consists of two contiguous parcels identified as Weber County Assessor parcel numbers 22-009-0040 (18.04 acres, on the west) and 22-014-0014 (25.5 acres, on the east). The site is on gentle east-facing slopes overlooking North Fork Ogden River in the SE1/4 Section 19 and SW1/4 Section 20, Township 7 North, Range 1 East (Salt Lake Base Line and Meridian). Elevation of the site is 5,092 to 5,156 feet above sea level. It is our understanding that the intended development is for one single-family residential home in the eastern parcel south of an existing barn structure.

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 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. 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. However, 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.

HYDROLOGY

The U.S. Geological Survey (USGS) topographic map of the North Ogden and Huntsville Quadrangles shows the site is about 0.97 miles southwest of the confluence between Sheep Creek and North Fork Ogden River, which flow southward into the valley to Pineview Reservoir (Figure 1). Liberty Spring Creek flows eastward across the southern part of the property about 150 feet south of the proposed home location and merges downslope with North Fork Ogden River. Several springs are mapped in the Project area on Figure 1; Liberty Spring Creek is sourced in springs upslope from the site to the west. During our reconnaissance a seep that flows to the creek was observed about 50 feet south of the home location. Three piezometers are southeast of the proposed home location that were installed to monitor groundwater levels for the onsite septic system. The nearest piezometer reportedly showed groundwater depths ranging between 2.5 to 6 feet below the ground surface (bgs), although the remaining piezometers were dry (groundwater was below their installed depth). Given the above, we anticipate groundwater in the area of the proposed home is generally less than 10 feet deep.

The site is in northern Ogden Valley, which is dominated in the valley bottom by unconsolidated lacustrine and alluvial basin-fill deposits. Slopes in the site area are generally underlain by mixed alluvial and lacustrine sediments and what we infer is a relic rockslide deposit sourced in Cambrian-age Maxfield Limestone. The Utah Division of Water Rights Well Driller Database indicates seven water wells are within 0.5 miles of the Project (Figure 1). Static groundwater in these wells was at depths ranging between 5 feet above (artesian) to 31 feet bgs (Figure 1); groundwater levels generally deepen southeastward. However, groundwater depths at the site likely vary locally, seasonally, and annually from climatic fluctuations. Such variations would be typical for an alpine environment. Perched conditions may also be present in the subsurface that could cause locally groundwater variations.

Avery (1994) indicates groundwater in Ogden Valley occurs under perched, confined, and unconfined conditions in the valley fill to depths of 750 feet or more. A well-stratified lacustrine silt layer forms a leaky confining bed in the upper part of the valley-fill aquifer. The aquifer below the confining beds is the principal aquifer, which is in primarily fluvial and alluvial-fan deposits. The principal aquifer is recharged from precipitation, seepage from surface water, and subsurface inflow from bedrock into valley fill along the valley margins (Avery, 1994). The confined aquifer is typically overlain by a shallow, unconfined aquifer recharged from surface flow and upward leakage. Groundwater flow is generally from the valley margins into the valley fill, and then toward the head of Ogden Canyon (Avery, 1994).

GEOLOGY

Surficial Geology

The site is located in northern Ogden Valley, a sediment-filled intermontane valley within 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). Surficial geology of the site is mapped by Coogan and King (2016) as mainly lacustrine deposits from upper Pleistocene Lake Bonneville (units Qla and Qlsb) surrounding an older, relic landslide deposit (units Qmso and Qmso?; Figure 2). The proposed home location appears to be on the toe of the landslide deposit (Figure 2).

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

> ***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.
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> 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.
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> ***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.

***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).

***Qmdf, Qmdf?** – Debris- and mud-flow deposits (Holocene and upper and middle? Pleistocene).* Very poorly sorted, clay- to boulder-sized material in unstratified deposits characterized by rubbly surface and debris-flow levees with channels, lobes, and mounding; variably vegetated; in drainages typically form mounds, an indication of more viscous Qmdf, rather than being flat like unit Qac; Qmdf queried where may not be mostly debris- and mud-flow deposits; many debris flows cannot be shown separately from alluvial fans at map scale; 0 to 40 feet (0-12 m) thick. Age(s) uncertain; deposits in drainages likely post-date the Provo shoreline of Lake Bonneville, while deposits above drainages, like north of the Right Hand Fork Peterson Creek, are likely as old as Bull Lake glaciation, but could pre-date Bull Lake glaciation and be middle Pleistocene.

***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.

***Qls, Qls?, Qlsp, Qlsb, Qlsb?** – Lake Bonneville sand (upper Pleistocene).* Mostly sand with some silt and gravel deposited nearshore below and near the Provo shoreline (Qlsp) and between the Provo and Bonneville shorelines (Qlsb); Qls mapped downslope from slope break below Provo shoreline beach deposits where thin Lake Bonneville regressional sand may overlie transgressional sand; grades downslope into unit Qlf with decreasing sand content and laterally with more gravel into units Qdlp, Qdlb, and upslope with more gravel into unit Qlgb; Qls and Qlsb queried where grain size or unit identification uncertain; may be as much as 75 feet (25 m) thick, and thickest near Ogden; typically less than 20 feet (6 m) thick in Morgan Valley; may include small deltas and deltas that lack typical delta shape.

***Qdlb, Qdlb?** – Transgressive and Bonneville-shoreline deltaic and lacustrine deposits (upper Pleistocene)* – Mostly sand, silty sand, and gravelly sand deposited near shore in Lake Bonneville; extensive at mouth of Weber Canyon; related to transgression to and occupation of the Bonneville shoreline with lacustrine deposits covering deltaic deposits; in Morgan Valley and near mouth of Coldwater Canyon (North Ogden quadrangle) contain more cobbles and overall more gravel; 0 to at least 40 feet (12 m) thick in Ogden and Morgan Valleys; about 400 feet (120 m) thick in bluff at the mouth of Weber Canyon. These deposits are prone to slope failures.

***Qadb, Qadb?** – Transgressive and Bonneville-shoreline 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; include rounded to subangular clasts in a matrix of sand and silt with interbeds of sand and silt; mapped above the Provo shoreline and deposited as lake transgressed to and was at the Bonneville shoreline; typically better sorted delta and lake deposits over poorly sorted alluvial-fan deposits; Qadb prominent along Deep Creek (Morgan quadrangle) and Strawberry Creek (Snow Basin quadrangle); 0 to at least 40 feet (0-12+ m) thick. Note that the Bonneville-shoreline fan-delta unit (Qadb), at 80 to 100 feet (24-30 m) above present drainages, is typically higher than the related alluvial units (Qab, Qafb) (see table 1). A fan-delta is built when an alluvial fan enters a lake or ocean and includes both the fan and the delta.

***Qla, Qla?** – Lake Bonneville lacustrine deposits and post- and pre-Lake Bonneville alluvial deposits, undivided (Holocene and upper? Pleistocene).* Mostly poorly sorted and poorly bedded sand, silt, and clay, with some gravel; mapped where Lake Bonneville deposits are reworked by later stream action or covered by thin stream and fan deposits, and where lake deposits are thin and overlie older alluvial deposits; unit queried where may be dominantly alluvium; deposits typically eroded from shallow Norwood Formation; mostly mapped near Bonneville shoreline; also mapped in Peterson quadrangle along upper Deep Creek above Bonneville shoreline where lake deposits seem to indicate landslide dam of creek; thickness uncertain.

***Qafo, Qafo?** – Older alluvial-fan deposits (mostly upper Pleistocene).* Incised and at least locally dissected fans of mostly sand, silt, and gravel that is poorly bedded and poorly sorted; includes debris flows, particularly in drainages and at drainage mouths (fan heads); older fans are typically above the Bonneville shoreline, with an eroded bench at the shoreline; upstream and above the Bonneville shoreline, unit Qafo is topographically higher than fans graded to the Bonneville shoreline (Qafb), and is typically dissected; generally less than 60 feet (18 m) thick. In Mantua Valley, exposed thickness up to about 100 feet (30 m), but water wells (sections 26 and 27, T. 9 N., R. 1 W.) were still in gravelly to bouldery valley fill at depths of 505 and 467 feet (154 and 142 m), respectively, and red coloration that may indicate Wasatch Formation bedrock was not noted (see Bjorklund and McGreevy, 1973, p. 16).

Qafo queried where relative age is uncertain (see Qaf for details), for example in Mantua quadrangle where it is as high as Qafoe in Morgan Valley (see table 1). Qafo queried in East Canyon graben because the deposits are not dissected and some deposits mantle Qafoe (see also unit Qafm above), resulting in a reversal of relative height and only local incision. These irregular deposits are likely the result of salt movement in the East Canyon graben. Our Qafo is roughly shown to south by Bryant (1990) as Qgp (pediment gravel); farther south he showed Qoa (dissected alluvium) adjacent to the East Canyon fault, which may be the QTaf or Qafoe we mapped.

Amino-acid age estimates presented in Sullivan and Nelson (1992) imply Qafo north of Morgan considerably predates Lake Bonneville and is middle Pleistocene in age (>400 ka). However, the Bonneville shoreline is obscure on this fan, and soil-carbonate age estimates (>70-100 ka) and other amino acid age estimates (~98-155 ka) in Sullivan and others (1988) imply these older fans are related to Bull Lake glaciation (95,000 to 130,000 years old; see Chadwick and others, 1997; Phillips and others, 1997). As noted under Qao, Qafo deposits may contain two ages (levels) of alluvial surfaces that are not easily recognized in Morgan Valley but are recognized upstream in the Henefer and Lost Creek Valleys (Devils Slide quadrangle) and along the North and South Forks of Ogden River.

***Qafoe-QTaf** – Older eroded fan and/or pediment-mantle deposits (middle or lower Pleistocene).* Gravel, sand, silt, and clay in alluvium and colluvium that cap surfaces that are partly correlative with the pre-Lake Bonneville McKenzie Flat geomorphic surface of Williams (1948) (see McCalpin, 1989); in Paradise quadrangle, McCalpin (1989) described this unit (his afo) as forming dissected surfaces 50 to 1000 feet (15-300 m) above active streams, and commonly present as a relatively thin discontinuous veneer, less than 33 feet

(10 m) thick, on a surface (pediment) "cut" on Tertiary Salt Lake Formation; but our mapping, which reduces colluvium bias ("slough"), indicates the surface edges are about 100 to 400 feet (30-120 m) above adjacent drainages.

McKenzie Flat is a gently north-inclined little-dissected bench capped by these deposits in the James Peak and Paradise quadrangles, with the flat along the axis of a broad open syncline in the underlying Salt Lake Formation. Dissected surfaces on eroded remnants of these deposits dip west from the East Cache fault zone to McKenzie Flat, with dips that are nearly the same as bedding in the underlying Salt Lake Formation in the east limb of the syncline. This implies the west-dipping surfaces are capped by residual deposits rather than being tilted fan deposits, and the flat may have the same origin. Alternatively the flat and limb deposits have two different origins, fan and lag/residual, respectively. Fans on McKenzie Flat could be middle Pleistocene (McCalpin, 1989; see also Sullivan and Nelson, 1992) (Little Valley or Pokes Point lake cycle) and/or early Pleistocene (after Sullivan and others, 1988) in age; although the lower heights above the adjacent drainages fit this middle and early Pleistocene age (Qafoe), the upper limit is in the range of Quaternary-Pliocene fans (QTaf).

Mullens and Izett (1964) did not map the McKenzie Flat deposits but described them as an upper 20 to 40 feet (6-12 m) of conglomerate that rests with angular unconformity on the main Salt Lake Formation conglomerate. They noted that exposures in the James Peak quadrangle, pointed out by Dr. C.T. Hardy of Utah State University, show this relationship. The angular unconformity supports a fan origin for the deposits on the north-inclined McKenzie Flat. Mullens and Izett (1964) also noted that sub-rounded boulders of quartzite derived from Precambrian and Cambrian formations are scattered on McKenzie Flat and boulders average about 1 foot (30 cm) in diameter, but some are as much as 3 feet (90 cm) in diameter.

The Precambrian (Neoproterozoic) and Cambrian quartzite boulders could be recycled from the Salt Lake Formation conglomerate, the Wasatch Formation, or be from quartzite exposures to the south in the James Peak quadrangle. The latter implies transport to the north into lower parts of Cache Valley. When the boulders were transported is more problematic, since they could be a lag from the underlying Salt Lake Formation rather than being transported during Pleistocene fan deposition.

QTms(ZYp) – Quaternary and/or Tertiary mega-landslide (Pleistocene and/or Pliocene). Jumbled mass of formation of Perry Canyon (ZYp) with blocks of rock from North Ogden divide klippe out of stratigraphic position and "floating" in muddy Perry Canyon; mostly mapped as ZYpm and ZYpg by Crittenden and Sorensen (1985b); inconsistent and divergent attitudes shown by Crittenden and Sorensen (1985b) also support mass movement; north margin of landslide uncertain due to overturned dips in adjacent ZYpm outcrop; mass seems to have slid down Willard thrust plane; estimate up to about 700 feet (210 m) thick. Younger landslides, including Qms(QTms) and Qms?(QTms) are mapped on this mass, indicating continued instability.

Tn, Tn? *– Norwood Formation (lower Oligocene and upper Eocene).* Typically light-gray to light-brown altered tuff (claystone), altered tuffaceous siltstone and sandstone, and conglomerate; unaltered tuff, present in type section south of Morgan, is rare; locally colored light shades of red and green; variable calcareous cement and zeolitization; involved in numerous landslides of various sizes; estimate 2000-foot (600 m) thick in exposures on west side of Ogden Valley (based on bedding dip, outcrop width, and topography). Norwood Formation queried where poor exposures may actually be surficial deposits. For detailed Norwood Formation information see description under heading "Sub-Willard Thrust - Ogden Canyon Area" since most of this unit is in and near Morgan Valley and covers the Willard thrust, Ogden Canyon, and Durst Mountain areas.

Csc, Csc? *– St. Charles Formation (Lower Ordovician and Upper Cambrian).* Mostly dark-gray, medium- to thick-bedded dolomite; contains subordinate medium-gray dolomite and limestone; all with tan-weathering mottling and recesses of crude laminae to inch-scale layers of sandstone and siltstone; overall gray to tan weathering and ledge forming; uppermost part contains light-colored, typically pink, chert; lower part is less resistant, light-gray, tannish-gray weathering, thin-bedded, silty and sandy limestone and dolomite, and silty shale, with tannish-gray, medium-bedded, cross-bedded Worm Creek Quartzite Member (Upper Cambrian) that is locally present; total thickness about 500 to 1000 feet (150-300 m) and may thin to south and east over Tooele arch (see Hintze, 1959).

The St. Charles Formation is 723 feet (220 m) thick, including the Worm Creek, in the Monte Cristo Peak area (Smith, 1965) and to the west it is 970 feet (295 m) thick, including Worm Creek, in the Sharp Mountain quadrangle (Hafen, 1961). To the south near Causey Dam, the entire St. Charles appears to be about 650 feet (200 m) thick (King). To the east the St. Charles thins southward from 700 feet (215 m) thick along Sugar Pine Creek in the Dairy Ridge quadrangle, with about 75 feet (25 m) of Worm Creek, to about 500 feet (150 m) thick in the Horse Ridge quadrangle, with no Worm Creek (Coogan, 2006a-b).

As determined from trilobite and conodont fossils in the Bear River Range, the St. Charles age is earliest Ordovician and Late Cambrian (Taylor and others, 1981).

The Worm Creek Quartzite Member has been inconsistently mapped. Carbonate and clastic sedimentary rocks are sometimes included, so it does not always contain a quartzite. Therefore this member is not shown separately on our map. The quartzite is about 0 to 90 feet (0-27 m) thick (Hafen, 1961; Rigo, 1968; Mullens, 1969; Coogan, 2006a-b) in the map area. In particular in the Mantua quadrangle, the quartzite is only locally recognizable and is an estimated 50 feet (15 m) thick south of the fish hatchery. Some geologists only map and report the quartzite portion of the member (see for example Ezell, 1953, versus Hafen, 1961), ignoring other lithologies and placing the contact at the top of the quartzite, and in Utah the quartzite is at least locally absent (Haynie, 1957). This has led to problems with the presence or absence of the member as well as thicknesses. Just north of the map area in the Wellsville Mountains, Elvinia zone trilobite fossils indicate a Late Cambrian age for the Worm Creek (Oviatt, 1986).

Cm, Cm? – Maxfield Limestone (Middle Cambrian). From top down includes dolomite, limestone, argillaceous to silty limestone and calcareous siltstone and argillite, and basal limestone with argillaceous interval (see Yonkee and Lowe, 2004; King and others, 2008 for more member details); members mappable at 1:24,000 scale, but like Ophir Formation thicknesses highly variable due to deformation; total thickness about 600 to 900 feet (180-270 m) (King and others, 2008).

According to Yonkee and Lowe (2004), the Bathyuriscus sp., Elrathina sp., Peronopsis sp., and Ptychagnostus sp. trilobite fossils reported by Rigo (1968, USGS No. 5948-CO in the middle limestone of the Ophir Shale) in Ogden Canyon are in the basal limestone member of the Maxfield. Elrathia can be used as a proxy for the Middle Cambrian Bolaspidella zone (see Robison, 1976, figure 4) and this zone is in the Bloomington Formation shales on the Willard thrust sheet (see Oviatt, 1986; Jensen and King, 1996, table 2). This supports the Maxfield Limestone as partly equivalent to the Bloomington Formation, but leaves the Blacksmith Dolomite without an equivalent carbonate unit below the Willard thrust sheet. However, Rigo (1968) did not provide a usable sample location and the sample location is not on the map of Crittenden and Sorensen (1985b).

Ct, Ct? – Tintic Quartzite (Middle and Lower Cambrian). Tan-weathering, cliff-forming, very well-cemented quartzite, with lenses and beds of quartz-pebble conglomerate, and lesser thin argillite layers; quartzite is tan, white, reddish tan and pale-orange tan with abundant cross-bedding; argillite more abundant at top and quartz-pebble conglomerate increases downward; greenish-tan to purplish-tan to tan, arkosic sandstone, conglomerate, and micaceous argillite at base that is 50 to 200 feet (15-60 m) thick and derived from unconformably underlying gneissic and schistose Farmington Canyon Complex; about 1100 to 1500 feet (335-450 m) thick.

Zpu, Zpu? – Formation of Perry Canyon, Upper member (Neoproterozoic). Olive drab to gray, thin-bedded slate to argillite to phyllite to micaceous meta-siltstone to meta-graywacke to meta-sandstone in variable proportions such that unit looks like both the "greywacke-sandstone" and "mudstone" members of previous workers; unit identification based on underlying diamictite in Mantua quadrangle; rare meta-gritstone and meta-diamictite (actually conglomerate?); locally schistose; meta-sandstone contains poorly sorted lithic, quartz, and feldspar grains in silty to micaceous matrix; meta-sandstone is quartzose in outcrops on west margin of Mantua quadrangle (Crittenden and Sorensen, 1985a) and medial zone of sandstone is feldspathic east of Ogden Valley, where mapped and described as argillite member of Maple Canyon Formation by Crittenden (1972) and Sorensen and Crittenden (1979); thickness uncertain, but appears to be about 600 feet (180 m) thick on west flank of Grizzly Peak in the Mantua quadrangle and about 1000 feet (300 m) thick between Ogden Canyon and North Ogden divide. In Ogden Valley typically non-resistant and tan weathering such that gray to green to dark-gray fresh color is seldom seen except in cut slopes and excavations. This unit is prone to slope failures.

Zpd, Zpd? – Diamictite member (Neoproterozoic). Tan to gray weathering, gray to dark-gray meta-diamictite containing pebble to boulder-sized quartzite and granitoid (quartzo-feldspathic gneiss) clasts in dark-gray sandy (up to granule size) to micaceous argillite matrix; fuschsite-bearing quartzite clasts minor but distinctive; local meta-pillow lava (unit

Zpb) and meta-limestone at and near base, and local altered intrusive diorite (unit Zpi) (Crittenden and Sorensen, 1985b); appears to be up to 200 to 400 feet (60-120 m) thick in our map area but is about 1000 feet (300 m) thick to the west in the Willard quadrangle.

From Balgord and others (2013, and Balgord, 2011) detrital zircon uranium-lead and lead-lead maximum depositional ages on the upper part of the diamictite are about 650 to 690 Ma with about a 120 million year gap to about 800 Ma on the lower part of the diamictite. This major unconformity is within the metavolcanics (Zpb) unit to the west of the map area on Fremont Island, such that the diamictite above the metavolcanics and where the meta-volcanics are missing in the Ogden map area may be considerably younger than the lower diamictite.

In Perry Canyon a "felsic tuff" is present at the base of the diamictite (or top of "mudstone"), and it contains columbite-tantalite and monazite (reworked felsic lava flow of Balgord, 2011, p. 60; volcanic sandstone in her figure 16, p. 53).

The diamictite reportedly has a large volcanic component in the klippe north of the North Ogden divide with the majority of clasts being mafic volcanic rocks from the underlying meta-basalt (Zpb) and a few large "basement" clasts in a greenish-colored matrix with about 50% sand and silt (Balgord, 2011). This implies the klippe diamictite lacks the quartzite and granitoid clasts of the typical diamictite, and may be a volcanic unit rather than part of the diamictite member.

Near Lewis Peak in the North Ogden quadrangle, the diamictite contains typical granitoid and quartzite clasts with minor sedimentary and volcanic rock clasts of cobble to boulder size in a dark gray quartzose pebbly to sandy to micaceous argillite matrix (after Balgord, 2011). Granitoid clasts look like they are from the Farmington Canyon Complex.

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

Seismotectonic Setting

The property is located in Ogden Valley, a roughly 40-square mile back valley described by Gilbert (1928) as a structural trough similar to Cache and Morgan Valleys to the north and south, respectively. The back valleys of the northern Wasatch Range are in a transition zone between the Basin and Range and Middle Rocky Mountains physiographic provinces (Stokes, 1977, 1986). The Basin and Range 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 marked by the Wasatch fault zone 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 back valleys are morphologically similar to valleys in the Basin and Range, but exhibit less structural relief (Sullivan and others 1988).

Ogden Valley occupies a structural trough created by up to 2,000 feet of vertical displacement on normal faults bounding the east and west sides of the valley. The Utah Geological Survey Quaternary Fault Database (Black and others, 2003; January 2017 update) shows two Quaternary faults in the Project vicinity: (1) the Ogden Valley Northeastern Margin fault about 1,750 feet to the northeast, and (2) the Ogden Valley Southwestern Margin faults about 2,350 feet to the southwest. Both of these faults are pre-Holocene in age (Sullivan and others, 1986). The nearest active (Holocene-age) fault to the site is the Weber segment of the Wasatch fault zone about 3.0 miles to the west.

The site is also situated near the central portion of the Intermountain Seismic Belt (ISB). The ISB is a north-south-trending zone of historical seismicity along the eastern margin of the Basin and Range province which extends for approximately 900 miles 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, with the largest of these events the M_S 7.5 1959 Hebgen Lake, Montana earthquake. However, none of these events have occurred along the Wasatch fault zone or other known late Quaternary faults in the region (Arabasz and others, 1992; Smith and Arabasz, 1991). The closest of these events to the site was the 1934 Hansel Valley (M_S 6.6) event north of the Great Salt Lake and south of the town of Snowville.

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). Portions of Ogden Valley were inundated by Lake Bonneville at its highstand and sediments from Lake Bonneville are mapped underlying the site area on Figure 2.

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 emanating from 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).

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. Drainages that fed Lake Bonneville then began downcutting through stranded deltaic complexes and near-shore deposits as the lake receded. Oviatt and others (1992) deem this low stage the end of the Bonneville lake cycle. 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 July 17, 2019 Bill D. Black, P.G. of Western Geologic conducted a brief reconnaissance of the property and nearby area. Weather at the time of the site visit was clear and sunny with temperatures in the upper 70's (°F). A photographic record of our reconnaissance is included in the Appendix.

The site is in northern Ogden Valley on relatively gentle slopes east of North Ogden Divide. North Fork Ogden River is further east. Liberty Spring Creek flows eastward across the southern part of the property to North Fork Ogden River; the creek source is several springs upslope of the site to the west. The proposed home location is in the eastern half of the site about 150 feet north of the creek; a seep that flows to the creek is about 50 feet south of the home location. The creek was flowing at the time of our investigation. Three piezometers to monitor groundwater for the onsite septic system were observed east of the seep. The nearest piezometer reportedly showed groundwater depths ranging between 2.5 to 6 feet bgs at various times, but the remaining piezometers were dry (groundwater was below their installed depth). This suggests groundwater in the area of the proposed home may be less than 10 feet deep. The planned home will reportedly include a walk-out basement.

Several low mounds are in the area of the proposed home that are mantled by limestone rock. The furthest west mound has been partly excavated. The excavation exposed a thin veneer of lacustrine sand and gravel overlying fractured limestone enriched with carbonate. Several limestone boulders are also found at the surface in the area, at least one of which is vehicle sized. The limestone appears to be Cambrian-age Maxfield Limestone, which is not found nearby but is exposed in the range front about 0.5 miles to the west. We infer the limestone-cored mounds are relics of a prehistoric rockslide that occurred prior to when Lake Bonneville occupied Ogden Valley in Pleistocene time; the rockslide was likely subsequently debrided by near-shore oscillations and currents. No other evidence of seeps or springs, ongoing or prior slope instability or landslides, characteristic debris flow features, bedrock outcrops, or other geologic hazards was observed.

Air Photo Observations

Black and white aerial photography from 1997, high-resolution orthophotography from 2012, 2018 National Agriculture Imagery Program (NAIP) DOQQ photography, and bare earth DEM LIDAR from 2011 available from the Utah AGRC were reviewed to obtain information about the geomorphology of the Project area (Figures 3A-3D). The proposed home location is at the toe (eastern edge) of a relic rockslide deposit that includes several limestone-cored mounds.

Lake Bonneville silt, sand and gravel deposits surround the mounds and generally underlie most of the property. Liberty Spring Creek is about 150 feet south of the proposed home location and flows to the east into Ogden Valley; a seep is about 50 feet south that flows to the creek. Slopes at the property are mainly gentler than 5:1 (< 20%, as shaded in green on Figure 3D) except for areas bounding the limestone mounds. Slopes in the area of the proposed home location shown an overall roughly 20:1 (horizontal:vertical) dip to the southeast. No other evidence for geologic hazards was observed on the air photos.

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**
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. The Utah Geological Survey Quaternary Fault Database (Black and others, 2003; January 2017 update) shows numerous class A faults within 60 miles of the Project that may pose potential seismic sources.

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. Based on 2015 IBC provisions, a site class of D (stiff soil), and a risk category of II, 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: 41.32708° N, -111.87266° W)

S_S	*1.059 g*
S_1	*0.373 g*
S_{MS} (F_a x S_S)	*1.14 g*
S_{M1} (F_v x S_1)	*0.617 g*
S_{DS} (2/3 x S_{MS})	*0.76 g*
S_{D1} (2/3 x S_{M1})	*0.412 g*
Site Coefficient, F_a	*= 1.077*
Site Coefficient, F_v	*= 1.653*
PGA, Peak Ground Acceleration	*0.426 g*

Given the above information, earthquake ground shaking poses a high risk to the site. Earthquake ground shaking is a regional hazard common to all Wasatch Front areas. The hazard is mitigated by design and construction of homes in accordance with current building codes.

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.

No evidence of active surface faulting is mapped or was evident at the site. The nearest active (Holocene-age) fault to the site is the Weber segment of the WFZ about 3.0 miles to the west. Given the above, the risk from surface faulting is 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.

The site is in an area of potentially strong ground shaking and groundwater appears to be about 10 feet deep. However, no soils likely susceptible to liquefaction appear to be present in the area of the proposed home based on our surficial observations and review of NRCS soil data (discussed below). Given this, the liquefaction potential at the site would be low. Weber County hazard mapping also shows the site in an area of low liquefaction potential (code 1).

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 site is not on the downthrown side of any active faults and the risk from tectonic subsidence is therefore low.

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 site elevation and distance from the nearest large body of water, the risk from seismic seiches and storm surges is 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.

Liberty Spring Creek flows across the southern part of the property about 150 feet south of the proposed home location. The creek is fed by springs upslope to the west and was flowing at the time of our investigation. Based on the above, the risk from stream flooding is equivocal for the inclusive property but would be low in the area of the proposed home. Weber County hazard mapping shows the proposed home location is in an area of zone X not subject to flooding.

Shallow Groundwater

Based on evidence discussed in the Hydrology Section above, groundwater in the area of the proposed home is likely less than 10 feet deep and may vary by a few feet seasonally, as would be expected for an alpine environment. Given the above, we rate the risk from shallow groundwater to the proposed home location as high. The proposed home will reportedly include a walk-out basement and will therefore require a foundation drainage system to ensure that proper subsurface drainage is maintained. We recommend the design be provided or reviewed (and approved) by a licensed geotechnical engineer.

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 proposed home location is on what we infer is a pre-Lake Bonneville rockslide that came off the range front about a half mile to the west. Several limestone-cored mounds are in the area that resemble Cambrian-age Maxfield Limestone; this bedrock unit is found in the range front to the west, but not in the site area. The mounds are surrounded and mantled by lacustrine sediments, suggesting they were likely inundated by the lake. Slopes in the area of the proposed home location show a steepness of about 25:1 (horizontal:vertical). Given all the above, the risk from landsliding and slope instability would be equivocal to the inclusive property, but the risk to the proposed home appears low. We recommend that the home excavation be inspected by a licensed geotechnical engineer once it is open to assess subsurface conditions and evaluate the need for slope stability analyses.

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. Debris flows have historically significant damage in the Wasatch Front area. The Project is not in an area subject to alluvial-fan flooding and no debris-flow channels, levees, or other debris-flow features were observed. We therefore rate the hazard from debris flows to the Project 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. We therefore rate the hazard from rock falls to the Project as low.

Problem Soil and Rock

Weber County hazard mapping does not show any expansive soil at the Project and the U.S. Department of Agriculture Natural Resources Conservation Service (USDA NRCS, https://websoilsurvey.nrcs.usda.gov/app/) maps the soil in the area of the proposed home as "Crooked Creek silty clay loam" and "Kahler gravelly loam, 3 to 6 percent slopes." The Crooked Creek loam is a poorly drained soil formed in alluvium with a typical soil profile consisting of a 14-inch thick A horizon comprised of silty clay loam overlying a C horizon comprised of silty clay, clay loam and sandy loam to a depth of 63 inches. The Kahler loam is a well-drained soil formed in slope alluvium with a typical soil profile consisting of a 6-inch thick A horizon comprised of gravelly loam overlying a B horizon comprised of gravelly loam to very gravelly sandy loam to a depth of 73 inches.

Given all the above, we rate the risk from problem soils as low. However, we recommend that a licensed geotechnical engineer inspect the foundation excavation to ensure that no subsurface soil conditions are present that would affect performance of the planned structure.

CONCLUSIONS AND RECOMMENDATIONS

Earthquake ground shaking and shallow groundwater are identified as posing a high relative risk to the proposed home. We recommend the following:

- ***Seismic Design*** – All habitable structures developed at the property should be designed and constructed to current seismic building codes to reduce the risk of damage, injury, or loss of life from earthquake ground shaking.

- ***Foundation Drainage*** – The proposed home will require a foundation drainage system to reduce the risk from shallow groundwater and ensure proper subsurface drainage is maintained. We recommend the design be provided or reviewed (and approved) by a licensed geotechnical engineer.

- ***Geotechnical Excavation Inspection*** – A licensed geotechnical engineer should inspect the foundation excavation for the home once it is open to ensure that no subsurface soil conditions are present that would affect performance of the planned structure and evaluate the need for slope stability analyses.

- ***Report Availability*** – This report and any subsequent reports regarding geologic conditions at the property should be made available to the architect and building contractor, as well as real estate agents and potential buyers in the event of a future sale. 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 the authors and should not be copied, used, or modified without their express permission.

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 the Project. Should you have any questions, please call.

Sincerely,
Western Geologic & Environmental LLC

7/20/2019
BILL DUANE
BLACK
NO. 5224898-2250

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

Reviewed By:

20 July 2019
KEVIN J
THOMAS
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Kevin Thomas

Kevin J. Thomas, P.G.
Principal Geologist

ATTACHMENTS

- Figure 1. Location Map (8.5" x 11" portrait)
- Figure 2. Geologic Map (8.5" x 11" portrait)
- Figure 3A. 1997 Air Photo (8.5" x 11" landscape)
- Figure 3B. 2012 Air Photo (8.5" x 11" landscape)
- Figure 3C. 2018 Air Photo (8.5" x 11" landscape)
- Figure 3D. LIDAR Analysis (8.5" x 11" landscape)
- Appendix. Photographic Record of Site Reconnaissance

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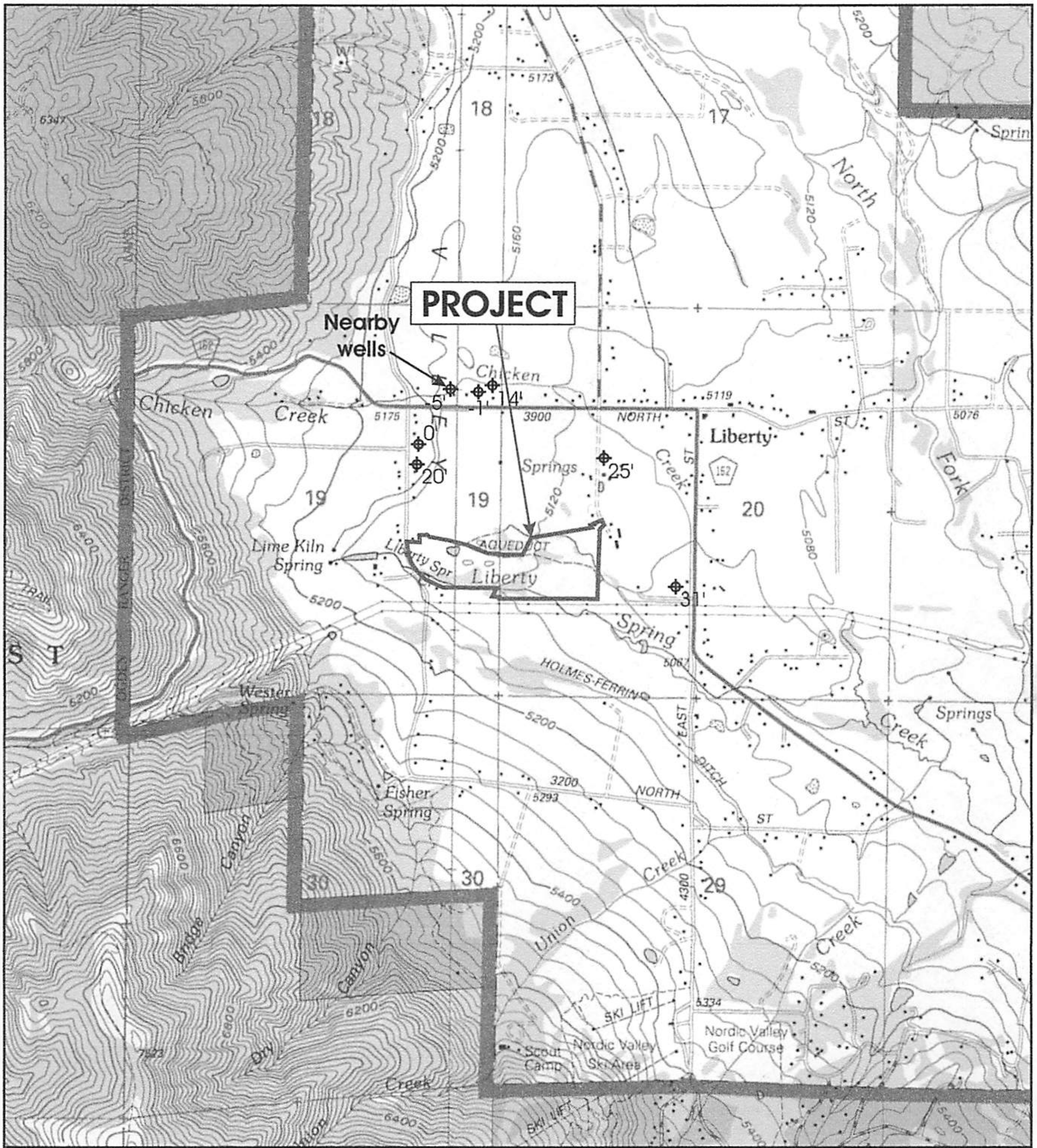
FIGURES



Source: U.S. Geological Survey 7.5 Minute Series Topographic Maps, Utah - North Ogden and Huntsville, 1998;
Project location: SE1/4 Section 19 and SW1/4 Section 20, T7N, R1E (SLBM).

WESTERN GEOLOGIC

0 1000 2000 feet

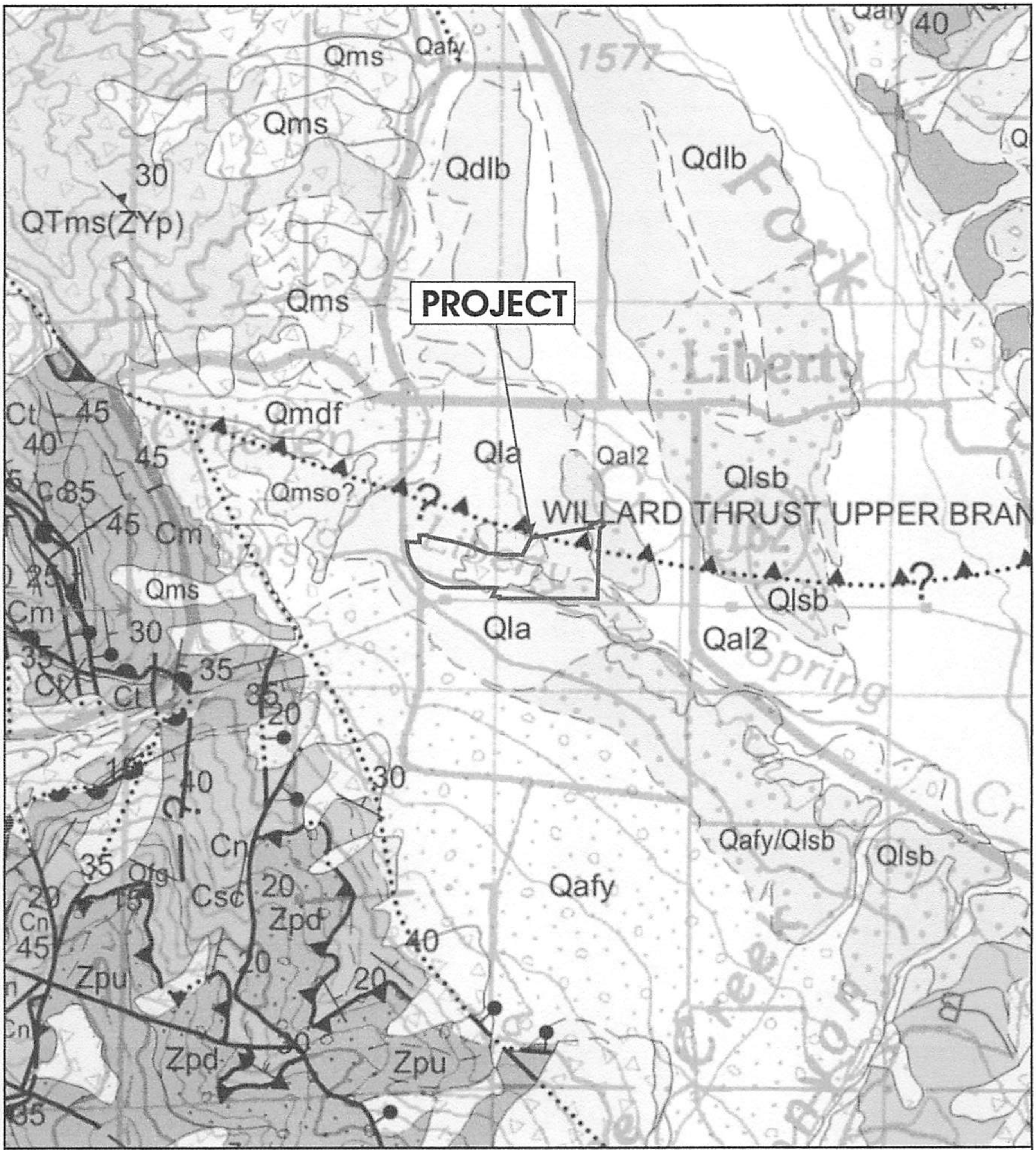
Scale 1:24,000
(1 inch = 2000 feet)

LOCATION MAP

GEOLOGIC HAZARDS RECONNAISSANCE

Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

FIGURE 1



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

GEOLOGIC MAP

GEOLOGIC HAZARDS RECONNAISSANCE

Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

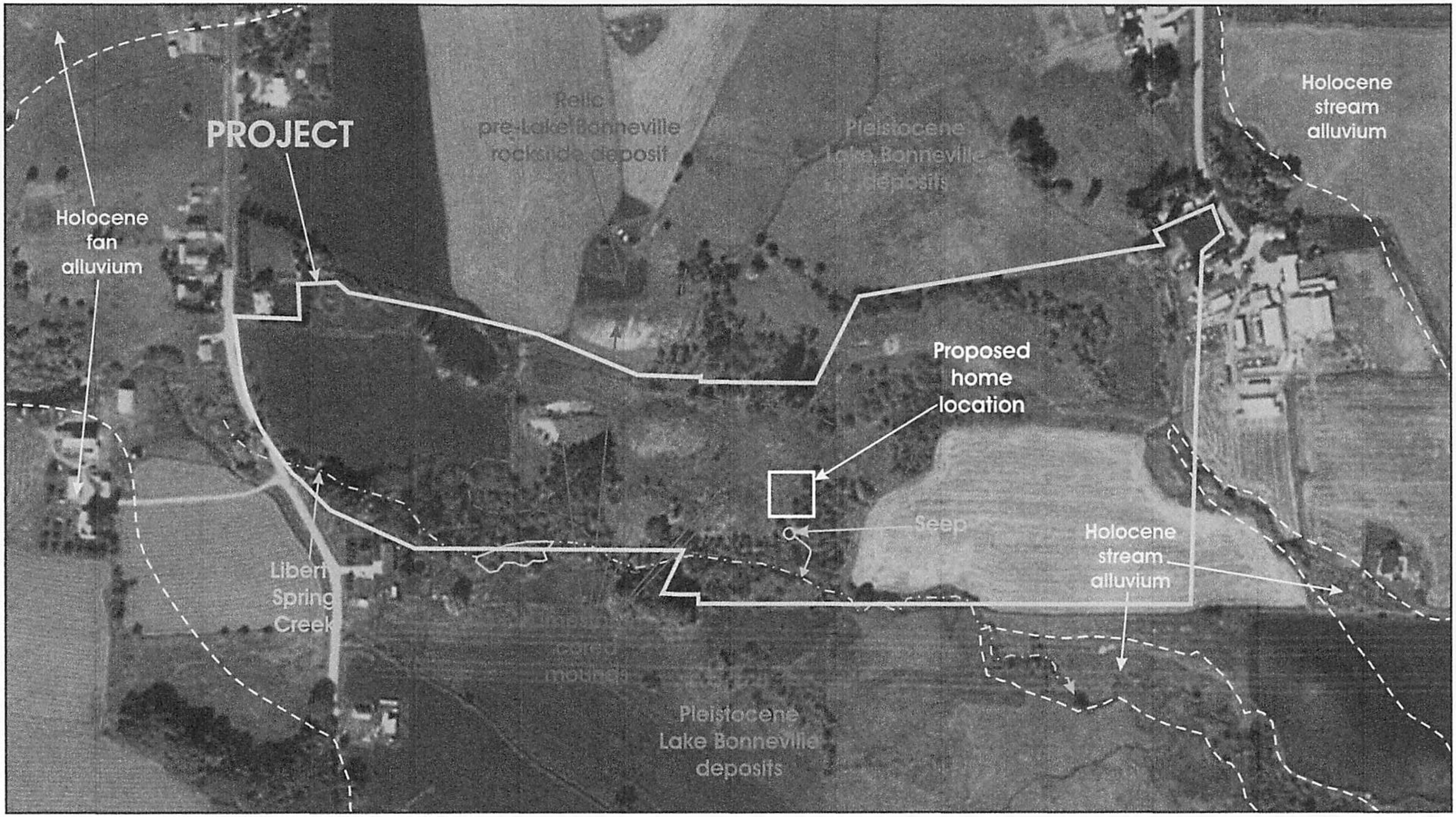
FIGURE 2

WESTERN GEOLOGIC

N W E S

0 1000 2000 feet

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



Source: Utah AGRC 1997 Digital Orthophoto, 1 m resolution.

Scale 1:4,800
(1 inch = 400 feet)

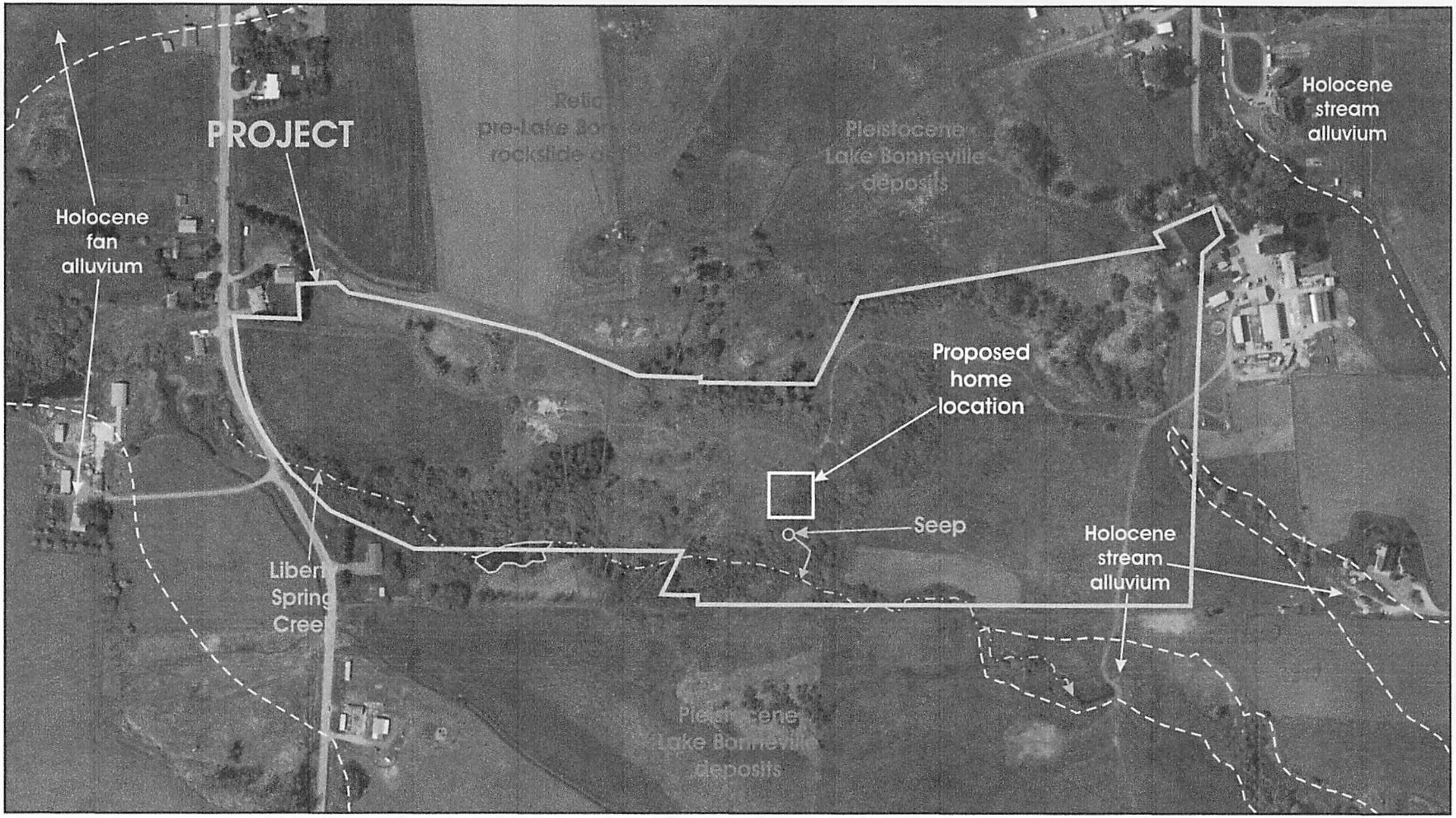
WESTERN GEOLOGIC

1997 AERIAL PHOTO

GEOLOGIC HAZARDS RECONNAISSANCE

Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

FIGURE 3A



Source: Utah AGRC, 2012 High Resolution Orthophoto, 12.5 cm resolution.

Scale 1:4,800
(1 inch = 400 feet)

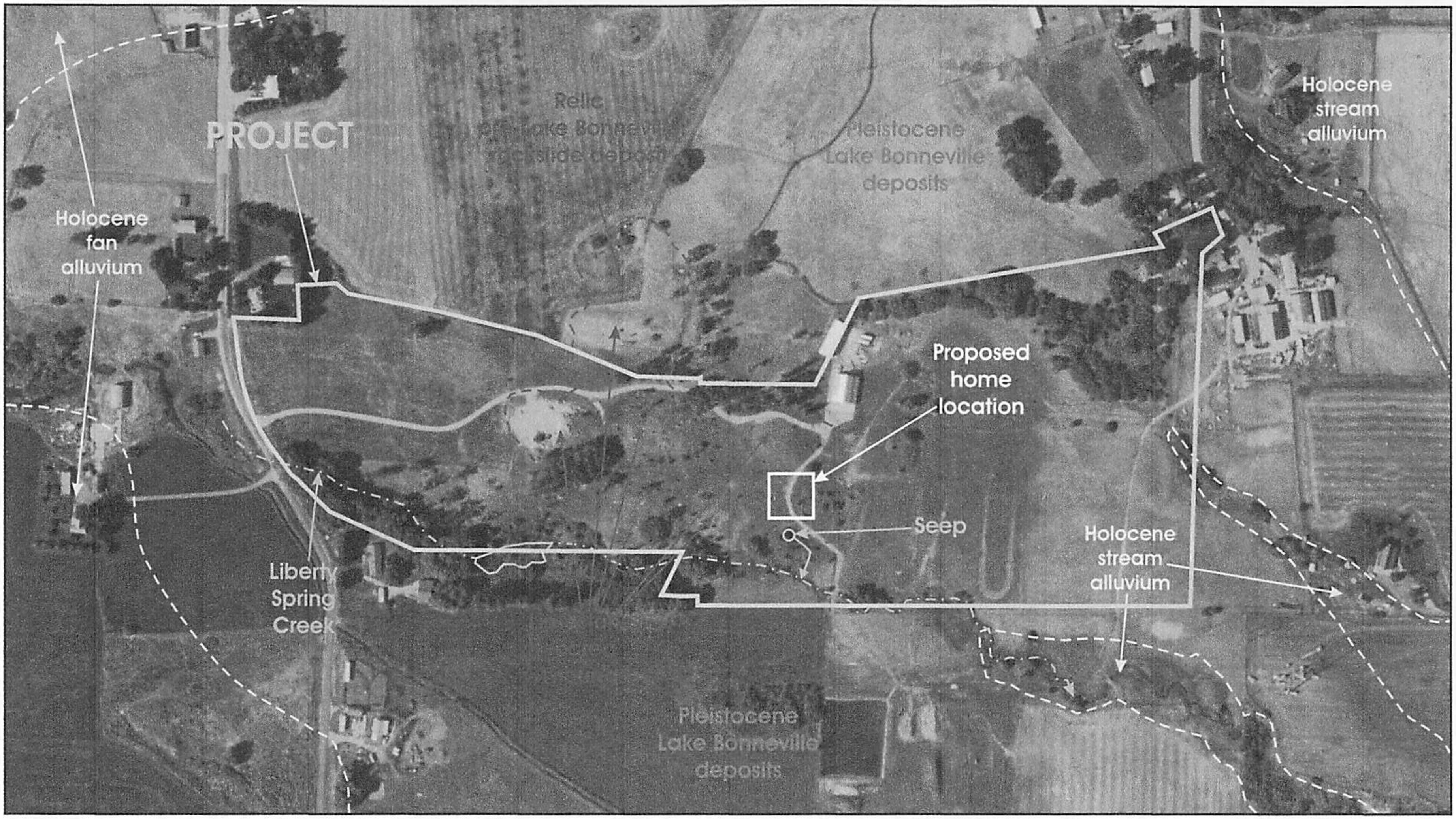
WESTERN GEOLOGIC

2012 AERIAL PHOTO

GEOLOGIC HAZARDS RECONNAISSANCE

Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

FIGURE 3B



Source: Utah AGRC, 2018 NAIP, 60 cm resolution.

2018 AERIAL PHOTO

GEOLOGIC HAZARDS RECONNAISSANCE

Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

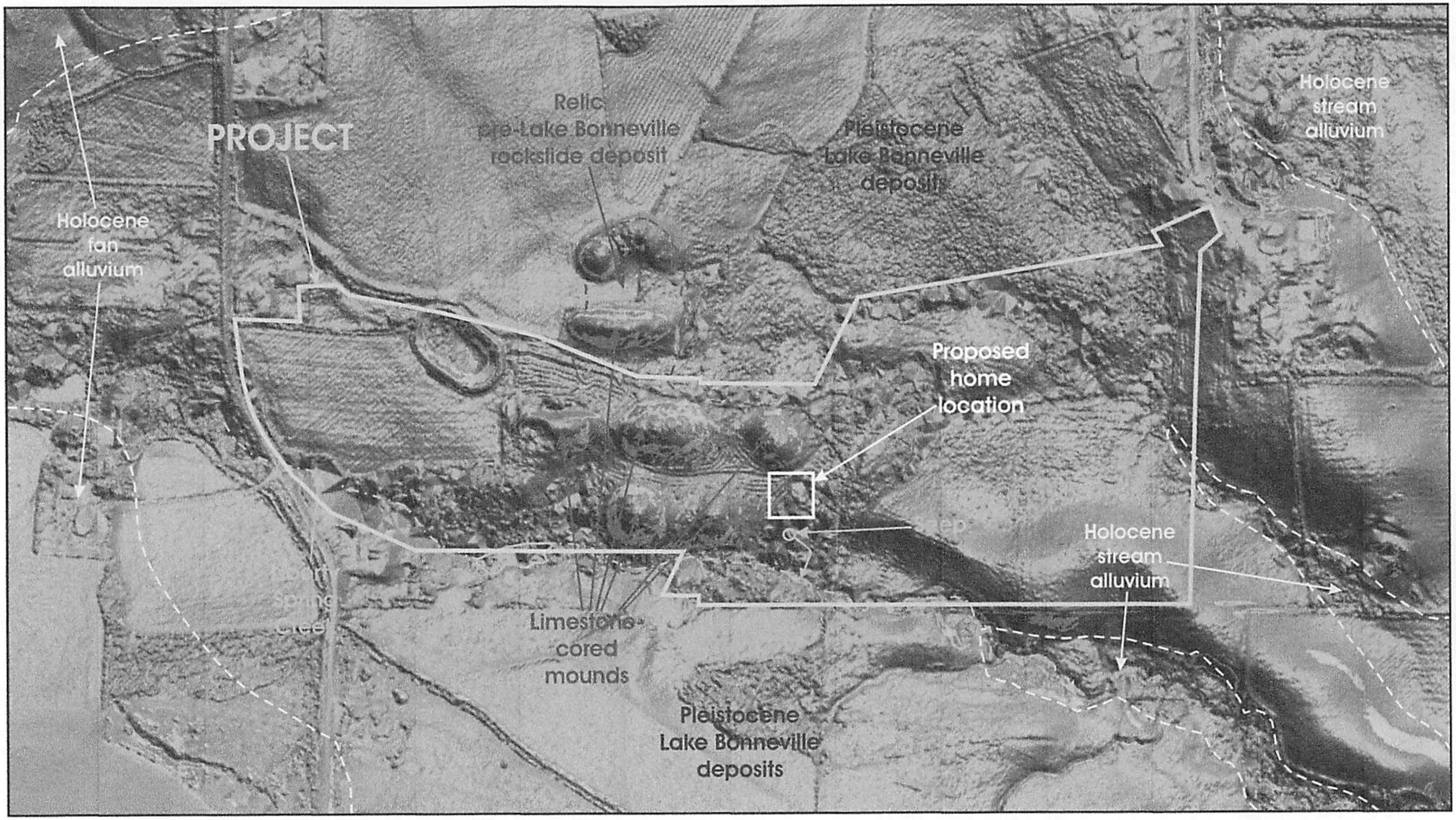
FIGURE 3C

N
W E
S

0 200 400 feet

Scale 1:4,800
(1 inch = 400 feet)

WESTERN
GEOLOGIC



Source: Utah AGRC, 2011 LIDAR Bare Earth DEM, 1 m resolution;
slope gradients <20% shaded in green, 20-30% in yellow, and >30% in red.

Scale 1:4,800
(1 inch = 400 feet)

WESTERN GEOLOGIC

LIDAR ANALYSIS

GEOLOGIC HAZARDS RECONNAISSANCE

Liberty Creek Investments Land
About 3800 North 2900 East
Liberty, Weber County, Utah

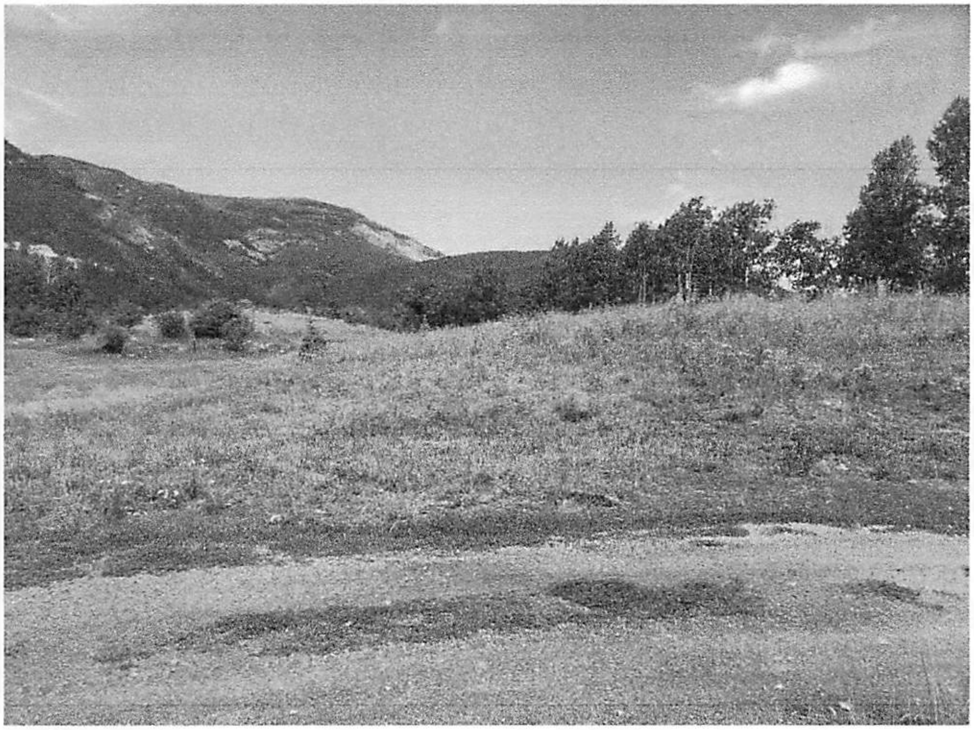
FIGURE 3D

APPENDIX

Photographic Record of Site Reconnaissance
Liberty Creek Investments Land – About 3800 North 2900 East
Liberty, Weber County, Utah

Photo 1. South view of proposed home location at property.

Photo 2. Limestone-cored hummock west of proposed home location.



Photographic Record of Site Reconnaissance
Liberty Creek Investments Land – About 3800 North 2900 East
Liberty, Weber County, Utah

Photo 3. Seep south of proposed home location

Photo 4. Liberty Spring Creek.

Photo 5. Nearby piezometers for septic system.

Photo 6. View west toward North Ogden Pass and series of hummocks.

Photographic Record of Site Reconnaissance
Liberty Creek Investments Land – About 3800 North 2900 East
Liberty, Weber County, Utah

Photo 7. Excavation in one of the limestone hummocks.

Photo 8. Large limestone boulder in flat-lying field.