# REPORT

# GEOLOGIC HAZARDS EVALUATION
## THE POINTE AT WOLF CREEK
## 3818 NORTH WOLF CREEK DRIVE
## EDEN, WEBER COUNTY, UTAH

*Prepared for*

Lewis Homes
3718 North Wolf Creek Drive
Eden, Utah 84310

November 4, 2019

*Prepared by*

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November 4, 2019

Eric Householder
Lewis Homes
3718 North Wolf Creek Drive
Eden, Utah 84310

**Letter of Transmittal:** REPORT
Geologic Hazards Evaluation
The Point at Wolf Creek
3718 North Wolf Creek Drive
Eden, Weber County, Utah

Dear Mr. Householder:

Western Geologic & Environmental has completed a Geologic Hazards Evaluation for the proposed The Point at Wolf Creek condominium development at 3718 North Wolf Creek Drive in Eden, Utah and submits the attached report for your review.

If you have any questions regarding this report, please contact us at (801) 359-7222.

Sincerely,
Western Geologic & Environmental LLC

LICENSED PROFESSIONAL GEOLOGIST
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**WG&E Project No. 5254**

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## FIGURES

## 1.0 INTRODUCTION

This report presents the results of a geology and geologic hazards review and evaluation conducted by Western Geologic & Environmental LLC (Western Geologic) for the proposed The Point at Wolf Creek development at 3718 North Wolf Creek Drive in Eden, Utah (Figure 1 – Project Location). The Project consists of a 2.51-acre parcel identified as Weber County Assessor Parcel Number 22-016-0034. The site is located on southwest-facing slopes in northeastern Ogden Valley adjacent to the 10th and 11th fairways for the Wolf Creek Resort golf course, and is in the SW 1/4 of Section 22, Township 7 North, Range 1 East (Salt Lake Base Line and Meridian; Figure 1). Patio Springs is adjacent to the site on the southeast (Figure 1). Elevation of the site ranges between 5,218 and 5,248 feet above sea level. The site is currently undeveloped. It is our understanding that the property is proposed for development of three multi-family condominium buildings, although no formalized plans were provided.

## 2.0 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. Our investigation was conducted concurrently with a geotechnical engineering study performed at the Project by Christensen Geotechnical.

### 2.1 Methodology

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;
- Logging of three walk-in test pits at the site;
- Preparation of one cross section profile based on the subsurface data; 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.

## 2.2 Limitations and Exceptions

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.

## 3.0 HYDROLOGY

The U.S. Geological Survey (USGS) topographic map of the Huntsville Quadrangle shows the site is in Ogden Valley about 0.8 miles southwest of Wolf Creek Canyon (Figure 1). The Project is located within the Wolf Creek Resort adjacent to Patio Springs (Figure 1). The Wolf Creek Resort was developed in various stages after 1962; Patio Springs, which is now part of Wolf Creek Village, was developed prior to 1958 and enlarged and improved since then. The condominiums of Wolf Creek Village appear to have been developed in the early 2000s. No springs or active drainages were observed during our reconnaissance, or are mapped at the site or crossing the Project on Figure 1. The nearest active drainage is a branch of Wolf Creek that flows southwestward across the existing golf course near the northwest site boundary. The main channel for Wolf Creek is located about 1,300 feet to the northwest of the site.

The site is at the northeastern margin of Ogden Valley, which is dominated in the valley bottom by unconsolidated lacustrine and alluvial basin-fill deposits. Slopes in the site area are mainly in alluvial and colluvial deposits of varying ages that extend southwestward from the mountain range front. The range front to the northeast is comprised of weathered quartzite bedrock. All three test pits conducted for our evaluation (Section 5.3) encountered groundwater at depths between 6.3 to 9.0 feet below the ground surface. Test pits TP-1 and TP-2 were inundated by the time of our logging (within a day after excavation), whereas TP-3 only contained seepage. Given the above, we anticipate groundwater at the Project is likely less than 10 feet deep. Groundwater levels may vary annually from climatic fluctuations, and also seasonally from snowmelt runoff and man-made sources such as landscape irrigation. Such variations would be typical for the site area. Perched conditions above less-permeable, clay-rich bedrock layers may also cause locally shallower groundwater levels and could, at least in part, be responsible for the observed shallow groundwater in our test pit exposures.

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). Based on groundwater depths observed in our test pits, we expect groundwater flow at the site to be to the southwest.

## 4.0 GEOLOGY

### 4.1 Surficial Geology

The site is located on the northeastern margin of Ogden Valley, a sediment-filled intermontane valley within 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 landslide colluvium on the northwest, mixed alluvium and colluvium on the west, colluvial gravel deposits on the south, and old alluvial-fan deposits on the east (units Qms, Qac, Qcg, and Qafo respectively; Figure 2).

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.

***Qay, Qa2, Qa2?, Qa3, Qa3?, Qa4, Qa4?, Qa4-5, Qa5, Qa6*** - *Alluvium (Holocene and Pleistocene).* Sand, silt, clay, and gravel in stream and alluvial-fan deposits that are not close to late Pleistocene Lake Bonneville and are geographically in the Huff Creek and upper Bear River drainages; variably sorted; variably consolidated; composition depends on source area; deposits lack fan shape of Qaf and are distinguished from terraces (Qat) based on upper surface sloping toward adjacent streams from sides of drainage, or are shown where fans and terraces are too small to show separately at map scale; Qay is at to slightly above present drainages and not incised by active drainages, so is the youngest unit; generally 6 to 20 feet (2-6 m) thick.

Age-number and letter suffixes on alluvium (undivided, channel, flood plain, terrace, and fan) that is not close to late Pleistocene Lake Bonneville are relative and only apply to the local drainage, with suffix 2 being the second youngest; the relative age is queried where age uncertain, generally due to the height not fitting into the typical order of surfaces. The various numbered deposits listed, Qa2 through Qa6, are 20 to 180 feet (6-55 m) above the Bear River, Saleratus Creek, and Yellow Creek. Qa5 and Qa3? are only used in stacked units (Qa5/Tfb and Qa3?/Tfb).

***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.

***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.

***Qafp, Qafp?, Qafb, Qafb?, Qafpb, Qafpb?*** - *Lake Bonneville-age alluvial-fan deposits (upper Pleistocene).* Like undivided alluvial fans, but height above present drainages appears to be related to shorelines of Lake Bonneville and is within certain limits (see table 1); these fans are inactive, unconsolidated to weakly consolidated, and locally dissected; fans labeled Qafp and Qafb are related to the Provo (and slightly lower) and Bonneville shorelines of late Pleistocene Lake Bonneville, respectively, while unit Qafpb is used where fans may be related to the Provo or Bonneville shoreline (for example Qafpb is ~40 feet [12 m] above Lost Creek Valley), or where fans of different ages cannot be shown separately at map scale; Qafp fans typically contain well-rounded, recycled Lake Bonneville gravel and sand and are moderately well sorted; generally 10 to less than 60 feet (3-18 m) thick. Lake Bonneville-age fans are queried where relative age is uncertain (see Qaf for details); fans labeled Qafpb? are above the Bonneville shoreline and might be Qafo or like Qafm; see the note under Qao about two possible ages of older alluvium (Qao, Qato, and Qafo).

Most of the Lake Bonneville-age fans in the James Peak quadrangle are far from the Bonneville shoreline and their age is inferred from their stratigraphic relationship(s) to coeval Pinedale glacial outwash (see age equality in Table 3).

The channels (Qafp/Qdlb) on the Weber River delta and Lake Bonneville fines (Qafp on Qlfb) probably record scour and fill during the rapid drawdown of the lake as it fell from the Bonneville shoreline to the Provo shoreline.

***Qap, Qap?, Qab, Qab?, Qapb*** - *Lake Bonneville-age alluvium (upper Pleistocene).* Like undivided alluvium but height above present drainages appears to be related to shorelines of Lake Bonneville and is within certain limits, and unconsolidated to weakly consolidated; alluvium labeled Qap and Qab is related to Provo (and slightly lower) and Bonneville shorelines of Lake Bonneville (at ~4800 to 4840 feet [1463-1475 m] and 5180 feet [1580 m] in Morgan Valley), respectively; suffixes partly based on heights above adjacent drainages near Morgan Valley (see tables 1 and 2); Qap is typically about 15 to 40 feet (5-12 m) above present adjacent drainages, but is locally 45 feet (12 m) above; Qapb is used where more exact age cannot be determined, typically away from Lake Bonneville, or where alluvium of different ages cannot be shown separately at map scale; Qap is up to about 50 feet (15 m) thick, with Qapb and Qab, at least locally up to 40 and 90 feet (12 and 27 m) thick, respectively. Queried where classification or relative age uncertain (see Qa).

A prominent surface (“bench”) is present on Qap and Qatp at about 4900 feet (1494 m) elevation and about 25 to 40 feet (8-12 m) above the Weber River in Morgan Valley and along the South Fork Ogden River.

In the Devils Slide quadrangle, the Qab that is mapped about 80 to 95 feet (24-29 m) above Round Valley and 40 to 50 feet (12-15 m) above adjacent drainages at the mouth of Geary Hollow appears unique. Based on heights above adjacent drainages, these deposits would be Qao (see table 1), but similar alluvial deposits to the east near Phil Shop Hollow have a Bonneville shoreline cut in them and are much thinner than 40 feet (12 m). The lack of a Bonneville shoreline, and small thickness and heights above drainages indicate the deposits could be a Bonneville shoreline fan-delta.

***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).

***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.

***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 subrounded 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.

***QTcg, QTcg?*** - *Gravelly colluvial deposits (Pleistocene and/or Pliocene).* Unconsolidated, poorly sorted pebble to cobble to boulder clasts in light-colored gravelly silt and sand matrix that weathers to an indistinct soil; mapped on east side of Ogden Valley; no tuff noticed in soil but thin Norwood Formation may be present in subsurface; rounded quartzite and Paleozoic carbonate clasts are like those upslope in the gravel-rich Wasatch Formation, but matrix not reddish like material typically derived from Wasatch Formation; angular clasts appear to be from underlying Geertsen Canyon Quartzite; unlike younger colluvial gravels (Qcg), stone stripes, which trend downhill, are not present or visible on aerial photographs; generally 6 to 20 feet (2-6 m) thick, but may be as much as 80 feet (25 m) thick. Some QTcg deposits previously shown as Pliocene(?) (Huntsville) fanglomerate (see Lofgren, 1955, in particular figure 19). QTcg queried where material may be units QTng or QTaf.

***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.

***Cgc, Cgc?*** - *Geertsen Canyon Quartzite (Middle and Lower Cambrian and possibly Neoproterozoic).* In the west mostly buff (off-white and tan) quartzite, with pebble conglomerate beds; pebbles are mostly rounded light colored quartzite; contains cross bedding, and pebble layers and lenses; colors vary from tan and light to medium gray, with pinkish, orangish, reddish, and purplish hues; outcrops darker than these fresh quartzite colors; cliff forming; some brown-weathering, interbedded micaceous argillite and quartzite common at top and mappable locally; pebble to cobble conglomerate lenses more abundant in middle part of quartzite, and basal, very coarse-grained arkose locally; near Huntsville, total thickness about 4200 feet (1280 m), including upper argillite about 375 feet (114 m) thick and basal coarse-grained arkose (arkosic to feldspathic quartzite) about 300 to 400 feet (90-120 m) thick (Crittenden and others, 1971). Overall seems to be thinner near Browns Hole. Called Prospect Mountain Quartzite and Pioche Shale (argillite at top) by some previous workers.

Upper and lower parts of Crittenden and others (1971; Crittenden, 1972; Sorensen and Crittenden, 1979) are not mappable outside the Browns Hole and Huntsville quadrangles, likely because the marker cobble conglomerate and change in grain size and feldspar content reported by Crittenden and others (1971) is not at a consistent horizon; quartz-pebble conglomerate beds are present in most of the Geertsen Canyon Quartzite.

To the east on leading margin of Willard thrust sheet, the Geertsen Canyon is thinner, an estimated 3200 feet (975 m) total thickness (Coogan, 2006a-b), and may be divided into different members, though informal members to west and east are based on conglomerate lenses near member contact and feldspathic lower member (see Crittenden and others, 1971; Coogan, 2006a-b).

Lower part in west (Cgcl, Cgcl?) is typically conglomeratic and feldspathic quartzite (only up to 20% feldspar reported by Crittenden and Sorensen, 1985a, so not an arkosic), with 300- to 400-foot (90-120 m), basal, very coarse-grained, more feldspathic or arkosic quartzite; 1175 to 1700 feet (360-520 m) thick (Crittenden and others, 1971; Crittenden, 1972; Sorensen and Crittenden, 1979) and at least 200 to 400 feet (60-120 m) thinner near Browns Hole (compare Crittenden, 1972 to Sorensen and Crittenden, 1979). Unit queried where poor exposures may actually be surficial deposits.

***Zm, Zm?*** *- Mutual Formation (Neoproterozoic).* Grayish-red to purplish-gray, medium to thick-bedded quartzite with pebble conglomerate lenses; also reddish-gray, pink, tan, and light-gray in color and typically weathering to darker shades than, but at least locally indistinguishable from, Geertsen Canyon Quartzite; commonly cross-bedded and locally feldspathic; contains argillite beds and, in the James Peak quadrangle, a locally mappable medial argillite unit; 435 to 1200 feet (130-370 m) thick in Browns Hole quadrangle (Crittenden, 1972) and thinnest near South Fork Ogden River (W. Adolph Yonkee, Weber State University, verbal communication, 2006); thicker to northwest, up to 2600 feet (800 m) thick in Huntsville quadrangle (Crittenden and others, 1971) and 2556 feet (780 m) thick in James Peak quadrangle (Blau, 1975); may be as little as 300 feet (90 m) thick south of the South Fork Ogden River (King this report); absent or thin on leading edge of Willard thrust sheet (see unit Zm?c); thins to south and east.

***Zmcg, Zmcg?*** *- Maple Canyon Formation, Lower (green arkose) member (Neoproterozoic).* Grayish-green, fine-grained arkosic (feldspathic) meta-sandstone and sandy argillite (meta-graywacke), with local quartzite lenses up to 200 feet (60 m) thick; weathers darker gray to brown to greenish-gray and greenish-brown; 500 to 1000 feet (150-305 m) thick and lower thickness would eliminate the need for faulting in southwest part of Huntsville quadrangle. This unit is prone to slope failures.

***Zkc, Zkc?*** *- Kelley Canyon Formation (Neoproterozoic).* Dark-gray to black, gray to olive-gray-weathering argillite to phyllite, with rare metacarbonate (for example basal meta-dolomite); grades into overlying Caddy Canyon quartzite with increasing quartzite; gradational interval mapped as Papoose Creek Formation (Zpc); 1000 feet (300 m) thick in Mantua quadrangle (this report), where Papoose Creek Formation is mapped separately, and reportedly 2000 feet (600 m) thick near Huntsville (Crittenden and others, 1971, figure 7), but only shown as about 1600 feet (500 m) thick to Papoose Creek transition zone by Crittenden (1972). The Kelley Canyon Formation is prone to slope failures.

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

### 4.2 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 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 the prominent, west-facing escarpment along 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 (UGS) Quaternary Fault and Fold Database (Black and others, 2003; updated May 2019) indicates the Ogden Valley northeastern margin fault is about 1.3 miles northeast of the Project. The most recent movement on this fault is pre-Holocene (Sullivan and others, 1986). Figure 2 also shows numerous dot-dashed lineaments in the site area, as well as one southwest-dipping fault that displaces various alluvial and landslide deposits. The latter fault is not indicated in Black and others (2003) and has uncertain provenance, but is likely pre-Holocene based on information in Sullivan and others (1986). Jon King (Utah Geological Survey, verbal communication, April 2016) indicated that the lineaments have an uncertain origin and appear to correspond to bedding within the underlying bedrock beneath the unconsolidated gravel cap. Coogan and King (2016) reportedly mapped the lineaments because they are also near the Ogden Valley northeastern margin fault and could be related to pre-Holocene faulting.

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.

### 4.3 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 situated above the highest (Bonneville) shoreline, which is shown on Figure 2 about 1.5 miles southwest of the Project at an elevation of roughly 5,180 feet (blue line and B).

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).

## 5.0 SITE CHARACTERIZATION

### 5.1 Empirical Observations

On October 30-31, 2019, Mr. Bill D. Black of Western Geologic conducted a brief reconnaissance of the property to observe geomorphic and surficial conditions. Weather at the time of the reconnaissance was clear and sunny with temperatures in the 20's (°F). The Project is located in northeastern Ogden Valley on relatively gentle southwest-facing slopes wedged between two fairways of the Wolf Creek Resort golf course. Native vegetation appeared to consist of grasses, thistle, and scattered trees and brush. Several existing condominiums of Wolf Creek Village, as well as ancillary buildings and sports courts were observed to the east and south. No active streams or ephemeral drainage courses were evident crossing the Project and no springs or seeps were also observed. However, the site is located in an area where there are known springs and shallow groundwater issues. The surface of site was covered by about an inch of snow at the time of the reconnaissance. Various cobbles and boulders were evident protruding from surface soils. The boulders were likely deposited by alluvial and/or colluvial processes when the canyons to the northeast were significantly larger and conditions were wetter during Pleistocene time. No evidence for characteristic debris-flow features, landslides, recent or ongoing slope instability, or other geologic hazards was observed during the reconnaissance.

### 5.2 Air Photo Observations

Black and white orthophotography from 1997, color orthophotography from 2012, and bare earth DEM LIDAR imagery from 2011 (Figures 3A-3C) were reviewed to obtain information about the geomorphology of the Project area. Site-specific surficial geologic mapping for the area is shown on Figures 3A-C based on our air photo interpretations and mapping in Coogan and King (2016; Figure 2). The site is underlain by a sequence of alluvial sediments deposited since Pleistocene time along the range front and at the mouth of Wolf Creek Canyon (Figures 3A-C). The alluvial deposits generally appear to become younger northwestward. The landslide deposit mapped by Coogan and King (2016) at the Project does not appear to extend into the site based on our air photo review and subsurface data from the test pits (Section 5.3). No evidence for other geologic hazards was observed on the air photos at the site.

### 5.3 Subsurface Investigation

Three short trenches (walk-in test pits) were excavated at the site on October 30, 2019 to evaluate subsurface conditions. The test pits were logged by Bill D. Black, P.G. of Western Geologic on October 31, 2019 concurrently with the Project geotechnical investigation conducted by Christensen Geotechnical. Locations of the test pits are shown on Figures 3A-C. The test pit locations were measured using a hand-held GPS unit and by trend and distance methods from known points. The test pits were logged at a scale of one-inch equals five feet (1:60) following methodology in McAlpin (1996), and digitally photographed at five-foot intervals to document the exposures. The photos are not provided herein, but are available on request. Logs of the test pits are provided on Figure 4A-C. Stratigraphic interpretations and descriptions are provided on the test pit logs.

Test pits TP-1 and TP-2 at the site exposed a similar sequence of alluvial deposits comprised of cobbles and boulders in a matrix of clay with sand and gravel (units 1 and 2, respectively; Figures 4A-B); the modern A-horizon soil and a $B_t$ horizon were observed forming in unit 2 at the surface (units 2A and 2B, Figures 4A-B). We infer the deposits are of Pleistocene age based on the degree of soil development and character of the deposits. Test pit TP-3 exposed the same lower deposit as test pits TP-1 and TP-2 (unit 1, Figures 4A-C), but the deposit was instead overlain by sandier alluvium (unit 3, Figure 4C) that appeared younger than unit 2 in test pits TP-1 and TP-2. A modern A-horizon soil was observed at the surface in unit 3 (unit 3A, Figure 4C), but no B horizon could be delineated in test pit TP-3. Groundwater was encountered in all three test pits at depths of between 6.3 to 9.0 feet, and test pits TP-1 and TP-2 were partly inundated at the time of the logging. Groundwater depths encountered in the test pits are shown on Figures 3A-C.

### 5.4 Cross Section

Figure 5 shows a cross section across the site (A-A’, Figures 3A-C) at a scale of one-inch equals 40 feet with no vertical exaggeration. Units, contacts and approximate groundwater depth are based on subsurface data from the test pits (Figures 4A-C) and/or inferred from the geologic mapping on Figures 3A-C. The topographic profile is based on geoprocessed 2011 LIDAR data. The cross section shows a sequence Pleistocene-age alluvium that was likely deposited prior to and possibly contemporaneous with the transgression of Lake Bonneville. We infer the alluvium overlies bedrock of either the Tertiary Norwood Formation or Precambrian Mutual Formation, although the thickness of the alluvial sequence is unknown. No well logs were found in the immediate vicinity of the Project in the Utah Division of Water Rights well driller database to confirm the bedrock depth. We anticipate the cross section accurately depicts near-surface conditions along the selected profile location, but some variation may be found at depth and laterally.

## 6.0 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 and Rock** | | | X |

## 6.1 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 2018 IBC provisions, a site class of D (stiff soil), and a risk category of II, calculated seismic values for the site (centered on 41.32882° N, -111. 82835° W) are summarized below:

**Table 2.** *Seismic hazards summary.*

| | |
|---|---|
| **$S_S$** | *0.951 g* |
| **$S_1$** | *0.338 g* |
| **$S_{MS}$ ($F_a$ x $S_S$)** | *1.065 g* |
| **$S_{M1}$ ($F_v$ x $S_1$)** | *See ASCE 7-16 Section 11.4.8* |
| **$S_{DS}$ (2/3 x $S_{MS}$)** | *0.71 g* |
| **$S_{D1}$ (2/3 x $S_{M1}$)** | *See ASCE 7-16 Section 11.4.8* |
| **Site Coefficient, $F_a$** | *= 1.12* |
| **Site Coefficient, $F_v$** | *See ASCE 7-16 Section 11.4.8* |
| **Peak Ground Acceleration, PGA** | *= 0.421 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 the current adopted building code. We note that IBC 2018 provisions require calculation of the spectral acceleration value ($S_{M1}$), seismic design value ($S_{D1}$), and site coefficient ($F_v$) differently from IBC 2015. In municipalities where IBC 2018 has been adopted, the Project engineer or architect should determine these seismic values in accordance with ASCE 7-16 Section 11.4.8 guidelines.

## 6.2 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 and the UGS Quaternary Fault and Fold Database (Black and others, 2003) indicates the Weber segment of the WFZ about 5.5 miles to the west is the nearest active fault to the Project. Although Coogan and King (2016; Figure 2) map a short, northwest trending fault that displaces Quaternary-age mass-movement deposits and alluvium about 1,100 feet east of the Project, this fault is not in close proximity to the site and not likely in an activity class for risk category II structures where further evaluation is recommended by Bowman and Lund (2016). Based on all the above, the existing hazard from surface faulting is rated as low.

### 6.3 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.

Soils at the site are mapped by the NRCS (https://websoilsurvey.nrcs.usda.gov/app/WebSoilSurvey.aspx) as Yeates Hollow very stony loam, 10 to 30 percent slopes, which is comprised of very stony, gravelly, and gravelly clay loam soils formed in range-front alluvial and colluvial sediments derived from conglomeratic bedrock. Weber County GIS mapping further shows the site in a very low liquefaction hazard zone (zone 1) and no soils susceptible to liquefaction were also observed in the test pits at the Project (Figures 4A-C). Given all the above, we rate the risk from liquefaction as low.

### 6.4 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. The Project is not in close proximity to and on the downthrown side of any mapped active (Holocene) faults. Based on this, we rate the risk from tectonic subsidence as low.

### 6.5 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.

## 6.6 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 or ephemeral drainages were observed crossing the Project, although a branch of Wolf Creek flows across the Wolf Creek Resort golf course near the northwest site boundary. Federal Emergency Management Agency flood insurance rate mapping (Map Number 49057C0229F, June 2015) classifies the Project in "Zone X - Area of Minimal Flood Hazard". Given all the above, we rate the risk from stream flooding as low.

## 6.7 Shallow Groundwater

The Project is adjacent to Patio Springs in an area with known shallow groundwater issues, and groundwater was observed in all three test pits at the site at depths of from 6.3 to 9.0 feet. Given the above, groundwater at the Project is likely less than 10 feet deep. However, groundwater levels may vary annually from climatic fluctuations, and also seasonally from snowmelt runoff and man-made sources such as landscape irrigation. Such variations would be typical for the area. Perched conditions above less-permeable stratigraphic layers, such as those observed in the test pits, may also cause locally shallower groundwater levels. Given all the above, we rate the hazard from shallow groundwater as high. The hazard from shallow groundwater should therefore be assessed and discussed in the Project geotechnical engineering evaluation. Shallow groundwater is often a significant factor in slope instability, as discussed below.

## 6.8 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.

No landslide deposits were identified in any of the test pits at the Project, no landslides are mapped or were observed in our reconnaissance or on air photos at the site, and no evidence for recent or ongoing slope instability was observed during our reconnaissance. Figure 5 also shows slopes at the site have an overall 15:1 (6.7%) gradient. Given all the above, we rate the existing risk from landslides as low. However, groundwater at the Project appears to be shallow (less than 10 feet deep) and landslide deposits are mapped nearby on Figures 2 and 3A-C that suggest that the Project may be in an area prone to instability. The Project geotechnical engineer may therefore conservatively choose to evaluate slope stability based on site-specific data and the geologic characterizations provided in this report. Recommendations will be needed to reduce the risk of slope instability if factors of safety are determined to be unsuitable. Water, steep man-made cuts, and non-engineered fill materials are often major contributors to slope instability. Care should therefore be taken to maintain proper site drainage, and that site grading does not destabilize slopes at the site without prior geotechnical analysis and grading plans.

### 6.9 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 site is not in a mapped active alluvial fan, and no evidence for debris-flow channels, levees, or other debris-flow features was observed at the site on air photos or during our reconnaissance. Given the above, we rate the risk as low.

### 6.10 Rock Fall

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

### 6.11 Problem Soil and Rock

Surficial soils that contain certain clays can swell or collapse when wet. A geotechnical engineering evaluation should be performed to address soil conditions and provide specific recommendations for site grading, subgrade preparation, and footing and foundation design.

## 7.0 CONCLUSIONS AND RECOMMENDATIONS

Geologic hazards posing a high relative risk to the site include earthquake ground shaking and shallow groundwater. The following recommendations are provided with regard to the geologic characterizations in this report:

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

- ***Geotechnical Evaluation*** – A design-level geotechnical engineering study should be conducted prior to construction to assess soil foundation conditions and provide recommendations to reduce the risk from shallow groundwater. The Project geotechnical engineer may also conservatively choose to evaluate slope stability given that the site has shallow groundwater conditions and landslides are mapped nearby. The stability evaluation should be based on geologic characterizations in this report and site-specific geotechnical data, and provide recommendations for reducing the risk of landsliding if the factors of safety are deemed unsuitable.

- ***Site Modifications and Drainage*** – No unplanned cuts should be made in the slopes at the site without prior geotechnical analyses, and proper site drainage should be maintained during the construction phase of the Project.

- ***Excavation Backfill Considerations*** – The test pits may be in areas where a structure could subsequently be placed. However, backfill may not have been replaced in the excavations in compacted layers. The fill could settle with time and upon saturation. Should structures be located in an excavated area, no footings or structure should be founded over the excavation unless the backfill has been removed and replaced with structural fill.

- ***Availability of Report*** – The report should 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.

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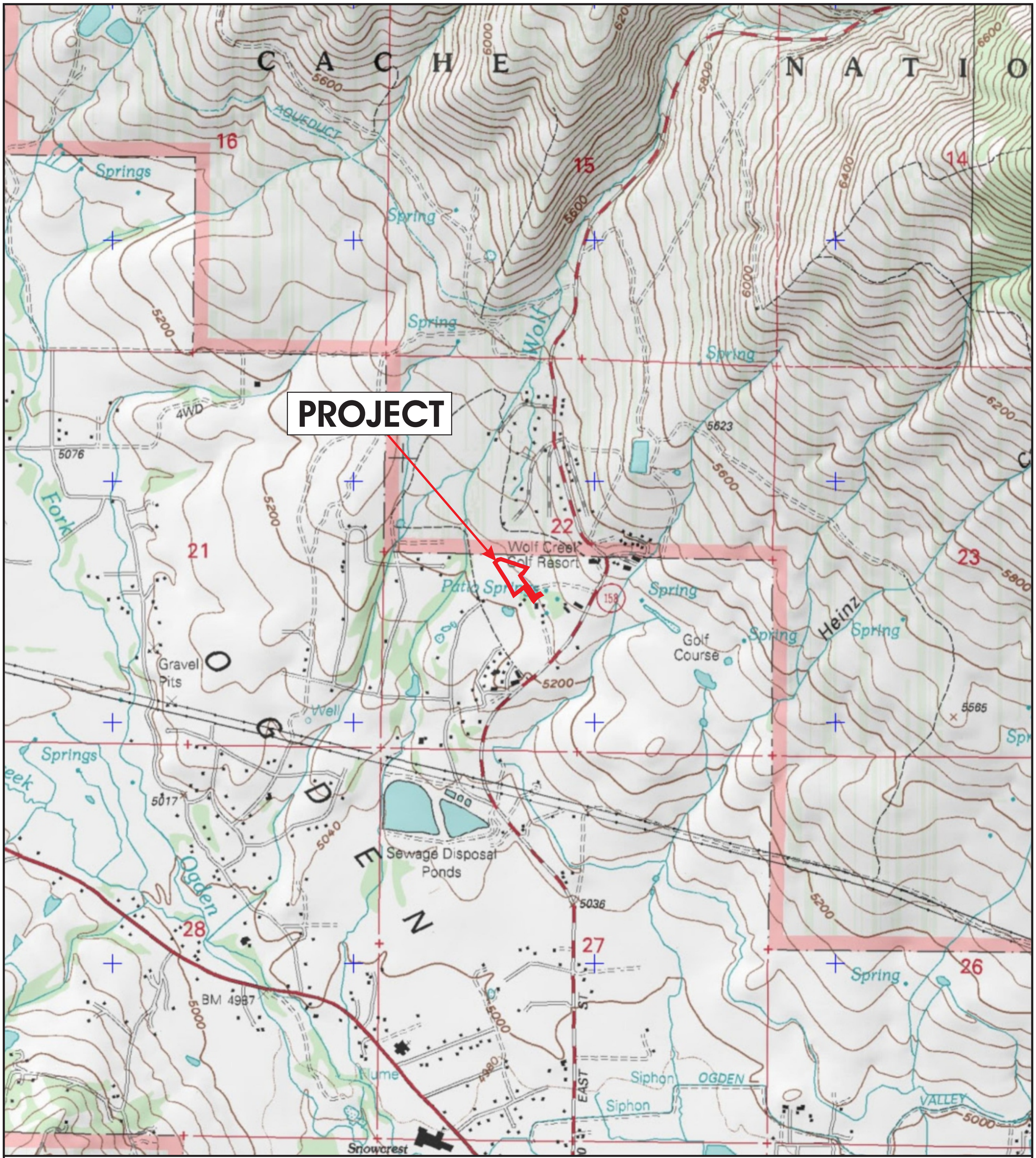
# FIGURES



Source: U.S. Geological Survey 7.5 Minute Series Topographic Maps, Utah - Huntsville, 1998;
Project location SW1/4, Section 22, T7N, R1E (SLBM).

WESTERN GEOLOGIC

N
W E
S

0 1000 2000 feet

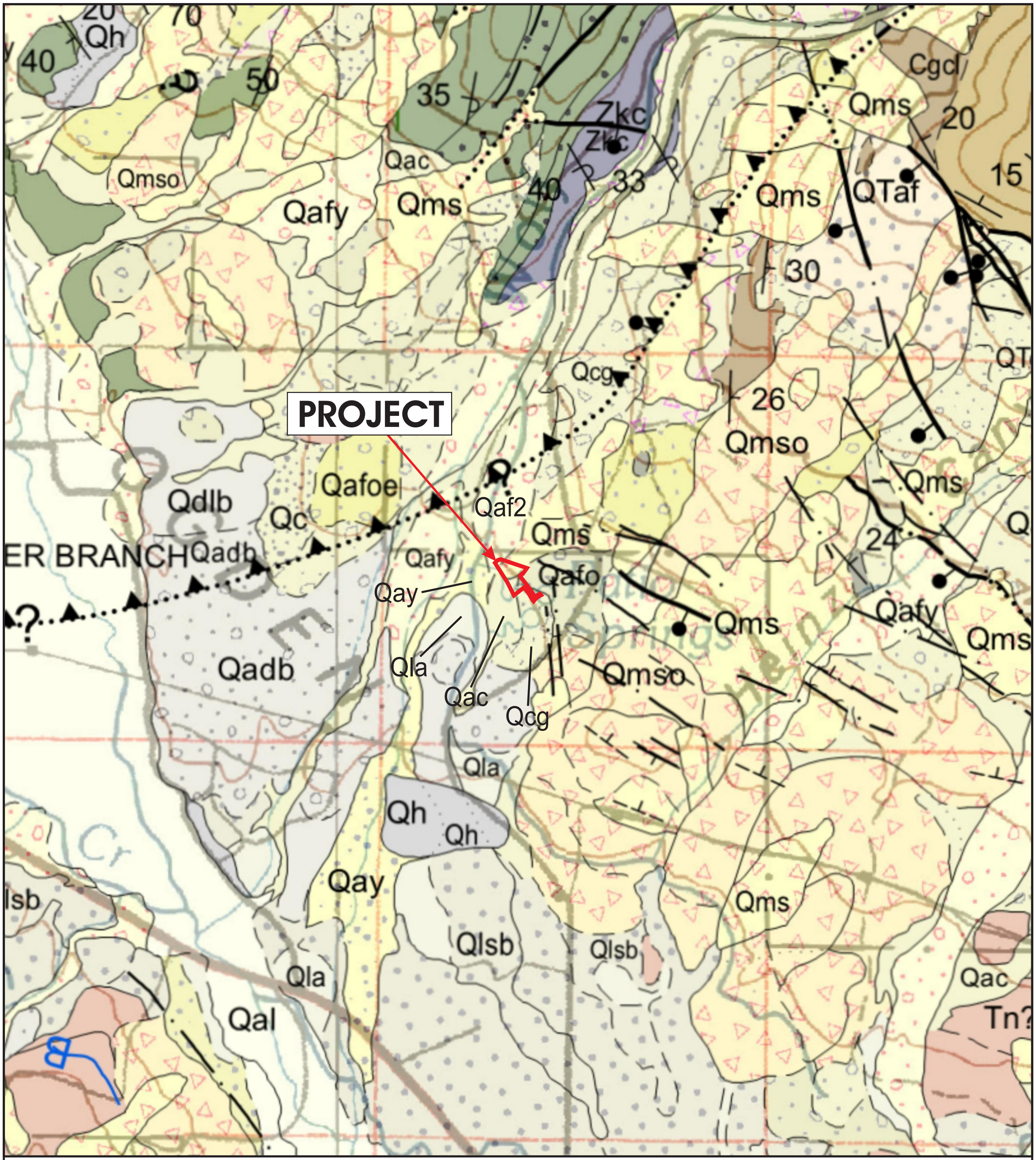
Scale 1:24,000
(1 inch = 2000 feet)

# LOCATION MAP

## GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, 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.

N
W E
S

0 1000 2000 feet

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

WESTERN GEOLOGIC

## GEOLOGIC MAP

### GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 2**

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

WESTERN GEOLOGIC

N
W E
S

0 100 200 feet

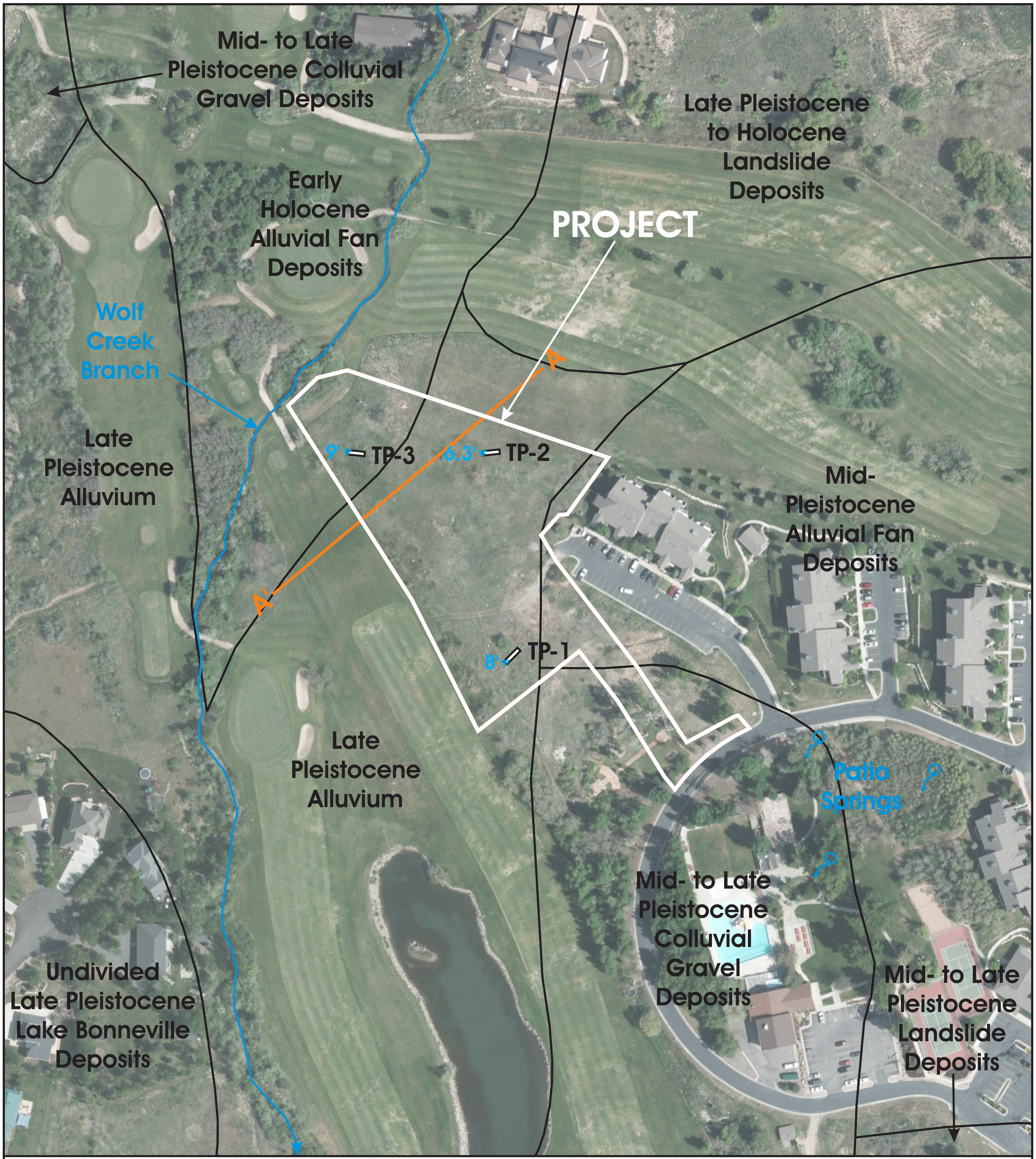
Scale 1:2,400
(1 inch = 200 feet)

## 1997 AERIAL PHOTO

## GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 3A**



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

WESTERN GEOLOGIC

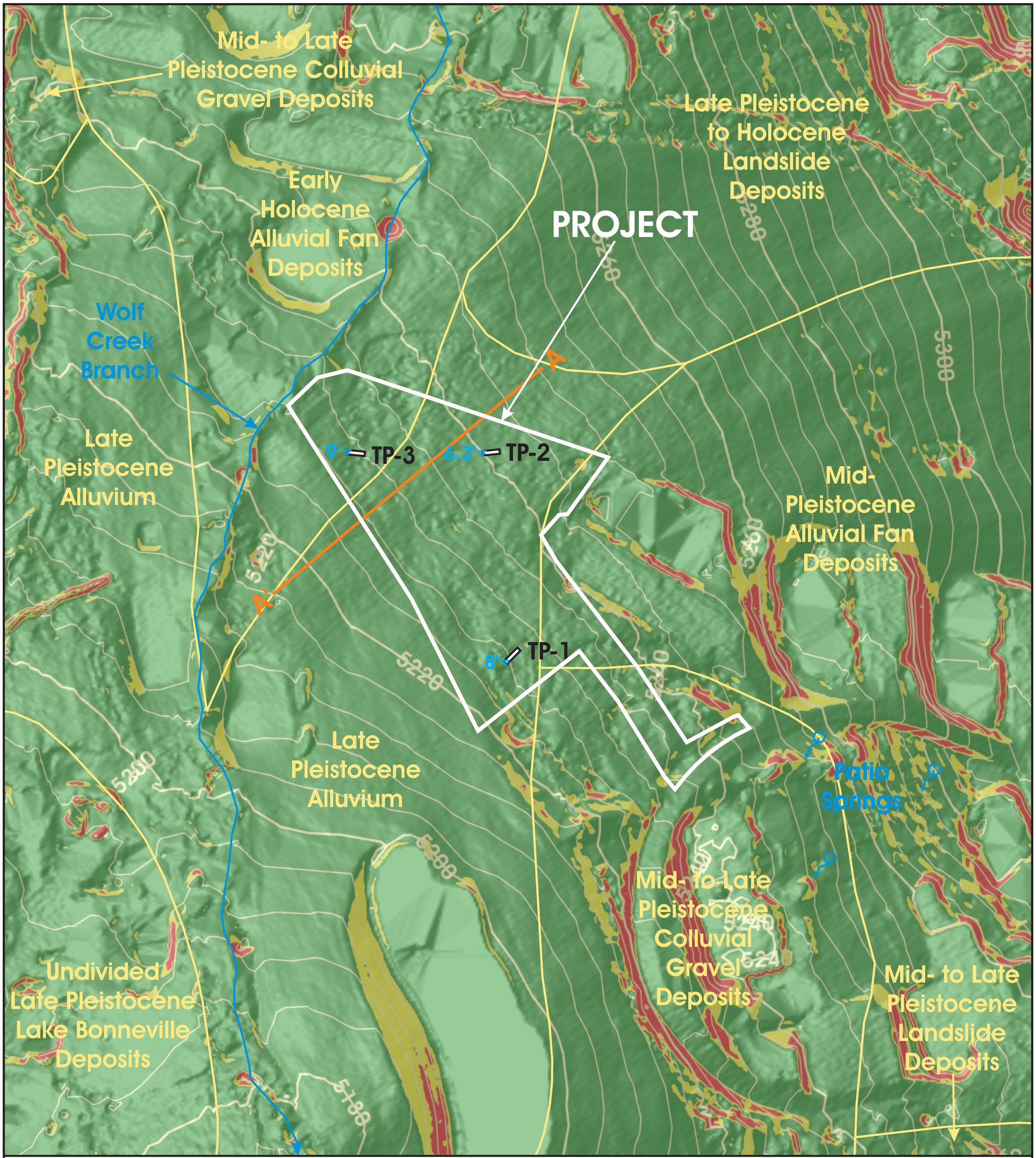
Scale 1:2,400
(1 inch = 200 feet)

## 2012 AIR PHOTO

## GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 3B**



Source: Utah AGRC, 2011 LIDAR Bare Earth DEM, 1 m resolution; contours generated by Global Mapper, 4-foot contour interval; slope gradients <20% shaded in green, 20-30% in yellow, and >30% in red.

WESTERN GEOLOGIC

N
W E
S

0 100 200 feet

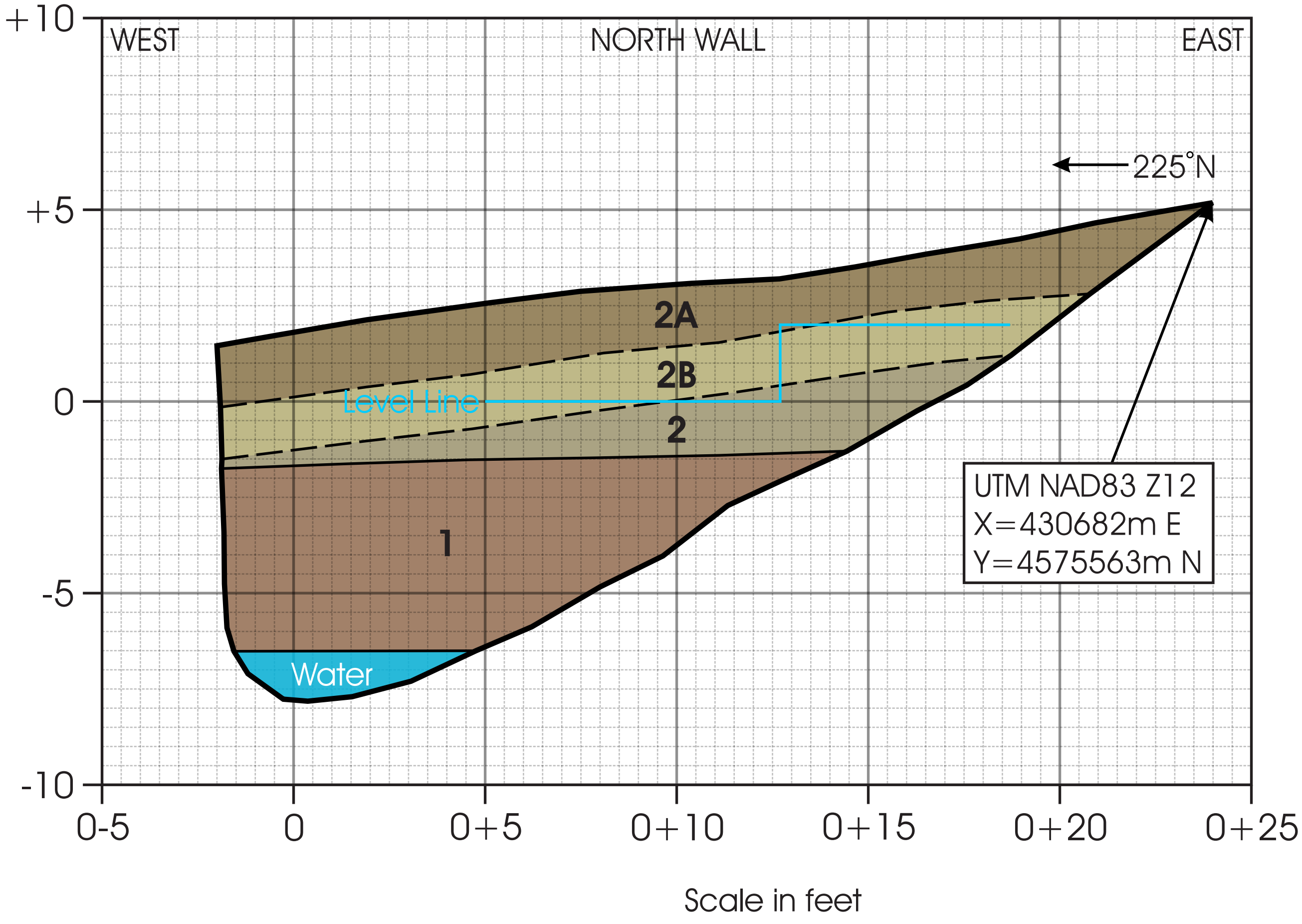
Scale 1:2,400
(1 inch = 200 feet)

## LIDAR ANALYSIS

## GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 3C**



## UNIT DESCRIPTIONS

**Unit 1.** *Mid-Pleistocene alluvium* - Reddish- to grayish-brown, moderate to high density, poorly bedded, sandy clay (CL) with gravel, cobbles, and large boulders; clasts subround to subangular with strong stage II carbonate; color varies between test pit walls; pre-Lake Bonneville in age.

**Unit 2.** *Late Pleistocene alluvium* - Olive, brown and reddish-brown, moderate to high density, generally massive, clay (CL) with sand, gravel, cobbles and boulders; clasts subround to subangular with strong stage II carbonate; possibly deposited contemporaneous with the Lake Bonneville transgression; modern A-horizon soil and B horizon at surface (units **2A** and **2B**, respectively).

WESTERN GEOLOGIC

SCALE: 1 inch = 5 feet
(no vertical exaggeration)

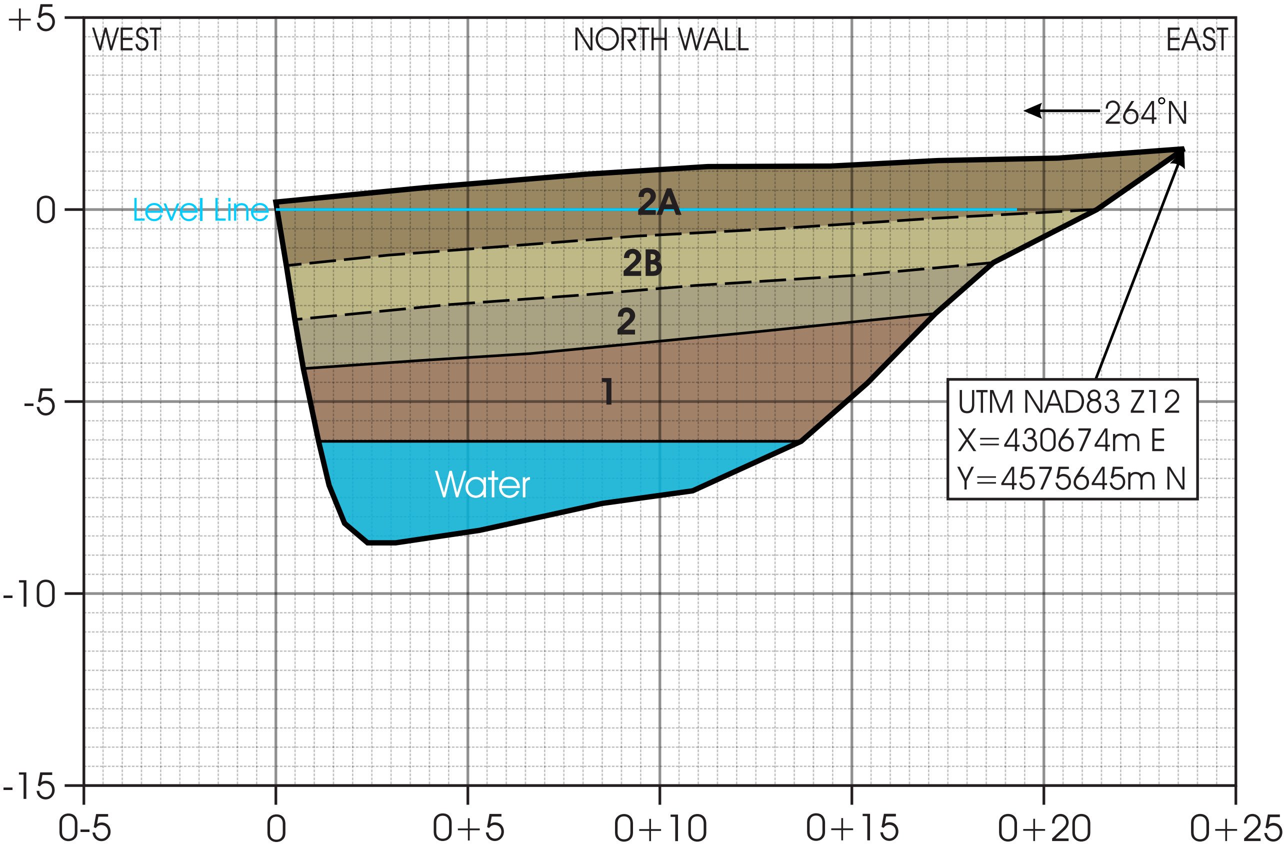
Logged by Bill D. Black, P.G.
on October 31, 2019

## TEST PIT 1 LOG

## GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 4A**



Scale in feet

## UNIT DESCRIPTIONS

**Unit 1.** *Mid-Pleistocene alluvium* - Reddish-brown to pale-grayish-olive, moderate to high density, poorly bedded to massive, sandy clay (CL) with gravel, cobbles, and large boulders; clasts subround to subangular with strong stage II carbonate; matrix with blue-green staining in zones, likely from sodium-enriched groundwater; pre-Lake Bonneville in age.

**Unit 2.** *Late Pleistocene alluvium* - Olive, brown and reddish-brown, moderate to high density, generally massive, clay (CL) with sand, gravel, cobbles and boulders; clasts subround to subangular with strong stage II carbonate; possibly deposited contemporaneous with the Lake Bonneville transgression; modern A-horizon soil and B horizon at surface (units **2A** and **2B**, respectively).

SCALE: 1 inch = 5 feet
(no vertical exaggeration)

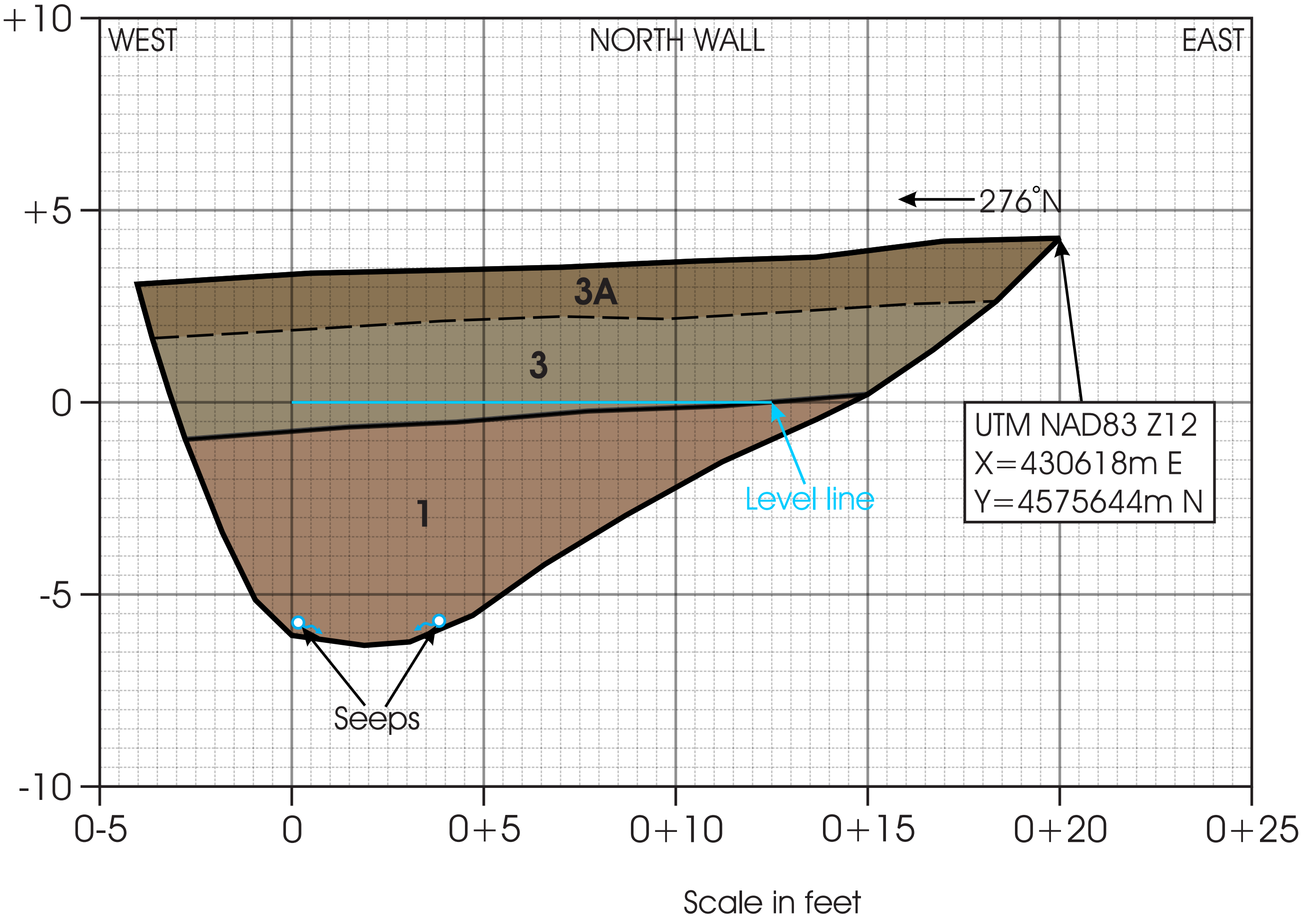
Logged by Bill D. Black, P.G.
on October 31, 2019

# TEST PIT 2 LOG

## GEOLOGIC HAZARDS EVALUATION

The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 4B**



## UNIT DESCRIPTIONS

**Unit 1.** *Mid-Pleistocene alluvium* - Reddish-brown, moderate to high density, poorly bedded to massive, clayey gravel (GM) with sand, cobbles, and large boulders; clasts subround to subangular with strong stage II carbonate; pre-Lake Bonneville in age.

**Unit 2.** *Not present, exposed in test pits TP-1 and TP-2.*

**Unit 3.** *Early Holocene alluvium* - Brown, generally massive, moderate density, clayey sand (SM) with cobbles, boulders and trace gravel; clasts with stage II carbonate; modern A-horizon soil (unit **3A**) formed in unit at surface, B horizon weak to not evident.

WESTERN GEOLOGIC

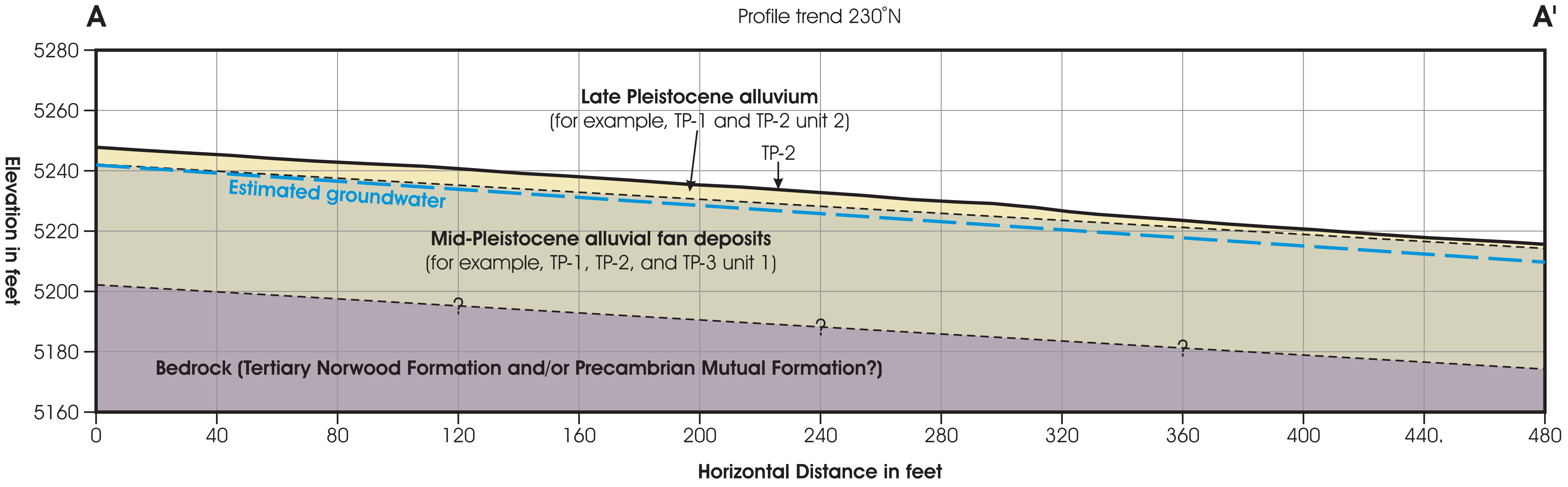
SCALE: 1 inch = 5 feet
(no vertical exaggeration)

Logged by Bill D. Black, P.G.
on October 31, 2019

## TEST PIT 3 LOG

**GEOLOGIC HAZARDS EVALUATION**
The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 4C**



Scale 1 inch equals 40 feet, no vertical exaggeration.
Topographic profile from 2011 LIDAR data. Profile location on Figures 3A-C.
Units and contacts are inferred and approximate based on available subsurface information.

WESTERN GEOLOGIC

# CROSS SECTION

**GEOLOGIC HAZARDS EVALUATION**
The Point at Wolf Creek
3818 North Wolf Creek Drive
Eden, Weber County, Utah

**FIGURE 5**