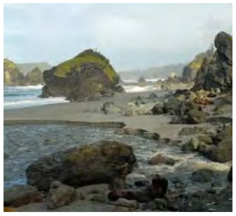
City of Trinidad

ASBS Stormwater Improvement Project
Geotechnical Analysis

October 2012



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CITY OF TRINIDAD GEOTECHNICAL EVALUATION REPORT
TRINIDAD, CALIFORNIA

Project No. 0106311005

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GEOLOGIC TERMS

Bedding
The arrangement of igneous, metamorphic, and sedimentary rock in layers.

Biogenic Rock (as used to define ribbon chert)
An organic rock produced directly by the physiological activities of organisms, for example, coral reefs and coal.

Blueschist
A metavolcanic rock that forms by metamorphism of basalt. The blue color of the rock comes from the presence of the mineral glaucophane.

Chert
A hard, dense sedimentary rock consisting of interlocking crystals of quartz less than 30 micrometers in diameter.

Clastic
Pertaining to a rock or sediment composed principally of fragments derived from pre-existing rocks or minerals and transported some distance from their place of origin.

Competent
A bed or stratum that is able to withstand the pressure of folding without flowage or change in original thickness. Competent strata form parallel folds.

Deformation
A general term for the process of folding, faulting, shearing, compression, or extension of rocks as a result of various earth forces.

Dip (Dipping)
The angle that a stratum or any planar feature makes with the horizontal, measured perpendicular to the strike and in the vertical plane.

Facies
The aspect, appearance, and characteristics of a rock unit, usually reflecting the conditions of origin.

Fault Plane
A fault surface that is more or less situated in a plane.

Feldspar
A group of abundant rock-forming minerals of the general formula $MAl(Al,Si)_3O_8$, where M can be potassium, sodium, calcium, barium, rubidium, strontium or iron. Feldspars are the most widespread of any mineral group and constitute 60 percent of the earth's crust.

Ferromagnesian
Containing iron or magnesium.

Footwall
The mass of rock beneath a fault; especially the wall rock beneath an inclined fault.

Fluvial
Of or pertaining to rivers, produced by the action of a stream or river.

Gradient
Degree of inclination of steepness of slope of the groundwater surface. It may be expressed as a ratio (of vertical to horizontal), fraction, percent, or angle.

Graywacke
An old term now generally applied to a dark gray firmly indurated coarse-grained sandstone that consists of poorly sorted angular to subangular grains of quartz and and feldspar.

Hanging Wall
The overlying side of a fault; especially the wall rock above an inclined fault.

Igneous
Said of a rock or mineral that solidified from molten or partially molten material.

Indurated
Said of a rock or soil hardened or consolidated by pressure, cementation, or heat.

Mafic
Said of igneous rock composed chiefly of dark, ferromagnesian minerals.

Marine terrace
A wave-cut platform that has been exposed by uplift along a seacoast or by lowering of sea level.

Matrix
The finer-grained material enclosing the larger grains in sediment or sedimentary rock.

Mélange
A mappable body of rock that includes fragments and blocks of all sizes, both exotic and native, embedded in a fragmented and generally sheared matrix.

Metamorphic rock
Any rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, especially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.

Normal fault
A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of dip is usually 45 to 90 degrees (°).

Outcrop
The part of a geologic formation or structure that appears at the surface of the earth; also, bedrock that is covered by surficial deposits.

Paleo-(as used to describe a channel [Paleochannel])
A combining form meaning old or ancient, for example paleoclimate. This term is used in this report to describe an old channel identified in the project area subsurface.

Paleoseismic
Pertaining to an old earthquake or earth vibration.

Pleistocene
An epoch of the Quaternary period. It began two (2) to three (3) million years ago and lasted until the start of the Holocene (approximately 8,000 years ago).

Plutonic Rock
A rock formed at considerable depth by crystallization of magma and/or by chemical alteration.

Poorly graded
An engineering term pertaining to a soil or sediment in which all the particles are of about the same size or in which a continuous distribution of particle sizes from the coarsest to the finest are lacking.

Poorly Sorted
Said of clastic sediment or rock that consists of particles of many sizes mixed together in an unsystematic manner so that no one size class predominates.

Quartz
Crystalline silica, an important rock-forming mineral, SiO_2.

Quaternary
The second period of the Cenozoic era. It began two (2) to three 93) million years ago and extends to the present.

Ribbon rock
A rock characterized by a succession of thin layers of differing composition or color.

Sea Stack
An isolated, pillarlike rocky island, detached from a headland by wave erosion.

Scarp
A line of cliffs produced by faulting or erosion.

Sedimentary Rock
A layered rock resulting from the consolidation of sediment.

Shear
A deformation resulting from stresses that cause contiguous parts of a body to slide relative to each other in a direction parallel to their plane of contact. In geological literature the term refers almost invariably to strain rather than to stress. It is also used to refer to the surfaces and zones of failure by shear, and to surfaces along which differential movement has taken place.

Strain
Change in shape or volume of a body as a result of stress.

Stress
In a solid, the force per unit area, acting on any surface within it, and variously expressed as pounds or tons per square inch.

Strike

The direction taken by a structural surface (e.g. a bedding or fault plane), as it intersects the horizontal.

Thrust Fault

A fault with a dip of 45 degrees or less over much of its extent on which the hanging wall appears to have moved upward relative to the footwall. Horizontal compression rather than vertical displacement is its characteristic feature.

Ultramafic

Said of an igneous rock composed chiefly of mafic minerals.

Unconformable (Unconformably)

Strata that do not succeed the underlying rocks in immediate order of age or in parallel position; especially younger strata that do not have the same dip and strike as the underlying rocks. Also, said of the contact between unconformable rocks.

Wave-cut platform

A gently sloping surface produced by wave erosion, extending far into the sea or lake from the base of the wave-cut cliff.

Well graded

An engineering term pertaining to soil or sediment with a continuous distribution of particle sizes from coarsest to finest.

*Unless otherwise noted, definitions are from “Dictionary of Geological Terms, 3rd Edition.

ABBREVIATIONS

ASBS	Area of Special Biological Significance
ASTM	American Society for Testing and Materials
bgs	below ground surface
BMPs	Best Management Practices
DTW	Depth-to-groundwater
HCDEH	Humboldt County Division of Environmental Health
Ks	saturated hydraulic conductivity
LID	Low Impact Development
LiDAR	Light Detection and Ranging
ML	silt
msl	mean sea level
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
PSD	particle size distribution
PVC	polyvinyl chloride
SOP	Standard Operating Procedure
SM	Silty Sand
SP	Poorly graded sand
SW	Well graded sand
TOC	Top of casing

1. Introduction

The City of Trinidad (the City) is undertaking the Trinidad ASBS Stormwater Improvement Project (the Project) to make improvements to the municipal stormwater drainage system. The City's existing stormwater system was constructed in the early 1970's. The system discharges to a single 32-inch stormwater outfall (TRI032), which discharges just south of the boat launch at Trinidad Head to Trinidad Bay, as shown on Figure A-1, in Appendix A. The current system is designed to carry runoff to the outfall and does not incorporate modern retention, treatment or infiltration features.

Trinidad Bay is designated as an Area of Special Biological Significance (ASBS). It is one of 34 ASBS ocean areas monitored and maintained for water quality by the State Water Resources Control Board. ASBS cover much of the length of California's coastal waters. They support an unusual variety of aquatic life, and often host unique individual species. Trindad Bay was designated as an ASBS in part because of the fluctuating presence of bull kelp (*Nereocystis luetkeana*), which are considered biologically significant in providing an ecological base for fish and invertebrate habitats by supplying food and shelter. All ASBS may be adversely affected by polluted stormwater discharges, which could damage their unique ecoysystems.

The long term goal of the City in implementing the stormwater improvement project is to protect the ASBS by making improvements to the stormwater drainage system including implementation of Low Impact Development Best Management Practices (LID/BMPs) to capture, treat, and infiltrate stormwater runoff from rainfall events.

1.1 Project Area

The project is generally located within the City limits of Trinidad, Humboldt County, California and is shown on Figures A-1 and A-2. The City of Trinidad is located in rural northern California, approximately 25 miles from the county seat of Eureka and 300 miles from San Francisco. The community has a population of approximately 1,000 people with approximately 350 living within the City limits.

The project area is encompassed by Mill Creek in the north, Highway 101 and Parker Creek in the east, Trinidad Head to the southwest, and the Pacific Ocean on the west and south. The project encompasses portions of three watersheds: Mill Creek, the City of Trinidad, and Parker Creek. Currently, stormwater that accumulates in the northern portions of the City, drain into Mill Creek, which discharges near Trinidad State Beach approximately 500 feet north of the ASBS. The City of Trinidad watershed encompasses most of the City, the surrounding coastal bluffs, and Trinidad Head. Parker Creek drains a small portion of the eastern edge of the City. The City's stormwater system collects much of the precipitation that accumulates on the many paved and impermeable surfaces in the City and discharges it directly to the ASBS through discharge TRI032.

The City of Trinidad does not have a wastewater system and all residences and businesses use on-site wastewater treatment systems, also referred to as septic systems. The majority of the City of Trinidad Watershed is developed. Mill Creek is slightly less populated and is heavily forested in the upper watershed, as is Parker Creek. Highway 101 cuts across the north end of town and generally marks the transition from urban landscape to forested areas. The western and southern boundaries of the project area are bounded by coastal bluff with relatively steep slopes down to the ocean.

1.2 Project Objectives

The objective of this geotechnical evaluation is to gather information to support a groundwater model of the City of Trinidad, which will be used in the design of Stormwater LID/BMPs to help protect the Trinidad ASBS. The final groundwater model will be used to inform the design of LID/BMPs in considerations of the existing septic systems and the coastal bluffs.

To meet the objectives of the Project, this geotechnical evaluation includes the following information for the future project groundwater model:

- Characterization of the bounding hydrologic features including creeks, seeps and springs, the ocean, and coastal bluffs
- Characterization of the marine terrace aquifer and Franciscan bedrock, including saturated hydraulic conductivity
- Characterization of the flow of water into and through the marine terrace aquifer, including groundwater flow, gradient, and direction.

1.3 Scope and limitations

This report: has been prepared by GHD for City of Trinidad and may only be used and relied on by City of Trinidad and the SWRCB for the purpose agreed between GHD and the City of Trinidad as set out in section 1.2 of this report.

GHD otherwise disclaims responsibility to any person other than City of Trinidad arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

GHD has prepared this report on the basis of information provided by City of Trinidad and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

The opinions, conclusions and any recommendations in this report are based in part on information obtained from, and testing undertaken at or in connection with, specific sample points. Site conditions at other parts of the site may be different from the site conditions found at the specific sample points.

Investigations undertaken in respect of this report are constrained by the particular site conditions, such as the location of buildings, services and vegetation. As a result, not all relevant site features and conditions may have been identified in this report.

Site conditions (including the presence of hazardous substances and/or site contamination) may change after the date of this Report. GHD does not accept responsibility arising from, or in connection with, any change to the site conditions. GHD is also not responsible for updating this report if the site conditions change.

2. Field Investigations

As a first step for this project, a literature review of relevant information was conducted, and documents reviewed are included in the reference section at the end of this report. This literature review was used in the development of the geologic setting for this project which is presented below. The geologic setting is followed by a discussion of the completion of soil borings, installation of monitoring wells, mapping of springs and seeps, and geophysical investigation. Appendix I includes definitions of geologic terms and abbreviations.

2.1 Geologic Setting

The project area is underlain by Franciscan Bedrock. The Franciscan Complex is a late Mesozoic complex of rocks composed of highly sheared oceanic sediments that were deformed above the oceanic plate (which is sliding underneath western North America) (Aalto, 1982). These Franciscan rocks comprise the competent rocks of resistant headlands and sea stacks along the Trinidad coast and consist of greywacke, sandstone, marine sandstones, biogenic ribbon chert, limestone, greenstone, ultramafic and mafic plutonic rocks, and bluechist-facies metamorphic rocks (Aalto, 1976). The lesser constituents exist as blocks, or mixtures of blocks, ranging on a scale from centimeters to kilometers in length along the northern California coast within mélange units.

The Franciscan Formation is unconformably overlain by Pleistocene marine terraces along the Trinidad coast, within the project area, and up to several miles inland. The presence of stair-stepping, progressively older (and higher in elevation) marine terraces inland is a result of the ongoing deformation of the northern California coast along thrust faults, which account for most of the uplift. In the project area, a series of three terraces were previously mapped as follows: (Rust, 1982, Stephens, 1982); Trinidad Low marine terrace (approximately 40,000 years old), located closest to Trinidad Head, the Luffenholtz marine terrace (approximately 60,000 years old) and the Patrick's Point terrace (approximately 83,000 years old). According to the map produced by Rust (1982), the City was built on the Patrick's Point terrace. Additionally, the Trinidad Low marine terrace and/or the Luffenholtz marine terrace unconformably overlies an older (approximately 370,000 years old) marine terrace, marked with a paleosol (buried soil) at the contact (Stephens, 1982, Rust, 1982). These marine terraces can be generally described as thin to massive intervals of fine to coarse beach sands (mixed with various quantities of silt) containing local stringers of beach and fluvial gravel.

The project area is complicated by ongoing faulting of the Franciscan Complex rocks and the younger overlying marine terrace sediments. The close proximity of the offshore Cascadia Subduction Zone has resulted in crustal shortening and onshore tectonic deformation. At least two faults exist within the project area and have been mapped and trenched for paleoseismic information (by others); the Anderson Ranch (also called the Trinidad Fault) and the Trinidad Head Fault. The Anderson Ranch fault is located at the eastern boundary of the project area. The rise in land north of the Chevron Station (at the intersection of Scenic Drive and Main Street) is the fault line scarp of the Anderson Ranch Fault. The Trinidad Head Fault is northwest/southeast trending and mapped in the low elevation notch between Trinidad Head and the slope that rises toward Trinidad from the beach. According to Rust (1982), the Trinidad Head fault is interpreted as northeast-dipping. However, later interpretation by K.R. Aalto (2009), observed this fault to be a southwest-dipping normal fault.

Additionally, mass movements, including but not limited to debris flows, hillslope creep, and slumps, commonly occur along the coast north and south of the project area where more competent mélange blocks are relatively small and the surrounding matrix materials are dominant. The majority of the coast (north of Trinidad to Patrick's Point and south to Moonstone Beach), have been found to be extremely susceptible to small and large scale erosion (Aalto, 1977, Aalto, 2009, Rust, 1982) within the less competent mélange matrix. Identification of the general type and condition of the underlying Franciscan Complex mélange is critical to planning and engineering on the northern Californian coastline. However, as seen in Trinidad, the marine terrace margin is generally found to be more stable when overlying massive beachfront sandstone and greenstone units that buffer the high energy ocean waves. Nestled between these competent rocks that form much of the seastacks and headlands are sandy coves and beaches.

2.2 Bedrock, Seep, and Spring Mapping

On January 25, 2012, GHD's project geologist conducted a preliminary seep/spring and bedrock mapping survey of the cliffs, bluffs, gulleys, and slopes to the north, west, and south of the project area. A portion of the southern cliff area includes the Tsauri Village Site, part of the ancestral lands of the Yurok Tribe, which contains irreplaceable cultural resources significant to the Yurok People. For this reason, the portion of field mapping within the Tsurai Village Area in the southern portion of the project area, was conducted with Joe Lundgren of the Tsurai Ancestral Society. Mr. Lundgren provided key current and historical information on seep and spring locations.

The identified locations of seeps, springs, and bedrock outcrops were approximately placed on high resolution satellite imagery (see Figure A-4), and generally agree with historical mapping (Rust, 1982). Seeps and springs were generally observed at the bedrock/marine terrace interface on the exposed bluffs, gulleys, and slopes to the north, west, and south of the project area. It was noted that the seeps and springs were very noticeable when surveyed at the end of the dry season, indicating there is year round flow. This was confirmed in the Tsauri Village area via communications with Mr. Lundgren. The bedrock and seep/spring observations were used in conjunction with the depth to bedrock observations in borings and geophysical data in order to estimate bedrock elevations in the areas where bedrock could not be physically observed.

2.3 Soil Borings

Prior to conducting soil borings and installation of monitoring wells, approvals were obtained and preliminary reconnaissance of the project area was conducted. A drilling permit was obtained from the Humboldt County Department of Environmental Health (HCDEH), a copy of which is included in Appendix B. The proposed location of each boring was marked with white paint and Underground Service Alert was notified at least 48 hours prior to subsurface investigation to mark the locations of subsurface utilities. The HCDEH and the City of Trinidad were notified in advance of scheduled drilling and sampling activities and information on the subsurface investigation was made available to the public. The borings were observed by Ruby Rollins, a cultural monitor with Trinidad Rancheria's Tribal Historic Preservation Office. Ms. Rollins did not note any items of cultural or historical significance with the soil cuttings of the borings

In January and February 2012, GHD oversaw Clear Heart Drilling Inc. of Santa Rosa, California, during the drilling of 18 soil borings (SB-1 through SB-18). The borings were drilled using a truck-mounted drill rig fitted with 8-inch diameter hollow stem augers. As the borings were located in areas with numerous subsurface utilities, each location was hand augered prior to drilling to a depth of approximately 5 feet below ground surface (bgs). The soil borings (SB-1 through SB-18) were drilled to varying total depths based on the depth of the encountered bedrock surface. The location of the soil borings are shown on Figure A-2. Boring logs are included in Appendix C.

Soil samples were collected using either a 2-inch split-spoon sampler continuously, or at 5-foot intervals. The soil profile was classified and entered on a field boring log using the American Society for Testing and Materials, (ASTM Visual Manual Procedure D 2488 09a) and Munsell Soil Color Charts. Observations on lithology, moisture, consistency/density, plasticity, first encountered groundwater estimates, oxidation and mottling, and sample depths were noted on the boring logs as appropriate. Representative samples of the subsurface materials were retained and labeled for sieve analysis and stratigraphic reference from each boring location.

Franciscan Complex bedrock was encountered in borings SB-1 through SB-18. Each boring was generally terminated within a foot or less into bedrock surface. Where possible, a bedrock sample was collected from the cutting shoe of the soil sampler. In some borings, approximately 1 to 2 feet of weathered bedrock was encountered above the competent bedrock surface.

The field geologist identified the type of bedrock encountered, which is interpreted here as a block of Franciscan Complex mélange marine sandstone and shale rocks previously mapped/identified by Aalto and others. These rocks ranged from having no obvious deformation to being highly sheared. Laboratory analysis was not completed on the bedrock samples to determine the degree of competency or shear strength properties.

Table 1 presents the boring location, total depth of exploration for each borehole, depth to competent bedrock, and the type of bedrock encountered.

Table 1 Soil Boings SB-1 through SB-18 Completion Data

Boring	Completed Depth (feet bgs)	Depth to Bedrock (feet bgs)	Bedrock Type	Ground Elevation (msl)
SB-1	39	39	Siltstone	171
SB-2	34	34	Siltstone	153
SB-3	43	43	Graywacke/Sandstone	171
SB-4	55	53	Graywacke	176
SB-5	58	58	Sandstone	172
SB-6	60	58	Highly Sheared Siltstone	178
SB-7	66.5	62.5	Hard Siltstone	178
SB-8	50.5	50	Mudstone	177
SB-9	40.5	40.5	Siltstone	173
SB-10	43.5	43	Sandstone/Graywacke	172
SB-11	63	63	Sandstone	178
SB-12	61.5	61.5	Sandstone	179
SB-13	39.5	39.5	Highly Sheared Siltstone	94
SB-14	22	10	Highly Sheared Siltstone	140
SB-15	23	23	Sandstone	171
SB-16	29	29	Sandstone	29
SB-17	51.5	51	Siltstone	120
SB-18	70	70	Sandstone	175

2.4 Groundwater Monitoring Wells

Nine groundwater monitoring wells (MW-1 through MW-9) were installed throughout the project area using existing borings drilled during this investigation. The locations of the monitoring wells are identified on Figure A-2. Table 2 identifies the soil boring locations which were converted into the 9 monitoring wells installed.

Monitoring wells MW-1 through MW-9 were constructed of two-inch diameter blank polyvinyl chloride (PVC) well casing from the surface down to the slotted screen intervals. The factory-slotted well screens (0.010-inch) were placed at 10 to 20 foot intervals and depth to the top of the screens ranges from approximately 19 feet to 50 feet bgs in the monitoring wells. A uniform filter pack of Cemex #2/12 washed silica sand was placed around the well screens from a minimum of 2 feet above the slotted screens to the bottom of the wells. A 2-foot thick seal of hydrated bentonite pellets was placed over the filter pack, then a surface/sanitary seal of cement was placed to within 1 foot of the surface and finished with one foot of concrete. The top of each well casing was cut at approximately 2-inches below the well vault grade.

Table 2 Soil Borings Completed as Monitoring Wells

Soil Boring	Corresponding Monitoring Well	Total Depth (feet bgs)	TOC Elevation (msl)	Screened Interval	
				(bgs)	(msl)
SB-16	MW-1	29	28.26	19-29	9 to -1
SB-13	MW-2	39	93.46	29-39	64 to 54
SB-17	MW-3	51.5	118.99	41.5-51.5	77 to 67
SB-1	MW-4	39	170.98	29-39	142 to 132
SB-10	MW-5	43	171.62	33-43	139 to 129
SB-2	MW-6	34	152.73	24-34	129 to 119
SB-4	MW-7	55	175.33	45-55	130 to 120
SB-8	MW-8	49	176.72	29-49	148 to 128
SB-18	MW-9	70	174.23	50-70	134 to 104

The new monitoring wells are protected by flush-mounted traffic rated vaults set in concrete, expandable well plugs, and a lock. The top of the traffic vaults are set slightly above the adjacent surface grade with a gently sloping concrete rim to avoid ponding water during the winter months. The horizontal location and top-of-casing (TOC) elevation of each new monitoring well were surveyed as describedbelow. Monitoring well construction diagrams are included in Appendix D.

2.5 Soil Boring and Monitoring Well Survey

Horizontal soil boring and monitoring well locations and ground surface and TOC elevations were surveyed on March 23, 2012, by Phil Gutierez, a licensed surveyor, to facilitate calculations for groundwater flow direction and gradient. Ground surface and TOC elevations were surveyed to the nearest 0.01 foot mean sea level (msl) relative to the North American Vertical Datum of 1988 (NAVD88). Horizontal soil boring and monitoring well locations were surveyed relative to State Plane Coordinate System and in degrees latitude/longitude to 7 decimal places relative to the North American Datum of 1983 (NAD83).

2.6 Groundwater Monitoring

The depth-to-groundwater (DTW) was measured in each of the 9 monitoring wells (MW-1 through MW-9) on March 12, 2012, April 2, 2012, June 28, 2012 and September 20, 2012 per GHD standard operating procedures (SOPs). GHD SOPs are included as Appendix E. The final DTW measurement at each monitoring well was recorded after groundwater levels had equilibrated to atmospheric pressure for at least 15 minutes. Measurements were obtained using an electronic water level meter. DTW measurements for the 4 gauging events are presented on Table 3, below. DTW measurement field forms are included as Appendix F.

Table 3 Groundwater Elevation in Monitoring Wells

Well	Date	Groundwater Elevation (feet MSL)	Top of Casing (feet MSL)	Depth to Water (feet below TOC)
MW-1	3/12/12	11.27	28.26	16.99
	4/2/12	13.84	28.26	14.42
	6/28/12	10.52	28.26	17.74
	9/20/12	8.74	28.26	19.52
MW-2	3/12/12	64.11	93.46	29.35
	4/2/12	65.60	93.46	27.86
	6/28/12	66.13	93.46	27.33
	9/20/12	63.40	93.46	30.06
MW-3	3/12/12	78.37	118.99	40.62
	4/2/12	79.98	118.99	39.01
	6/28/12	78.48	118.99	40.51
	9/20/12	76.11	118.99	42.88
MW-4	3/12/12	136.38	170.98	34.60
	4/2/12	137.16	170.98	33.82
	6/28/12	136.10	170.98	34.88
	9/20/12	134.54	170.98	36.44
MW-5	3/12/12	133.40	171.62	38.22
	4/2/12	133.93	171.62	37.69
	6/28/12	134.62	171.62	37.00
	9/20/12	132.51	171.62	39.11
MW-6	3/12/12	134.48	152.73	18.25
	4/2/12	136.38	152.73	16.35
	6/28/12	135.83	152.73	16.90
	9/20/12	134.04	152.73	18.69
MW-7	3/12/12	134.98	175.33	40.35
	4/2/12	135.42	175.33	39.91
	6/28/12	137.57	175.33	37.76
	9/20/12	135.82	175.33	39.51
MW-8	3/12/12	132.51	176.72	44.21
	4/2/12	133.04	176.72	43.68
	6/28/12	134.91	176.72	41.81
	9/20/12	143.52	176.72	33.20
MW-9	3/12/12	120.35	174.23	53.88
	4/2/12	118.10	174.23	56.13
	6/28/12	118.68	174.23	55.55
	9/20/12	117.71	174.23	56.52

2.7 Geophysical Investigation

Spectrum Geophysics, a subconsultant to GHD, conducted a geophysical investigation from August 8 to August 17, 2012 in the project area to further define the subsurface including location of bedrock surface and marine terrace materials. Geophysical methods were used for the purpose of delineating detailed geologic stratigraphy and structure and to augment existing boring and well information within the project area. During this investigation, four linear transects, shown on Figure A-2, were established, and both seismic reflection and electrical resistivity data were collected along each transect. A discussion of the methods, field procedures, and data processing is presented in the full Geophysical Report, included as Appendix G.

3. Geotechnical Investigation Results

This section presents the results and interpretations of the field data collected and discussed in Section 2. First, the physical boundaries of the aquifer are discussed, which include the two area creeks, ocean, coastal bluffs, and watersheds. Next, the composition of the subsurface is presented, including the uplifted marine terrace deposits and underlying Franciscan bedrock. Lastly, the groundwater flow and direction is presented. This is followed by a conclusions and recommendations section, which summarizes the key report finding and recommendations for additional data collection and analysis during the next phases of the project.

3.1 Hydrogeologic Setting

The aerial extent of the aquifer below the project area is relatively small, bounded to the north and east by Mill and Parker Creeks, respectively, and to the west and south by the Pacific Ocean. The term aquifer is used here as a general term for a water bearing formation of unconsolidated sediments, that could theoretically yield useable water to a well or spring. The aquifer is not currently used for extraction purposes, due to its low storage capacity, relatively shallow depth and proximity to the residential septic systems. The top of the aquifer is considered unconfined (the groundwater rises and declines freely within the unsaturated/saturated zone) and the bottom of the aquifer is confined by the underlying bedrock surface that impedes the vertical migration of infiltrating surface water and then directs the majority of groundwater horizontally through the pore spaces of the marine terrace sand. The aquifer is comprised of primarily one connected hydraulic unit. While there are localized variations in the composition, it is primarily comprised of sand on top of bedrock. Groundwater input to the aquifer is limited by the incised creek drainages and coastal bluffs.

The zone of infiltration is approximately 15 to 55 feet below the surface of the project area (depending on how deep bedrock is encountered). This zone is characterized by grey, brown, and red mottling (leopard spot colorings in hand specimen) and red oxidation bands due to the repeated cycle of infiltrating water and the precipitation of iron oxides. The vertical migration of water in the upper 5 feet underlying the project area is assumed to be relatively slower, due to the higher silt content observed in undisturbed areas, and the compaction of imported fill materials to build houses and roads in the disturbed areas.

Below the upper silty/compacted/disturbed zone is up to 70 feet of silty sand, poorly graded fine to medium-grained sand, and well graded sand. The vertical and horizontal flow (hydraulic conductivity) is generally thought to increase due to the reduced silt content, increased porosity (space between soil gains), and loose consistency of the sand. Despite the presence of relatively thin (less than 2 feet thick) silt layers, which can impede flow, in a few project area borings, the vertical migration of infiltrating water is likely not significantly reduced because the lateral extent of the silt layers is discontinuous. Additionally, there are thin localized layers of well graded, well rounded, sandy gravel. Like the silt layers, the gravel layers were discontinuous, and not expected to have a significant effect on the overall vertical and horizontal groundwater migration.

Bedrock underlying the marine terrace sand serves as the principle confining layer to the vertical migration of infiltrating water in the project area. This is due to the Franciscan Complex mélange rocks encountered at the bottom of the borings and observed surrounding the project area being composed of massive sandstone, siltstone greywacke, and mudstone units. The massive bedrock units are considerably more competent and durable than unconsolidated marine sand, and relatively impermeable. Thus, when groundwater reaches the bedrock surface it flows horizontally down gradient toward the ocean (south and west) and towards the creek systems (north and east).

Thus, accurately incorporating septic system inputs to the marine terrace aquifer in the groundwater model will be important, as it has the potential to be a large contributor to groundwater flow, especially in the summer. Each of the properties within the City discharges wastewater to individual septic systems. The volume of water introduced into the subsurface is referred to as the septic loading rate. The septic loading rate will be developed based on water use records for a one year period. The water use will be modified to account for consumptive use and outdoor irrigation. A generalized loading rate for residential properties will be developed. This generalized residential loading rate removes the variability due to changes in residential occupancy. Larger businesses will be modeled individually. Based on a preliminary analysis of water use, it is estimated that total septic loading to the project area is between 19,000 gallons and 25,000 gallons per day.

3.1.1 Marine Terrace Outlets

There are several outlets for groundwater to leave the aquifer, which include seeps and springs, creeks, and the ocean. The creeks intercept the groundwater table to the north and east as previously discussed and act as a divide to preventing water movement into the City aquifer from other watersheds and also act as a drain allowing movement of water generally from the City watershed to the creeks. The Ocean acts as the final outlet, receiving water from the creeks, seeps and springs, and the groundwater aquifer.

Where encountered, seeps and springs were generally found to be at the bedrock/marine terrace contact along the north, west, and south bluffs surrounding the project area. In general, seeps, or clusters of seeps, were more prevalent on the low point of bedrock cliff slopes containing paleochannels, pervasive jointing, and sheared bedrock, and areas with active and historical marine terrace slope failures. Larger clusters of springs and seeps were observed on the beachfront bluffs in the northwest and southeastern portion of the project area. The observed seeps ranged from a trickle of water flow (less than approximately 1/4 gallon per minute) around the north and west boundaries of the project area, to that of an open garden hose (greater than approximately 5 gallons per minute) on the southern boundary bluffs below Trinity Street, Ocean Avenue, and Wagner Street within the Tsurai Village Site. Figure A-4, shows approximate seep locations.

3.2 Physical Properties of the Marine Terrace Aquifer and Franciscan Bedrock

The previous section discussed the general hydrogeologic characteristics of the project area. This section provides more detail on of the physical properties of the marine terrace aquifer and Franciscan bedrock.

3.2.1 Marine Terrace Aquifer

The description of the marine terrace stratigraphy is taken from the sediment types identified on project area boring logs obtained during this study (SB-1 through SB-18). Boring and trench logs from previous consultants (Busch Geotechnical Consultants [BGC], LACO, Taber Consultants [Taber], California Department of Transportation [Caltrans], GHD, and Oscar Larson Associates [OLA]) were also reviewed and discussed via personal communication (BGC, 2012).

Stratigraphy of the upper five (5) feet to the surface in the project area has been described from boring logs (using the ASTM D2488-09a) as loose to compact disturbed and mixed fill materials of imported river gravel, sand, and silt. Where undisturbed, the upper five (5) feet is generally loose to compact organic-rich silt (ML), silt with fine sand, or fine silty sandy (SM).

Underlying the upper fill and silty sand layer, the majority of the subsurface materials encountered were generally dominated by loose, poorly graded, fine and medium-grained sand (SP) down to bedrock (up to 70' thick, see Table 4 below). Lesser quantities of coarse grained sand were observed within well graded sand (SW) intervals ranging from approximately one (1) foot to 20 feet thick. The SW units were found overlying bedrock in 14 of the 18 borings, and often contained highly oxidized fines (silt and clay) and precipitates on grains. A thin (approximately ½ foot to 2 feet) interval of well graded and well-rounded gravel was encountered within a few borings, at depths ranging from approximately 13 feet to 20 feet bgs, and were generally bounded above, and below, by poorly graded sand.

Sieve results (Appendix H, and further discussed in Section 3.2.2) of well graded sand (SW) sand samples indicate the majority of those units are dominated by fine to medium grained sand. Additionally, sediment units described as silty sand (SM), after sieving were also found to be generally dominated by fine sand. Therefore, as discussed further in the conclusions and recommendations, the groundwater in the project area should be modeled to reflect unconsolidated marine sand (fine to medium-grain size) with relatively high porosity (approximately 25 to 50%).

Marine Terrace Surfaces

A conceptual model of the marine terrace surfaces was created from the boring log data, the bedrock surface model, and the LiDAR surface model. Upper and lower surfaces of the marine terrace were created using elevations from the bedrock surface model (Figure A-3) and LiDAR surface model (Figure A-4) respectively. The marine terrace stratigraphy was generally interpreted using boring log data and is shown in the Conceptual Cross Sections A-A' through H-H' (Figures A-7 through A-9).

Marine Terrace Stratigraphy

The stratigraphy of the project area marine terrace sediments form one primary water bearing unit and, as described in detail above, are generally interpreted in conceptual cross sections of the project area (Figure A-7). Eight conceptual cross sections, A-A' through H-H', were developed to convey general trends in the bedrock surface, basic stratigraphy, and groundwater elevations (Figure A-8 and Figure A-9). Soil boring logs, from this and previous studies, indicated that the marine terrace sediments in the project area are generally comprised of thin (generally 2-5 feet and up to 10 feet thick) silt (ML) and fine silty sand (SM) layers at the near surface (where undisturbed), with poorly graded fine and medium-grained sand (SP), and well graded sand (SW) intervals, of varying thickness down to bedrock. A particle size (sieve) analysis of selected samples was performed, and is described below. The results of the sieve analysis are presented in tabular form in Appendix H.

The northern California coast has a relatively high energy near shore erosional and depositional environment, perpetual daily tidal swings, and historical sea elevation variations due to climate change and tectonic uplift. Therefore, stratigraphy of the marine terrace is often observed to be laterally discontinuous, pinching, interbedded, and unconformable on a lateral scale of hundreds of feet. This process is indicated, for example in conceptual cross section A-A', where the well graded sand and gravel layers observed below the surface in boring SB-4/MW-7 are underlain by a poorly graded sand to the bottom and overlying bedrock. These same stratigraphic layers were observed in an inverted orientation approximately 500 feet west in boring SB-3.

Groundwater elevations observed during the construction of the borings and measured in the monitoring wells during subsequent monitoring events are also indicated in the conceptual cross sections A-A' through H-H' (Figures A-8 and A-9) , therefore, the apparent groundwater flow direction and saturated thickness can again be generally interpreted.

3.2.2 Estimated Hydraulic Conductivity

Hydraulic conductivity is an important parameter in predicting water movement through porous media like the marine terrace formations found on the northern California coast. Saturated hydraulic conductivity (K_s, the ability of a fully water saturated porous material to transmit water though its pore spaces) can be estimated from the particle size distribution (PSD) of the marine terrace materials. Investigators from 1892 (Hazen) to the present (Freeze and Cherry [1979], Shepard [1989], Alyamani and Sen [1993], and Salarashayeri, et. al. [2012]) have related and estimated hydraulic conductivity to PSD.

Particle Size Analysis

A mechanical sieve analysis was performed by GHD on 18 representative samples collected from the borings in the project area using the ASTM Standard Test Method for Particle-Size Analysis of Soils (ASTM D422-63[2007]). The boring logs which depict the vertical stratigraphy and depth of samples are presented in Appendix C. Since sand is the dominant material underlying the project area above bedrock, samples described in the field as poorly graded sand, well graded sand, and silty sand, were chosen to be sieved. 6 sieve sizes (Numbers 10, 16, 30, 50, 100, and 200) were used to separate the various particle sizes. Further separation of particle size through sedimentation processes was not completed on the material which passed the Number 200 sieve, as the materials that passed through the smallest sieve (number 200) were assumed to be dominated by silt with minor quantities clay. Material retained on the largest sieve (number 10) was identified as coarse sand.

Estimated Hydraulic Conductivity Evaluation

Using the distribution expressions D_{10}, D_{50}, and D_{60} (where 10%, 50%, and 60%, respectively, of the sample's mass is smaller than the corresponding diameter), K_s can be expressed in meters per day. Equations for K_s have been generated using D_{10} (Hazen 1892), and extended with power regression analysis (Shepard, 1989), and from multiple linear regressions (also using D_{50} and D_{60}) and statistically compared to observed values of K_s of sand (Salarashayeri, et. al., 2012). Studies have shown (Hazen, 1892, Alyamani and Sen, 1993, and Salarashayeri, et. al., 2012) that the relatively finer zone of PSD (D_{10}) plays a more significant role in estimating/ calculating K_s using PSD data. For the purposes of this investigation 10 equations were identified to calculate K_s, from Salarashayeri, et. al.,(2012) to establish a range of potential values. By utilizing the mean D_{10}, D_{50}, and D_{60} of the samples collected as the effective parameters, the range of K_s values for the marine terrace sediments in the project area was calculated.

Fine and medium-grained sand were the bulk of the materials retained in the test samples sieved. The range of K_s values for each sample is shown in Table 4, with a low of 11 and a high of 26. These values are similar to those of other investigators calculations (Alyamani and Sen, 1993), and are planned to be used for the future project area model calibration for the lower portion of the marine terrace.

As discussed previously, the shallower sediments have higher silt content in undisturbed areas and in disturbed areas fill soil and compaction have occurred to allow for construction of roads and buildings. Thus, the K_s value near the surface from 0 to approximately 3 to 10 feet bgs is recommended to be 1 to 2 orders of magnitude slower than the ~12 to ~26 meters per day for the lower portion of the marine terrace. The spatial distribution of the sieve analysis results is presented in Figure A-10. Particular attention should be paid to the level of disturbance (grading and compaction from road and house building activities) and depth of silt and/or silty sand encountered at specific locations for proposed surface infiltration designs. Previous studies in the project area (OLA, 1977) estimating vertical hydraulic conductivity from samples collected less than 10 feet bgs (Using a repacked falling head method of estimation instead), have indicated values much less than 1 meter per day (m/day).

Despite the pervasive deformation observed (fractures, faults, and folds) here and by others of the Franciscan Complex mélange rocks, the overall hydraulic conductivity of the bedrock is probably much slower (centimeters per day at most) than the overlying marine terrace sand (tens of meters per day).

Therefore, assumptions of the project area subsurface hydrology are that the majority of the downward vertical migration of water through the marine terrace sand is fast, and stops upon contact with bedrock. After the vertical migration of infiltrating water collects on the bedrock-marine terrace contact surface, it flows horizontally down gradient toward the ocean (south and west) and towards the creek systems (north and east). Although considered here to be insignificant at this time for the sake of the project area conceptual model of subsurface hydrology, there may be localized areas within the fractured bedrock allowing for further vertical migration of unknown quantities of groundwater.

Table 4 Particle Size Distribution and Estimated Hydraulic Conductivity (K_s)

			Particle Size (µm) & Soil Type[1]						K_s (m/day)[2]										K_s (m/day)	
Soil Unit	Soil Boring	Sample Depth (ft bgs)	D10	D10 Soil Type	D50	D50 Soil Type	D60	D60 Soil Type	EQ 7	EQ 8	EQ 9	EQ 10	EQ 11	EQ 12	EQ 13	EQ 14	EQ 15	EQ 16	Min	Max
ML	SB-5	30	43	Silt	150	Fine Sand	182	Fine Sand	11.6	17.3	16.9	16.4	21.0	20.9	12.0	12.0	18.1	12.0	12	21
SM	SB-8	4	162		253		275		18.8	18.6	17.9	19.4	21.3	21.1	23.5	24.3	18.8	24.1	18	24
SM	SB-12	5	150	Fine Sand	279	Fine Sand	330	Fine Sand	18.1	18.5	17.8	18.9	21.4	21.2	21.5	22.0	19.3	21.9	18	22
SM	SB-15	6	152		262		290		18.2	18.5	17.8	19.0	21.3	21.1	22.1	22.9	18.9	22.7	18	23
SM	SB-17	30-32	161		464		577		18.7	18.6	17.9	19.3	22.3	22.1	18.9	19.3	21.4	19.1	18	22
SM	SB-18	10-12	151		249		274		18.1	18.5	17.8	18.9	21.3	21.1	22.3	23.0	18.8	22.9	18	23
		Average	155		301		349		18.4	18.5	17.8	19.1	21.5	21.3	21.6	22.3	19.4	22.2	18	22
SP	SB-3	20-22	139		239		262		17.4	18.4	17.7	18.5	21.3	21.1	21.1	21.8	18.7	21.6	17	22
SP	SB-8	35	128	Fine Sand	229	Fine Sand	250	Fine Sand	16.8	18.2	17.6	18.2	21.2	21.0	20.1	20.8	18.6	20.6	17	21
SP	SB-10	26	80		155		185		13.8	17.7	17.2	16.9	21.1	20.9	16.0	16.1	18.2	16.2	14	21
SP	SB-13	20-22	78		150		215		13.7	17.7	17.2	16.9	21.0	21.0	15.9	15.5	18.5	15.9	14	21
		Average	106		193		228		15.4	18.0	17.4	17.5	21.1	21.0	18.3	18.5	18.5	18.6	15	21
SW	SB-1	35-37	179		912		1084		19.8	18.8	18.0	20.0	26.3	25.3	11.6	13.4	25.3	11.9	12	26
SW	SB-2	25	189		823		924		20.4	18.9	18.1	20.5	25.3	24.1	14.5	17.0	23.9	15.4	15	25
SW	SB-4	45-47	121		276		368		16.3	18.2	17.6	17.9	21.4	21.3	18.2	18.0	19.7	18.2	16	21
SW	SB-5	55-57	270	Fine Sand	864	Medium Sand	959	Medium Sand	25.4	19.7	18.8	25.0	25.8	24.3	23.0	25.9	24.2	24.2	19	26
SW	SB-6	50-52	131		272		330		16.9	18.3	17.6	18.3	21.4	21.2	19.5	19.8	19.3	19.8	17	21
SW	SB-11	60-62	158		643		890		18.6	18.6	17.9	19.2	23.6	23.8	14.8	14.0	24.1	14.2	14	24
SW	SB-16	20-22	130		328		394		16.8	18.3	17.6	18.2	21.6	21.4	18.2	18.7	19.8	18.5	17	22
SW	SB-18	60-61	166		755		949		19.0	18.6	17.9	19.5	24.6	24.2	13.3	14.0	24.4	13.3	13	25
		Average	168		609		737		19.2	18.7	17.9	19.6	23.3	22.9	16.6	17.6	22.6	17.0	17	23

[1] USDA classification of particle size for soil separates (soil types)

[2] K_s estimated using Equations 7 thru 16 from A.F. Salarashayeri and M. Siosemarde (2012)

3.2.3 Franciscan Bed Rock

A model of the bedrock surface (See Figure A-3) was created from depth to bedrock information collected from the drilling of 18 soil borings, geophysical transects (seismic reflection and electrical resistivity) conducted for this investigation, field observations from this and previous studies, and a Light Detection And Ranging (LiDAR) surface model.

Bedrock elevations from soil borings (See Appendix C) and geophysical transects (presented in Appendix G) were used to interpolate the bedrock surface throughout the project area. Observed bedrock elevations from soil borings and interpreted elevations from geophysical transects were used to estimate bedrock elevations between soil borings. Locations of exposed bedrock and bedrock boundaries such as the adjacent creeks and beach were used to establish boundaries and elevations. These model boundaries included the coastal bluffs to the west and south, and the creeks to the north (Mill Creek) and east (Parker Creek).

The seep/ spring observations were, in some cases, used as an indicator marker of the bedrock/marine terrace contact at locations where bedrock was not physically observed (covered in landslide materials, debris, etc.). Physically observed bedrock exposures were approximately located and placed on a LiDAR field map and those horizontal locations and corresponding vertical elevations were then estimated. Bedrock elevation data were then entered into Rockworks, an industry standard software program used for subsurface data visualization, and the bedrock surface was then developed. Based on the developed bedrock surface, as shown in Figure A-3, a bedrock ridge which divides the groundwater basin exists in the vicinity of main street and beneath the school. The bedrock surface is also shown on the cross sections previously discussed.

Figures A-3 and A-4 present observations of the bedrock surface as interpreted from geophysical data and depth to bedrock encountered during subsurface investigation, respectively, within the project area.

3.2.4 Groundwater Gradient and Flow Direction

Groundwater moves quickly through sandy aquifers with low amounts of fines. In the marine terrace aquifer below the City of Trinidad, where there are no groundwater extraction wells, groundwater flow direction is primarily influenced by the contour and slope of the confining bedrock layer, which is shown in Figure A-3. The gradient and flow direction may also be assessed using measured groundwater levels from the monitoring wells.

Using simple multi-linear regressions, groundwater flow directions and gradient were calculated using the data collected from monitoring wells MW-1 through MW-9, and show similar flow patterns to those anticipated from the bedrock surface. The measured groundwater level data is presented in Appendix F. An overall flow direction was also calculated using the 9 wellsHowever, due to the site vertical boundary conditions (topographic differences of the marine terrace and the vertical geometry of the monitoring wells relative to each other and variable bedrock elevations), and the various lateral boundary conditions to the north (Mill Creek), east (Parker Creek), south (cliffs and beach), and west (cliffs and beach), groups of 3 and 4 nearest monitoring wells were used to estimate groundwater gradient and flow direction within each of those locales (cells). Individual cells and groundwater flow direction maps for March 2012 and September 2012 are presented as Figures A-5 and A-6 (Appendix A), respectively.

From groundwater elevations collected in March, April, June, and September of 2012, groundwater below the northern half of the City generally flows (inferred in the northwest portion from subsurface topography) to the north-northwest towards Mill Creek at a calculated hydraulic gradient up to 0.012 feet per foot (ft/ft). Below the southern half of the City, groundwater generally flows to the south and southwest with a hydraulic gradient up to 0.12 ft/ft. In the western portion of the City, groundwater flows to the west-southwest at a gradient up to 0.087 ft/ft. In the southeastern portion of the City groundwater flows general south with a hydraulic gradient of 0.030 ft/ft. Groundwater flow directions and gradient did not significantly change between the Spring and Fall. Further support for groundwater flow directions are presented in Figure A-5 and Figure A-6 for wet and dry seasons respectively.

Groundwater Flow and Gradient

The direction of groundwater flow and gradient below the project area is believed to be controlled by the bedrock surface and the volume of infiltrating water. The direction of groundwater flow and the hydraulic gradient was calculated from the groundwater monitoring well network constructed during this investigation. Looking at the modeled bedrock surface, one can now reasonably estimate and independently verify the groundwater flow direction in the project area by using the basic concept that groundwater will flow from areas of higher elevation to areas of lower elevation.

The bedrock surface varies in elevation throughout the project area and shows ridges and valleys that are thought to control the overall groundwater flow and gradient. As shown in Figure A-3, there is a bedrock surface high at approximately 120 feet msl, running southwest to northest through the center of Trinidad. Groundwater north of this surface is flows toward Mill Creek or along seeps on Trinidad’s bluffs to the northwest. Groundwater to the south of the central bedrock surface is thought to flow in a southerly direction eventually daylighting as seeps and springs along Trindad’s southern bluffs. Figure A-3 also shows an area of higher bedrock, at approximately 150 feet msl in the southern portion of the project area. This area of higher bedrock is thought to direct groundwater around either side in troughs to the east and west of it on the southern bluffs. This is supported by geophysical evidence and the fact that boring SB-15 did not have groundwater or moisture at the bedrock marine terrace contact.

Field observations of groundwater seeps (Figure A-4) generally agree with estimated groundwater flow patterns created by the bedrock surface. Groundwater directed north daylights through seeps along the north-northwest portion of the project area at Mill Creek and along the western bluff. Groundwater directed south generally daylights through seeps along the southern bluffs.

4. Conclusions and Recommendations

This geotechnical evaluation was completed to better understand subsurface conditions below the City of Trinidad. The focus of the evaluation was to determine existing groundwater flow patterns and physical properties of the marine terrace aquifer to aid in the design of an effective stormwater treatment system which minimizes impacts to septic systems and the surrounding environment and natural resources.

This geotechnical evaluation consisted of:

- Reviewing previous studies and reports
- Drilling 18 soil borings, which extended from the surface to bedrock
- Installing groundwater monitoring wells in 9 of the soil borings
- Monitoring of groundwater elevation for 4 events
- Surveying and mapping of major surface features, geological features, and identified groundwater seeps and springs
- Conducting seismic reflection and electrical resistivity tomography along 4 transects

Based on the evaluation, it was found that the site is comprised of two predominant geologic formations; the overlaying marine terrace (sand) and a confining Franciscan bedrock layer. The bedrock surface is considered to be a larger block of competent Franciscan Complex mélange material ranging from approximately 15 to 70 feet below ground surface.

The marine terrace aquifer is an isolated unit above the bedrock dominated by poorly to well graded fine to medium-grained beach sand. The marine terrace aquifer ranges from 15 to 70 feet thick, with local discontinuous thin layers of silt and gravel. The estimated saturated hydraulic conductivity of the marine terrace below approximately 5 to 10 feet bgs, ranges from 11 to 26 meters per day. The upper 5 to 10 feet of the marine terrace typically has a higher percentage of fine grains, and thus the saturated hydraulic conductivity for this layer should be one to two orders of magnitude slower than the deeper sediments.

Groundwater flow into the marine terrace aquifer is constrained by natural drainages (creeks) to the north and the east and the ocean to the west and south. Groundwater flow direction and gradient appear to be controlled by the shape and slope of the bedrock surface. Water entering the aquifer either from upgradient marine terrace sediments, precipitation, or septic systems quickly migrates vertically until it reaches the confining bedrock layer, as evidenced by the groundwater level monitoring discussed in the results section. Groundwater flows from the bedrock ridges to the troughs, along the sloping bedrock surface, and out the bedrock/marine terrace interface at the exposed bluffs to the northwest and south, Mill Creek to the north, and Parker Creek to the east. Generally, the groundwater flow paths extend radially from a point in the northern segment of Trinity Street with the bulk of the aquifer collecting and flowing south within the two north-south trending troughs. Groundwater flow patterns are shown graphically in Figures A-5 and A-6.

Near Main Street and Highway 101 the underlying bedrock slopes to Mill Creek limiting the groundwater contributions to flow along this boundary. Water also enters the system via infiltration of precipitation and infiltration of septic discharge. Groundwater recharge from the creeks likely does not occur as the creek beds are incised and lower than the surrounding bedrock.

4.1 Recommendations

Representative infiltration tests should be conducted for potential locations of LID/ BMPs in the upper 5 to 10 feet of the marine terrace, where grading and compaction from road and other infrastructure and development has likely reduced the hydraulic conductivity compared to lower undisturbed portions of the marine terrace deposits.

With numerous groundwater seeps that exhibit continual flow out of the marine terrace aquifer and limited dry weather inputs, recharge of the aquifer from anthropogenic sources (septic systems, leaking water lines, irrigation, etc.) will be further evaluated during groundwater modeling and design processes.

4.2 Next Steps

The next step in the City's ASBS Stormwater Improvement Project will be to use the data from this geotechnical evaluation to develop a groundwater model. The groundwater model will be used to further delineate groundwater flow paths, quantify groundwater flow velocities and directions, and evaluate the impacts of potential stormwater LID/ BMPs on groundwater patterns in the marine terrace aquifer.

Based upon the preliminary groundwater flow characteristics developed in this geotechnical evaluation, there appear to be two potential primary locations for stormwater infiltration that could meet project objectives: the north side of Main Street near Stagecoach Road and the southwest between the Trinidad Head and the City. These locations will be further evaluated along with other potential infiltration sites during the future modeling/ design analysis.

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