SUNRISE ENGINEERING

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January 22, 2021

Mayor Richard Hirschi
La Verkin City
435 North Main Street
La Verkin, UT 84745

Subject: Slope Stability Evaluation – Overlook Subdivision
La Verkin, Utah

Honorable Mayor Hirschi,

Enclosed herein is the report for a slope stability evaluation at in the Overlook Subdivision in La Verkin, Utah.

If you have any questions concerning this report, or if we may be of further assistance in any way, please let us know.

Prepared by:

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1/22/2021
STATE OF UTAH

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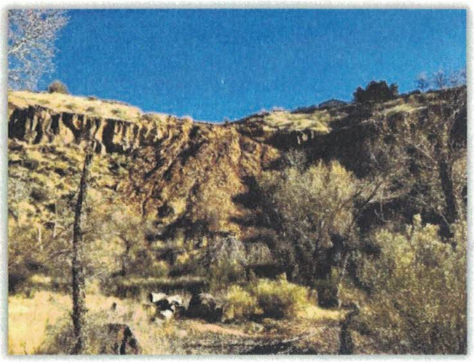
SLOPE STABILITY EVALUATION

Overlook Subdivision



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JANUARY 2021

SUNRISE ENGINEERING

SLOPE STABILITY EVALUATION – OVERLOOK SUBDIVISION

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EXECUTIVE SUMMARY

Sunrise Engineering, Inc. has completed a slope stability evaluation to identify the potential causes of the slope failure in the Overlook Subdivision in La Verkin, Utah.

Based on data collection and analysis, a summary of the potential causes of and factors that may have contributed to the slope failure is provided as follows:

1. The Overlook Subdivision is in a moderate landslide hazard zone.
2. The structural fill used for the foundation improvements of the two demolished residences appears to consist of gravel and fines. The fill, if properly compacted and drained, should be good for use under normal dry conditions.
3. An adequate drain system did not appear to have been installed in the foundation soils during the construction of the houses.
4. Without an adequate drain system, groundwater could cause problems in the foundation. Even though groundwater would have been initially blocked by compacted gravel and fines, groundwater found a path in the soils beneath the foundations of the two houses. The path beneath the foundations is believed to be within the contact between the Pintura basaltic flow (which appears to be impermeable or has a very low permeability) and the overlying stream-terrace deposits. As groundwater flowed through this horizon, the soil would have become gradually loosened. The accumulative effect of the groundwater flow beneath the foundations would be that the soil lost its original shearing strength.
5. Portions of the properties along the west side of 560 West Street were graded to drain surface runoff to the steep slope behind the properties. Surface runoff can cause soil erosion on the slope and also impact the stability of the slope.
6. The source of the groundwater appears to be primarily the infiltration of unconsumed irrigation water applied by irrigation water users with green fields and/or lawns across the La Verkin Bench generally and the local recharge zone specifically. Recharge from precipitation also contributes to the groundwater flow. However, the contribution from the unconsumed irrigation water is estimated to be approximately 4 times that of precipitation during an average precipitation year and when the irrigation water users only apply enough irrigation water. However, if too much irrigation water is used on green lands/lawns, the contribution from the unconsumed irrigation water would play an even larger role. On the other hand, if the precipitation is much higher than normal, the precipitation can contribute more recharge to the groundwater.
7. Therefore, it is concluded that the slope failure at the two residence is a result of unconsumed irrigation water and precipitation present as groundwater flowing along the plane between the alluvium surface strata and the Pintura basaltic flow, occasionally manifesting as seeps in certain years depending on prior year's cumulative irrigation water use and precipitation levels.

Based on the data presented in the above, the following recommendations are made:

1. The shallow groundwater that flows towards the slope west of the subdivision should be intercepted and drained through a horizontal drain system (horizontal wells installed from the slope or a French drain system consisting of perforated pipes along 560 West Street).
2. To design a proper drain system, a hydrogeologic study should be performed to evaluate the hydraulic conductivity of the shallow aquifer. A study should include the following:
   a) Monitoring wells should be installed on both sides of 560 West Street. At least one monitoring well should be installed in each undeveloped lot on the west side of the street. Several monitoring wells should also be installed beyond the east side of the street. The average depth of the monitoring wells is estimated to be approximately 40 feet (or the bottom of each monitoring well will be the top of the Pintura basaltic flow).
   b) A survey should be performed to determine the location and elevation of the top of casing of each monitoring well so that groundwater surface elevations may be accurately determined.
   c) Slug tests should be performed at each monitoring well to estimate the hydraulic conductivity of the aquifer.
   d) Groundwater levels should be monitored for at least a year after the initial measurement and data collection. Potentiometric surface maps should be generated based on water level measurements. With the hydraulic gradient and hydraulic conductivity of the shallow aquifer, the average groundwater flow may be estimated.
3. Based on the data collected from item 2, a drain system may be designed. Without a study, the drain system could either be over or under designed, resulting in too high of costs or undesirable functionality.

1 INTRODUCTION

1.1 Background

At the Overlook Subdivision in La Verkin, Utah, two houses, including the house at 265 North 560 West, were damaged due to a landslide that occurred in April 2020 (Baggaley, 2020). Reportedly, landslides also occurred at the subdivision in 2005 (Applied Geotechnical Engineering Consultants, Inc. or AGEC, 2007). One of the contributing factors to the landslides is believed to be the groundwater that seeps out on the slope behind the two houses. Sunrise Engineering, Inc. (Sunrise) (2020) collected water samples from La Verkin City's water system, irrigation system, and the seepage from the slope behind the two houses. Water samples were collected for laboratory analysis of pH, arsenic, calcium, chloride, magnesium, total nitrate, sodium and sulfate. The laboratory results indicate the groundwater seepage from the slope behind the two houses shows some correlation with the irrigation water.

Therefore, La Verkin City is looking for a feasible mitigation approach to the unstable slope at the Overlook Subdivision.

1.2 Objective

The primary objective of this evaluation was to identify the potential principal causes of landslides at the subdivision and identify a feasible mitigation approach.

1.3 Scope of Work

To accomplish the project objective, the following tasks were performed:

1. **Data Collection**: Available geologic and well data were collected and reviewed.
2. **Site Visit**: A site visit was conducted to collect onsite data and better understand the onsite conditions.
3. **Data Analysis**: A general description of the geologic information was developed based on geologic maps.
4. **Report Preparation**: A reconnaissance report was prepared using the collected data and evaluation results.

2 SITE CHARACTERISTICS

2.1 Site Location

The topographic locale of the subdivision is in Section 23, Township 41 South, Range 13 West, Salt Lake Base and Meridian (**Figure 1**).

2.2 Land Use

Land use in La Verkin is primarily residential houses, open space, and irrigated fields, as shown in **Figure 2**. The irrigated areas (green areas in **Figure 2**) receive irrigation water applied by the property owners. The unconsumed irrigation water infiltrates the soil and eventually becomes groundwater. The infiltration rate is dependent on the soil type. Fine soils (silt and clay) have a lower infiltration rate, or groundwater resulting from irrigation activities migrates slower and stays in subsoil longer. Sandy and gravelly soils have a higher infiltration rate, or groundwater originating from unconsumed irrigation water can migrate from irrigated fields much faster to downgradient properties.

2.3 Topography/Drainage

The project is in a residential area (**Figure 2**) where surface drainage is controlled by streets (**Figure 3**). Along 560 West, where the Overlook Subdivision is located, the surface water runoff is directed to the street and collected by the stormwater collection system. However, surface runoff from most parts of the properties west of 560 West is directed to the west towards the steep slope where landslides have occurred. The average gradient of the steep slope to the west of the subdivision is estimated to be approximately 50% or 2:1 (horizontal : vertical).

2.4 Climate

The climate of the study area is arid (desert). According to the weather record collected at the La Verkin, Utah weather station (Western Regional Climate Center, 2020), between April 19, 1950 and June 9, 2016, the average annual precipitation is 10.96 inches with a standard deviation of 3.72 inches. Temperatures during the winters are cool with periods of very cold weather with average minimum/maximum temperatures in January of 26.7/53.4 degrees Fahrenheit (°F). Summers are dry with average minimum/maximum temperatures in July of 65.3/99.1°F.

2.5 Soil

According to the Natural Resources Conservation Service (NRCS) (1977), nine soil types are present in the area, as shown in **Figure 4**. These soils are summarized in **Table 1**.

As shown in **Figure 4** and **Table 1**, eight of the nine soil types in the area consist of either fines or rocky/stony materials. The other soil type (LcC) is a sandy loam where unconsumed irrigation water may readily infiltrate the subsurface and quickly migrate to downgradient properties. This soil type (LcC) is located in irrigated fields northeast of the project area. Presently, there is a French drain system in the area that can help drain the groundwater originating from the irrigated fields. Other irrigated fields in the area with fine soils likely hold unconsumed irrigation water longer locally, delaying the migration of groundwater to the subdivision.

Table 1: Soil Data Summary

Soil Symbol	Description	Soil Type	Location Relative to Subdivision
FA	Fluvaquents and torrifluvents	Fines: silt & clay	Open space, west
LcC	LaVerkin fine sandy loam with 2-5% slopes	Sandy soil	Irrigated fields, northeast
LdB	LaVerkin silty clay loam with 1-2% slopes	Fines: silt & clay	Vast area east, northeast and southeast
LeA	Leeds silty clay loam with 0-1% slopes	Fines: silt & clay	Area east and southeast
LeD	Leeds silty clay loam with 5-10% slopes	Fines: silt & clay	Area far east and southeast
RT	Rock outcrop	Bedrock	Far east
RU	Rough broken land	Rocky	At subdivision
SY	Stony colluvial land	Stony land	West
Td	Tobler silty clay loam	Fines: silt & clay	West

2.6 Geologic and Shallow Groundwater Conditions

2.6.1 General Geologic Setting

The project area is located in the transition zone between the Colorado Plateau and Basin and Range physiographic provinces. Strata in the area are typical of the generally flat-lying rocks of the Colorado Plateau. However, locally the strata are cut by thrust faults and folded into the Virgin anticline and subsidiary folds by the Late Cretaceous Sevier orogeny, cut by the Tertiary-Quaternary Hurricane fault, and partially covered by Quaternary basalt flows and cinder cones. **Figure 5** is a surficial geologic map of the area based on published mapping by Biek (2002).

2.6.2 Stratigraphy

Figure 6 is a geologic cross section modified from Biek (2002). The stratigraphic sequence from the cross section represents Lower Jurassic to Quaternary formations. The individual stratigraphic units in the area include: Quaternary Deposits (Qaf1, Qal1, Qmt, Qae, Qat6 and Qbp), Iron Springs Formation (Kis), Carmel Formation (Jcco), Temple Cap Formation (Jts), Navajo Sandstone (Jn) and Kayenta Formation (Jk). The following is a description of the shallow geologic units (from youngest to oldest):

The **Quaternary younger alluvial and eolian deposits** (Qae) overlay the rock formation in the region and consist of poorly to moderately sorted, locally gypsiferous, clay- to boulder-size sediment with well sorted eolian sand and reworked eolian sand. The thickness of this unit is less than 20 feet.

The **Quaternary talus deposits** (Qmt) are present on and at the base of steep slopes and consist of locally derived, very poorly sorted, angular boulders and minor fine-grained interstitial sediments and are deposited principally by rock fall. The deposits grade into colluvial deposits and are probably several tens of feet thick.

The **Quaternary stream deposits** (Qal1) are present along the Virgin River and other principal drainages and include river-channel and floodplain deposits and minor terraces up to about 10 feet above current stream levels. The deposits are moderately to well sorted sand, silt, clay and local pebble to boulder gravel normally less than 10 feet thick.

The **Quaternary alluvial-fan deposits** (Qaf1) are present at the base of the Hurricane Cliffs and locally at the mouths of active drainages, and consist of poorly to moderately sorted, boulder- to clay-size sediment. The thickness of the unit ranges from 0 to 50 feet.

The **Quaternary stream-terrace deposits** (Qat6) are restricted to modern drainages and locally truncate older alluvial-fan deposits. The deposits are moderately to well sorted, typically poorly cemented sand, silt, clay and pebble to boulder gravel. The thickness of this unit ranges from 0 to 30 feet.

The **Quaternary Pintura flow** (Qbp) erupted principally from the Pintura volcanic field, which is 2 miles north of Pintura. The Pintura flow forms a broad, east-dipping slope southwest of Toquerville where it is about 20 to 30 feet thick. It thickens significantly to the east, where it fills the ancestral Ash Creek drainage to a depth greater than 120 feet. The Pintura flow thins to the south and interfingers with older alluvial deposits above La Verkin Creek. At its southern end, the Pintura flow lies 200 feet above the Virgin River. The Pintura flow is the most distinctive basaltic flow in the area. It is generally a medium-light-gray, medium- to coarse- grained basalt with sparse small olive phenocrysts and abundant larger plagioclase phenocrysts up to 0.25 inches in length. The thickness of the Pintura flow is about 100 feet in the La Verkin area.

The **Cretaceous Iron Springs Formation** (Kis) is a rock formation that consists of interbedded, ledge-forming, mildly calcareous, cross-bedded, fine- to medium-grained sandstone and less resistant, poorly exposed sandstone, siltstone and mudstone. The formation is 3,500-4,000 feet thick.

The **Jurassic Carmel Formation – Co-op Creek Limestone Member** (Jcco) is a thin-bedded, yellowish-gray to very pale-orange limy mudstone, and interbedded, similarly colored siltstone and limestone. The thickness of the member is about 130 feet.

The **Jurassic Temple Cap Formation – Sinawava Member** (Jts) typically consists of interbedded, slope-forming, moderate-reddish brown, yellowish-gray mudstone, siltstone, very fine-grained silty sandstone and lesser gypsum. The thickness of the member is about 220 feet.

The **Jurassic Navajo Sandstone** (Jn) is a white, pink and brown, highly cross-bedded sandstone that forms cliffs, domes and bare rock outcrops. It is considered an excellent aquifer and ranges in thickness from 950 to 2,000 feet.

Surface Drainage and Erosion

It is apparent that the western part of the properties had been graded to drain to the steep slope (**Figure 3**). Water flowing down the slope has caused soil erosion. The cumulative effect of the erosion has eroded the slope integrity.

2.6.3.2 Thickness of the Shallow Unconsolidated Deposits

A water rights search from the database administered by the Utah Division of Water Rights identified two shallow wells in the area. The well logs are provided in **Appendix A**. The location of each well is shown in **Figures 1** and **5**. The wells are approximately 0.6 miles southeast of the two demolished houses and 35 feet in depth. Groundwater was recorded at 18 feet below grade when the wells were completed. It is likely that the two wells were drilled to the top of the Pintura basaltic flow. At the two well locations, the shallow unconsolidated deposits are estimated to be 35 feet thick. Based on observations at the two demolished houses, the thickness of the unconsolidated material above the Pintura basaltic flow was estimated to be between 30 and 40 feet.

2.6.3.3 General Shallow Groundwater Movement

There is no shallow groundwater flow map for the area. The shallow groundwater flow is believed to mirror the surface contours. Thus, shallow groundwater in southern and southeastern La Verkin likely flows southwards towards the Virgin River, and groundwater in the northern and northern area adjacent to the Overlook Subdivision moves westwards or southwestwards towards the steep slope west of the subdivision. However, the groundwater divides do not always coincide with the topographic divides. There is the possibility that more or less area may contribute recharge to the groundwater in the area of concern.

2.6.3.4 Recharge

The following recharge estimates were made under the assumption that the groundwater boundary coincides with the topographic divide in the area of interest. As stated previously, this assumption is not always true. It is possible that more or less area may contribute recharge to the area of concern.

Recharge to the shallow groundwater in the area is believed to be primarily from unconsumed irrigation water. Recharge from precipitation is minimal since the average annual precipitation is only 10.96 inches. Using the method reported by Maxey and Eakin (1949) and Eakin and others (1951), the estimated recharge from precipitation is 0.4 inches/year. Based on the topographic map, the potential recharge area of precipitation is estimated to be approximately 110 acres (**Figures 1** and **2**) and the average recharge from precipitation to the area of concern is estimated to yield approximately 2.3 gallons/minute (gpm) of groundwater along the roughly 2,000-foot-long west edge of the area. Thus, the average groundwater flow resulting from the recharge of precipitation per lot is minimal (about 0.1

The **Jurassic Kayenta Formation** (Jk) is a ledge and slope-forming lenticular sandstone, siltstone, limestone and intraformational conglomerate. The general color is reddish; however, lavender, white and brown sandstones are also common. The thickness ranges from 190 to 340 feet.

2.6.3 General Shallow Groundwater Conditions

2.6.3.1 Observations during Site Visit

<u>Groundwater</u>

A site visit to the subdivision was performed on December 21, 2020. Special attention was given to the two residences that have been demolished following the April 2020 landslide. Groundwater was observed seeping at several locations along the contact between the Pintura basaltic flow (which is believed to be impermeable or has a very low permeability) and stream-terrace deposits. Evidence of seeps from the same contact elevation was also observed along the slope behind residences in the northern part of the subdivision. A French drain system located in the northeastern portion of the subdivision and along the east side of 560 West Street was also observed to discharge water to the stormwater collection system in the street.

In the backyard of a residence to the northeast and on the east side of 560 West Street, moist to saturated sandy and silty soils and stream-terrace gravels were observed. Tamarak and willow trees were noted to be densely distributed in the moist soils, which is indicative of groundwater flows beneath the surface. Based on **Figure 2**, the groundwater in this particular area is most likely associated with the irrigation activities locally (at the green fields to the northeast of the residence) and regionally (other irrigated areas further to the north-northeast). Unconsumed irrigation water is stored in the soil and gradually flows to the downgradient area. The undrained groundwater beneath the area is estimated to continue to flow to the west side of the street and eventually seep out along the steep slope.

<u>Fill and Groundwater</u>

At the site of the two demolished residential houses, structural fill was noted to consist of gravel and fines. This material, after properly compacted and drained, generally has a high shearing strength. It was apparent that a drain system had not been installed in the foundation during the construction of the two houses. Groundwater found its way in the weakest area through the soil beneath the foundations, eventually seeping out along the steep slope behind the residences. The weakest zone beneath the foundations is the contact between the Pintura basaltic flow and the stream-terrace deposits.

gpm/lot). However, precipitation in wet years can provide more recharge and may result in higher shallow groundwater flows.

According to Hely and others (1971) and Waddell and others (1987), infiltration of unconsumed irrigation water from fields may range from 18% to 30% of the total water applied to those fields. Thus, a lot more recharge may result from irrigation water applied to the green fields and lawns. According to the Utah Division of Water Rights (1994), the net irrigation water required for turf in La Verkin during an average precipitation year is 26.01 inches/year. Under the assumption of an irrigation efficiency of 60% (which is typical in the dry and warm Washington County), the average applied irrigation water is estimated to be approximately 43.35 inches/year. If the infiltration of unconsumed irrigation water from the fields and lawns is assumed to be 20% of the total water applied, the average infiltration rate is estimated to be 8.67 inches/year. Based on **Figure 2**, the green areas within the recharge zone are estimated to be at least 18 acres, and the average recharge due to infiltration from unconsumed irrigation water to the area of concern is estimated to yield approximately 8.1 gpm of groundwater along the roughly 2,000-foot-long west edge of the area. As a result, the average groundwater flow resulting from the infiltration of unconsumed irrigation water is 0.4 gpm/lot, about 4 times the contribution from precipitation.

2.6.3.5 Aquifer Properties

Aquifer properties describe the ability of a groundwater system to transmit and store water. The distribution of these properties of the shallow aquifer within the study area vary by location. Aquifer properties can be estimated with aquifer tests by pumping groundwater from a well and monitoring the water-level changes in the pumped well or in nearby observation wells. Since this method results in localized values that are generally representative of conditions near the pumped well, it may not represent the variability and heterogeneity throughout the aquifer.

Aquifer test data is commonly used to estimate values of transmissivity (T) and hydraulic conductivity (K). Both are measurements that describe the ease with which water can move through the pore spaces or conduits within an aquifer. More specifically, K is the volume of water flowing through a unit cross-sectional area of an aquifer under a unit hydraulic gradient in a given amount of time, and T is the volume of water flowing through a cross-sectional area that is one unit wide multiplied by the aquifer thickness in a given amount of time.

The permeability of the shallow groundwater-bearing zone differs from place to place. In addition, the permeability of a particular high (or low) permeability zone in any locality may be more or less than that of the other zones of high (or low) permeability zone in the same locality. Locally, the high-permeability zones include small units of low permeability that have not been distinguished in the lithologic section.

Since no aquifer tests have been performed, it is not possible to estimate the shallow aquifer properties from aquifer tests.

Based on the soil types, the hydraulic conductivity is estimated to range from less than 1 foot/day for clayey soil to less than 10 feet/day for sandy soil (NRCS, 1977). Due to the generally low to moderate permeability of the soil in the area, the unconsumed irrigation water may be stored in the soil and slowly flow downgradient, maintaining seeps along the steep slope. During the non-irrigation season, the groundwater flowrate would be lower due to the lowered hydraulic gradient without recharge. During the irrigation season, the hydraulic gradient would be increased with recharge and thus more groundwater would flow in the French drain and the west slope of the subdivision. If a storm event occurs, local instantaneous recharge would increase, which would also result in higher groundwater flow. Storms may also result in soil erosion and weakening of the slope stability.

Higher irrigation water use or precipitation years may manifest themselves as seeps many years after the event due to the storativity and hydraulic conductivity of the soils.

2.7 Geologic Hazard

Figure 7 presents a landslide hazard map for the La Verkin area. The map was modified from Lund and others (2008). **Figure 7** indicates the subdivision is in the Moderate C (Mc) landslide hazard zone. For lands with this hazard category, geologic evaluation and reconnaissance geotechnical-engineering evaluation is necessary prior to development; and detailed engineering geologic and geotechnical evaluation may be necessary (Lund and others, 2008).

3 SUMMARY OF POTENTIAL CAUSES OF SLOPE FAILURE

Based on data collection and analysis, a summary of the potential causes of and factors that may have contributed to the slope failure in the vicinity of the two residential houses in the Overlook Subdivision is provided as follows:

1. The Overlook Subdivision is in a moderate landslide hazard zone.
2. The structural fill used for the foundation improvements of the two demolished residences appears to consist of gravel and fines. The fill, if properly compacted and drained, should be good for use under normal dry conditions.
3. An adequate drain system did not appear to have been installed in the foundation soils during the construction of the houses.
4. Without an adequate drain system, groundwater could cause problems in the foundation. Even though groundwater would have been initially blocked by compacted gravel and fines, groundwater found a path in the soils beneath the foundations of the two houses. The path beneath the foundations is believed to be within the contact between the Pintura basaltic flow (which appears to be impermeable or has a very low permeability) and the overlying stream-terrace deposits. As groundwater flowed through this horizon, the soil would have become

gradually loosened. The accumulative effect of the groundwater flow beneath the foundations would be that the soil lost its original shearing strength.

5. Portions of the properties along the west side of 560 West Street were graded to drain surface runoff to the steep slope behind the properties. Surface runoff can cause soil erosion on the slope and also impact the stability of the slope.
6. The source of the groundwater appears to be primarily the infiltration of unconsumed irrigation water applied by irrigation water users with green fields and/or lawns across the La Verkin Bench generally and the local recharge zone specifically. Recharge from precipitation also contributes to the groundwater flow. However, the contribution from the unconsumed irrigation water is estimated to be approximately 4 times that of precipitation during an average precipitation year and when the irrigation water users only apply enough irrigation water. However, if too much irrigation water is used on green lands/lawns, the contribution from the unconsumed irrigation water would play an even larger role. On the other hand, if the precipitation is much higher than normal, the precipitation can contribute more recharge to the groundwater.
7. Therefore, it is concluded that the slope failure at the two residence is a result of unconsumed irrigation water and precipitation present as groundwater flowing along the plane between the alluvium surface strata and the Pintura basaltic flow, occasionally manifesting as seeps in certain years depending on prior year's cumulative irrigation water use and precipitation levels.

4 RECOMMENDATIONS

Based on the data presented in the previous sections, the following recommendations are made:

1. The shallow groundwater that flows towards the slope west of the subdivision should be intercepted and drained through a horizontal drain system (horizontal wells installed from the slope or a French drain system consisting of perforated pipes along 560 West Street).
2. To design a proper drain system, a hydrogeologic study should be performed to evaluate the hydraulic conductivity of the shallow aquifer. A study should include the following:
    a) Monitoring wells should be installed on both sides of 560 West Street. At least one monitoring well should be installed in each undeveloped lot on the west side of the street. Several monitoring wells should also be installed beyond the east side of the street. The average depth of the monitoring wells is estimated to be approximately 40 feet (or the bottom of each monitoring well will be the top of the Pintura basaltic flow).
    b) A survey should be performed to determine the location and elevation of the top of casing of each monitoring well so that groundwater surface elevations may be accurately determined.
    c) Slug tests should be performed at each monitoring well to estimate the hydraulic conductivity of the aquifer.

d) Groundwater levels should be monitored for at least a year after the initial measurement and data collection. Potentiometric surface maps should be generated based on water level measurements. With the hydraulic gradient and hydraulic conductivity of the shallow aquifer, the average groundwater flow may be estimated.

3. Based on the data collected from item 2, a drain system may be designed. Without a study, the drain system could either be over or under designed, resulting in too high of costs or undesirable functionality.

5 GENERAL COMMENTS

The services provided on this project, as described in this report, include professional opinions and judgments based on the data collected and analyzed. These services were performed in accordance with current generally accepted water resources engineering principles and practices in this area at this time. This report does not apply to the areas outside of the study area. In addition, evaluation of geologic and hydrogeologic conditions is a difficult task. Engineers and hydrogeologists must occasionally make general judgments leading to conclusions with incomplete knowledge of the geologic history, subsurface conditions, and hydraulic characteristics present. The estimated aquifer parameter values are based on geologic information gathered from geologic maps, published and unpublished reports, and have not been verified by subsurface field investigations. As additional information becomes available, the interpretations and recommendations expressed in this report will be subject to revision.

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