FINAL
Drainage Feasibility Study
Volume II (Geotechnical Component Vol. 1)

Community of Rimforest
County of San Bernardino, CA

Prepared For:

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November 8, 2010

GEOLOGICAL INVESTIGATION AND FEASIBILITY EVALUATION OF PROPOSED MITIGATION PROCEDURES TO REDUCE THE POTENTIAL FOR ACTIVE LANDSLIDING IMMEDIATELY SOUTH OF THE COMMUNITY OF RIMFOREST SAN BERNARDINO COUNTY, CALIFORNIA

PROJECT NO.: 168-H09
REPORT NO.: 1

JANUARY 20, 2010

SUBMITTED TO:

JOSEPH E. BONADIMAN AND ASSOCIATES, INC.
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January 20, 2010

Joseph E. Bonadiman and Associates, Inc.
234 N. Arrowhead Avenue
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Project No. 168-H09
Report No. 1

Attention: Mr. Bonadiman

Subject: **Geological Investigation and Feasibility Evaluation of Proposed Mitigation Procedures to Reduce the Potential for Active Landsliding Immediately South of the Community of Rimforest, San Bernardino County, California.**

References: See Appendix C.

According to your request, we have completed a geological investigation of the community of Rimforest and adjacent areas. While there appears to be no practical solution to prevent earth movement from continuing, it may be possible to reduce erosion and potentially slow landslide movement in areas south of the town. The purpose of this study was to estimate the efficacy of slope stabilization that may result from one of several proposed surface drainage mitigation procedures.

To accomplish these goals, an investigation of the area surrounding Rimforest was conducted to identify contributing factors of the current Rimforest landslides, and to determine, within the limits of this investigation, the past history, and future probability for continued landslide activity near the town, which will be based on interpretation of local geomorphology, type and conditions of involved rock types, geologic structure, tectonic situation, and hydrologic conditions. Additionally, we have provided estimates of the current slope failure rate and estimated future failure rate should a drainage mitigation measure be implemented. We are presenting, herein, our findings and recommendations.

If you have any questions after reviewing the findings and recommendations contained in the attached report, please do not hesitate to contact this office. This opportunity to be of professional service is sincerely appreciated.

Respectfully submitted,
HILLTOP GEOTECHNICAL, INC.

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Executive Summary

An investigation into causes and possible mitigation of causal elements pertaining to the Rimforest Landslide was commissioned by the County of San Bernardino. Based on observations of this and past investigations, there appears to be no practical means of stopping the headward retrogression of the Rimforest landslides. As early as 1978, it was believed that uncontrolled runoff cascading over the cliff at the south edge of Rimforest was the primary cause of slope instability. As such, Ramussen (1978) recommended diversion of runoff waters away from the cliff in order to slow erosion and retard cliff face retrogression.

Based on this current investigation, heavy runoff during large storms is only partially responsible for continued landsliding in Rimforest; increased groundwater levels during several seasons of above-normal precipitation appears to be of equal or nearly equal importance. Rerouting as much runoff as possible away from unstable cliffs will reduce erosion at the base of the steep slopes, but will have little affect upon groundwater conditions. Since there clearly is a groundwater component contributing to slope instability, rerouting surface runoff cannot be expected to prevent all future landsliding in the area. However, because all large movements have occurred when heavy runoff was coincident with a certain threshold of accumulated, above normal rainfall, preventing the bulk of runoff water from reaching the cliffs would be expected to reduce the frequency of large slope movement by a significant amount. This would reduce the average slope retrogression over a period of time.

It must be noted, there is insufficient information at this time to allow for more than a preliminary estimate of slope retrogression rate reduction resulting from diversion of runoff. Further study would be required to establish a more accurate and better supported estimate of potentially beneficial effects resulting from improved control and redirection of surface runoff.

There are presently two drainage options for mitigation of the Rimforest runoff problem. Option 1, diverting runoff water northeastward into Little Bear Creek,

appears to be the only viable option. Option 2, rerouting runoff into the canyon immediately east of Rimforest, has been found to be geotechnically infeasible, because it is likely to result in greatly increased erosion, destabilized slopes, and eventual slope failure.

A potentially active fault, referred to as the 'Rimforest fault' for the purpose of this document, was identified passing through the western landslide area, and it is coincident with much of the head scarp of the northeastern landslide immediately south of Blackfoot Trail East. If this fault ruptures within the landslide areas, it could result in sudden and potentially dangerous slope movement. Assessing the age of this fault and its potential for movement was beyond the scope of this investigation and would require further study. While the status and past activity of the Rimforest fault are unknown, major active faults, which pass very near the Rimforest area, are considered to be likely to rupture in the near future. Severe groundshaking from a major seismic event on other faults, such as the San Andreas, could result in sudden failure of any or all of the landslide areas south of Rimforest.

Slope stability analyses, carried out using rock slope stability and soil slope stability parameters and methods, determined that significant areas of potential slope failure extend beyond the present top of slope and incorporate some currently occupied residences. Preliminary hazard boundary lines have been created as a result of this investigation. The preliminary hazard boundary lines represent estimated limits of increased landslide risk and are depicted on Plate No. 1.

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PREFACE

Landslide activity within the Rimforest area over the last 30+ years has left many slopes below the town over-steepened and unstable to marginally stable, at best. Slope gradients in the Rimforest landslide area are shown on Plate No. 2. Localized over-steepened conditions have made much of the area more susceptible to additional failure. The over-steepened slopes act to undermine otherwise more stable areas above the slopes and, as such, produce larger areas beyond the slopes that are potentially unstable. Rock integrity, slope geometry and geomorphology, tectonics, seismicity, bedrock orientation, fractures, faulting, shear zones, groundwater and surface water runoff are all components that contribute to the future stability of slopes below Rimforest.

The primary purpose of this study was to estimate how effective controlling surface runoff may be with regards to slowing headward retrogression of landslide activity into the south edge of Rimforest. However, to accomplish this, we first needed to evaluate other factors and how they affect current conditions. Additionally, as part of our investigation, we have studied the history and development of the town and surrounding area as it pertains to the chronology of events that led up to the current situation. A large amount of data has been collected over the years, some more pertinent than others. All information made available to us has been reviewed. Although there is too much information to entirely include within this report, the data and evaluations of past interpretations were incorporated into our investigation and reflected within our findings and conclusions.

This study is very important to the County of San Bernardino and especially significant to the town of Rimforest. As such, we have tried to be as objective as possible in our evaluations. Our conclusions should be considered to be preliminary, as the project area in total is large and complex, especially with respect to slope stability. As stated above, an important purpose of this investigation is to address the efficacy of plans to redirect surface runoff as a means to improve slope stability in the Rimforest area. In evaluating this, we have studied other factors that affect slope stability to a degree, but additional work needs to be conducted to fully address these other aspects. Areas for additional study that specifically relate to these aspects are also presented in this report.

We have greatly enjoyed working on this project and being able to contribute to such a significant study. We sincerely thank all involved for such an award and hope our findings, conclusions and recommendations are considered to be useful.

GEOLOGICAL INVESTIGATION AND FEASIBILITY EVALUATION OF PROPOSED MITIGATION PROCEDURES TO REDUCE THE POTENTIAL FOR ACTIVE LANDSLIDING IMMEDIATELY SOUTH OF THE COMMUNITY OF RIMFOREST SAN BERNARDINO COUNTY, CALIFORNIA

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INTRODUCTION

This report presents results of our geological investigation conducted in and around the Community of Rimforest, San Bernardino County, California. The general location of the subject site is indicated on the 'Site Location Map,' Figure No. 1.

AUTHORIZATION

Authorization to perform this study was in the form of a signed proposal from **Hilltop Geotechnical, Inc.** (Geotechnical Consultant) to **Joseph E. Bonadiman and Associates, Inc.** (Client), dated January 9, 2009, Proposal Number: P08138.

PURPOSE AND SCOPE OF STUDY

The Rimforest community lies at the south edge of the San Bernardino Mountains, an area characterized by very steep, south-facing slopes. Landsliding and erosion into the southern edge of town was first noted in 1978, when a sewage pump station was damaged. Since 1978, the active landslide area has grown laterally to involve a greater area, and has continued headward movement into the southern portion of the town. The pump station, several houses, and a residential street have been damaged or destroyed.

Prior studies indicated surface runoff appeared to be the most significant contributing cause of the landsliding by undercutting existing steep slopes, and that increased groundwater pore pressure probably contributed to slope destabilization. Based on prior studies, several alternative procedures to redirect surface runoff away from the unstable slopes have been proposed.

The scope of work performed for this study was designed to evaluate the proposed options within the framework of the geology and hydrogeology of Rimforest. The specific goals of this investigation are to:

- Estimate rate of bluff regression.
- Determine the feasibility of each of the proposed alternatives.
- Determine the degree to which each alternative may mitigate the potential for landslides surrounding Strawberry Creek;
- Determine whether the proposed alternatives will create any new problems or aggravate existing problems;
- Determine whether a basin will be beneficial either north or south of Highway 18; and,
- Compare alternatives and recommend the most geologically beneficial of the proposed mitigation projects.

To accomplish these goals, our investigation consisted of:

- Review of locally available published and unpublished geologic, geotechnical, and pertinent environmental reports, maps, and data for the area.

- Telephone conversations and progress meetings with the client, county representatives, and/or representatives of the client.

- Geologic mapping of major units, condition of bedrock, and geologic structural elements.

- Stereographic aerial photo analysis of the site and surrounding vicinity utilizing all available aerial photos.

- Subsurface exploration by means of exploratory borings to acquire undisturbed and bulk soil samples to determine subsurface conditions in areas proposed for basins, and to acquire subsurface information for correlation with surface observations.

- Logging of all subsurface excavations.

- Evaluating available hydrologic data.

- Slope stability analyses using both rock analysis and soil analysis methods.

- Perform limited laboratory testing of selected samples to determine in-situ conditions and strength parameters of the native soils and/or bedrock.

- Present our professional opinions in a report that will include our conclusions and recommendations with respect to the proposed surface runoff mitigation procedures.

The scope of work performed for this report did ***not*** include any testing of soil or groundwater for environmental purposes, an environmental assessment of the property, or opinions relating to the possibility of surface or subsurface contamination by hazardous or toxic substances.

This study was prepared for the exclusive use of **Joseph E. Bonadiman and Associates, Inc.** and their consultants for specific application to the proposed project in accordance with generally accepted standards of the geologic profession at the time this report was prepared. No other warranty, implied or expressed, is made. The conclusions and recommendations presented in this report are valid as of the date of the report. However, changes in conditions of a property can occur with the passage of time, whether they are due to natural processes or to the works of man on this and/or adjacent properties.

If conditions are observed or information becomes available during the design and construction process which are not reflected in this report, **Hilltop Geotechnical, Inc.** should be notified so that supplemental evaluations can be performed and the conclusions and recommendations presented in this report can be modified or verified in writing as necessary. Changes in applicable or appropriate standards of care in the geological profession occur, whether they result from legislation or the broadening of knowledge and experience. Accordingly, the conclusions and recommendations presented in this report may be invalidated, wholly or in part, by changes outside the control of the project Geotechnical Consultant which occur in the future.

ACKNOWLEDGMENTS

This report is a product of efforts performed by Hilltop Geotechnical, Inc. and assisted by Joseph E. Bonadiman & Associates, Inc. as well as prior efforts conducted by many other people, consultants and agencies over the years. We would like to acknowledge the many people that provided us with an overwhelming amount of information that pertained to the Rimforest area over the last 30+ years. Specifically, we recognize Mr. Suitt who conducted two studies on the Rimforest landslide (one of which was shortly after the 1995 event) and who was particularly helpful to us by sharing his recollections at the time as well as opening his file and providing us with his field data that he gathered shortly after the 1995 failure event. Much of his field information was obtained in extremely difficult areas to access and taken when exposures were fresh and easily recognizable. His field data was found to be very pertinent to our study and was utilized and combined with our field data in developing our interpretations.

Additionally, we recognize Mr. Wes Reeder, the County Geologist for the San Bernardino County Department of Building and Safety for sharing his recollections

and experiences over the years as well as providing us with many photographs, infrared aerial photographs, newspaper articles, professional reports, county memos and other correspondence that related to the Rimforest Landslide over the last 30 years. We would also like to recognize Mr. Butch Bowman of the Rimforest Lumber Company for providing us with significant historical information dating to the 1940's, including information pertaining to the man-made pond, lithology at the lumber yard, and historic groundwater information. We would also like to recognize the San Bernardino County Flood Control Department for researching water well information in the area, providing us with insight into the history of Rimforest, and supplying many of the aerial photograph reproductions.

PREVIOUS SITE STUDIES

An overwhelming amount of site studies, maps, photos, newspaper articles, memos and correspondence were made available to us and reviewed by this office. These reports, memos and other information were used to help provide a chronology of events. This information was very helpful in developing a background and history of events prior to and including the present conditions in and around Rimforest. Information contained in each report is not specifically repeated herein, but was utilized in this investigation and is referenced in Appendix C.

GENERAL GEOLOGY

REGIONAL GEOLOGIC SETTING

The Transverse Ranges Geomorphic Province is a nearly 300-mile-long belt of folded, faulted, and uplifted rocks of diverse lithologies, which contains the San Bernardino Mountains, the San Gabriel Mountains, and several other ranges extending toward the east and west. The east-west orientation of the Transverse Ranges markedly contrasts with the generally northwest-trending, structural grain of surrounding areas of California. The presence and orientation of these ranges are generally attributed to north-south directed compression and crustal shortening related to complications within the geometry of the San Andreas transform fault system. These complications are reflected in the kinematics of faults that bound virtually all sides of the San Bernardino Mountains block, faults that include right- and left-lateral strike-slip, normal, and reverse-slip displacements.

Basement rocks in the San Bernardino Mountains are similar to those observed in the Mojave Desert areas to the north, and consist of Triassic through Cretaceous granitoid rocks of various compositions that have intruded prebatholithic orthogneiss (Proterozoic) and Late Proterozoic to Paleozoic metasedimentary rocks. The layered metasedimentary units consist of quartzites, marbles, pelitic schists, and gneisses, and are stratigraphic equivalents to widespread, marine sedimentary rocks in the eastern Mojave Desert and Great Basin regions. Deformed and undeformed suites of Mesozoic plutonic rocks predominate in the western San Bernardino Mountains. Least-common rock types around the margins of the range include banded and layered Mesozoic metasediments and several Tertiary sedimentary units, usually located within fault-bounded slivers and blocks.

The San Andreas fault zone is the dominant structural element in the central Transverse Ranges. Extending over 650 miles from the Gulf of California to the vicinity of Cape Mendocino in northwestern California, the San Andreas fault zone often comprises a strip up to several miles wide of subparallel, branching, and anastamosing fault strands. The fault zone accommodates mostly right-lateral, strike-slip displacements, with small vertical components locally significant in some areas. Current understanding of California tectonics indicates that the fault can be divided into several discrete segments along its length, based upon differing geologic and seismologic characteristics. Each discrete segment appears to react to tectonic stress more or less independently from the others and to have its own characteristic large earthquake with differing maximum magnitude potential and recurrence interval. The San Bernardino segment lies coincident to the southern edge of the San Bernardino Mountains, approximately four miles from the Rimforest area. Geology in the area surrounding the subject property is graphically depicted on Figure Nos. 2a and 2b, “Regional Geology Map”, which is based on the USGS San Bernardino 30' x 60' geology map. A second regional geology map, Figure Nos. 3a and 3b, "Regional Geology Map, Dibblee" uses the Dibblee Harrison Mountain 7.5' geology map.

The Rimforest area is underlain by two Mesozoic-age, granitic basement rock units identified as Monzogranite of City Creek (map symbol Kcc), and Mixed Granitic Rocks of Silverwood Lake (map symbol Mzsl). Outcrops of both rock units are common in the area. The Mzsl unit appears to be limited to the western portion of Rimforest and a limited area to the south of the town. The Kcc unit predominates east of Strawberry Peak, north of Highway 18, and through most of Rimforest east of Blackfoot Trail West. Colluvial soils mantle most slopes and hilltops and generally range in thickness from a few inches to a few feet. Colluvium in excess of 12 feet in depth was found in the western portion of Rimforest. Talus material covered most of the south flank of the hill immediately east of Strawberry Peak. A small area of talus was also encountered south of Rimforest, below a hard rock outcrop. The deepest alluvial soils encountered in the area were present within the Little Bear Creek wash, northeast of Rimforest.

Available geology maps show no faults that cross through or adjacent to the town of Rimforest. Published maps show several faults near and at least one fault trending toward Rimforest, but locations and orientations of identified faults are shown differently on different maps. All faults identified on published maps and identified during this investigation have been composited and are depicted on Figure No. 4, "Composite Fault Map".

GEOMORPHOLOGY

The Community of Rimforest lies at the southern edge of the Northern Block of the San Bernardino Mountains, a broad plateau with relatively gentle highland topography. The southern flank of the mountain range just beyond the edge of the highland area is characterized by deeply incised, steep slopes. Below Rimforest, in areas not presently affected by landsliding, slope gradients of 90 percent or more are common. Many of the most prominent channels eroded into the descending slopes of the mountain flank extend downward in nearly straight lines, but are then intercepted and offset by northwest-trending, tectonic features including shutter ridges and strike valleys. Several small landslides are visible on hillsides south of Rimforest.

Rimforest lies at the transition between the relatively gentle to moderate relief of the highland plateau of the San Bernardino Mountains, and the steep southern flank of the range. Retrogression of the steep southern flank of the mountain range through mass wasting has resulted in the slope profile now present in the Rimforest area: the steepest portion of the slope is at the top, and the gradient becomes shallower farther down the slope. Translational and rotational landsliding, rock falls, and toppling have formed four clearly defined, arcuate escarpments south and southeast of Rimforest. One escarpment lies within the tributary drainage south of Daley Canyon and southeast of Rimforest and currently does not impact the Rimforest community. Three of the escarpments lie within the Strawberry Creek drainage at the south edge of Rimforest. As headward retrogression of the three Strawberry Creek escarpments continues to expand westward, northward and northeastward, they are increasing in lateral extent and likely will eventually merge into a single, arcuate, escarpment with a bowl-shaped profile. This pattern of retrogressive erosion along the south flank of the San Bernardino Mountains, usually but not always centered on currently active drainage channels, often results in broad, arcuate valley heads. This type of valley head erosion is common in most mountainous areas and can be seen throughout the San Bernardino Mountains.

The valley head centered on Strawberry Creek drainage is considered to be in a fairly early stage of development. This feature, referred to in this document as the 'Strawberry Creek valley head', is shown on Figure No. 6. To the west of Rimforest is a similarly-shaped valley head, which appears to have formed by the partial merging of two smaller features, and is referred to here as the 'Red Rock Wall valley head'. Westward retrogression of this valley head appears to be somewhat limited by hard, resistant rock of Red Rock Wall Point, although retrogression toward the west continues through a broad shear zone located immediately to the north of the Point. The northern limit of this valley head lies coincident with the southern flank of Strawberry Peak. There was no evidence found in this study to indicate imminent failure on the south flank of Strawberry Peak. The steep, southern slope of Strawberry Peak forms a jointed and fractured, granitic wall over 200 feet high that has an average slope angle of about 60 degrees. The east wall of the Red Rock Wall valley head is also the west slope of the topographic bench on which Rimforest is located. While most of this feature appears to be conditionally stable, based on the existing dense growth of vegetation over most of the valley head slopes, there are small, scattered areas that have loose surficial soil and rock. Observed vegetation within the Red Rock Wall valley head was very dense. Vegetation was primarily composed of brush and dense undergrowth, although some trees were observed within the area. While there are several small drainage channels located within and below the Red Rock Wall valley head, this feature is not centered on a major active drainage channel.

The valley head just east of Rimforest and south of Daley Canyon, is referred to here as the 'Daley Canyon valley head'. Unlike the Red Rock Wall valley head, the Daley Canyon valley head is situated in a larger drainage, which is a tributary of the West Fork of City Creek. The Daley Canyon valley head has shallower slopes within and adjacent to the drainage channel compared to slopes within either the Strawberry Creek drainage or the Red Rock Wall valley head. Additionally, most of the Daley Canyon valley head is heavily forested. The morphology and vegetation of the Daley Canyon valley head appear to be older and more mature than Red Rock Wall valley head or the active Strawberry Creek drainage in Rimforest.

Locations of the Daley Canyon and Red Rock Wall valley heads are shown on Figure No. 6.

AERIAL PHOTOGRAPH ANALYSIS

Several sets of aerial photographs were examined and analyzed. The dates ranged from 1938 to 2007; the scales ranged from 1:12,000 to 1:24,000. One set of infrared, false color photos, dated 1974, was provided by Mr. Wes Reeder for examination. The larger scale photos were used to examine the landslide areas. The smaller scale photos were used to analyze mountain areas surrounding

Rimforest. All photos were used, in conjunction with other information sources, to reconstruct a history of landsliding in the Rimforest area.

General Observations

Careful examination of available aerial stereo pairs of photos revealed large numbers of topographic lineaments, a few of which correlated with known fault locations. Lineaments were apparent in all areas surrounding Rimforest, including the highland areas to the northwest through northeast, the south edge of the highlands, and the descending slope to the south. In most areas, visible lineaments were so numerous as to form a nearly cross-hatch pattern. Identified lineaments can be seen on Plate No. 8, “Aerial Photo Lineaments”.

Looking at Plate No. 8, it is clear that not all visible lineaments are likely to be associated with faults or shear zones. Many likely result from joint trends, near linear contacts between rock types, large dikes, or other features. However, as noted on Plate No. 8, six lineaments that either crossed Rimforest or were located nearby and were deemed important for this investigation were field checked. All six locations, correlating with aerial photo lineaments, were found to contain shear zones (in which displacement could not be readily identified) or faults. As such, it seems likely that a relatively high percentage of photo lineaments identified during this investigation correlate to structurally important features and most likely represent zones of weakness that may relate to future stability of affected areas.

Rimforest Lineaments

At least eleven photo lineaments cross into or adjacent to the community of Rimforest. The locations and identifying numbers can be found on Plate No. 8. Lineament No. L1 passes through the topographic saddle and a hairpin turn on Highway 18, both of which are north of Red Rock Wall Point, then continues east-northeast through a topographic bench, which is located southeast of Strawberry Peak and is occupied by Rimforest. Lineament L1 continues east-northeastward through the campus of Rim-of-the-World High School, approximately one-half mile east-northeast of Rimforest. The western location of this lineament was verified and is clearly defined in a road cut as a shear zone with parallel and subparallel jointing. The shear zone attitude measured N82E86N.

Lineament L2 passes through the Highway 18 hairpin turn adjacent to Red Rock Wall Point. It is visible in the road cut just north of Lineament L1. This lineament passes to the south of Rimforest and appears to cross through the southeastern landslide area. This lineament is expressed as a broad shear zone where bedrock has been crushed and deeply weathered.

Lineament L3 is a northwest-trending lineament that passes to the south of Strawberry Peak and the town of Rimforest. The lineament passes to the southwest of a pair of water tanks, just north of Highway 18 and southwest of Strawberry Peak. A fairly well-defined shear zone, which comprised a generally vertical zone of crushed rock and rock flour surrounded by more competent, jointed rock, was found in a cut slope southeast of the water tanks. In the Rimforest area, Lineament L3 aligns with the major joint orientation of a hard, resistant rock mass at the south edge of the western slide area, south of Rimforest. This rock mass forms a prominent cliff in the lower portion of the slide area that juts out from the adjacent, eroded landslide. The eroded landslide north of this prominent cliff also contains at least one identifiable shear zone.

Lineament L4 is located to the west of Rimforest. It passes between the two highest summits in the Rimforest area, immediately to the east of Strawberry Peak. Lineament L4 passes approximately 400 feet to the west of Rimforest, and was verified in the field. A single, normal fault, which appeared to be down-dropped at least 20 feet to the east, was found on the cut slope south of Strawberry Peak. While this lineament does not directly affect the geologic structure controlling the Rimforest landslides, it crosses multiple other lineaments within the large, arcuate valley head to the west of Rimforest.

A single photo lineament passes towards the southeast between the two highest summits, immediately east of Strawberry Peak, then splits into two lineaments (L5 & L6). Both lineaments pass through the area of the fire station, on the north side of Highway 18, near the western end of Rimforest. While no shear zones were positively identified in this area, neither were competent bedrock outcrops nor was bedrock exposed in road cuts. The nearest road cut to these lineaments exposes an area of highly weathered granitic rock, which quickly grades into more competent rock toward the west. Lineament L5 (the southerly branch), which has a south-southeasterly trend, passes through Rimforest and crosses through the western slide zone. This lineament coincides fairly closely with the contact between the geologic units Kcc and Mzsl as the contact passes through the western portion of Rimforest. Lineament L5 extends toward the southeast and appears to cross through the southeastern landslide area. Lineament L6 (the northerly branch) crosses through the head scarp of the northeastern slide zone, See Figure No. 5, "Landslide Locations Map". Much of this escarpment is composed of shattered and crushed rock. No differentiation could be made between a possible shear zone associated with Lineament L6 and other faults, slide planes, and other shear zones visible in and around this scarp.

Lineament L7 crosses the western portion of Rimforest towards the southwest, and passes through the same area around the Fire Station as do Lineaments L5 and L6. While this lineament does not directly affect the geologic structure controlling the Rimforest landslides, it crosses multiple other lineaments within the large, arcuate valley head to the west of Rimforest.

Lineament L8 extends across Rimforest from the northeast. It passes through the western slide area and appears to coincide with the southeast face of the prominent, hard rock cliff, which is located just south of the lower portion of the western slide area. The trend of Lineament L8 is approximately parallel to the northeast-trending joint attitudes that control the shape of southeast cliff face below the western landslide area. The location of Lineament L8 was verified as a well-defined shear zone exposed in a road cut on Daley Canyon Road.

Lineament L9 extends across Rimforest from the east-northeast. It is found onsite as a fault zone that contains a pair of parallel fault traces, one or both of which are visible in several locations. For purposes of this report, this fault has been named the Rimforest fault and is identified as such hereafter. One fault trace coincides with a portion of the northeastern landslide head scarp. Both traces are visible within the west slide area. The two traces cross out of the west landslide toward the west-southwest. The southern trace is clearly visible within the western wall of the west slide as a nearly vertical line surrounded by distorted and crushed rock. The northern trace forms a topographic break on the relatively stable slope just west of the slide. These faults can be traced to the west-southwest where they coincide with an Arrowhead Water Company well. The well appears to have been drilled horizontally northward into the slope north of the fault zone. This well is still active.

Lineament L10 is a curvilinear feature that aligns with Daley Canyon, extends generally south-southeastward as it passes immediately east of Rimforest, and continues south-southeastward along a fairly straight, steep-walled canyon. Since this feature runs parallel to Daley Canyon Road, it could not be found crossing exposed bedrock. While this lineament does not directly affect the geologic structure controlling the Rimforest landslides, it crosses multiple other photo lineaments within the large, arcuate valley head located to the east of Rimforest.

Lineament L11 is a nearly straight lineament that extends from well north of the Twin Peaks area southward, nearly bisecting Rimforest. The lineament passes through the east end of the western landslide, and extends southwards along the Strawberry Creek wash, which becomes a nearly straight erosion gully as it passes south of the active landslide zones. This lineament crosses the on-site fault trace near the middle of the western landslide area. The fault trace correlates with lineament L8.

Infrared Aerial Photos

One set of infrared, false-color aerial photos were available for examination and analysis. This set, dated 1974, preceded destructive landsliding in Rimforest, the first of which occurred in 1978. Lineaments identified in other aerial photos were often more prominent in the infrared photos. Changes in vegetation water content indicated significant groundwater differences on different sides of lineaments.

Although there were no slope failures associated with the on-site Rimforest fault in 1974, a corresponding photo lineament was prominent and highly visible starting in an area southwest of Rimforest and continuing northeastward until it crossed Highway 18. This lineament was primarily delineated by significant changes in vegetation water content.

LANDSLIDE HISTORY

The San Bernardino Mountains have been pushed upward by tectonic forces resulting from differential movements of blocks situated north of the San Andreas fault and south of the North Frontal fault system. The mountain range has risen rapidly relative to geologic time, resulting in an over-steepened south face. The complexity of faulting and relative motion of the tectonic blocks has resulted in large areas of the south slope that have been shattered and crushed. The highly jointed, often shattered rock material allows meteoric waters to penetrate deeply, contributing to accelerated, deep weathering. Unstable conditions along the southern flank of the mountain range have been caused by over-steepened slopes, weakened bedrock, groundwater, and other conditions, which have been exacerbated by frequent seismic activity. Landslides are common throughout the southern face of the San Bernardino Mountains.

Three geomorphic valley heads are located in the Rimforest vicinity. The smallest and youngest valley head, located south of Rimforest, is currently undergoing rapid erosion; the remaining two valley heads are much older features and are located to the west and east of Rimforest. Both older valley head areas had eroded to their present, relatively stable condition prior to development of the Rimforest area, which began in the late 1800s.

Determining the ages of the amphitheatrical valley heads west and east of Rimforest was beyond the scope of this investigation. However, based on morphological evidence and on the nature of the vegetative cover, it appears that the Daley Canyon valley head is somewhat more mature than the Red Rock Wall valley head. As such, major erosion and landslide activity that formed the Daley

Canyon valley head probably terminated before major erosion ended in the Red Rock Wall valley head.

Despite the mature form of the valley heads on either side of Rimforest, erosion and mass wasting continue, albeit at a much slower pace. One active landslide was observed within the Daley Canyon valley head. This landslide was visible and active in the 1938 photos. More areas of instability, including talus slopes and other evidence of active erosion, were observed within the Red Rock Wall valley head. More areas of apparently active erosion were visible within Red Rock Wall valley head compared to the Daley Canyon valley head. However, this may simply result from easier access and greater visibility within the Red Rock Wall valley head.

The Strawberry Creek valley head, along the south edge of Rimforest, is just beginning its major, headward retrogression centered on the Strawberry Creek drainage. All studied landslide activity was located within the Strawberry Creek drainage.

CURRENTLY ACTIVE LANDSLIDES

Upon reviewing the landslide history in conjunction with available aerial photographs and Rimforest area development, an argument can be made that much of the landslide history is largely a result of the unknowing, yet adverse acts of man related to town development and fire protection over a period of several decades. We cannot say with certainty that these acts of man are the definitive trigger of such slope instability, but the chronology of the man-made events in relation to the chronology of the known slope failures is conspicuous and deserves mention. Based on geologic history of these slopes, eventually they would have become unstable on their own, but the process appears to have been accelerated by human activity.

The earliest documentation of landslides in the Rimforest area is a stereo pair of aerial photographs from 1938. All areas that are currently experiencing instability and landslide activity are visible on the photographs. Only two relatively small areas demonstrated active landsliding in the 1938 photos. A few buildings were visible along Highway 18, but there were no residential areas in Rimforest.

One slide area was located approximately 1,200 feet to the south-southeast of Blackfoot Trail East, just east of the abandoned Daley Road Truck Trail at latitude 34.226 N, longitude 117.219 W. This slide was situated on an uninhabited hill at the west edge of the Daley Canyon valley head. Active mass wasting was apparent. The affected area appeared to be somewhat smaller than the area appears today,

The second area, which is the Rimforest southeastern slide area, was located approximately 1,100 feet south of Blackfoot Trail East, at latitude 34.226 N, longitude 117.222 W. In the 1938 photos, this slide area appeared to be a very recent feature, and it was significantly smaller than it is today. Based on its apparent age, size, and general appearance, and on its proximity to a dozer-cut firebreak along the ridge, it seems likely that dozer activity may have initially triggered this slide. The dozer cut, which was partially overgrown in the 1938 photos, started in the Blackfoot Trail East area, which was undeveloped at the time. The firebreak continued downward along the ridge line, cut through a prominent hard rock outcrop approximately 800 feet to the south of Blackfoot Trail East, and continued southward along the ridge line past the limits of the photographs. In the 1938 photos, this landslide covered an area less than three acres. Today, the same slide covers approximately 6.5 acres, has retrogressed eastward, and involved part of an access road that used to be located to the east of the slide scarp.

The remaining areas, which are identified as the west and northeast slide areas, appeared to have oversteepened slopes with loose rocks and surface material visible through the vegetation. Although vegetation in these areas appeared to be relatively sparse, trees and brush were visible in the western and northeastern slide areas.

It should be noted that between the 1938 and 1953 photographs, development on the town of Rimforest had begun. The town of Rimforest primarily consisted of two tracts near the southern slopes at the south edge of town (See Plate No. 9). Both tracts were accepted by the County of San Bernardino in 1946. Tract No. 2986 makes up the eastern portion of Rimforest. Tract No. 2797 essentially contains the western side of Rimforest. As part of the tract development, a storm drain system was installed, which is still used today. The storm drain system collects runoff water through pipes and culverts and empties directly on the south facing slope near the present day sewer lift station (See Plate No. 1). Another drain lies immediately below the lumber yard (where the old pond use to drain) and also exits directly over the natural slope. This drain appears to carry surface water from both tracts.

By 1953, considerable development had occurred. The southeastern landslide had visibly expanded. Between 1953 and 1964, the southeastern slide had continued to expand, and mass wasting had begun in the western slide area. Rock fall activity appeared to be the predominant form of mass wasting in the western landslide area. No residential or other structures were affected at that time.

In 1978, the western landslide area below the storm drain pipe moved sufficiently in one incident to damage a sewage lift station that had been located south of Apache Trail. After the 1978 event, easily observed areas of the western landslide showed little to no activity for about eight years. In 1986, some additional movement of the western landslide was observed. By 1986, mass wasting in the western landslide included block slide and rock fall activity. Additionally, a new scarp appeared on the east flank of the drainage, south of Blackfoot Trail East. As described in previous reports, the new scarp was up to two meters in height.

In February 1993, a new landslide, located south of Blackfoot Trail East, began moving. This new landslide, identified in this document as the northeastern landslide, did not appear to be related to the large scarp originally reported in 1986. The 1986 scarp was located south and east of the northeast landslide area. Some earth movement of the western slide also was observed, although no additional structures were lost at that time. The newly activated landslide area, south of Blackfoot Trail East, was the largest single earth movement yet recorded in the Rimforest area. The slide covered an area of nearly 12 acres. The landslide activity in this area differed from the western slide area activity. While small block slides and rock fall defines the slide activity in the western slide area, a large, translational block slide occurred in the northeastern slide area. In 1995 the slide moved more than 60 feet downhill and may be 100 feet deep or more in its thickest sections. Several houses and a section of the Blackfoot Trail East road were damaged or destroyed during this slide. Much of the landslide material moved downhill as a single block, leaving numerous trees still standing and remaining in the same positions relative to each other. After the slide, the standing trees generally leaned a few degrees to more than 10 degrees toward the head scarp. After 16 years, many of these trees were still growing; many of the living trees have lower trunks that lean toward the head scarp, while the upper portions of the trunks have grown upright. Heavy precipitation in 1995 reactivated the Blackfoot Trail East landslide activity.

Since 1995, there have been two heavy rainfall years: 1998 and 2005. There has been no reported large scale, landslide activity in the Rimforest area since 1995. However, slow movement of earth material appears to have continued in at least two areas. Movement in these areas is likely to accelerate in the future when conditions occur that can trigger earth movement.

The first of the two areas which appear at most risk for new movement is located south of Apache Trail, south of the main portion of the western slide area. Sub-parallel scarps and fissures are present, including one that is almost two feet wide and is partially filled with loose boulders. Vertical visibility into this fissure is more than four feet, and the crevice appears open beneath the infilling rocks. Photographs of this area are included on Photo Plate Nos. 36 (2009) and 42 (1993) in the appendix of this report. The second area of concern is located to the east and southeast of the existing northeast landslide, south of Blackfoot Trail East. A head scarp was observed above and to the east of the existing slide, extending toward the south. This scarp is large enough, over ten feet in height in one area, that it is visible in aerial photographs. It was first described in 1986. The accessible portion of the scarp begins near the north edge of the southeastern slide area and continues northward to a point near the east edge of the northeastern landslide, approximately 240 feet south of a residence on Blackfoot Trail East. The scarp generally has about a 50 to 52 degree downward dip toward west. The failure plane angle is approximately the same as the measured scarp face on the northeastern landslide. Below the scarp, rock outcrops tend to be loose, often with the positions of large boulders visibly shifted. Photos of this feature are included on Photo Plate Nos. 16-18 (2009) and 43 (1993) within the appendix of this report.

PROJECT AREA GEOHYDROLOGY

The watershed that drains through Rimforest and to the slopes south of town is about 200 acres in size. Figure 6, “Drainage Features”, shows the watershed area outlined in red. The watershed is very small and contributes only a fraction of the water contained in the ground beneath the project area. As only a few percent of all precipitation is able to percolate to the water table, only a few tens of acre-feet can be contributed by the drainage area under the best of conditions. A small to moderate spring is capable of discharging almost 10 acre-feet of water in a year.

SURFACE WATER AND GROUNDWATER INTERACTION

Groundwater in the area is controlled by the geologic structure. Groundwater occurs in zones of fractured granitic bedrock and where the rock is highly weathered. Groundwater in areas of deeply weathered granitic rock will saturate the porous material, build up pore pressure, and behave more as soils. Where faults trap and impede (but not necessarily prevent) the downhill movement of groundwater, springs can occur when groundwater builds up behind (uphill of) faults from percolating rainfall, runoff, or snow melt. In the project area, the dominant orientations of the faults are ENE-WSW and WNW-ESE as shown on Plate 1. Other fracture zones are oriented more toward N-S and correlate with photo lineaments, as shown on Plate 8, “Photo Lineaments”. The north-south fracture orientation is also apparent in rosette diagrams of joint orientations, which are included in Appendix D. In the project area, the regional structure bends, slightly complicating the general pattern of faults and fractures perpendicular to one another. There are fault zones which are interpreted as representing compressional stresses and others interpreted as tensional in nature. Our opinion is that the tensional fault systems will behave as groundwater reservoirs similar to the fracture systems.

Figure 7 presents a simplified view of groundwater conditions interpreted from surface features near the project area. Southerly on the left and northerly on the right from the affected slopes to over the crest north of Highway 18, groundwater occurs in fractured rock zones trending north-south. Groundwater flow is impeded by faults in its attempt to reach lower levels. As rainfall and snow melt percolates into the ground, the water beneath the surface collects in "cells" between faults, rises and emits from the ground as springs at the intersections of fracture zones and faults. Springs will discharge until the water in the cell drains to the elevation of the ground surface intersection with the fault (when the blue water table line meets the dashed horizontal line).

A well placed into the fracture zone within a cell can lower the water table within the cell further, at times to the level of the intake within the well. If the well is sufficiently deep and the pump intake set sufficiently low, the water table within the cell could be lowered to the point that it may cease the gradual seepage of some groundwater toward the adjacent cell.

The area was formerly served water from local groundwater sources (a well) through Southern California Water Services (personal communication with Jason Hall, Big Bear Lake Department of Water and Power). When the water service was taken over by BBLDWP, about 20 years ago, the well was destroyed. The area has been served since then by a connection to Crestline-Lake Arrowhead Water Agency, with no local groundwater production.

Groundwater production from private wells continues to the west and south of the currently unstable area.

Figure 8, Rimforest Lumber Groundwater Elevation, shows observations of groundwater elevations in monitoring wells at the lumber yard. As is evident in the graph, these shallow wells were dry in most documented years.

PRECIPITATION

Rainfall records were viewed from the Lake Arrowhead Fire Station weather recording station. This is one of two weather recording stations in the project area vicinity; the second is located at the Lake Arrowhead Country Club. The fire Station records were chosen because they are more complete, and the geography of the station is closer to the drainage divide, and therefore may be more similar to the conditions at Rimforest.

Rainfall averages about 40 inches per year in the area. The rainfall over the period of recent slope failures in the project area generally has been above normal. Figure 9, Cumulative Departure from Normal Rainfall, presents annual rainfall from the Lake Arrowhead Fire Station weather station from 1965 until present. The starting year is based upon the fact that it represents a normal rainfall year. We then look at the annual rainfall, and the accumulated change from the previous year compared to normal. This is the easiest method for determining dry versus wet cycles, particularly when considering the potential impact of rainfall upon groundwater recharge.

RELATIONSHIP OF GROUNDWATER TO SLOPE INSTABILITY

We reviewed the groundwater levels observed in monitoring wells, which were located at Rimforest Lumber, the rainfall records, the accumulated departure from normal, and the timing of slope failure events. While the slope failures and occurrence of measurable groundwater were generally correlative with above-average annual rainfall, they were also correlative with accumulated departure from normal rainfall of greater than 40 inches above the zero departure level. The 1986 slope failure is evidenced by below normal rainfall; however, the accumulated departure from normal was 80 inches over normal (zero departure). While surface runoff may exacerbate slope instability, lateral hydrostatic pressure also must be considered in any mitigation solution. The presence of the Arrowhead

Water Company, horizontal well in the slope face southwest of Rimforest may be a contributing factor to the continuing stability of that slope by continually dewatering the slope.

LITHOLOGY

There were relatively few geologic units identified during this investigation, despite the large area of study. However, this is a fairly common occurrence in regions where widespread batholiths are exposed at the surface. All naturally occurring, geologic units encountered during the study were either some type of granitic rocks, in various states of weathering, or soil units composed predominantly of weathering products from the granitic rocks. The approximate boundaries and extent of major geologic units in the study area are presented graphically on Plate No. 1.

Artificial Fill, af (Latest Holocene)

Artificial fill soils were observed in association with structures, roadways, and the large, graded pads on the west side of Rimforest, immediately south of Highway 18. Small amounts of fill were observed along many of the roads, including the old, abandoned Daley Road Truck Trail, which is located east of Rimforest. While areas of fill were noted when encountered, investigation of the composition and condition of fill soils was not part of the project scope.

A second type of artificial fill (**afc**)was noted along the southwestern edge of Rimforest. A large deposit of disposed fluid concrete, concrete wash waste, and construction debris formed a large apron that extended from one empty building pad at the upper edge of the slope, at least 180 feet down the slope. The deposit appeared to be several feet thick in places and now blocks the access road for the Arrowhead Water Company well.

Alluvium, Qal (Latest Holocene)

Alluvium, in the form of active wash deposits, was encountered in two places in the study area. The first is located within the Little Bear Creek, northeast of Rimforest and north of Highway 18. This valley appears to receive drainage from hills located to the west and east, and it receives some runoff from Highway 18. The surface water flow direction is toward the north. Wash deposits within this valley were generally composed of very young, unconsolidated, gray, coarse-grained clastic sediments. Drilling through shallow wash deposits (Boring No. B-1) revealed alluvial material that contained cobbles and boulders. The composition of the sediments included granitic rock fragments, feldspars, quartz, and micas. The composition of these valley wash deposits was consistent with a granitic rock source.

The second area of active wash deposits is located on the other side of Highway 18, to the south of the first area. The environment of deposition is different, and the wash deposits in the area tend to be discontinuous and poorly developed. The wash deposits are found within a deeply incised gully, which begins near the top of the slope just south of the highway, and continues downhill toward the south-southeast. Runoff water from the south side of Highway 18 appears to have accelerated the natural erosion and resulted in significant damage to the abandoned Daley Road Truck Trail. The gully appears to become deeper as it continues down the slope. The wash deposits in this area were generally composed of very young, unconsolidated, light brownish gray, very coarse-grained clastic sediments. Cobbles and boulders in some places provided an impediment to stream flow velocity resulting in limited areas of sandy gravel deposits. Basement rock was exposed in much of the observed length of gully. Areas such as these contained little if any alluvial material.

An area of alluvial sediment was found in the town of Rimforest, centered near Rimforest Lumber on Pine Street. This area was visible on older aerial photos, prior to development along Pine Street. A new soil boring, which was being drilled by an environmental firm adjacent to the north edge of the Rimforest Lumber property on Pine Street, revealed alluvial soils to a depth of more than 40 feet below the surface. This area of alluvium aligns with a drainage flow pattern that has been redirected. Alluvial soils were also documented in field logs from a geotechnical report pertaining to the “Ultramar Gas Station”. Alluvial soils also would be expected within the old pond area near the south edge of town, but there was no documentation available concerning the areal extent or depth of this alluvium. Drainage from the hills north of Highway 18, including Strawberry Peak, used to flow eastward through what is now Rimforest, then turn northward and connect to Little Bear Creek, the remnant, north-flowing drainage system (located northeast of Rimforest).

Undifferentiated alluvial deposits were encountered in many places scattered around the Rimforest area. Sourced from granitic parent rocks, the alluvial soils appeared to have a similar mineralogical makeup over most of the study area. Differences in sorting, weathering, oxidation, and organic content accounted for most of the physical differences between differing alluvial deposits in the Rimforest area. Observed alluvium ranged from light gray and light brown, fine to coarse sand (SP) with varying amounts of gravel, to yellow gray, sandy silt (ML). Within forested areas, the addition of organic detritus to the soil resulted in a brown to dark brown humus.

Landslide Deposits, Qls (Latest Holocene)

Deposits of active landslide material were observed in three areas within the Strawberry Creek drainage south of Rimforest: the western slide lies south of Apache Trail; the second, the northeastern slide, is located south of Blackfoot Trail East; and the third is approximately one quarter-mile south of the town. A fourth active landslide area is located approximately one-quarter mile to the southeast of Rimforest within the Daley Canyon valley head. Talus deposits were also observed on the south-facing hillside just north of Highway 18, and within the valley head erosional features to the east and west of Rimforest.

The single largest earth movement associated with the Rimforest landslides is the northeastern slide. The upper end of this slide contains moderately disturbed rock and soil that moved downhill as a relatively cohesive unit. Observed from the surface and along the edges of the slide, the landslide material is composed primarily of highly weathered and fractured monzogranite and related granitic material, which appears to belong to the Monzogranite of City Creek. Surficial material also included displaced alluvial and colluvial soils. Surface soils generally appeared to be sands (SP) and silty sands (SM) derived from weathering of the parent granitic rock. While soil and rock that comprised the upper portion of the slide appeared to be only moderately disturbed by downhill movement of the slide block, the lower portion of this slide was much steeper, and the landslide deposit appeared to be less competent. The lower portion of this slide had a similar appearance to the other two slide areas south of Rimforest. The loose and highly disturbed material appeared to be moving downhill primarily as rock and debris slides.

The remaining two active landslide areas south of Rimforest are the western slide and the southeastern slide. Both slides, and the Daley Canyon valley head landslide, appear to have been shaped primarily by topple, rock fall, and debris slides. Steeply dipping joint planes subparallel to the cliff face and within the deeply weathered and highly jointed granitic basement rock, apparently form large slabs that, when triggered, result in translational block slides, rock slides, and debris flows. The resulting landslide deposits, partially collected at the bases of steep, landslide scars, are composed of unconsolidated, massive mixtures of silt, sand, cobbles, and boulders. Much of the slide debris is formed from very weathered and friable material, which is relatively easily eroded from the slope base by heavy runoff. The larger, competent cobbles and boulders more often tend to remain near the slide base for a longer period of time, as it takes exceptionally heavy runoff to provide sufficient energy to move them. However, topographic maps, aerial photographs, and visual observations confirm that runoff within the Strawberry Creek wash has cut very steep slopes into the landslide deposits and into the weathered basement rock at the bases of the adjoining slopes.

Most of the granitic rock within the latter three landslide scarps appears to be part of the Monzogranite of City Creek (Kcc). The southern one-third to one-half of the western slide is a slightly different composition and appears to belong to the Mixed

Granitics of Silverwood Lake (Mzsl). Observed Mzsl within the Rimforest area generally tends to form steeper, more stable cliffs than the Kcc. Within the western landslide, the Mzsl is less weathered, more competent, and has larger joint spacing. As a result, rock fall and topple apparently occurs within the Mzsl more easily and more frequently than it does within any exposure of Kcc south of Rimforest.

Colluvium, col (Holocene)
Colluvial soils can be observed on most of the slopes in and around Rimforest. Formed from weathering of underlying basement rock, the colluvium in this area was generally observed to be a light yellow brown to gray brown, slightly silty to silty, fine to coarse sand (SM, and SP/SM). Observed colluvium was generally poorly consolidated. In most places around Rimforest, the colluvial soils were a few inches to a few feet in thickness. In a few, limited locations, the colluvial soils were observed to be up to 13 feet thick, and may have been thicker.

Grading of the pads on the west side of town exposed sections of colluvial soils up to 13 feet in thickness. Deep colluvial deposits are often found below the head scarp of older landslides, formed as the colluvial soil collects at the base of the scarp, on top of the landslide deposit. Earlier studies in Rimforest concluded that deep colluvial soils on the Rimforest bench could have been formed as part of an ancient, very large landslide. However, the deep colluvium west of Rimforest was found just east of a north-south trending fault that had measured vertical displacement of at least 15 feet. Further research could more accurately establish total horizontal and vertical displacement of this fault and its association with deep colluvial deposits above the footwall.

Fault Breccia, Qfb (Quaternary)
An area of crushed and brecciated rock debris is visible on the southern end of the western landslide. This material is located within and adjacent to the fault zone. Because of the steep and unstable nature of the cliff face, the fault breccia was not directly examined. From a distance, and based on its color and apparent hardness, it appeared to be composed Mzsl.

Monzogranite of City Creek, Kcc (Middle Cretaceous)

The entire Rimforest area is underlain by Mesozoic age, granitic basement rock. Generally, the rock underlying the Rimforest area is a coarse-grained, leucocratic, phaneritic to porphyritic, intrusive igneous rock complex with an average mineralogical content that classifies it as monzogranite to granodiorite. Of the two, named geologic units, Monzogranite of City Creek (Kcc) was found to be the underlying basement rock in most of the Rimforest area. Kcc is variable in mineralogical content, color, texture, and weathering. Fresh to slightly weathered specimens and outcrops are usually medium- to coarse-grained. However, pegmatite dikes within the Kcc, which had feldspar crystals more than 3/4 of an inch in size, were observed in several locations. Melanocratic inclusions, ranging from a few millimeters to several feet in size, were found in the Kcc. Most of the heterogeneous inclusions were observed in the eastern part of the study area. Although Kcc is classified as a monzogranite, mineralogical variation in limited areas resulted in differing colors and rock types. Colors ranged from white, to pinkish gray, to medium gray. Identified rock types in limited areas within the monzogranite included granite, granodiorite, and small amounts of diorite.

While there is great variability within this unit, a few characteristics generally distinguished Kcc from the other named geologic unit, Mixed Granitic Rocks of Silverwood Lake (Mzsl). Pink orthoclase feldspar crystals were very common within the Kcc. In areas where the monzogranite was porphyritic, large phenocrysts of orthoclase were characteristic of Kcc and were not observed in any samples of Mzsl. The Kcc, within the Rimforest area, tends to weather more deeply than the Mzsl. Near vertical cliffs composed of Kcc were rare: only one was found south of Rimforest. In an oversteepened slope, the Kcc was observed to be less competent and tends to erode, often by mass-wasting, to a shallower slope. Variability of mineral content within the Kcc unit included definable areas of granodiorite (**Kccgd**) within the primary unit. While there are some resistant outcrops, none form a cliff face higher than about 10 feet. Most of the hillside, which is not part of a resistant outcrop, is covered with talus composed of fragments of Kcc.

Extensive areas of crushed and deeply weathered bedrock zones were primarily found in the Kcc unit, and crushed, weathered Kcc was observed in most slope faces immediately below Rimforest. The only observed zone of crushed and deeply weathered Mzsl was found within the fault zone in the area of the Arrowhead Water Company production well, south of the western part of Rimforest. Severely decomposed zones within the Kcc unit were found in and around all three active landslides south of Rimforest, in a large zone to the east of the southeastern landslide, surrounding the active landslide southeast of Rimforest within the Daley Canyon valley head, and in several zones along the old Daley Road Truck Trail, between the southeastern landslide and Highway 18. Most of the material in the Qls deposits is composed of Kcc. Some Mzsl is present in the landslide deposits, but it appears to be limited to materials resulting primarily from rock fall originating in the spur of hard, resistant Mzsl found at the south edge of the western landslide.

All drilled bedrock samples obtained during this investigation were either Kcc or deeply weathered and altered Kcc. Our field observations and laboratory testing, indicated that the characteristics of the crushed and deeply weathered samples of Kcc behave more as soil than as rock.

Mixed Granitic Rocks of Silverwood Lake, Mzsl (Early Triassic to Middle Cretaceous)

Mzsl was only found in the western part of Rimforest and on the steep, south-facing cliff of Strawberry Peak. While Mzsl is quite variable in appearance, on average it is darker gray and slightly finer-grained than the Kcc observed during this study. The darker gray color results from a higher biotite and amphibole content, on average, than was observed in the Kcc. In places where the Mzsl has a porphyritic texture, the phenocrysts are composed of a white feldspar.

The Mzsl in the Rimforest area tends to be more resistant and has wider joint spacing than observed Kcc. As such, Mzsl commonly forms nearly vertical cliffs, as seen on the south face of Strawberry Peak. Nearly vertical cliffs over 30 feet in height were found southwest of Rimforest along the abandoned Arrowhead Water Company well access road. Much higher, nearly vertical cliffs can be seen in the southern portion of the western landslide. Instability of the western landslide cliffs and the orientation of their major joints has resulted in rock fall and topple.

GEOLOGIC STRUCTURE

In most areas, varying depths of colluvial soils, top soil, and moderate to heavy vegetation covered the basement rock, leaving only hard rock outcrops and fragments of rock at the soil surface (float) as visible evidence of underlying geologic units. Several road cuts in the Rimforest area exposed substantial amounts of bedrock, providing greater information about the lithology, geologic structure, and bedrock conditions. Two roads provided most of the cut slope exposure around Rimforest: approximately 1,600 of exposed rock in road cut along an unnamed road southwest of Rimforest (which was used to access an Arrowhead Water Company well); and, the Daley Road Truck Trail, which had over 3,200 feet of exposed rock in road cut. One of the most important aspects of geologic structure in Rimforest is the on-site Rimforest fault. The zone of sheared and weathered rock surrounding this fault has poor strength, is easily eroded, and is visible within the head scarps of the western and northeastern landslides. This fault is discussed in the following seismicity and faulting section.

BASEMENT ROCK JOINTING

Local and regional joint patterns, formed by directed stress of tectonic forces along nearby active faulting, comprise much of the geologic structure in the Rimforest area. As seen in aerial photos, the Rimforest area is crisscrossed by photo lineaments. Some of the lineaments have been field verified to be faults and shear zones. Others simply reflect dominant joint patterns or other linear structures or zones of weakness within the basement rock.

Rosette diagrams of joint attitudes along the five cross-section lines, which are included in Appendix D, demonstrate moderate to strong correlation between predominant joint patterns and observed photo lineaments.

The western landslide initially appeared to be controlled by the Rimforest fault. However, a prominent north-south lineament crosses the fault near the middle of the failed area. A rosette diagram of nearby joint attitudes confirms the presence of significant north-south jointing. It appears likely that the degraded condition of the rock in the western landslide is largely due to the fault. However, the intersection of the Rimforest fault and the north trending joint pattern appears to have created a significantly larger volume of weathered and weakened rock. Based on other observations, it is reasonably assumed that a shear zone could be associated with the north trending jointing and prominent photo lineament in this location. While it was guessed that a north trending shear zone may be found in the north wall of the western landslide, it could not be verified by direct observation. The location of the landslide may be significantly affected by the north trending joint pattern, however, it is impractical to try to separate the potential influence of the north trending joint pattern from the visible effects of the storm drain, which lies immediately above the western landslide area, and which focuses much of the Rimforest runoff into a stream that impacts the base of the slope after a free fall approximately 200 feet in height. It is assumed that a significant amount of erosion and undercutting has occurred in this area over the years.

The Rimforest fault passes along the north edge of the northeastern landslide. A significant north trending photo lineament crosses through the head of the landslide, and a northwest trending photo lineament passes above the toe of the northeastern landslide. A rosette diagram shows strong north trending and east-northeast trending patterns to the joints, nearly parallel to a photo lineament and the on-site Rimforest fault.

SHEAR ZONES

The 1978 Rasmussen report identified a west-northwest trending fault that crossed through the neighborhood immediately north of the current location of the western landslide. Projecting the Rasmussen's un-named fault eastward showed it passing through the north end of the northeast landslide. This fault was not directly recognized within Rimforest during our field study. If projected eastward, the fault identified by Rasmussen appears to align fairly closely with a shear zone found in a Daley Road Truck Trail road cut. While this is not proof of the presence of this fault, neither can the possibility of its existence be eliminated.

In addition to the confirmed on-site Rimforest fault, there were numerous shear zones observed in road cuts, cut slopes, and natural slopes in and around the Rimforest area.

A few large shear zones, characterized by areas of crushed, pulverized, and deeply weathered basement rock, were found in the Daley Road Truck Trail road cut as it passes Rimforest. There was insufficient evidence found during this study to determine the amount or direction of displacement for most of these shear zones. The extent and quantity of shattered and weathered material along this slope resembles exposed rock within the landslide areas and indicates its vulnerability to erosion. Erosion vulnerability is demonstrated by deep, recent erosion resulting from Highway 18 runoff that is directed down the north end of this slope. Additional runoff water probably would rapidly accelerate existing erosion in this location.

A large shear zone was found in the road cut just east of the southeast landslide. This shear zone had no measurable offset. However, by its size and location, as the southeastern landslide retrogrades eastward, it will continue to cut into the highly weathered material in this shear zone.

A significant shear zone was found in the slope cut south of the Rimforest self-storage. This shear zone was over 50 feet in width, but it had no discernable offset. The projected location of the Rimforest fault passes through this shear zone area, as does a very small northwest trending fault observed in the Blackfoot Trail East road cut.

Numerous smaller shear zones, some only a few inches wide, were observed primarily in the eastern part of Rimforest in slope cuts along Highway 18, Blackfoot Trail East, and in the large cut slope located south of the gas station and self storage.

RECENT CHANGES IN DRAINAGE PATTERNS

Evidence from topographic maps, alluvial patterns, and aerial photos shows that drainage has changed direction in the recent past. Drainage from Strawberry Peak, the hills north of Rimforest, and most of the Rimforest area previously flowed eastward along what is now Pine Street, then turned northeastward to connect with Little Bear Creek, northeast of Rimforest. Erosion along the southern edge of the Rimforest bench eventually intercepted some of the natural runoff flow, redirected it toward the south, down the steep slope, and into the Strawberry Creek channel. Construction of Highway 18 appears to have altered the natural flow of runoff and may have contributed to redirecting additional runoff toward the steep slopes south of Rimforest. Natural redirection of surface runoff flow and construction of Highway 18 occurred prior to the 1938 aerial photos, but evidence of past drainage had not yet been disturbed by development. During development of Rimforest, the southerly drainage through town was dammed to produce a small, man-made lake. The lake was used for recreation and to entice new buyers to the area. The lake was drained following recommendations included in the 1978 Rasmussen report.

Development has altered natural surface drainage patterns. As Highway 18 passes through Rimforest, it runs between the base of the hills, north of the road, and the bench on which the town of Rimforest is located. Highway 18 intercepts some of the runoff water from adjacent hills and directs it southward through two culverts. Some runoff from the highway drains into Little Bear Creek, as evidenced by very recent erosion and active wash deposits within the branched stream channels. Some runoff from Highway 18 is directed southward, downhill, and into the Daley Canyon valley head immediately adjacent to the east-facing slope below Blackfoot Trail East. Excess runoff, which exceeds culvert capacity, can cross Highway 18, where it can flow into town and drain southward toward the western landslide area. As runoff approaches the cliff south of Apache Trail, it is collected into two storm drain pipes, which then direct runoff over the cliff and into the western landslide. Runoff continues to drain southward through the Strawberry Creek wash toward the San Bernardino area.

TECTONICS AND FAULTING

ON-SITE FAULTING

The 'Rimforest fault' was a significant fault identified on the subject site. This fault has been observed, measured, and photographed by several individuals and was studied during this investigation. The Rimforest fault zone consists of at least two, nearly parallel traces that cross the southern edge of town from the west-southwest toward the east-northeast. This fault, as shown on Plate No. 1, passes to the south of all houses located on Apache Trail, through the head scarp of the large, northeastern landslide and across Blackfoot Trail East. Based on the best verified location and orientation, this fault crosses under or very near one residential structure before continuing off the subject site toward the east-northeast. There is insufficient data about the Rimforest fault to determine whether or not is active. Vertical offset of this fault was observed at the northern edge of the northeastern landslide head scarp where the fault passes out of the landslide area and continues through the east end of Rimforest. A thin soil layer, only a few inches thick, was observed on the south side of the fault, with soil up to about three feet deep on the north side of the fault. The Rimforest fault was examined in several places. However, no lateral offset was identified during the field study. Although there was apparent vertical offset at one spot on this fault, there was insufficient evidence found to indicate whether it was a strike-slip or dip-slip fault.

The 1978 study by Gary Rasmussen found a west-northwest trending fault that passed north of the western landslide area and into the north end of the northeastern landslide. The approximate location of this fault is shown on Plate No. 1. While this fault does agree with some photo lineament evidence, field evidence of this fault was not identified during this investigation. However, a west-northwest trending shear zone was found southeast of Rimforest. If projected westward, it aligns fairly closely with the Rasmussen fault. A flowing spring also is located along this shear zone. Further study would be required to confirm the existence of the Rasmussen fault, and to determine if it is connected to this shear zone.

Three east-west trending, planar discontinuities were found in road cuts east of Rimforest. They displayed north-dipping angles of 24 to 43 degrees; all three had somewhat less weathered, more competent granitic rock above and more softer, more deeply weathered granitic material beneath the contacts. Based on the physical condition of observed materials, on the shallow angles of the features, and the apparent bedrock displacement, which left rock units of significantly different physical condition in contact, all three appear to be old thrust faults. While it is possible these features may be old thrust faults, there was insufficient evidence to positively identify them. Unsuccessful attempts were made to connect these features to other features both east and west of their exposures.

A second confirmed fault was found to the west of Rimforest. Based on the offset, this north-trending fault was either a left-lateral strike slip, or a normal fault with the hanging wall on the west side and the down-dropped footwall on the east. Vertical offset between the two sides was observed to be approximately 15 feet at this location. The fault broke a layer of dark brown soil, indicating motion along this fault appeared to have occurred relatively recently. As such, this unnamed fault also should be considered to be potentially active, but further investigation would be needed for a determination. This fault aligns with a prominent photo lineament, Lineament No. L-9, as shown on Plate No. 8. All faults and shear zones located on-site or adjacent to the Rimforest area have been displayed graphically on Plate No. 1.

SLOPE STABILITY ANALYSIS

ROCK SLOPE STABILITY ANALYSIS

Analytical Procedure

Five cross-sections of slopes south and east of Rimforest were selected for analysis. Cross-section A is located on the slope south of the western portion of Rimforest. As of the date of this report, no evidence has been found in this location indicating eminent slope failure. Cross-sections B and C are located on the western and northeastern landslide areas, respectively. Cross-section D is located between the northeastern and southeastern landslides. A long, 10-foot high scarp, which appeared in the mid-1990s, is indicative of the eminent failure of this slope. Cross-section E is located on the large, east-facing slope, east of Rimforest and south of Daley Canyon within the Daley Canyon valley head. While no evidence of eminent failure was found during this investigation pertaining to this slope, one proposed mitigation for controlling surface runoff would reroute surface runoff waters down the wash adjacent to this slope. Locations and orientations of the five cross-sections are shown on Plate No. 1.

Slope stability analysis involved collating collected field data (bedrock discontinuity attitudes) and observations, and applying the data into a suite of slope stability software. The slope stability analytical software used for this study was procured from RocScience, Inc. Three programs were used for data processing and slope stability analyses: *Dips* v. 5.1, *Swedge* v. 5.0, and *RocPlane* v. 2.0.

Information on the behavior of seismic coefficients ('k' factor) in slope stability analyses, which pertained to the application of a 'k' value to the RocScience programs used in this study, was supplied by Dr. Reginald Hammah (personal communication, 2009). Further information on the application of 'k' factors to slope stability problems was obtained from California Special Publication SP-117A (2008). The 'k' factor, which was used in the pseudo-static analyses in this study, was determined by application of the equation: $k_{eq} = f_{eq} * MHA_r$. While SP-117A indicates that the use of strong motion records are preferred for establishing the value of MHA (maximum horizontal acceleration), available strong motion records for this project required extensive extrapolation in order to correlate with known site conditions. Because of the lack of reasonably correlative strong motion data, the PGA (peak ground acceleration) obtained from the USGS 'Probabilistic Seismic Hazard Deaggregation Program' website (http://eqint.cr.usgs.gov/deaggint/2002/index.php) was used as the MHA in the above equation. The factor f_{eq} was determined by applying the MHA to the Median f_{eq} curves (Blake and others, 2002). Based on information from Dr. Hammah and other sources, the Median f_{eq} curve based on a displacement threshold of 15cm was used giving an f_{eq} = 0.44. Then, applying these numbers, $k_{eq} = f_{eq} * MHA_r$ becomes k_{eq} = 0.44 * 1.0161g. The 'k' coefficient used for these analyses was k_{eq} = 0.45g.

Determination of laboratory rock strength and cohesion values were not part of the scope of work for this project. Estimated values for encountered rock types were obtained from Table I and Table III in, *Rock Slope Stability* (1974, Hoek and Bray). In order to simplify procedures, and because no rock strength analyses were conducted, the same rock strength parameters were used for all analyses. Based on field observations and descriptions in the text, the value of 0.5kgf/cm^2 was selected (converted to ton/ft^2) and used for all analyses. The angle of internal friction used for all analyses was 40°, which was the approximate midpoint of the given range within the text.

Dips was used to collate planar attitude data from each of the cross-section areas. Stereonets were plotted from the data, including equal angle, equatorial plots of the poles and planes. The data also were used to create contour plots on equal area, equatorial projection stereonets and rosette plots. The stereonets were examined for potentially important, out-of-slope planar features, for sets of intersecting plane pairs, and for analyzing apparent planar discontinuity trends.

Slope failure analysis techniques of *RocPlane* focus on planar, block slide, translational slope failures. While planar failures in igneous basement rock, which are not associated with existing joint attitudes, are generally uncommon, much of the observed rock in four of the five slopes examined in this analysis contained large areas of highly fractured, crushed, and deeply weathered material that may exhibit behavior that more closely resembles soil than that of typical, jointed crystalline rock. Observations of the Rimforest landslides support this hypothesis: the largest observed slope failure, the northeastern landslide just south of Blackfoot Trail East, was a translational slide along a nearly planar failure surface that did not correlate with observed planar discontinuity trends.

Initial analysis of potential planar failures focused on observed planar discontinuities with unfavorable, out-of-slope attitudes. Initial results did not correlate well with field observations, because existing failure planes did not correlate with major measured planar discontinuities. Because of the shattered and weathered nature of rock material in the studied slopes, a different approach for planar failure analysis was tried. The 'sensitivity analysis' feature of RocPlane was used to determine the highest probability failure plane based on slope geometry and estimated rock strength parameters. This conservative approach yielded results that more closely resembled observed conditions, compared to results of the initial analyses. Three diagrammatic plots were generated for each cross-section: static factor of safety; pseudo-static factor of safety; and a plot incorporating groundwater effects. The groundwater plot was achieved by using the groundwater void and pore percentage saturation that generated a factor of safety as close to FS=1.00 as possible. Groundwater content higher than designated in the groundwater plots will result in factors of safety below FS=1.0 and a greatly increased probability of slope failure.

Swedge v. 5.0 was used to analyze planar discontinuity sets for any potentially problematic intersections that could result in deep-seated wedge failures. Slope geometry and rock strength parameters used in the analyses were the same as those used in the RocPlane analyses for each cross-section. Additionally, while the default setting for joint length in Swedge assumes each joint has a maximum available trace length within the height and length of the slope, joint lengths are scalable to match field observations. For example, Cross-section A in this study was found to have one potential wedge failure. Scaling the joints down to 330 feet, rather than the default 950 feet for this potential wedge, increased the factor of safety to greater than FS=1.2, even with 100% groundwater saturation. However, for the purpose of this report, a conservative approach was used, wherein joint lengths were not scaled but were left at the program default length.

Most of the wedge-failure analyses resulted in very high factors of safety. As such, and because of the large number of planar intersection combinations, all analyses were screened by initially including both a seismic coefficient and a groundwater factor of 100% saturation. Only wedge-failure analyses that had a factor of safety less than FS=1.2 with combined seismic and groundwater factors were assigned wedge numbers and reexamined. If a potential wedge had a combined groundwater and seismic factor of safety greater than FS=1.2, analytical results were not elaborated in the report text and the data output for that wedge was not incorporated into Appendix D. Potential wedge failures identified by *Swedge* were analyzed for the groundwater saturation percentage that would result in a factor of safety as close to FS=1.00 as possible. A stereonet and a readout of analytical parameters and results were generated for each intersecting planar discontinuity set that represented a potential wedge failure.

The default setting for the rock slope stability programs were designed around generalized rock slopes, but most slope geometry, rock density and strength, and force parameters are user-configurable. Primary user input for groundwater parameters consists of varying the percentage saturation of the rock slope, or rather, the percentage of fractures and voids within the rock that are filled by groundwater. There are other user-variable, groundwater parameters as well, including water density and the location on the slope at which the greatest groundwater pressure would be expected. User configurable seismic parameters include the seismic coefficient, applied horizontally or with a user-defined, vertical component up to 90 degrees. Additionally, statistical means, deviations, and sampling methods can be applied independently each input parameter providing for probabilistic analyses as well deterministic.

One factor that cannot be configured into these programs is the presence of an active or potentially active fault within the slopes. The Rimforest fault is present south of Rimforest, and it passes through three of the geologic cross-sections in this report. Rupture of this fault within the weakened slopes could result in sudden, significant, and possibly dangerous slope failures that can be neither predicted nor accounted for through the use of predictive software.

Graphic plots and information readouts for pertinent slope stability analyses used in preparation of this report are included in Appendix D.

Cross-Section A

There were no slope failures observed in the area of cross-section A. Located on a south-facing slope, this section profile revealed a relatively uniform gradient, except along the line where the Rimforest fault zone traverses the slope. A bench, which is over 50 feet in width as shown in cross-section, appeared to result partially from the fault zone and partially from human activities. An Arrowhead Water Company supply well is present at this location. This well takes advantage of the groundwater barrier effect of the Rimforest fault by utilizing a horizontal well that taps northward into shallower groundwater on the upgradient side of the fault. Water from the well is carried by pipeline downslope toward San Bernardino.

Rock quality north of the fault was generally observed to be competent and very hard, with moderately-spaced jointing. Individual major joints in outcrop were continuous over distances often exceeding 30 feet; due to the discontinuous nature of rock exposures, maximum joint trace length could not be measured. Dominant joint trends, which were apparent in the field, were verified on a rosette diagram. No potentially problematic, out-of-slope planar discontinuities were indicated on the stereonet. The rosette diagram reveals a strong correlation between patterns of planar discontinuities and three photo lineaments (See Plate No. 8, “Photo Lineaments”): the northwest-trending L5, the northeast-trending L9 (which corresponds with the Rimforest fault), and the north-trending L11. Correlations between on-site, planar discontinuity patterns and major photo lineaments are more apparent with Cross-section A than with any other cross-section.

Wedge failure analysis of this cross-section was limited to the two-thirds of the slope above and to the north of the fault. The fault represents a nearly vertical, planar barrier beyond which planar features and joint intersections are unlikely to continue. Analysis found only one potential wedge failure from the set of planar attitudes utilized for this cross-section. The characteristics of this intersection would require groundwater saturation of 95% for the length of the projected intersection in order to reduce the factor of safety to FS=1.0. As such, deep-seated wedge failures are considered to be unlikely on this slope.

There were no out-of-slope planar discontinuities in Cross-section A that could lead to a planar failure. A planar failure based on the analyzed, highest probability failure plane appears to be unlikely on this slope, because of the competent, hard rock visible in outcrop at the surface. However, since the competence of the rock deeper beneath the surface is unknown and may be similar to the observed rock quality in the nearby, Cross-section B, a planar failure analysis was completed in the same manner as the other four cross-sections. Based on the highest probability failure plane, the analysis indicated this slope has a static factor of safety (FS) of FS=1.62 and a pseudo-static FS=0.73. The addition of significant groundwater, sufficient to fill 51% of fractures and voids in the lower portion of the slope, would reduce the FS to 1.01. If the upper portion of the slope, north of the fault, is analyzed separately, the static FS=1.76 and the pseudo-static FS=0.80. The upper slope is more sensitive to water than the slope taken as a whole. If groundwater water saturation reaches 61%, the factor of safety reduces to FS=1.00.

The Arrowhead Water Company has a water production well on this slope. Since its construction, the Arrowhead well has been dewatering the slope. Dewatering the slope north of the fault will help reduce groundwater quantity and reduce seepage through the fault plane to the lower portion of the slope. It appears to be likely that the presence of the Arrowhead Water Company well may be beneficial to maintaining the integrity of this slope.

Cross-Section B

This slope has significant and ongoing slope failures. While landsliding was first noted in 1978 when a sewage pump station was damaged, aerial photographs revealed slope failures beginning more than 20 years earlier. Located on a southeast-facing slope, the Rimforest fault zone crosses the south portion of this landslide area. Primary slope failures include rock fall and topple in the upper portion of the slope and apparent translational block sliding on the lower slope. The total height of the slope depicted in cross-section is approximately 670 feet, however, only the upper 300 feet of the slope was used in the rock slope stability evaluation. The lowest portion of the slope, which is approximately 370 feet in height, appears to be covered with landslide debris. Since this material appears to be composed of loose debris with an unknown depth, it was not included in the rock slope stability evaluation for Cross-section B.

Intersections of planar discontinuities are visible on the stereonet, which required analysis of the intersections to determine if potential wedge failures are likely. The rosette diagram indicated a fair correlation between the orientation of planar discontinuities and nearby, north-south and southwest-northeast photo-lineaments, including the lineament to the south of Cross-section B that correlates with the Rimforest fault.

Analysis of planar discontinuity intersections found no significant probability of deep-seated wedge failures for Cross-section B.

Planar failure analyses were conducted on Cross-section B using the highest probability failure plane. The upper slope analysis included only the upper 50 feet, which had an incline of nearly 61-degrees; the lower slope, which was approximately 250 feet in height, had an average inclination of 43 degrees. The lower slope had a static FS=1.75 and a pseudo-static FS=0.82. Factors of safety for the upper slope were: static FS=1.92 and pseudo-static FS=1.01. Adding a groundwater component to the upper slope analysis indicated that fracture and pore filling greater than 68% would be required for a high probability of slope failure. However, it should be noted that significant tension cracks, which would allow rapid infiltration of meteoric and runoff waters, were observed in the upper slope. As such, the probability for a failure of the upper slope of this cross-section appears to be likely at times when 1) there has been sufficient prior precipitation to significantly increase groundwater presence, and 2) during a heavy precipitation event that will be able to inject large quantities of water directly into existing tension cracks. This failure probably would extend up slope only as far as the tension cracks. However, based on observations from past slope movement in this area, new tension cracks probably would form above the new slope face, setting the stage for future slope failures as erosion continues in a headward direction. In the lower slope, groundwater saturation, filling greater than 48% of voids and pores, would substantially reduce the factor of safety and increase the probability of planar slope failure.

Cross-section C

This cross-section is located at the western edge of the largest landslide, by volume, in the Rimforest area. Some of the material within this cross section is composed of landslide debris. Normally, this part of the cross-section would have been excluded from rock slope stability analysis. However, most portions of the slide examined in the field appeared to show relatively little disturbance from landslide movement; it appears as though the slide block moved downhill while remaining largely coherent. Based on this observation, and the fact that the toe of this block has been eroded into a 60-degree slope, a rock stability analysis was performed that included the landslide deposit.

Analysis of bedrock discontinuity intersections revealed 19 joint sets in this slope have a significant potential to produce a deep-seated wedge failure. While most of the potential wedge failures required 70 to 90 percent saturation to produce a failure, one joint intersection set was more critical. Cross-section C, Wedge No. 19, required only 33% saturation to reduce to FS=1.05. Increasing the percentage saturation only slightly rapidly reduced the factor of safety well below FS=1.0.

Planar failure analysis indicated this section of slope to have a static factor of safety of FS=1.64 and a pseudo-static F=0.79. However, this slope was found to be very sensitive to groundwater. Adding a groundwater saturation factor of 27% (filled voids and fractures) resulted in an FS=1.01. Any increase in groundwater content above this level resulted in a rapidly reduced factor of safety.

Erosion from surface waters within the Strawberry Creek wash has cut a steep lower face out of the toe of the slope. The lower slope stands at about 60 degrees and is approximately 120 feet in height. The static and pseudo-static factors of safety for the lower slope were FS=1.44 and FS=0.72, respectively. Groundwater saturation of 50% (of filled voids and fractures) resulted in a factor of safety of FS=1.00 for the lower slope of Cross-section C.

Cross-section D

Cross-section D is located between the northeastern and southeastern landslides, although it includes neither. This cross-section includes a large scarp, which is located near the top of the section, that measures up to 10-foot in height and dips 52-degrees toward the southwest. The position and angle of the existing scarp was included as a tension crack in the slope stability calculations for this cross-section.

Except for the previously mentioned scarp, no other out-of-slope planar discontinuities, which appear to have a deleterious alignment with the existing slope face, were found on the stereonet. Several planar attitude intersections are apparent, which were addressed by wedge failure analysis. The rosette diagram indicates a strong correlation between joint attitudes and a nearby photo lineament L8, which correlates with the Rimforest fault. A weaker correlation with a northwest-trending photo lineament is also apparent.

Using the highest probability failure plane for this slope, the factors of safety were: static FS=1.63, and the pseudo-static FS= 0.74. Based on results of this analysis, the slope analyzed in Cross-section D appears to be very susceptible to groundwater. Adding a groundwater saturation factor of only 35 percent reduced the factor of safety to FS=1.01. This slope appears to have a very high failure risk during seasons with higher than normal precipitation.

As is the case with Cross-section C, the toe of the slope in Cross-section D has been eroded by runoff leaving a 125-foot high slope that has an average gradient of almost 59 degrees with a static FS=1.46 and a pseudo-static FS=0.73. Adding a 45% saturation factor resulted in an FS=1.01.

Wedge-failure analysis revealed three joint data sets in cross-section D that could be problematic. All have a static factor of safety above 1.5. Adding groundwater to these joint sets produced potential wedge failures in the analyses. One set required 73% saturation in order to reduce the factor of safety to FS=1.0. The other two joint sets required 88 and 90% to reduce to FS=1.0.

Cross-section E

Cross-section E is located to the east of Rimforest and lies on the western slope adjacent to a drainage gully. In its current condition, and utilizing the planar dip angle with the highest probability for failure, this slope has a calculated static factor of safety of FS=1.73. The pseudo-static factor of safety was FS=0.73. With a slope height of 680 feet, the addition of a groundwater factor of 53% (filled voids and fractures) reduces the factor of safety to 1.01.

Mitigation Option No. 2 would route most surface runoff water from the Rimforest area down this gully and across the toe of this cross-section. Based on the observed, recent gully erosion from the top of slope downward, beyond the Daley Road Truck Trail, and based on obserfved effects of water within the Strawberry Creek drainage, it is likely that increased water flow within the drainage gully would undercut the toe of the slope and significantly reduce its stability. Based on the topographic effects of erosion in the Strawberry Creek drainage, we reevaluated the slope stability of this cross-section, assuming a lower erosion-cut slope of 100 feet in height and a 60-degree slope face angle. Using the highest probability failure plane, the calculated static factor of safety was FS=1.37 and the pseudo-static was FS=0.71. Adding a groundwater factor of 50 percent saturation resulted in a factor of safety of FS=1.00. As has occurred within the Strawberry Creek drainage, water saturation at the toes of the slopes apparently is easily achieved when large amounts of runoff water are carried within the drainage channel. Based on observations of poor rock conditions within much of the slope in question, and based on results of slope stability calculations, there appears to be a high probability that rerouting surface runoff through this drainage gully would eventually result in active landslide activity similar to what is occurring south of Rimforest.

Wedge-failure analysis revealed three potentially problematic joint data sets in cross-section E. These joint sets are sensitive to added water. All three require 40% or less saturation of the intersecting planes to reduce the factor of safety to FS=1.0 or less. To illustrate the potentially catastrophic sensitivity of this slope to increased groundwater, one potential wedge failure was found to have a factor of safety of FS=1.2 with 40% saturation; increasing the saturation only one percent to 41% saturation (of voids and fractures) reduced the factor of safety to FS=0.8.

PRELIMINARY HAZARD BOUNDARY LINES

Preliminary hazard boundary lines (static) were established based on the resulting highest probability failure planes. By extending these potential failure planes upward from the toe-of-slope (or from the lowest area on the slope that was included in the analysis) to the top of slope created a point above the existing slope that represented the 'static' hazard boundary at each cross-section. The points were then extrapolated laterally as lines that connected the points on all five cross-sections . The same procedure was used to establish pseudo-static preliminary hazard boundary lines. The pseudo-static lines were based on results of the pseudo-static analyses. Based on rock slope stability analysis, areas of increased risk to existing structures are graphically depicted on Plate No. 1.

SLOPE STABILITY ANALYSIS, SOIL MATERIALS

Gross stability analyses were performed for two cross sections for existing slopes that are present within the project area. The slopes were evaluated for gross stability under static and pseudostatic (seismic) conditions.

Stability Parameters

The location of the slopes analyzed are presented on Plate No. 1, presented in the map pocket in the Appendix A. The stability analyses were based on the average peak shear strength parameters obtained from shearing relatively undisturbed samples obtained from the various materials on the site. The shear test results are presented in the Appendix A, and are summarized in the following table:

SAMPLE LOCATION	MATERIAL DESCRIPTION	MOIST UNIT WEIGHT (pcf)	PHI-ANGLE (Degrees)*		COHESION (psf)*	
			Peak	Ultimate	Peak	Ultimate
B-4, 13'-13.5'	Weathered Granitic Basement Rock: Breaks down into gray-brown, fine to coarse sand, trace silt, a little gravel (SM)	115.0	53	28	432	120
B-5, 8.5'-9'	Weathered Granitic Basement Rock: Breaks down into light gray, silty, fine to coarse sand (SM)	94.7	29	29	312	312
B-5, 26'-26.5'	Weathered Granitic Basement Rock: Breaks down into light orange-gray to white, clayey, fine to medium sand, some silt (SC)	119.3	32	33	512	56
B-5, 46'-46.5'	Weathered Granitic Basement Rock: Breaks down into olive-gray, clayey to silty, fine to coarse sand (SM/SC)	117.9	43	39	304	256
	Average	111.7	39	32	390	186
* Specimens were tested in submerged condition.						

Stability Analyses (Analyses Using Soil Type Material)

The computer program used to compute the safety factors for the gross slope stability under static and pseudo-static (seismic) conditions was GSTABL7 by **Garry H. Gregory**. This program is a 2-dimensional, limit equilibrium slope stability program, which works in conjunction with **STEDwin** program. The static and seismic (pseudo-static) analyses were performed in general accordance with guidelines in the California Department of Conservation, Division of Mines and Geology, 2008, Guidelines for Evaluating and Mitigating Seismic Hazards in California, Special Publication 117A.

Design Groundwater Conditions: Groundwater conditions for the static and pseudo-static slope stability evaluations for the subject site were not used in the analyses and have been assumed to be a depths deeper than the cross sections used.

Strength Parameters: The strength parameters used in the stability analyses were selected as the peak value of the shear test results. A Phi Angle (angle of internal friction) equivalent to 39 degrees and cohesion equivalent to 390 psf were used in the analyses.

Seismic Coefficient: A coefficient of horizontal acceleration (kh) of 0.2g was utilized for the pseudo-static analysis based on the close proximity of the subject site to the active faults and the guidelines presented in *Guidelines for Evaluating and Mitigating Seismic Hazards in California*, Special Publication 117A.

Static Slope Stability: The static analyses were performed in general accordance with **California Department of Conservation, Division of Mines and Geology**, 1997, *Guidelines for Evaluating and Mitigating Seismic Hazards in California*, Special Publication 117. The results of the static slope stability analyses are shown in Appendix E. The 10 lowest Factors of Safety are presented on the plates for each slope analyzed. In addition, a search was performed to determine a minimum set back distance from the top of the slope to where a Factor of Safety of 1.5 was achieved for static conditions. The results of the static slope stability analyses are summarized in the following table:

SUMMARY OF SAFETY FACTORS FOR GROSS STABILITY (STATIC)		
SECTION ANALYZED	**MINIMUM FACTOR OF SAFETY (STATIC)***	**DISTANCE FROM TOP OF SLOPE TO A MINIMUM FACTOR OF SAFETY OF 1.5 (STATIC) (Ft.)**
B-B’	1.2	300
C-C’	1.1	400

Actual factors of safety and set back zones for slopes may very significantly from those indicated due to actual slope heights, slope inclinations, soil and rock material type strength parameters, etc. at various locations for the various slopes throughout the Rimforest area. Although the overall slope inclinations are similar (i.e., 1.45H:1V for cross-section B-B' and 1.54H:1V for cross-section C-C') and the strength parameters were assumed to be the same for the two (2) slopes, differences in the set back distances for the required minimum factors of safety are present. It should be noted that the overall heights of the slopes analyzed were significantly different (i.e., 665 feet for cross-section B-B' and 1170 feet for cross-section C-C') and that cross-section B-B' was significantly steeper in the upper one-third of the slope while cross-section C-C' was significantly steeper at the toe of the slope. These differences account for the significant variances in the set backs for the minimum factor of safety for each slope evaluated.

Pseudo-Static Slope Stability: Pseudo-static analyses were performed using a coefficient of horizontal acceleration (k_h) of 0.2g. The results of the pseudo-static slope stability analyses are shown in Appendix E. The 10 lowest Factors of Safety are presented on the plates for each slope analyzed. In addition, a search was performed to determine a minimum set back distance from the top of the slope to where a minimum Factor of Safety of 1.1 was achieved for pseudo-static conditions. The results of the pseudo-static slope stability analyses are summarized in the following table:

SUMMARY OF SAFETY FACTORS FOR GROSS STABILITY (PSEUDO-STATIC)		
SECTION ANALYZED	MINIMUM FACTOR OF SAFETY (PSEUDO-STATIC)*	DISTANCE FROM TOP OF SLOPE TO A MINIMUM FACTOR OF SAFETY OF 1.1 (PSEUDO-STATIC) (Ft.)
B-B'	1.1	18
C-C'	0.8	600
* The seismic coefficient of horizontal acceleration used in this analysis was 0.2g.		

Actual factors of safety and set back zones for slopes may very significantly from those indicated due to actual slope heights, slope inclinations, soil and rock material type strength parameters, etc. at various locations for the various slopes throughout the Rimforest area. Although the overall slope inclinations are similar (i.e., 1.45H:1V for cross-section B-B' and 1.54H:1V for cross-section C-C') and the strength parameters were assumed to be the same for the two (2) slopes, differences in the set back distances for the required minimum factors of safety are present. It should be noted that the overall heights of the slopes analyzed were significantly different (i.e., 665 feet for cross-section B-B' and 1170 feet for cross-section C-C') and that cross-section B-B' was significantly steeper in the upper one-third of the slope while cross-section C-C' was significantly steeper at the toe of the slope. These differences account for the significant variances in the set backs for the minimum factor of safety for each slope evaluated.

SLOPE STABILITY DISCUSSION

The rock slope stability analysis relied on estimated rock strength parameters gleaned from texts. The ring samples acquired during drilling from an area near the western landslide provided strength parameters for highly decomposed bedrock materials and were obtained and tested using standards for testing soils. The measured strength parameters were much lower than expected for rock.

The soil slope stability analyses resulted in significantly lower static factors of safety than did the rock slope stability analyses of the same slopes. When the measured strength and density parameters that were used for the soil analyses were substituted into the rock slope stability analyses, similar static factors of safety results were attained.

The estimated strength and density parameters were used in the final rock slope stability analyses as a means of contrasting and comparing soil and rock stability results and reaching more realistic conclusions. When evaluating and contrasting results of the two types of slope stability analyses, the soil slope stability results appear to be too conservative for observed site conditions. This type of analysis can take into account neither areal limits of deeply weathered and degraded rock material, nor the competence and proximity of intact, crystalline rock. As seen in Boring No. 2, harder, more resistant rock material may underlie or be located adjacent to soft material. This would have the effect of rendering analyses based on soil slope stability unreasonably conservative for known conditions.

Likewise, the rock slope stability analyses appeared to be too optimistic for conditions at Rimforest, because they were based on estimated rock strength parameters that were much higher than existing conditions in some areas, as shown by shear data obtained during this study. In order to produce more accurate rock slope stability analyses, rock strength from different areas on each cross-section slope would need to determined. As such, the actual slope stability factor of safety and hazard setback boundary for the required minimum factor of safety probably lies between the two values determined by rock and soil stability analyses. The one slope for which rock slope stability analyses are probably not optimistic is the slope shown in Cross-section A, which, with the exception of material within the narrow fault zone, was primarily composed of hard and resistant rock.

Despite the optimistic rock slope stability analyses under static conditions, the critical nature of the amount and location of groundwater pressure added to these slopes was emphasized by their effects on the analyses. In all planar cases, sufficient groundwater resulted in reduced stability; groundwater pressure beyond a certain threshold resulted in rapidly reduced safety factors. The rock stability analyses also pointed out how the relatively small erosion cut slopes at the toes of larger slopes are very sensitive to groundwater pressure. The eroded slopes can fail resulting from a relatively small fraction of the amount of groundwater required to cause the larger slopes to fail. Of even greater concern, when one the lower slopes fail, it reduces support of the overlying slope and leads to future failure of the larger slope.

The probability of slope failure is also related to seismic events. If a major seismic event on nearby faults occurred, such as a projected magnitude **M7.5** on San Andreas fault, or a magnitude **M7.2** on the North Frontal fault zone, high ground accelerations would be experienced at the site. Under these conditions, all slopes analyzed for this investigation are subject to failure. Actual seismic forces in such an event would not be applied equally, nor would the force vector be the same for all affected slopes. To predict the most vulnerable slopes would require the use of actual, measured rock strength parameters, and it would need a more detailed analysis of seismic force parameters from a given seismic event and how force vectors from that event would apply to each slope. Analysis of this type was beyond the scope of this investigation.

Slope movement within the Rimforest landslide area has been sporadic. Years of inactivity have been punctuated by brief, large earth movements, and each landslide area has behaved independently of the others. While some estimates of past movement were available for the two slide areas closest to Rimforest, the southeastern landslide area does not affect any structures, and no measurements of slope movement were found during this investigation.

The first large movement in the western landslide was reported to be approximately 60 feet of headward retogression (Rasmussen 1978). Slope movement on the western landslide has been reported several times since 1978. The rate of movement from 1978 to 1989 estimated to be about 5 feet per year (Cody 1989). Headward retrogression of the western landslide toward Apache Trail from 1978 to 1993, inclusive, was approximately 115 to 120 feet, averaging up to eight feet per year. Joseph E. Bonadiman & Associates conducted a comparison of two topographic maps, one from April 1993 and the other from January 2009. The comparison provided information about bluff retreat near the storm drain pipe just south of Apache Trail during that time period. A metal pipe used for survey (MP13) was 18.5 feet behind the edge of the bluff in 1993. By 2009, the bluff had retreated about 7.5 feet behind the MP13 location, and MP13 had dropped about 12 feet in elevation. This portion of the bluff receded at a rate of up to 8 feet per year from 1978 to 1993, and at a rate of about 0.75 feet per year from 1993 to 2009. Recent headward retrogression of the landslide in this area appears to be related to continued erosion caused by runoff water discharged from the storm drain pipe.

The 1986 scarp, located south of Blackfoot Trail East, was reported to be about two meters in height in 1993. The scarp measured approximately three meters in height in July 2009. It is unknown whether the additional meter of movement occurred during or after 1995.

The Rimforest fault crosses through the two landslide areas that are closest to town. It appears to define much of the existing headscarp of the northeastern slide at Blackfoot Trail East. While this fault is clearly defined, including fault gouge observed within the fault trace, there is insufficient information at this time to determine how much displacement has occurred on the fault, what type and direction of displacement has occurred, or whether the Rimforest fault is active. A rupture of the Rimforest fault could further destabilize both landslide areas through which is passes. Since occupied residential structures still exist above areas where the Rimforest fault passes through both landslides, further destabilization of these two slopes could have potentially tragic results. However, there is insufficient information at this time to provide an assessment of either the probability of fault rupture or the probable effects of such a rupture on slope stability. Further study will be required to make such an assessment.

Mega-slide Discussion

Rasmussen and Associates, Inc. (1978) postulated the possibility that the entire Rimforest area is part of a large mega-slide. One interpretation of the Rimforest area geomorphology surely suggests its potential. However, no direct evidence was encountered during this study to confirm its existence, nor is a mega-slide needed to explain observed features. Additionally, several photolineaments, including the Rimforest fault, cross through the outlines of the postulated mega-slide without interruption. This would indicate that any such landslide would have to predate these lineaments, or that no mega-slide exists. Complex tectonic and bedrock structural elements and weathering patterns provided sufficient explanation for landslide activity and erosional patterns in and around the Rimforest area.

CONCLUSIONS

GENERAL CONCLUSIONS

On-site Faulting and General Seismicity

The town of Rimforest, as does most of southern California, lies within the seismic influence of numerous active faults. Active faults present a variety of potential risks to structures, the most relevant to Rimforest are strong ground shaking, mass wasting, and potential surface rupture along the Rimforest fault. No known seismic activity has been directly correlated with the Rimforest fault, and most observed displacements along this fault, noted during this study, are believed to be related to slope instabilities and probably are not seismically generated. At this time, the activity status of the Rimforest fault has not been determined. However, since overlying soils appear to have been displaced, and until additional work can be done, it is our opinion that the fault should be considered to be potentially active. A rupture on the Rimforest fault has the potential to further destabilize landslide areas adjacent to town.

Ground shaking and potentially catastrophic slope failure as a result of seismic ground shaking is considered to be one of the primary hazards most likely to affect the site, based upon proximity to the potentially active Rimforest fault and 10 other regionally significant active faults: the North Frontal fault (western segment), the Cleghorn fault, the San Andreas fault (San Bernardino, Coachella, and Mojave segments, and the 1857 rupture), the San Jacinto fault (San Bernardino and San Jacinto Valley segments), the Cucamonga fault, and the Helendale-S. Lockhardt fault. A seismic event capable of producing a maximum magnitude earthquake along any of these aforementioned faults has not been experienced in the Rimforest area since the town's inception. Based on results of our preliminary slope stability analyses, such an event could be catastrophic. Additionally, our analyses shows this condition would only worsen if underlying bedrock materials are saturated.

Slope Retrogression

Between 1978 and 1993, a period of frequent landslide movement in the area south of Apache Trail, headward retrogression was estimated to have been up to eight feet per year. As part of this study, Joseph E. Bonadiman and Associates, Inc. compared a topographic map based on a 1993 survey to a new topographic map, based on a 2009 survey, in the area near the top of the slope, south of Apache Trail. The 1993 survey information was obtained from previously installed metal pipe stations. This comparison of survey information has allowed us to estimate a rate of failure or slope retrogression over the last 16 + years. The most notable area of difference is near and immediately below the storm drain outlet where storm water currently free falls approximately 200 feet before hitting the eroded slope face. Based on results of their analysis, the top edge of the slope has receded approximately 26 feet over the past sixteen years, and the vertical loss of material at the pipe location was approximately 12 feet. Given this information, we estimate that this area has an annual slope regression of approximately 0.75 feet per year from 1993 to 2009. This estimated regression appears to be largely a result of erosion only and is expected to continue until this storm water can be diverted.

The remainder of slopes south of Rimforest are much more complex and less predictable. Using today's standards, our slope stability analyses shows much of the area south of Rimforest to be technically unstable to marginally stable, at best, under static conditions. This appears to result largely from the presence of very weak bedrock materials coupled with an abundance of jointing and faulting in the immediate area. Additionally, it is our opinion that the groundwater component and degree of bedrock saturation plays a significant role in overall stability of current slope faces and the overall stability of the area. Looking at the history of slope failures, our study indicates that timing of such events has appeared to be unpredictable, but it is largely dependent upon rainfall accumulations. Given that the area is marginally stable at best, the addition of a groundwater component has created a mode of failure that also may be potentially catastrophic.

The slope failures to date show a general migration west to east occurring largely along the Rimforest fault. This migration is further aggravated by continued erosion and undercutting of weak bedrock materials on the west side (immediately below the storm drain outlet), within the slide mass immediately below Rimforest, and at the toes of slopes in the Strawberry Creek wash that are being undercut by erosion from runoff carried within the channel. The north-south developing scarp on the east side, south of Blackfoot Trail East, has continued to creep downward and has enlarged somewhat since it was first recognized in 1986. In 1993, this scarp was estimated to be about '2 meters' in height. Since then, movement has enlarged the highest part of the scarp to more than 3 meters (10 feet). Its eventual failure will represent a further migration of failed slopes toward the east and fits with this model. As such, determining an annual rate of regression cannot be estimated with certainty but given the documented conditions, regression is expected to continue.

Slope failure as a result of a significant seismic event also cannot be predicted but would likely be potentially catastrophic. Seismically-induced landslide movement would be dependent upon the size, proximity and duration of a seismic event as well as the groundwater conditions and degree of saturation of bedrock materials at the time.

GEOTECHNICAL FEASIBILITY OF OPTION 1

Option 1, as described in the **Joseph E. Bonadiman & Associates Inc.** 'Drainage Feasability Study' for the subject project, is to divert runoff northward to Little Bear Creek. Runoff would be directed through the **Church of the Woods** property, which is located on the north side of State Highway 18. The hydrology study map for the project indicates, to alleviate future flooding and reduce negative impact on Little Bear Creek, three (3) interconnected basins would be constructed on the **Church of the Woods** property, as shown on the 'Proposed Options No. 1 & 2, Hydrology / Hydrologic Map,' Exhibit F, presented in the 'Drainage Feasibility Study.'

Two (2) borings (B-1 and B-1A) were advanced on the **Church of the Woods** property as part of this study. The borings encountered alluvium overlying granitic basement rock. Alluvium observed at the boring locations was approximately 13 feet thick. Groundwater was encountered in boring B-1A at a depth of 28.5 feet below existing ground surface at the boring location, which was 15.5 feet below the soil/bedrock contact within the boring.

An 'Engineering Geology and Soils Engineering Investigation', which was performed by **LOR Geotechnical Group, Inc.** for development of the **Church of the Woods** property, indicated there were approximately 2.0 to 15 feet of highly organic topsoil, alluvium, and colluvium overlying granitic basement rock on the property.

Topsoil generally consisted of silty sands with varying amounts of organic materials, fine, medium and, coarse sands. The alluvium / colluvium on the **Church of the Woods** property generally consisted of fine- to coarse-grained sands with a trace silt (SP), slightly silty to silty, fine- to coarse-grained sands with varying amounts of gravel, cobbles and small boulders (SP/SM to SM), and slightly silty, sandy gravel with cobbles (GP/GM).

From a geotechnical / geologic stand point, construction of the proposed three (3) basins should not present any adverse condition on the **Church of the Woods** and/or the adjoining properties. However, additional geotechnical / geologic studies should be performed on the **Church of the Woods** property to properly design the retention basin facilities. Additionally, as part of the future investigation, more information with respect to actual groundwater depths, groundwater flow direction, and groundwater gradient should be determined to further evaluate the potential impact of developing the basin system with respect to slope conditions south and east of the town of Rimforest. At this time, it is assumed that the groundwater gradient follows existing drainage and is towards the north. However, prior to development of this property, this condition should be verified by future studies.

GEOTECHNICAL FEASIBILITY OF OPTION 2

Option 2, as described in the Joseph E. Bonadiman & Associates Inc. 'Drainage Feasability Study' for the subject project, would divert runoff away from the Strawberry Creek drainage, then down the slope on the south side of Highway 18 just east of Rimforest, and ultimately into the tributary drainage located south of Daley Canyon. This is the least expensive option, and it would result in surface runoff waters remaining within the Santa Ana Watershed.

Most of the information required to evaluate this option resulted from mapping of geologic units, structure, apparent rock condition and quality, and attitudes of planar discontinuities. One exploratory boring, No. B-2, was drilled south of Highway 18 near the proposed runoff diversion. The drill rig, which used an 8-inch diameter, hollow-stem auger, reached refusal at 11 feet below ground surface in dense basement rock.

Several shear zones and at least one small fault were identified within the slope to the east of Rimforest, as shown on Plate No. 1. These features have resulted in large areas of crushed and deeply weathered rock on this slope.

While field mapping for geological data, we also observed deeply incised erosion in the precise path proposed as the runoff diversion location for Option 2. The erosion had severely damaged the old Daley Road Truck Trail. A steel gas main, which runs concurrent with the old Daley Road Truck Trail in this location, was exposed and left poorly supported by erosion that has occurred since the pipeline was installed. Much of the erosion damage, from about 100 feet below Highway 18 to well below old Daley Road Truck Trail, appeared to be relatively recent, and probably has been exacerbated by increased runoff down this slope created by construction of Highway 18.

Rock slope stability analysis for this slope used the same, ‘typical’ rock strength as was applied to four other areas during this study. The slope stability analysis found this slope to have adequate static stability characteristics. The addition of groundwater significantly increased the probability of slope failure.

Based on runoff erosion damage within the Strawberry Creek drainage, a second analysis was conducted, which assumed erosion would cut a 100-foot high, 60-degree notch into the toe of the subject slope similar to erosion features observed within the Strawberry Creek wash. The stability analysis indicated that a projected erosion cut at the toe of the larger slope would be very sensitive to groundwater pressure and would be expected eventually to result in failure, which would contribute to destabilizing the upper slope.

It must also be noted here that the slope stability analyses were conducted using estimated rock strength parameters. Since much of the affected slope contains zones of crushed and deeply weathered rock, the strength of those areas is likely to be closer to the shear data obtained by Hilltop Geotechnical, Inc. from drill samples in the area of the Rimforest western landslide. While the rock slope stability analyses conducted for the subject slope indicated an increased probability of slope failure if the toe of slope is undercut by erosion, the results of those analyses must be considered optimistic when compared to results expected when using strength parameters from the crushed zones.

Based on data analysis, observations of rock quality and recent erosion damage in the area that will be affected by Option 2, and based on observations concerning the causes of landsliding in the Strawberry Creek drainage, there appears to be a high probability that Option 2 will significantly increase erosion at the toe of slope immediately east of Rimforest. Removing support from the toe of the slope will reduce slope stability and could result in creating retrogressing landslide conditions similar to existing conditions in the Strawberry Creek drainage south of Rimforest.

Because of the high probability that runoff redirected to flow along the base of the subject slope would destabilize the slope, and because of the potentially serious consequences of triggering a new retrogressing landslide area, Option 2 is not considered to be feasible from a geotechnical standpoint.

RECOMMENDATIONS FOR ADDITIONAL STUDY

The primary purpose of this study was to estimate the efficacy of different plans that were designed to redirect surface runoff in an attempt to retard headward erosion of unstable slopes south of Rimforest. In evaluating this, it is our opinion that controlling surface runoff using Option 1 would significantly help slow the slope retrogression into the southern portion of Rimforest.

However, based upon our analysis, groundshaking as a result of a substantial earthquake could severely impact the community of Rimforest, especially the dwellings near the southern edge of town. Our slope stability evaluations, from both a soil and rock perspective, indicate significant failure areas beyond the current top of slope. Although quite variable, nearly all of our analyses show current conditions below today's standards (>1.1 F.S.). The addition of a groundwater component during a significant seismic event would significantly lower values even more.

Additionally, the Rimforest fault was identified within the unstable areas south of town in the mid-1990s and was confirmed during this investigation. The activity status of the Rimforest fault is currently unknown. Rupture of this fault within unstable slopes could have sudden and potentially catastrophic consequences. However, it was beyond the scope of this investigation to establish whether or not this fault is active. We recommend further study of the Rimforest fault that should be focused on past movement of the fault, its status as active or not, and evaluation of potential effects of fault rupture on landslide areas. A study of this type should help quantify the potential threat to the town of Rimforest should a rupture of the Rimforest fault occur within the unstable landslide areas.

With respect to groundwater, one problem encountered during this study was the lack of nearby, relevant groundwater information. Numerous water wells previously had existed in the Rimforest area, but none were found that recorded static water elevations, and nearly all of the wells have since been destroyed. Several monitoring wells have been installed at the Rimforest Lumber yard, but these wells are generally shallow (less than 50 feet deep) and often dry. The lack of groundwater information limited our analysis of the actual effect groundwater has on slope stability. Our stability analyses were based upon projections of degrees of saturation and not upon actual measurements. Still, results strongly suggest the degree of bedrock saturation will adversely affect slope stability below the town. Additionally, an evaluation of rainfall records suggests that the accumulated departure from normal rainfall appears to correlate well with the timing of past events, thereby suggesting that the presence of groundwater indeed impacts slope stability as well as affecting the timing of such events.

To better address future slope stability, we recommend additional groundwater investigations should be performed. Monitoring wells should be installed to obtain a better understanding of Rimforest hydrology. Additionally, if a significant amount of groundwater is encountered, de-watering alternatives should be considered in conjunction with proposed surface water mitigation. A significant amount of groundwater may warrant commercial development of such wells, thereby creating a win-win scenario.

Once Rimforest hydrology is better understood, more detailed slope stability evaluations should be performed. Due to wide variations of rock quality and the large amount of highly decomposed rock, the analyses should be conducted to include rock strength analyses in critical areas, and it should include both rock and soil stability evaluations. We recommend additional field exploration and sampling for rock and soil strength evaluations to be conducted for these analyses in order for more specific evaluations to be performed. More refined hazard boundary lines then can be established.

Much of the bedrock materials that make up the slopes below Rimforest consist of highly decomposed bedrock materials. These materials are much weaker than intact bedrock and much more erodible, more prone to becoming saturated and more prone to rotational and translational slope failure. As such, it is our opinion that controlling surface runoff by re-routing it away for the existing slopes will significantly help the town of Rimforest by reducing the impact of further slope erosion and instability. The storm drain that currently free falls 200+ feet can rapidly scour an already over-steepened area and should be re-routed.

APPENDIX A

Plate Nos. 1 thru 19

PLATE NO. 1 - GEOLOGIC MAP

COMMUNITY OF RIMFOREST, COUNTY OF SAN BERNARDINO, CA

PLATE NO. 1 - GEOLOGIC MAP
VICINITY OF THE COMMUNITY OF RIMFOREST
COUNTY OF SAN BERNARDINO, CA

HILLTOP GEOTECHNICAL INCORPORATED

BY	MARK	REVISION DESCRIPTION	DATE
JDN		ENTIRE EXHIBIT	01/2010

PREPARED FOR: S.B.C.F.C.D.
JOB NO.: -
PREPARED BY: JDN
CHECKED BY: MH

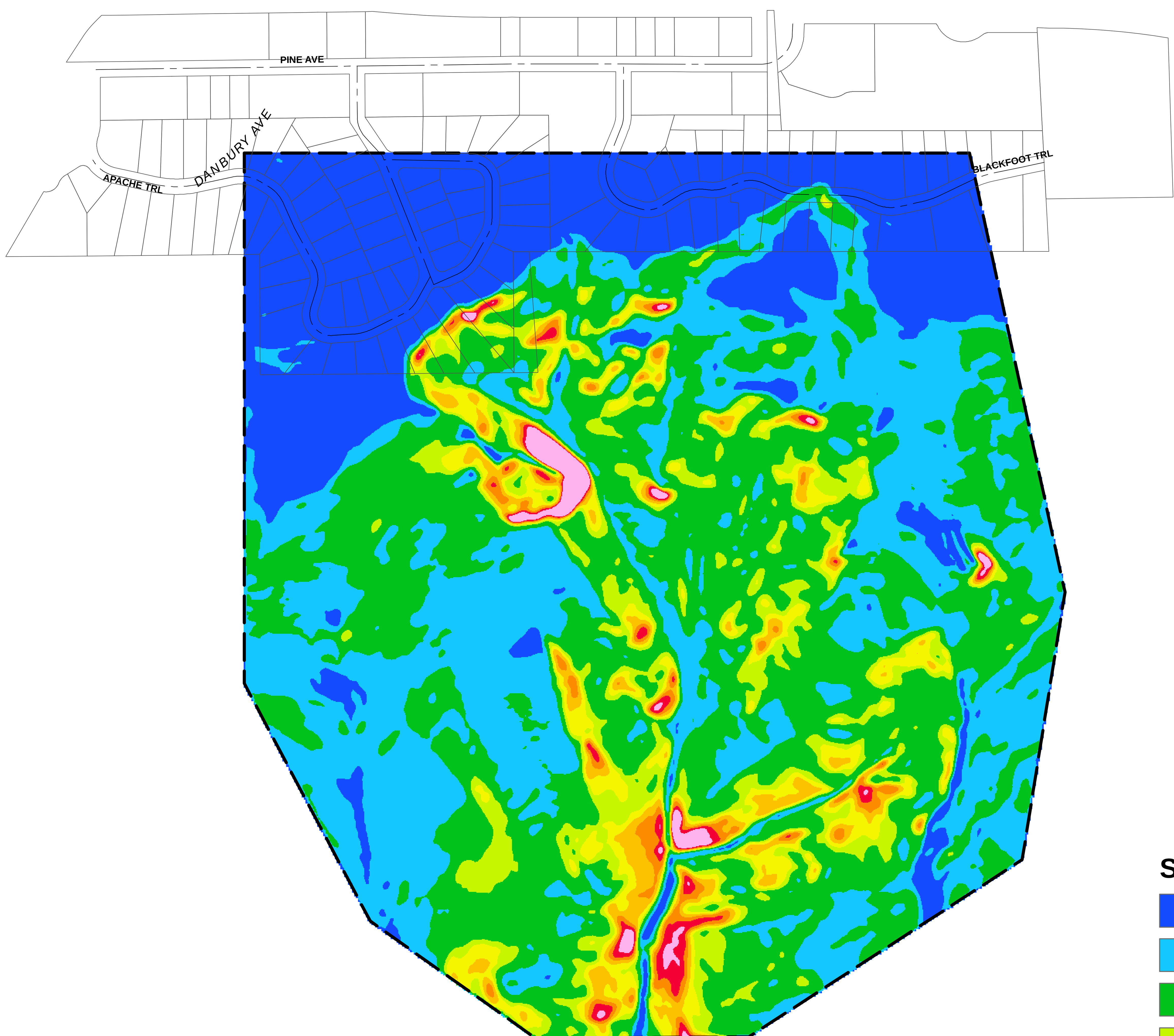
NOTE: Hilltop Geotechnical does not warranty the accuracy of the G.I.S. data presented in this Exhibit. This Exhibit may contain information copyrighted to the County of San Bernardino.

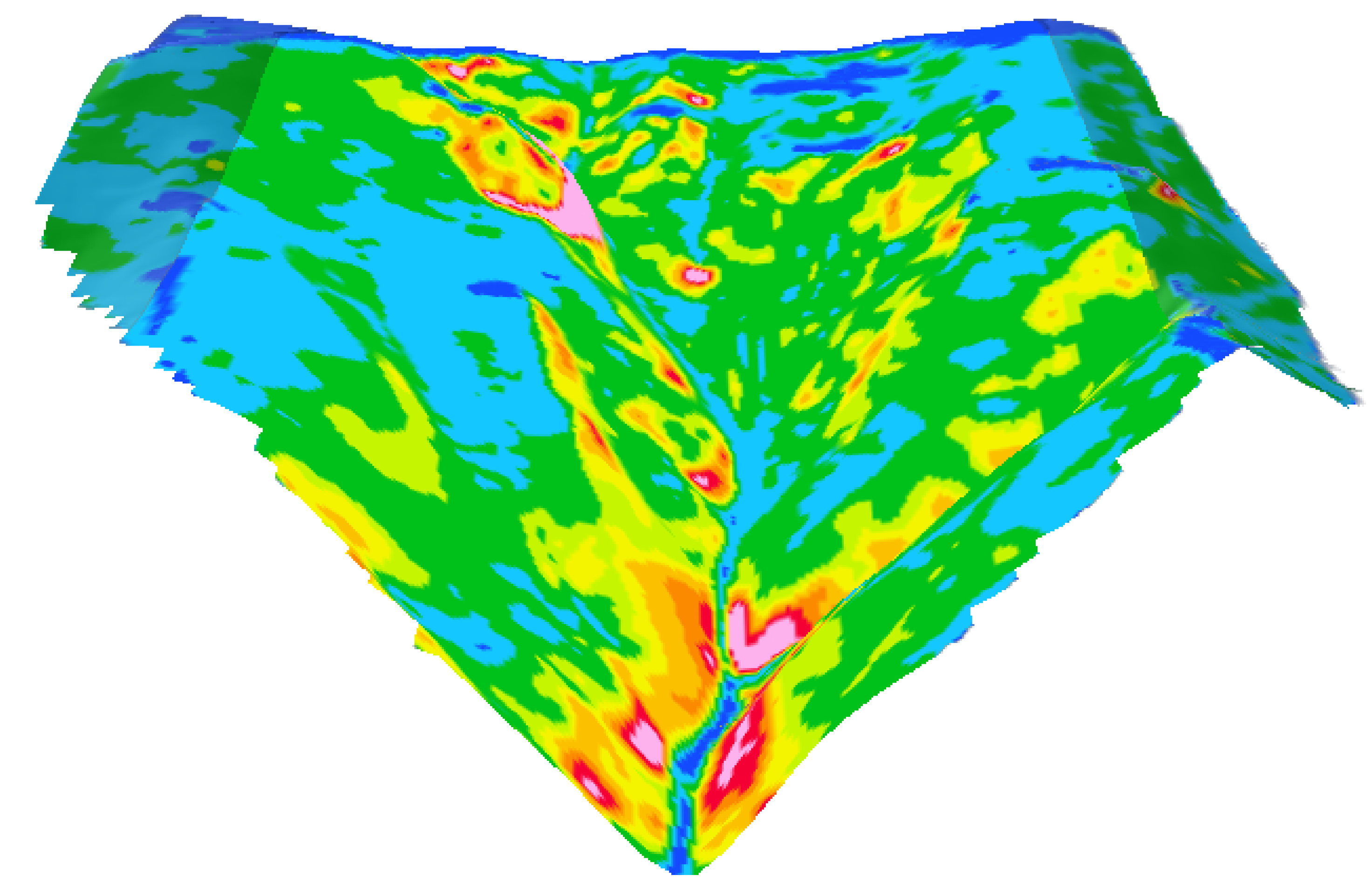
PLATE NO. 1 - GEOLOGIC MAP
IN THE VICINITY OF THE COMMUNITY OF RIMFOREST
COUNTY OF SAN BERNARDINO, CA

DISREGARD PRINTS BEARING EARLIER REVISION DATES 01/2010

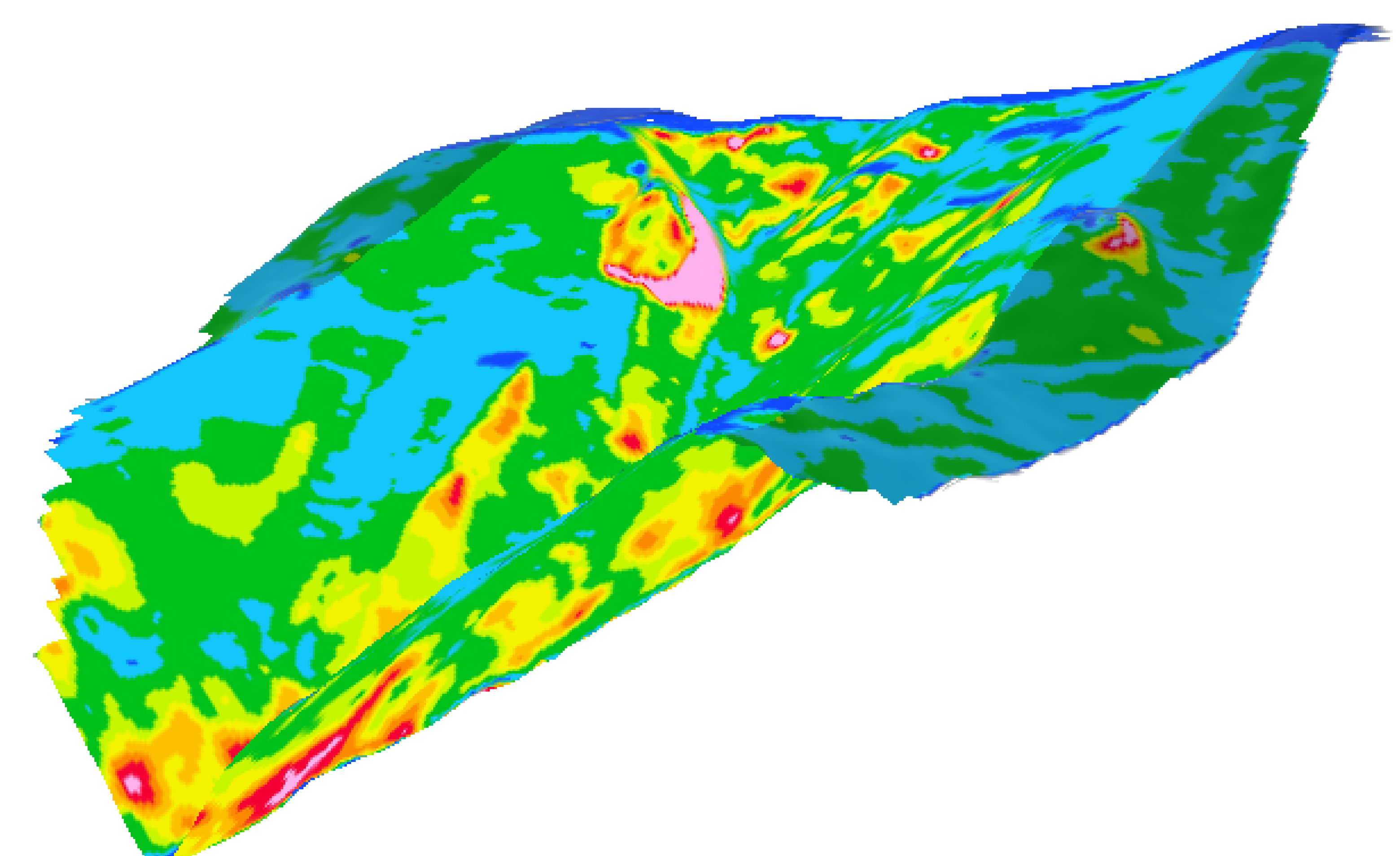
1
SHEET: 1 OF 1

SLOPE DENSITY ANALYSIS
VICINITY OF THE COMMUNITY OF RIMFOREST
IN THE COUNTY OF SAN BERNARDINO, CA





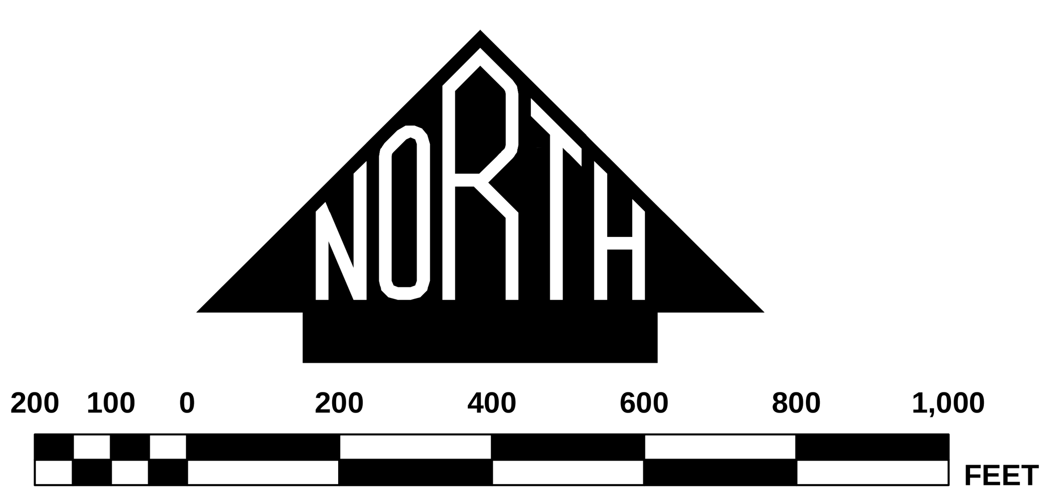
LOOKING NORTH UP RAVINE TOWARDS RIMFOREST
(N.T.S.)



LOOKING NORTHWEST ACROSS RAVINE
(N.T.S.)

SLOPE (% RISE):

- 0% - 50%
- 50% - 75%
- 75% - 100%
- 100% - 110%
- 110% - 120%
- 120% - 130%
- 130% - 140%
- 140% - 150%
- > 150%



GRAPHIC SCALE: 1" = 200'

PLATE NO. 2 - SLOPE DENSITY ANALYSIS
VICINITY OF THE COMMUNITY OF RIMFOREST
COUNTY OF SAN BERNARDINO, CA

BY	MARK	REVISION DESCRIPTION	DATE
JDN	1	ENTIRE EXHIBIT	10-13-09

PREPARED FOR:	S.B.C.F.C.D.
JOB NO:	-
PREPARED BY:	JDN
CHECKED BY:	MH

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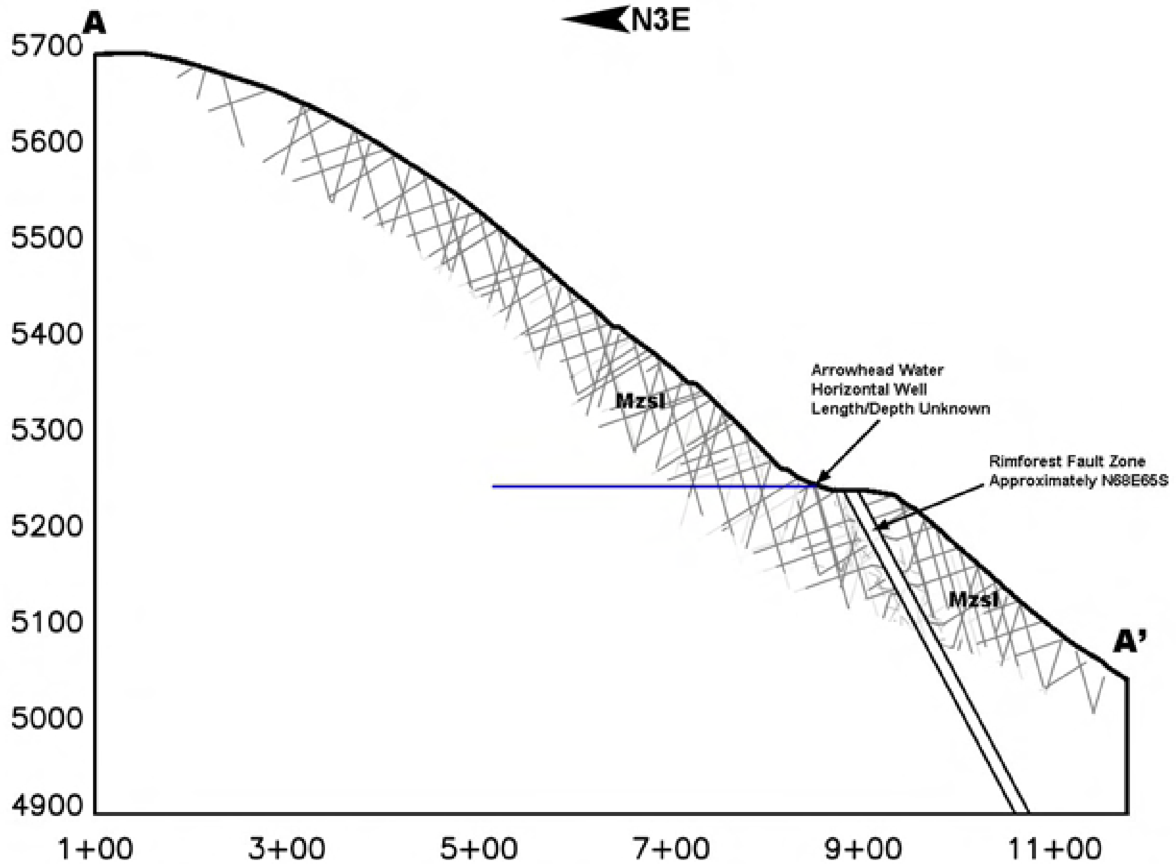
PLATE NO. 2 - SLOPE DENSITY ANALYSIS
IN THE VICINITY OF THE COMMUNITY OF RIMFOREST
COUNTY OF SAN BERNARDINO, CA

DISREGARD PRINTS BEARING EARLIER REVISION DATES → 10-13-09

2

SHEET: 1 OF 1



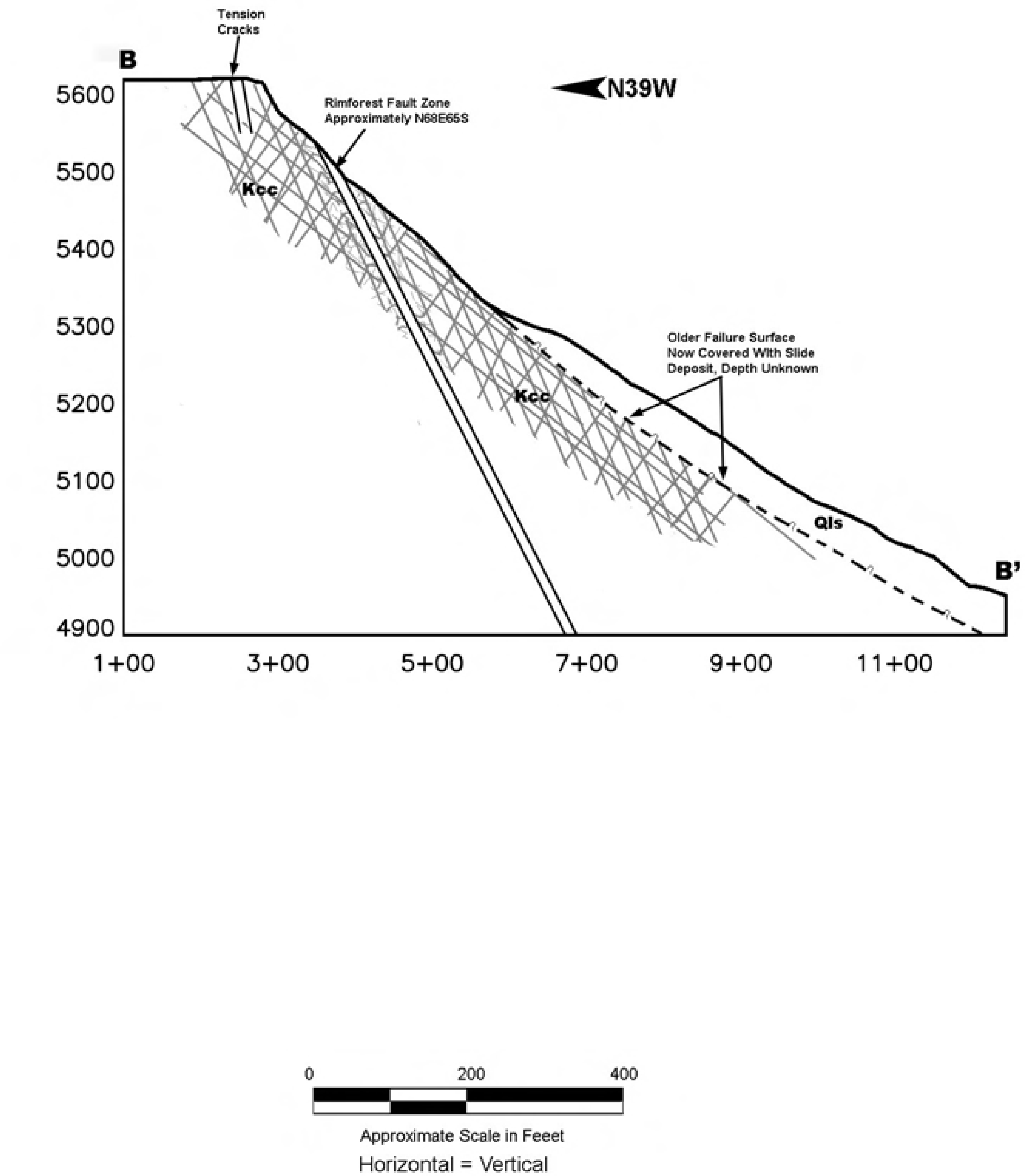
Approximate Scale in Feeet
Horizontal = Vertical

Legend

Mzsl - Mixed grantics of Silverwood Lake.

Joint attitudes shown as apparent dip. Joints selected for inclusion based on orientation predominance.

HILLTOP GEOTECHNICAL INCORPORATED	Cross-Section A-A'	
	By: RG	Date: 10/09
	Project No.: 168-H09.1	Plate No.: 3

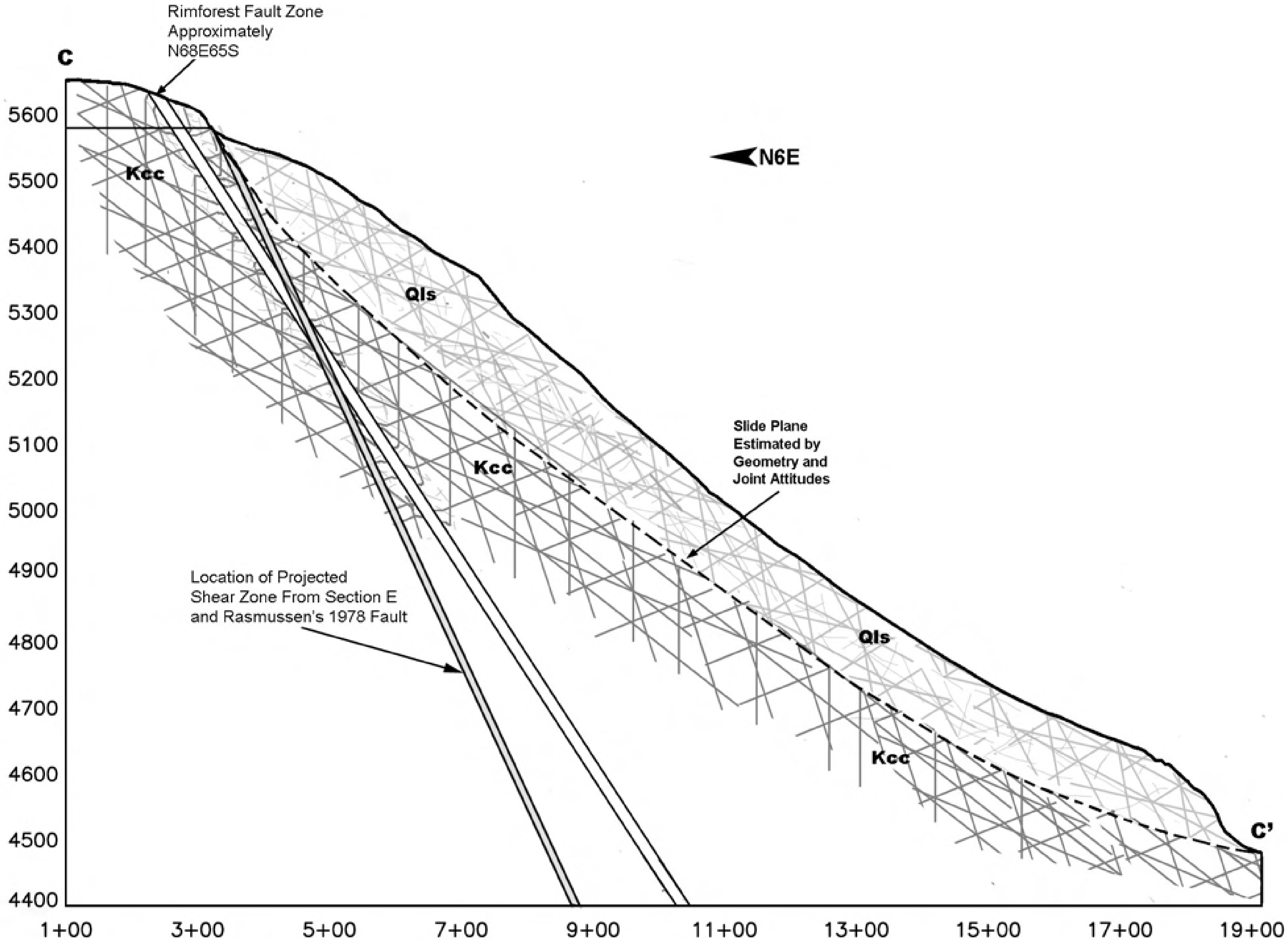


Legend

Kcc -Monzogranite of City Creek

Joint attitudes shown as apparent dip. Joints selected for inclusion based on orientation predominance.

Hilltop Geotechnical Incorporated	Cross-Section B-B'	
	By: RG	Date: 10/09
	Project No.: 168-H09.1	Plate No.: 4



Legend

Kcc -Monzogranite of City Creek

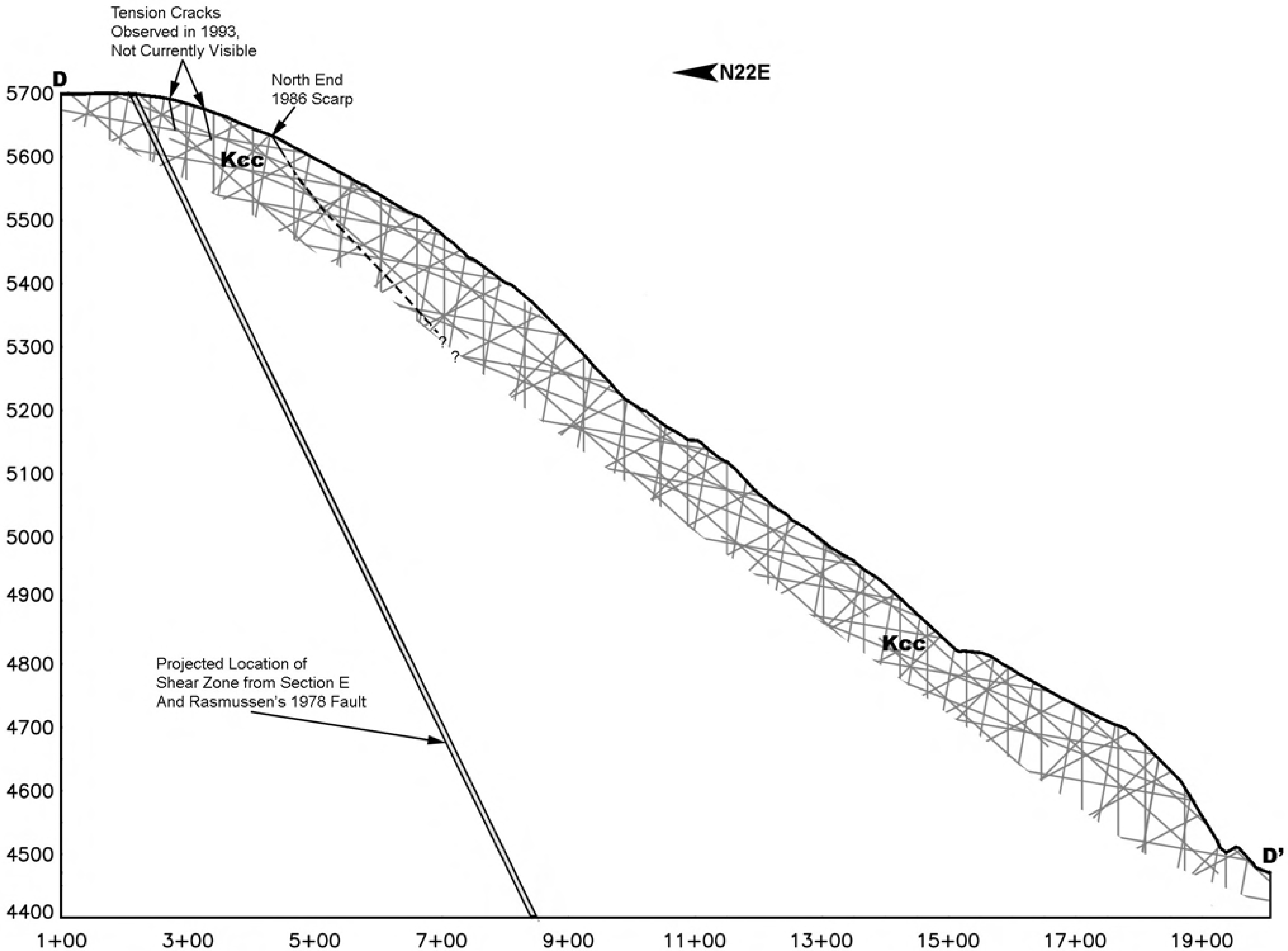
Joint attitudes shown as apparent dip. Joints selected for inclusion based on orientation predominance.

0 200 400

Approximate Scale in Feeet

Horizontal = Vertical

HILLTOP GEOTECHNICAL INCORPORATED	Cross-Section C-C'	
	By: RG	Date: 10/09
	Project No.: 168-H09.1	Plate No.: 5



Legend

Kcc -Monzogranite of City Creek

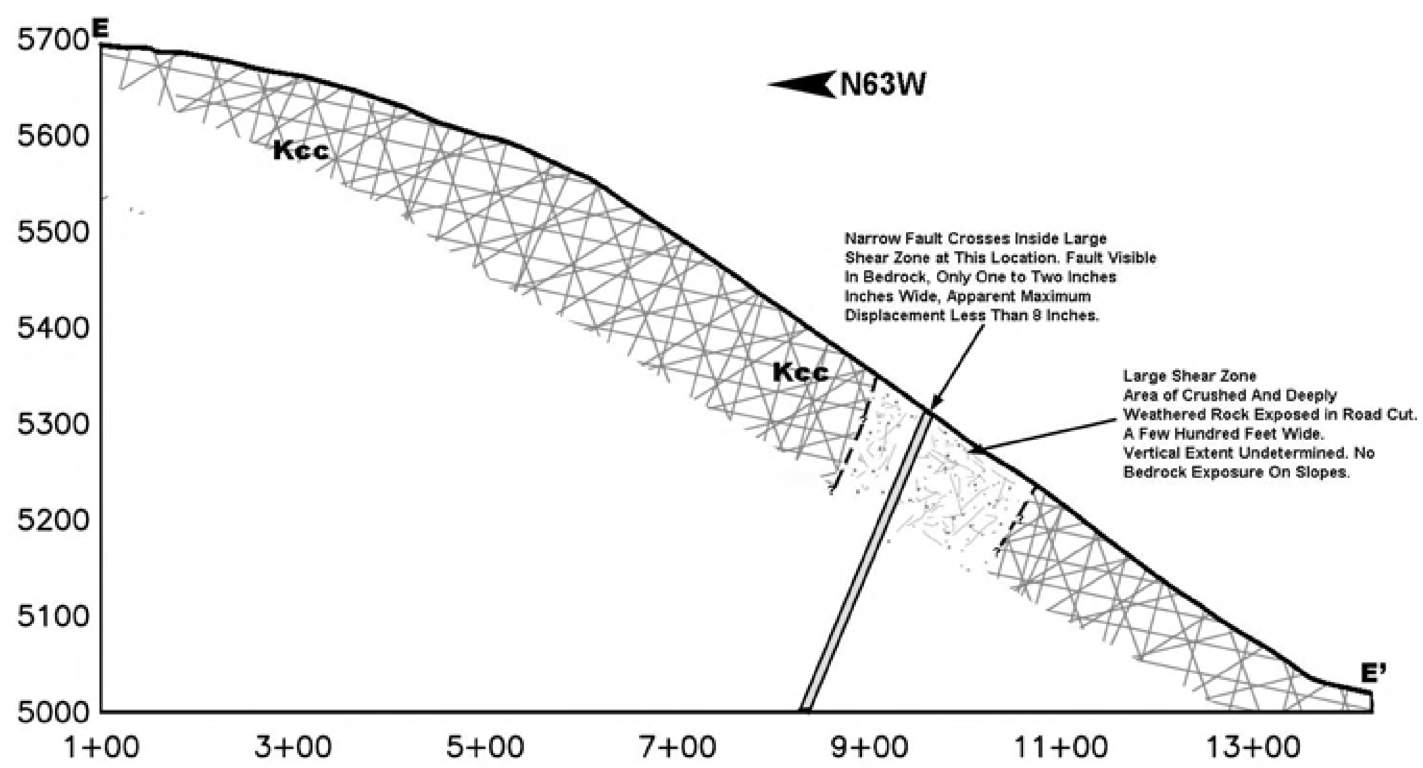
Joint attitudes shown as apparent dip. Joints selected for inclusion based on orientation predominance.

0 200 400

Approximate Scale in Feeet

Horizontal = Vertical

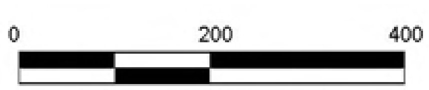
Hilltop Geotechnical Incorporated	Cross-Section D-D'	
	By: RG	Date: 10/09
	Project No.: 168-H09.1	Plate No.: 6



Legend

Kcc -Monzogranite of City Creek

Joint attitudes shown as apparent dip. Joints selected for inclusion based on orientation predominance.

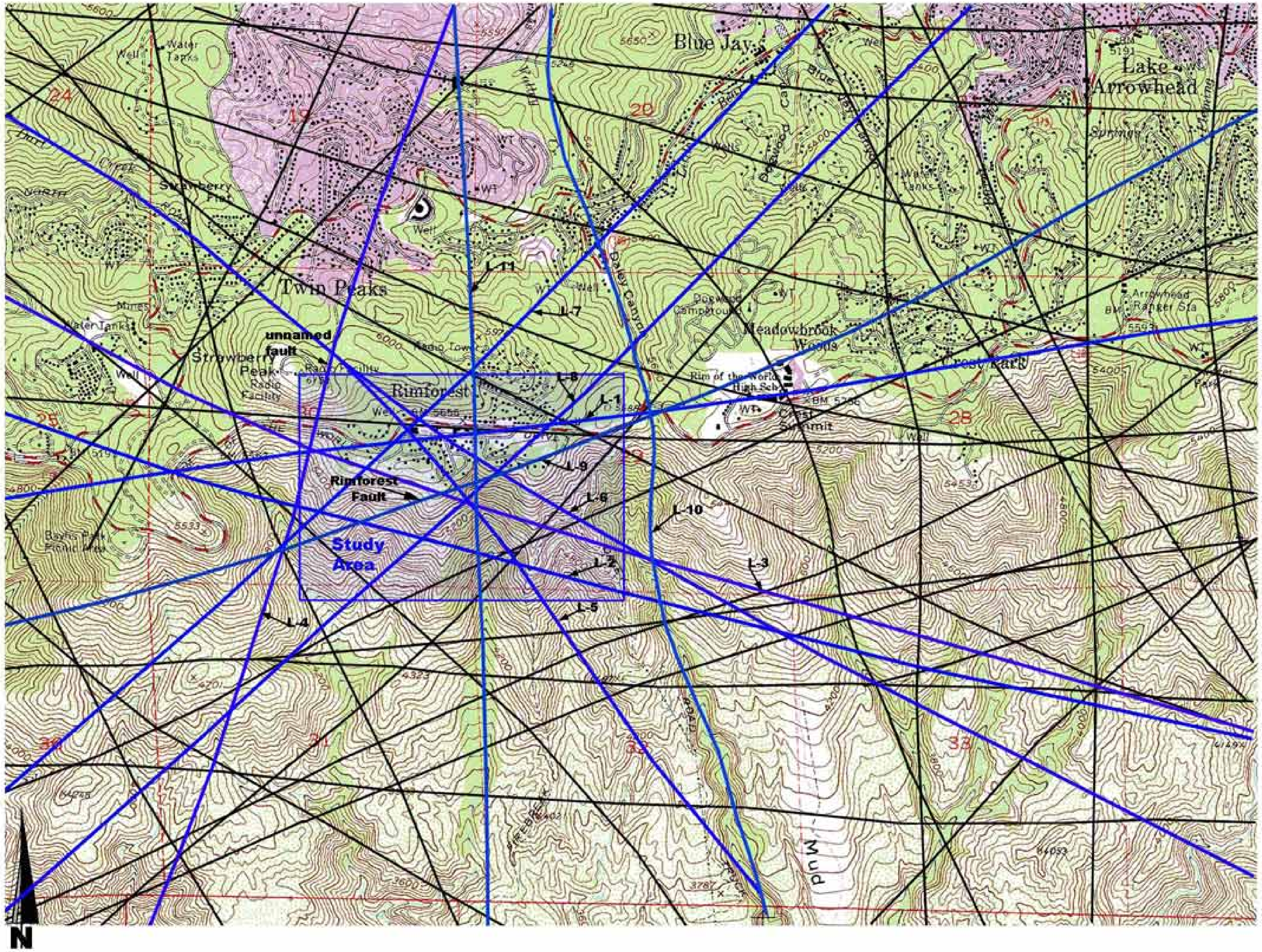


Approximate Scale in Feeet

Horizontal = Vertical

HILLTOP GEOTECHNICAL
INCORPORATED

Cross-Section E-E'	
By: RG	Date: 10/09
Project No.: 168-H09.1	Plate No.: 7



Legend

Lines on this map represent lineaments identified in aerial photographs. Stereo pairs of photos were inspected with the use of a aerial photo stereoscopic viewer.

Black lines represent photo lineaments that were not numbered for purposes of this report.

Colored lines represent photo lineaments that were numbered, L-1 through L-11, for purposes of this report.

The lines shown on this map are photo lineaments only. Some of these lines correlate roughly with published fault locations. Ten of eleven numbered lineaments were field checked; two were found to correlate with faults, and seven were found to correlate with shear zones and crushed rock.

0 2000 4000

Approximate Scale in Feet

Reference: United States Geological Survey, 1967, Photorevised 1988, *Harrison Mountain Quadrangle, California, San Bernardino County*, USGS Topographic, 7.5' Series, Scale 1:24,000.

HILLTOP GEOTECHNICAL INCORPORATED	Aerial Photograph Lineaments	
	By: RG	Date: 10/09
	Project No.: 168-H09.1	Plate No.: 8

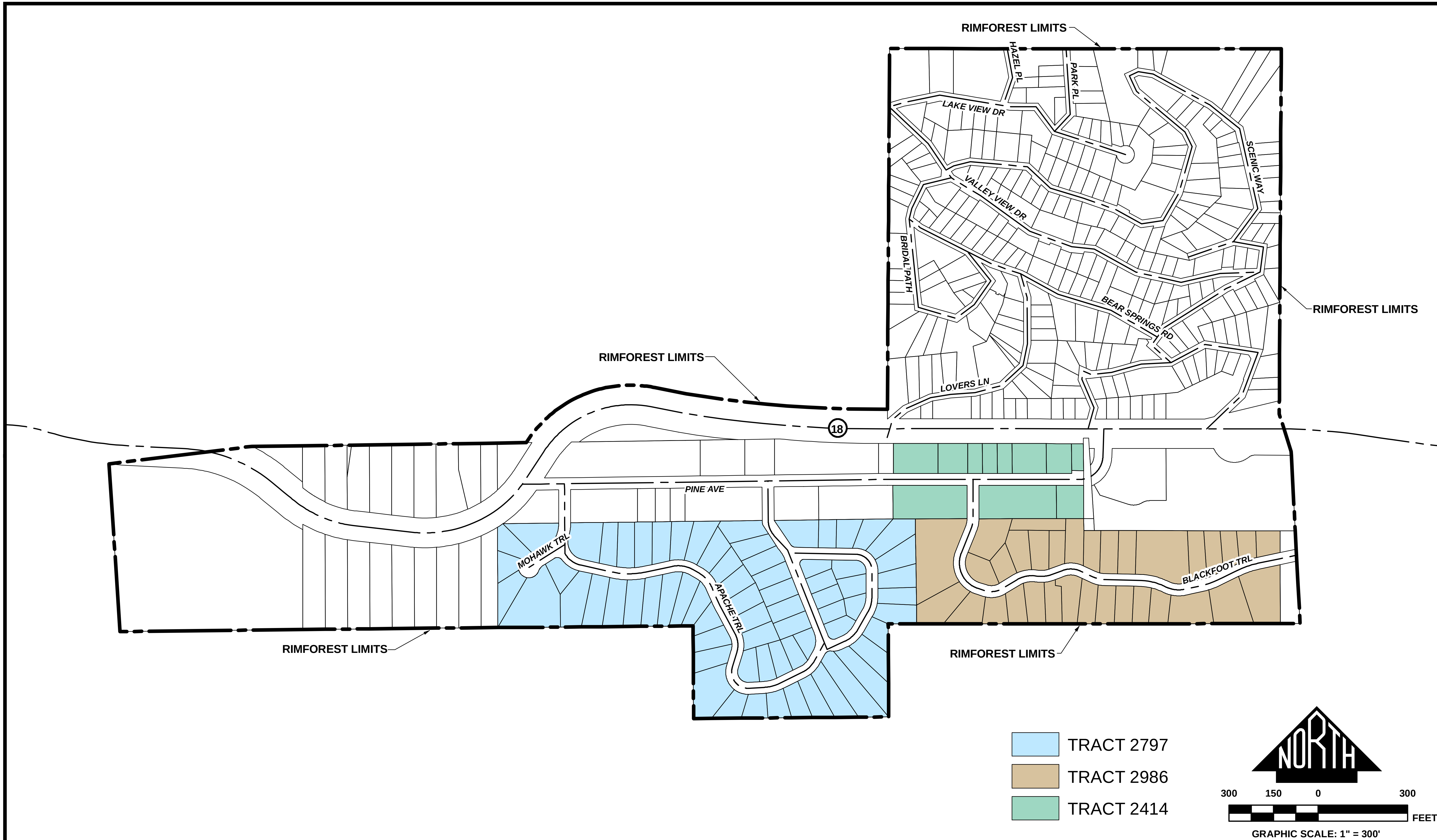


PLATE NO. 9 - TRACT MAP

IN THE COMMUNITY OF RIMFOREST

COUNTY OF SAN BERNARDINO, CA

HILLTOP GEOTECHNICAL INCORPORATED

BY	MARK	REVISION DESCRIPTION	DATE
JDN	1	ENTIRE EXHIBIT	10-13-09

PREPARED FOR:	S.B.C.F.C.D.
JOB NO:	-
PREPARED BY:	JDN
CHECKED BY:	MH

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PLATE NO. 9 - TRACT MAP

IN THE COMMUNITY OF RIMFOREST

COUNTY OF SAN BERNARDINO, CA

DISREGARD PRINTS BEARING EARLIER REVISION DATES → 10-13-09

9

SHEET: 1 OF 1

SUBSURFACE EXPLORATION LEGEND

UNIFIED SOIL CLASSIFICATION SYSTEM
Visual-Manual Procedure (ASTM D2488)

MAJOR DIVISIONS			GROUP SYMBOLS	TYPICAL NAMES
Coarse-Grained Soils* More than 50 % Retained on No. 200 Sieve	Gravels 50 % or more of Coarse Fraction Retained on No. 4 Sieve	Clean Gravels	GW	Well Graded Gravels and Gravel-Sand Mixtures, Little or no Fines
			GP	Poorly Graded Gravels and Gravel-Sand Mixtures, Little or no Fines
		Gravels with Fines	GM	Silty Gravels, Gravel-Sand-Silt Mixtures**
			GC	Clayey Gravel, Gravel-Sand-Clay Mixtures**
	Sands More than 50 % of Coarse Fraction Passes No. 4 Sieve	Clean Sands	SW	Well Graded Sands and Gravely Sands, Little or no Fines
			SP	Poorly Graded Sands and Gravelly Sands, Little or no Fines
		Sands with Fines	SM	Silty Sands, Sand-Silt Mixtures**
			SC	Clayey Sands, Sand-Clay Mixtures**
Fine Grained Soils* 50 % or more Passes No. 200 Sieve	Silts and Clays Liquid Limits 50 % or less		ML	Inorganic Silts, Sandy Silts, Rock Flour
			CL	Inorganic Clays of Low to Medium Plasticity, Gravelly Clays, Sandy Clays, Silty Clays, Lean Clays
			OL	Organic Silts and Organic silty Clays of Low Plasticity
	Silts and Clays Liquid Limits Greater than 50 %		MH	Inorganic Silts, Micaceous or Diatomaceous silts, Plastic Silts
			CH	Inorganic Clays of High Plasticity, Fat Clays
			OH	Organic Clays of Medium to High Plasticity
Highly Organic Soils			PT	Peat, Muck, or Other Highly Organic Soils

CONSISTENCY / RELATIVE DENSITY

CRITERIA

Reference: ‘Foundation Engineering’, Peck, Hansen, Thornburn, 2nd Edition.

Standard Penetration Test
Granular Soils

Penetration Resistance, N, (Blows / Foot)	Relative Density
0 - 4	Very Loose
4 - 10	Loose
10 - 30	Medium Dense
30 - 50	Dense
> 50	Very Dense

Standard Penetration Test
Cohesive Soils

Penetration Resistance, N, (Blows / Foot)	Consistency	Unconfined Compressive Strength, (Tons / Sq. Ft.)
< 2	Very Soft	< 0.25
2 - 4	Soft	0.25 - 0.5
4 - 8	Medium Stiff	0.5 - 1.0
8 - 15	Stiff	1.0 - 2.0
15 - 30	Very Stiff	2.0 - 4.0
> 30	Hard	> 4.0

* Based on material passing the 3-inch sieve.
** More than 12% passing the No. 200 sieve; 5% to 12% passing No. 200 sieve requires use of duel symbols (i.e., SP-SM., GP-GM, SP-SC, GP-GC, etc.); Border line classifications are designated as CH/Cl, GM/SM, SP/SW, etc.

U.S. Standard Sieve Size 12" 3" 3/4" #4 #10 #40 #200

Unified Soil Classification Designation	Boulders	Cobbles	Gravel		Sand			Silt and Clay
			Coarse	Fine	Coarse	Medium	Fine	

Moisture Condition

Dry	Absence of moisture, dusty, dry to the touch.
Moist	Damp but no visible moisture.
Wet	Visible free water, usually below the water table.

Material Quantity

Trace	< 5 %
Slightly	5 - 12%
Little	12 - 25%
Some	25 - 50 %

Other Symbols

C - Core Sample
S - SPT Sample
B - Bulk Sample
CK - Chunk Sample
R - Ring Sample
N - Nuclear Gauge Test
∇ - Water Table

HILLTOP GEOTECHNICAL INCORPORATED

SUBSURFACE EXPLORATION LOG
BORING NO. B-1

Hilltop Geotechnical

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	12

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
	R	5	SP			Qal		ALLUVIUM:
	B	5						Fine to coarse sand, trace silt, trace gravel; Light brown-gray;
1		6						Dry: Loose.
2			SM					Silty, fine to coarse sand, a little gravel, porous, with organic content and small, woody roots up to 1/4" diameter; Brown to dark brown; Moist; Loose.
3	R	2						
	B	3						
		5		99.8	8.4			
4								
5	R	2						
		3						
6		4		89.4	10.7			
7			GP/GM					Slightly silty, sandy gravel with cobbles; Light brown-gray; Moist; Dense.
8								
9								
10	R	18						
		50/5"		129.9	2.2			
11								
12								Bottom of boring 12 feet. Refusal on hard cobble or boulder. No groundwater. Backfilled with excavated material.
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

Plate No. 11a

SUBSURFACE EXPLORATION LOG
BORING NO. B-1A

Hilltop Geotechnical

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	31

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
						Qal		ALLUVIUM:
1								
2								
3								
4								
5								
6								
7								
8	R	4 4 5	SM	92.1	8.7			Silty, fine to coarse sand, trace gravel, porous with organic content; Brown; Moist; Loose.
9								
10	R	8 17 20	SP/SM	114.3	4.3			Slightly silty, fine to coarse sand with gravel and few cobbles; Orange-brown; Moist; Dense.
11								
12								
13			SP			Kcc		WEATHERED GRANITIC BASEMENT ROCK EXCAVATED TO: Fine to coarse sand, trace gravel.
14								
15	R	27 50/4"						
16								
17								
18								
19								
20	R	50/3"						- no sample recovery.
21								
22								
23			SP/SM					Slightly silty, fine to coarse sand, a little gravel; Pink-gray; Moist.
24								
25								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

Plate No. 11b

SUBSURFACE EXPLORATION LOG
BORING NO. B-1A (cont.)

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	31

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
	S	41 33 50/5"	SP/SM			Kcc		WEATHERED GRANITIC BASEMENT ROCK (Cont.) EXCAVATED TO: Slightly silty, fine to coarse sand, a little gravel; Pink-gray; Moist.
26								
27								
28			SP				▽	Fine to coarse sand, some gravel; Gray; Wet.
29								
30	S	50/5"						
31								Bottom of boring 31 feet. Refusal on hard basement rock. Groundwater measured at 28.5 feet. Backfilled with excavated material.
32								
33								
34								
35								
36								
37								
38								
39								
40								
41								
42								
43								
44								
45								
46								
47								
48								
49								
50								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

Plate No. 11c

SUBSURFACE EXPLORATION LOG
BORING NO. B-2

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	16

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
								2 1/2 inches asphalt pavement.
	R	4	SM			af		ARTIFICIAL FILL SOILS:
1		5	SM			Qal		Silty, fine to coarse sand, a little gravel; Brown; Moist.
		5						ALLUVIUM:
2								Silty, fine to coarse sand, some gravel; Brown and light gray;
	R	3						Moist; Loose.
3		3						
		3		91.9	11.4			
4			SM			Kcc		WEATHERED GRANITIC BASEMENT ROCK
								EXCAVATED TO:
5	R	4						Silty, fine to medium sand, trace clay; Light gray to white; Moist.
		8						
6		11		93.3	19.4			
7			SM/ML					Silty, fine to medium sand to sandy silt, trace clay; Light gray to white; Moist.
8	R	2						
		3						
		3						
9			SP					Fine to coarse sand, some silt; Light olive-gray; Moist.
10	R	3						
		3						
11		6		105.8	2.7			
12								
13	R	3						
		12						
14		50/3"		109.2	3.9			
15	R	50/3"		112.9	4.7			
16								Bottom of boring 16 feet.
17								Refusal on hard basement rock.
								No groundwater encountered.
18								Backfilled with excavated material.
								Street pavement repaired with cold patch asphalt.
19								
20								
21								
22								
23								
24								
25								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

Plate No. 12a

HILLTOP GEOTECHNICAL

SUBSURFACE EXPLORATION LOG
BORING NO. B-2A

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	17

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
								2 1/2 inches asphaltic pavement.
1			SM			af		ARTIFICIAL FILL: Silty, fine to coarse sand, a little gravel; Brown; Moist.
2–4			SM			Qal		ALLUVIUM: Silty, fine to coarse sand, some gravel; Brown and light gray; Moist.
5–8			SP			Kcc		WEATHERED GRANITIC BASEMENT ROCK EXCAVATED TO: Fine to coarse sand, trace gravel; Light gray to white; Moist. -Hard rock encountered. Large pink feldspar crystals, up to 1-1/2 inches in size, were found in the drill cuttings.
10								- Drilling became easier in softer material at 10 feet. Drill cuttings were white to light gray sand.
15	R	4 6 13						Fine to coarse sand, trace silt; Light olive-gray; Moist.
17								Bottom of boring 17 feet. Refusal on hard basement rock. No groundwater encountered. Backfilled with excavated material. Pavement repaired with asphalt cold patch.

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

SUBSURFACE EXPLORATION LOG
BORING NO. B-3

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	11

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
								4 inches of asphaltic pavement.
			GP			af		ARTIFICIAL FILL:
1	R	13	SM					9" of Gray Aggregate Base Material.
	B	16						Silty, fine to coarse sand, trace gravel; Brown; Dry; Med. dense.
2		17	SP			Kcc		WEATHERED GRANITIC BASEMENT ROCK
	R	15						EXCAVATED TO:
3		16						Fine to coarse sand, some gravel; Olive-gray; Moist.
		22		114.0	4.0			
4								
								- Same, with trace silt.
5	R	50		111.1	3.2			
6								
7								
	R	50		103.4	3.9			
8								- Drilling becoming more difficult.
9								
10	R	50/3"						
11								Bottom of boring 11 feet. Refusal on hard basement rock. No groundwater encountered. Backfilled with excavated material. Pavement repaired with asphalt cold patch.
12								
13								
14								
15								
16								
17								
18								
19								
20								
21								
22								
23								
24								
25								

S - SPT Sample   R - Ring Sample   B - Bulk Sample   N - Nuclear Gauge Test   D - Disturbed Sample

Plate No. 13

SUBSURFACE EXPLORATION LOG
BORING NO. B-4

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	41.5

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
0	R	18	SP/SM			af		ARTIFICIAL FILL:
1		18 11						Slightly silty, fine to coarse sand, a little gravel; Asphalt coated gravel in shoe of sampler; Brown-gray; Dry; Medium dense.
2	B		SM			Qal		ALLUVIUM:
3	R	2 3						Silty, fine to coarse sand, trace gravel, slightly porous; Light brown; Moist; Loose to medium dense.
4		4		88.4	6.4			
5	R	4						
6		10 8		99.3	5.7			
7								
8	R	4 7	SP/SM			Kcc		WEATHERED GRANITIC BASEMENT ROCK EXCAVATES TO:
9		7		86.4	9.3			Slightly silty, fine to coarse sand with few small roots; Orange-gray; Moist.
10	R	14						
11		18 21		116.5	6.5			
12			SP					Fine to coarse sand, a little gravel, trace silt; Olive-gray; Moist.
13	R	24 50		108.6	5.9			
14								
15	R	50/5"						
16								
17								
18								
19								
20	S	7						- Same, with thin (2mm), horizontal, planar zone of crushed material.
21		30	SM					Silty, fine to medium sand, trace clay; White; Moist.
		50/3"	SP					Fine to coarse sand, trace gravel; Olive-gray; Moist.
22								
23								
24								
25								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

Plate No. 14a

SUBSURFACE EXPLORATION LOG
BORING NO. B-4 (cont.)

HILLTOP GEOTECHNICAL

Project Name:	Rimforest						
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG		
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±		
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	41.5		

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
	S	34 50/5"	SP			Kcc		WEATHERED GRANITIC BASEMENT ROCK (Cont.) EXCAVATED TO: Fine to coarse sand, trace gravel; Olive-gray; Moist.
26								
27								
28								
29								
30	S	50/5"						
31								
32								
33			SC					Clayey, fine to medium sand, some silt; Olive-gray; Moist.
34								
35	S	18 19 14						
36								
37			SP					Fine to coarse sand, some silt; Olive-gray; Moist.
38			SP/SM					Slightly silty, fine to medium sand, trace coarse sand; Olive-gray; Moist.
39								
40	S	16 24 24						
41								
42								Bottom of boring 41.5 feet. Refusal, due to cuttings binding the auger. No groundwater encountered. Backfilled with excavated material.
43								
44								
45								
46								
47								
48								
49								
50								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

Plate No. 14b

SUBSURFACE EXPLORATION LOG
BORING NO. B-5

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	53

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
								5 inches asphalt pavement.
1	R, B	8 9 9	SP/SM			af		ARTIFICIAL FILL: Slightly silty, fine to coarse sand, some gravel and organics; Brown; Moist; Medium dense.
2–6	R	5 4 4	SP/SM	91.4	6.0	Qal		ALLUVIUM: Slightly silty, fine to coarse sand with organics and few small roots; Dark brown; Moist; Loose.
5	R	2 3 9		80.0	6.0			
7–9	R	10 12 10	SM	86.9	9.0	Kcc		WEATHERED GRANITIC BASEMENT ROCK EXCAVATED TO: Silty,fine to coarse sand with few small roots; Light gray; Moist.
10	R, B	18 50/3"	SP/SM	90.4	4.5			Slightly silty, fine to coarse sand with few small roots; Light gray to white; Moist.
13	R	30 50/4"		104.8	3.8			
15	S	22 30 45	SP					Fine to coarse sand, trace gravel; Light orange-gray mottled White; Moist.
20	S	14 12 7	SM					Silty fine to medium sand, trace coarse sand; Light orange-gray mottled white; Moist.
23			SC					Clayey, fine to medium sand, some silt; Light orange-gray mottled white; Moist.
25								

S - SPT Sample   R - Ring Sample   B - Bulk Sample   N - Nuclear Gauge Test   D - Disturbed Sample

SUBSURFACE EXPLORATION LOG
BORING NO. B-5 (cont.)

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	53

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
	R	15	SC			Kcc		WEATHERED GRANITIC BASEMENT ROCK (Cont.) EXCAVATED TO:
26		15 19		100.4	18.8			Clayey, fine to medium sand, some silt; Light orange-gray mottled white; Moist. Contained a nearly vertical, planar layer, 3/16 inch thick, of green-gray clay.
27								
28								
29								
30	R	14						- Same, with non-planar, irregular clay seam. Mafic minerals surrounded by iron oxide staining.
31		16 21		109.2	12.3			
32								
33								
34			SM					Silty, fine to coarse sand, trace gravel; Olive-gray mottled orange; Moist. Orange iron oxide staining common around mafic minerals.
35	R	13						
36		15 16		111.5	11.3			
37								
38			SM/SC					Clayey to silty, fine to coarse sand; Olive-gray; Moist. Olive-gray planar clay seam, approximately 2mm thick, dipping 70 to 80 degrees from vertical. (Direction unknown)
39								
40	R	12						
41		20 22		109.6	10.4			
42								
43								
44								
45	R	10						
46		15 18		106.3	10.9			
47								
48								
49								
50								

S - SPT Sample   R - Ring Sample   B - Bulk Sample   N - Nuclear Gauge Test   D - Disturbed Sample

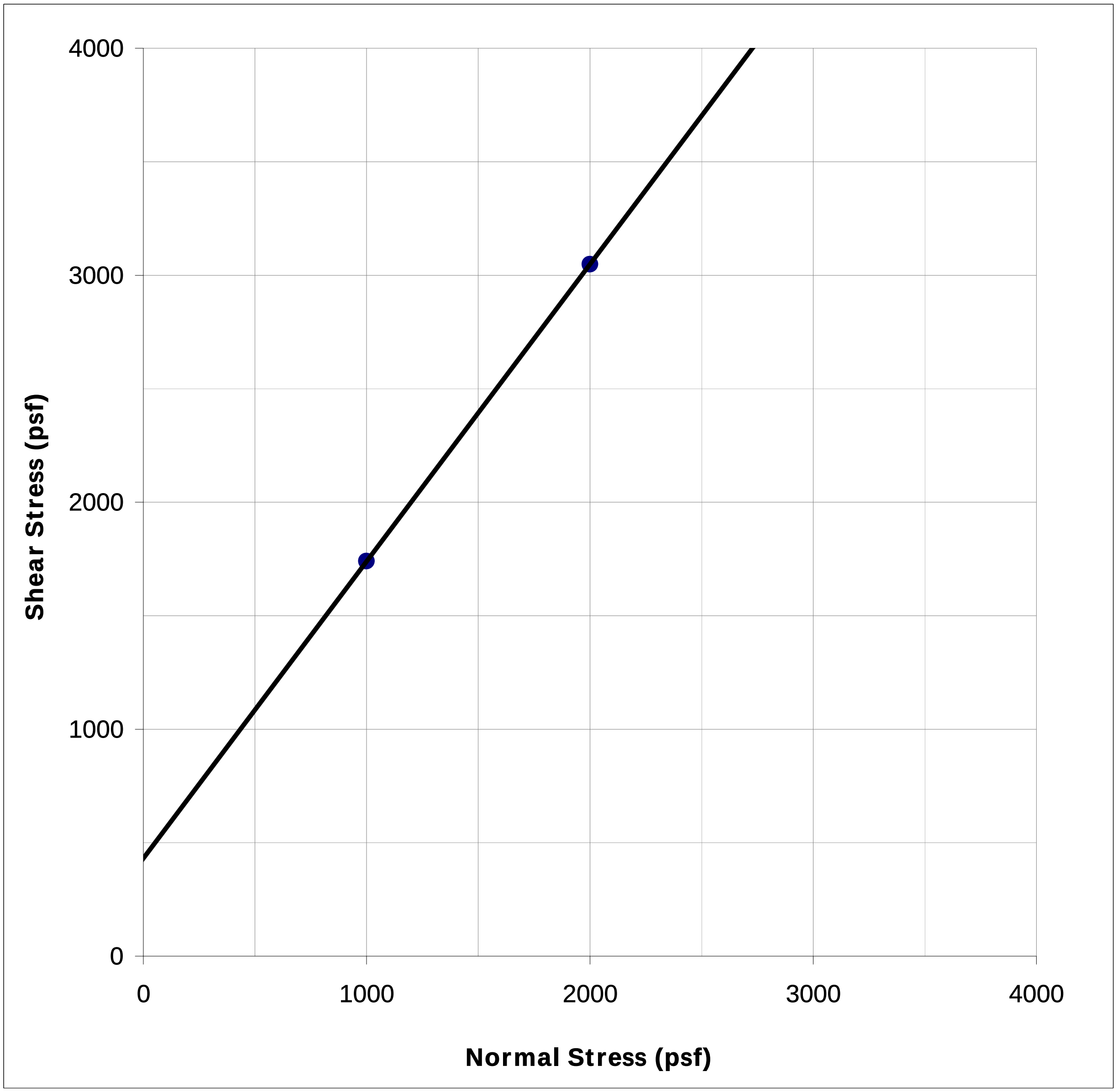
SUBSURFACE EXPLORATION LOG
BORING NO. B-5 (cont.)

HILLTOP GEOTECHNICAL

Project Name:	Rimforest				
Project No.	168-H09	Date:	9/21/2009	Logged By:	RG
Type of Rig:	Hollow-Stem Auger	Drive Wt.:	140 lb	Elevation:	±
Drill Hole Dia.:	8 in.	Drop:	30 in.	Depth of Boring (ft.):	53

Depth (ft.)	Sample Type	Penetration Resistance	Soil Classification	Dry Density (lb/ft3)	Moisture Content (%)	Lithology	Groundwater	Description
	R	15	SM/SC			Kcc		WEATHERED GRANITIC BASEMENT ROCK (Cont.)
		20						EXCAVATED TO:
51		36		110.6	16.5			Clayey to silty, fine to coarse sand; Olive-gray; Moist. Olive-gray planar clay seam, approximately 2mm thick, dipping 70 to 80 degrees from vertical. (Direction unknown)
52								
53								Bottom of boring 53 feet. Refusal due to clayey cuttings binding on auger. No groundwater encountered. Backfilled with excavated material. Pavement repaired with asphalt cold patch.
54								
55								
56								
57								
58								
59								
60								
61								
62								
63								
64								
65								
66								
67								
68								
69								
70								
71								
72								
73								
74								
75								

S - SPT Sample R - Ring Sample B - Bulk Sample N - Nuclear Gauge Test D - Disturbed Sample

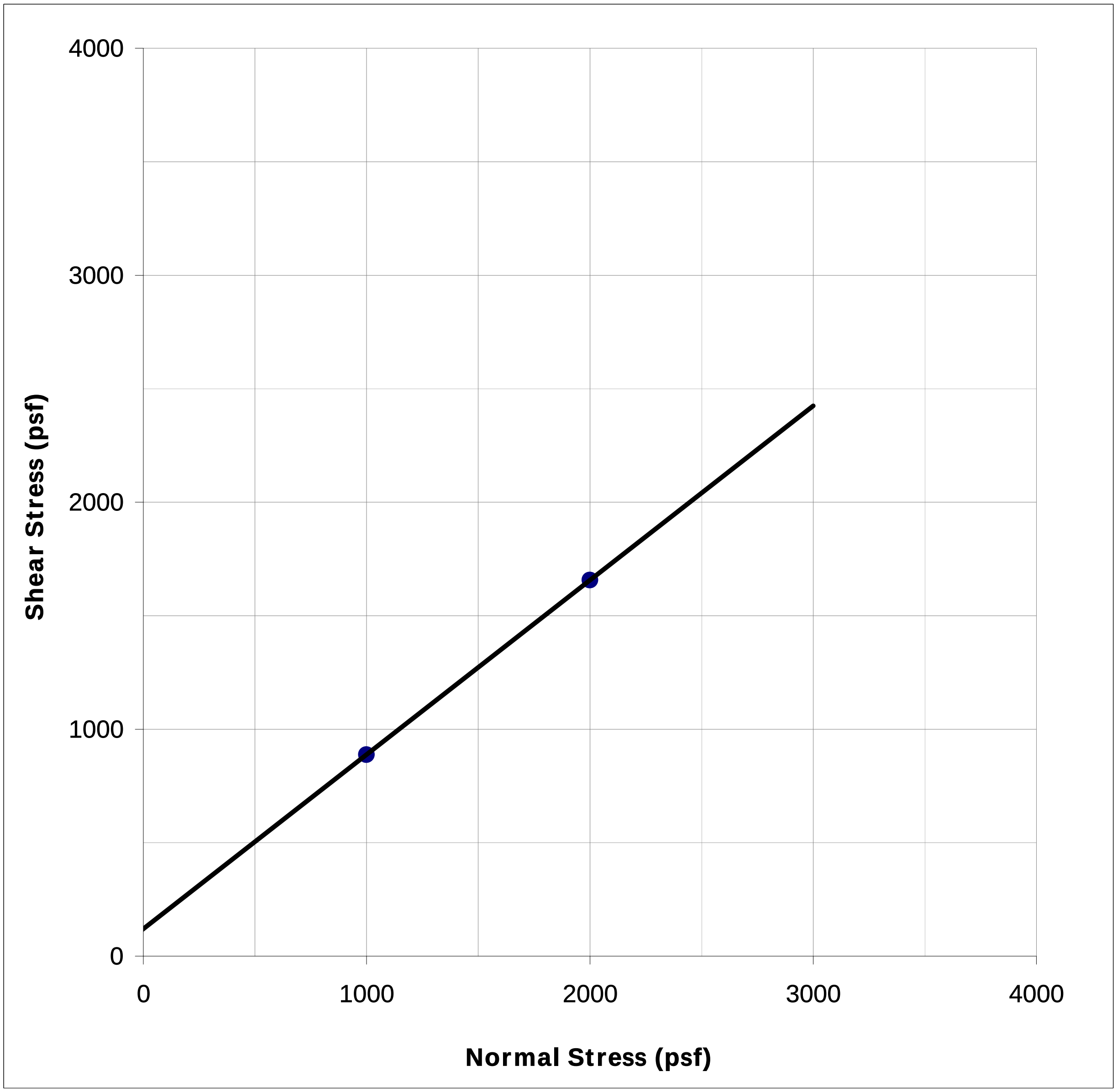


Shear Speed: 0.005 in. / sec.

Cohesion	432 psf
Internal Friction Angle	53 degrees

* Cohesion and angle of internal friction values are peak strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED	DIRECT SHEAR TEST RESULTS	
	SAMPLE: B-4, 13'-13.5'	
	SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)	
	BY: DLC	DATE: 10/09
	PROJECT NO.: 168-H09.1	PLATE NO. 16a



Shear Speed: 0.005 in. / sec.

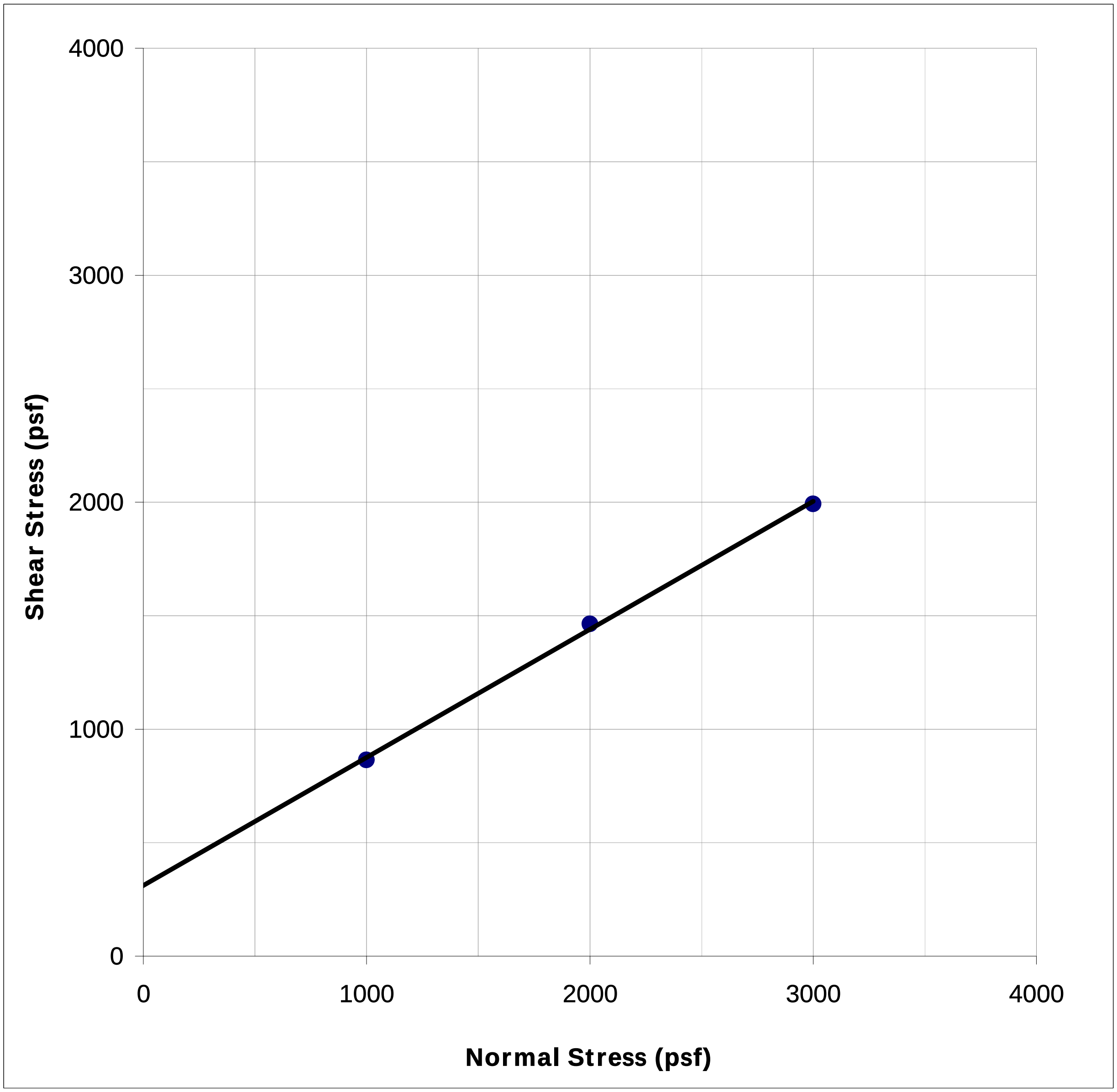
Cohesion	120 psf
Internal Friction Angle	38 degrees

* Cohesion and angle of internal friction values are ultimate strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED

DIRECT SHEAR TEST RESULTS

SAMPLE: B-4, 13'-13.5'			
SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)			
BY:	DLC	DATE:	10/09
PROJECT NO.:	168-H09.1	PLATE NO.	16b

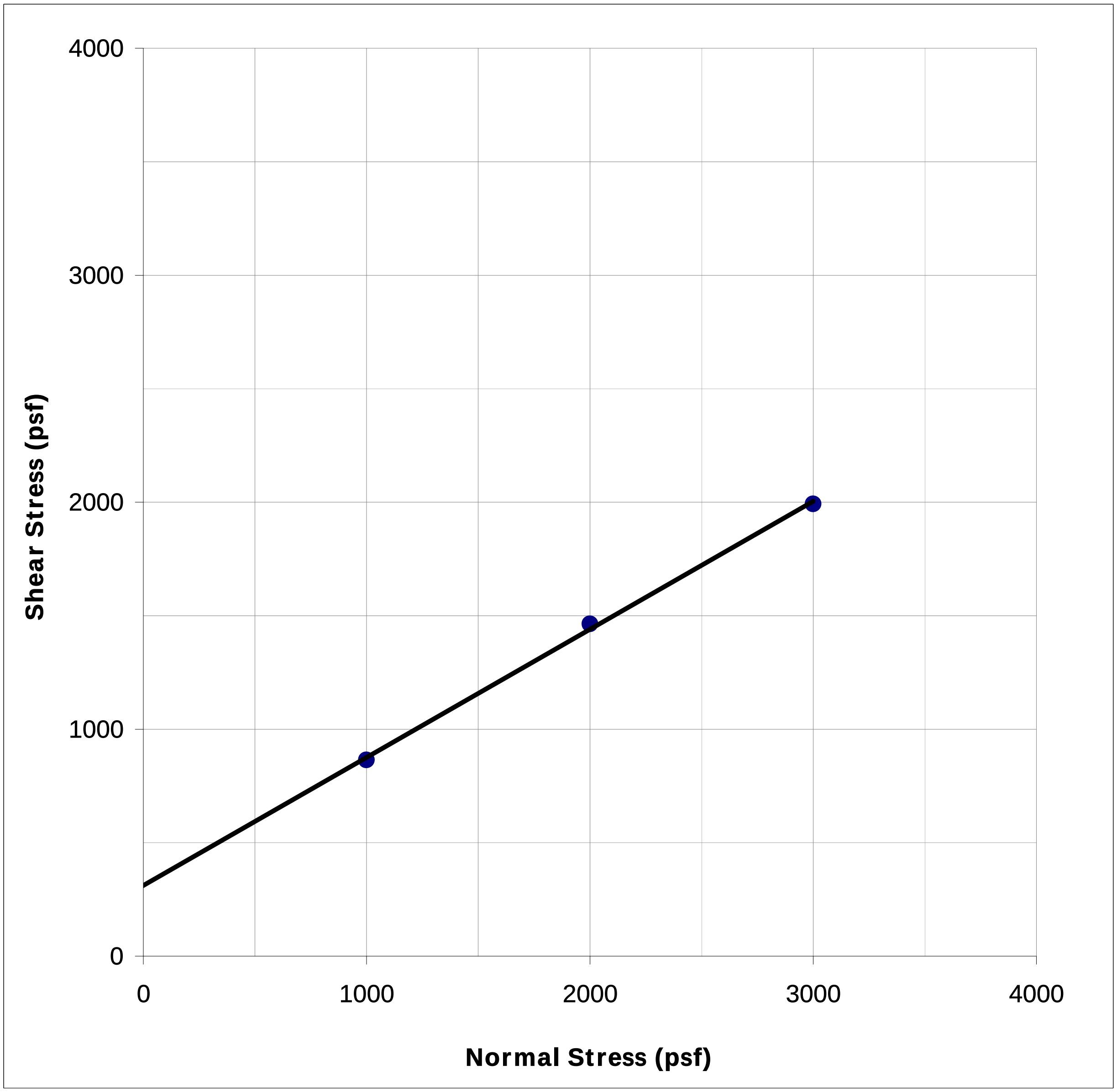


Shear Speed: 0.005 in. / sec.

Cohesion	312 psf
Internal Friction Angle	29 degrees

* Cohesion and angle of internal friction values are peak strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED	DIRECT SHEAR TEST RESULTS	
	SAMPLE: B-5, 8.5'-9'	
	SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)	
	BY: DLC	DATE: 10/09
	PROJECT NO.: 168-H09.1	PLATE NO. 17a



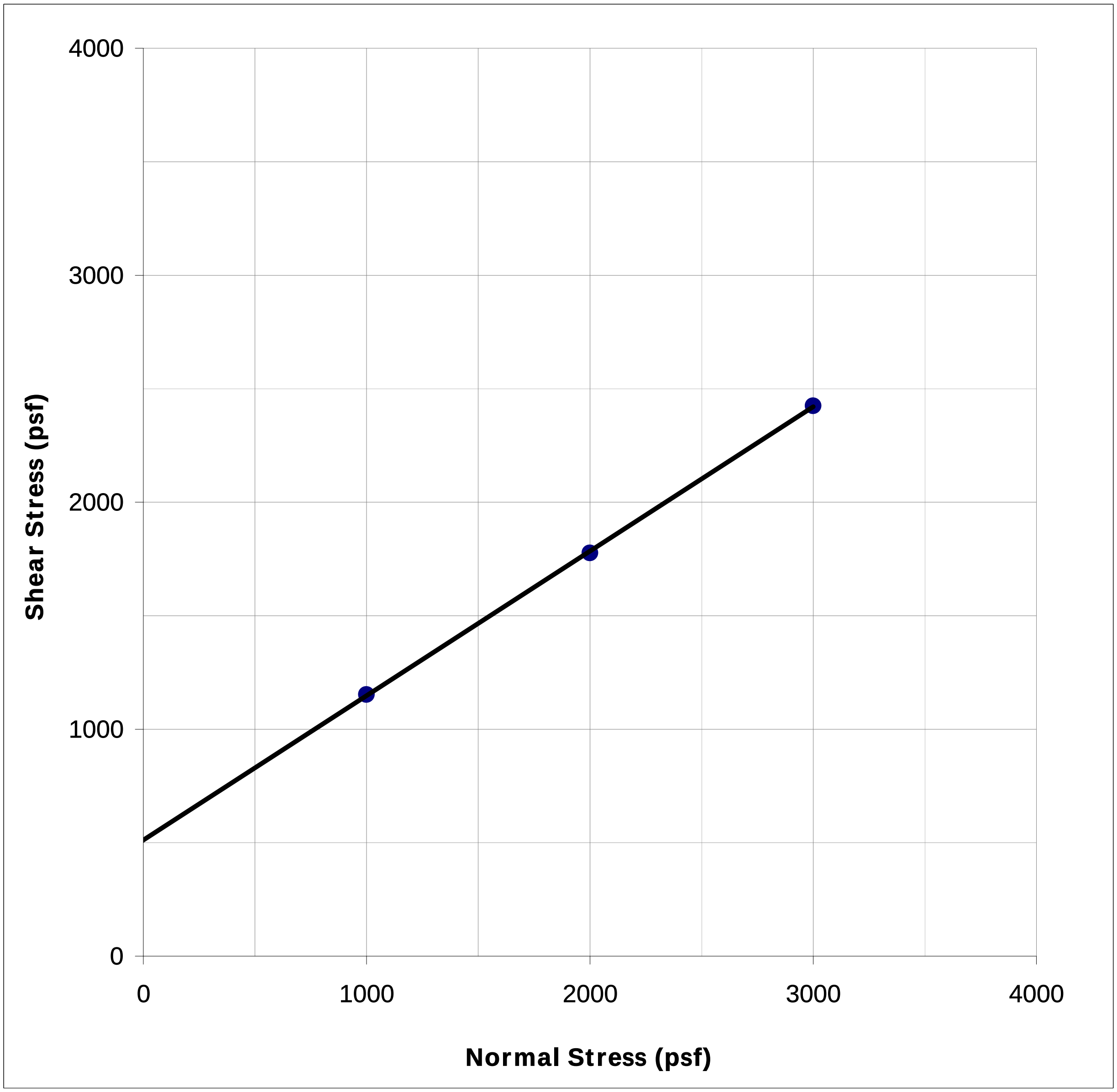
Shear Speed: 0.005 in. / sec.

Cohesion	312 psf
Internal Friction Angle	29 degrees

* Cohesion and angle of internal friction values are ultimate strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED

DIRECT SHEAR TEST RESULTS	
SAMPLE: B-5, 8.5'-9'	
SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)	
BY: DLC	DATE: 10/09
PROJECT NO.: 168-H09.1	PLATE NO. 17b

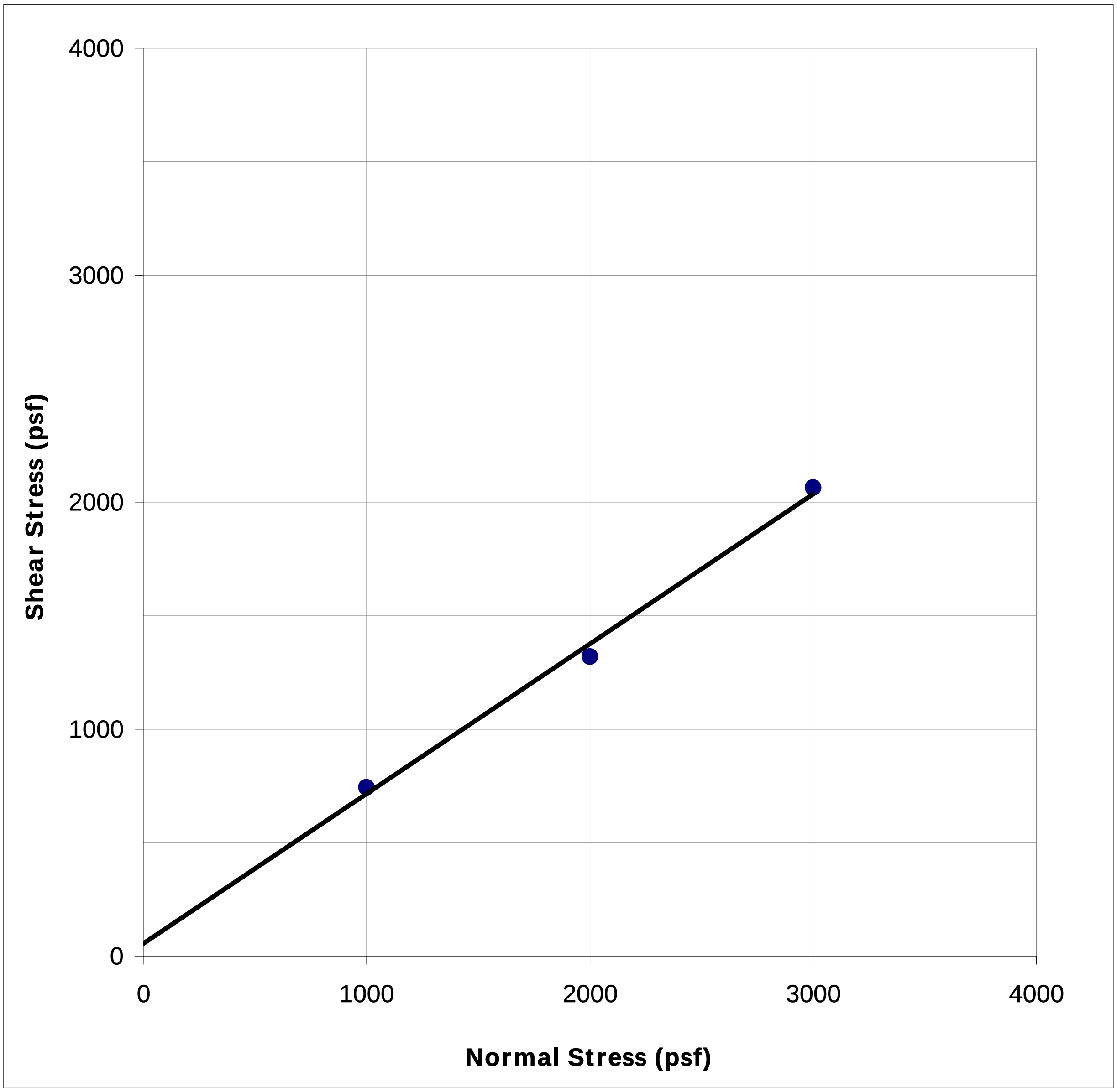


Shear Speed: 0.005 in. / sec.

Cohesion	512 psf
Internal Friction Angle	32 degrees

* Cohesion and angle of internal friction values are peak strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED	**DIRECT SHEAR TEST RESULTS**		
	SAMPLE: B-5, 26'-26.5'		
	SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)		
	BY: DLC	DATE:	10/09
	PROJECT NO.: 168-H09.1	PLATE NO.	18a

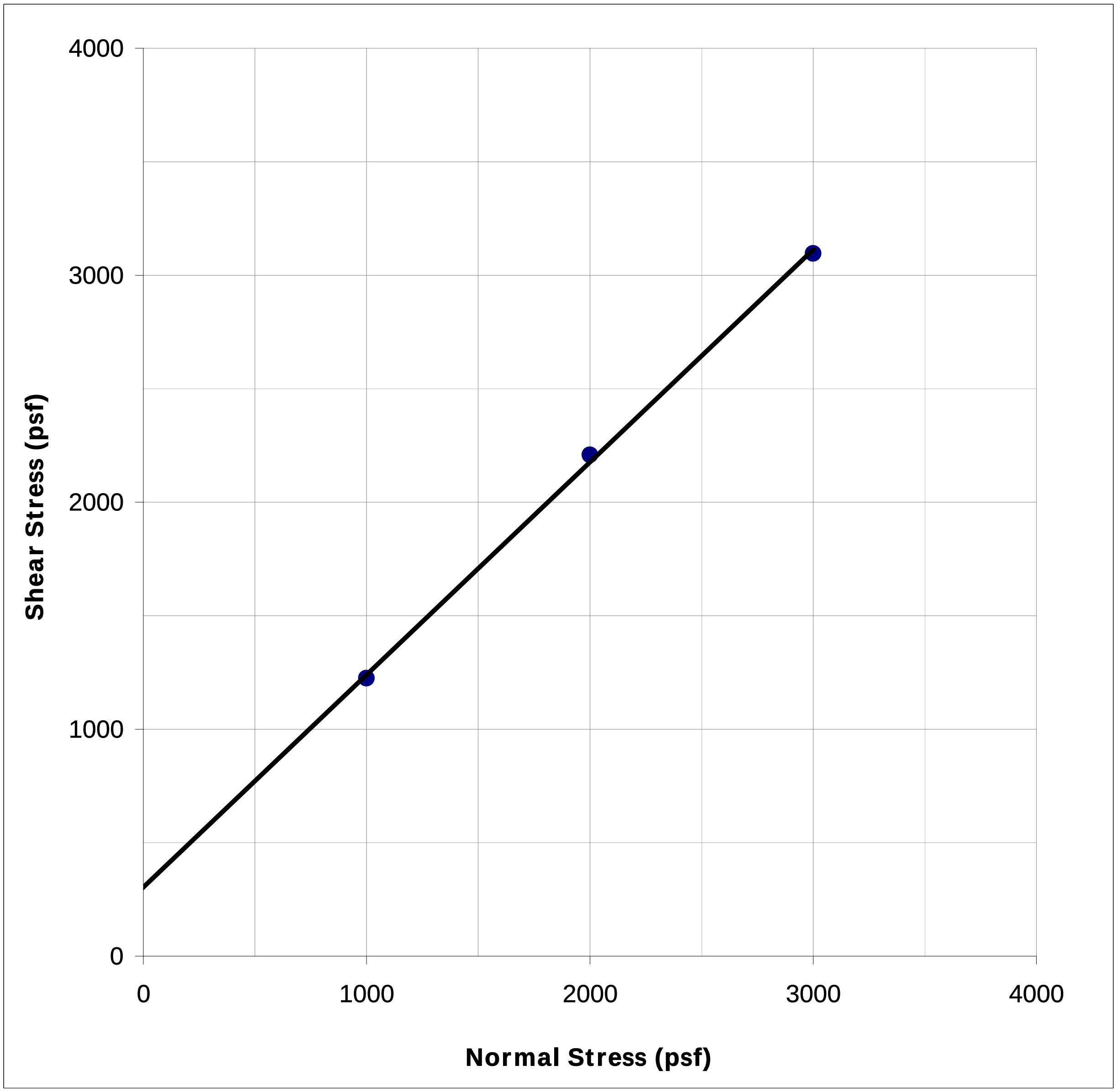


Shear Speed: 0.005 in. / sec.

Cohesion	56 psf
Internal Friction Angle	33 degrees

* Cohesion and angle of internal friction values are ultimate strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED	DIRECT SHEAR TEST RESULTS		
	SAMPLE: B-5, 26'-26.5'		
	SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)		
	BY: DLC	DATE:	10/09
	PROJECT NO.: 168-H09.1	PLATE NO.	18b

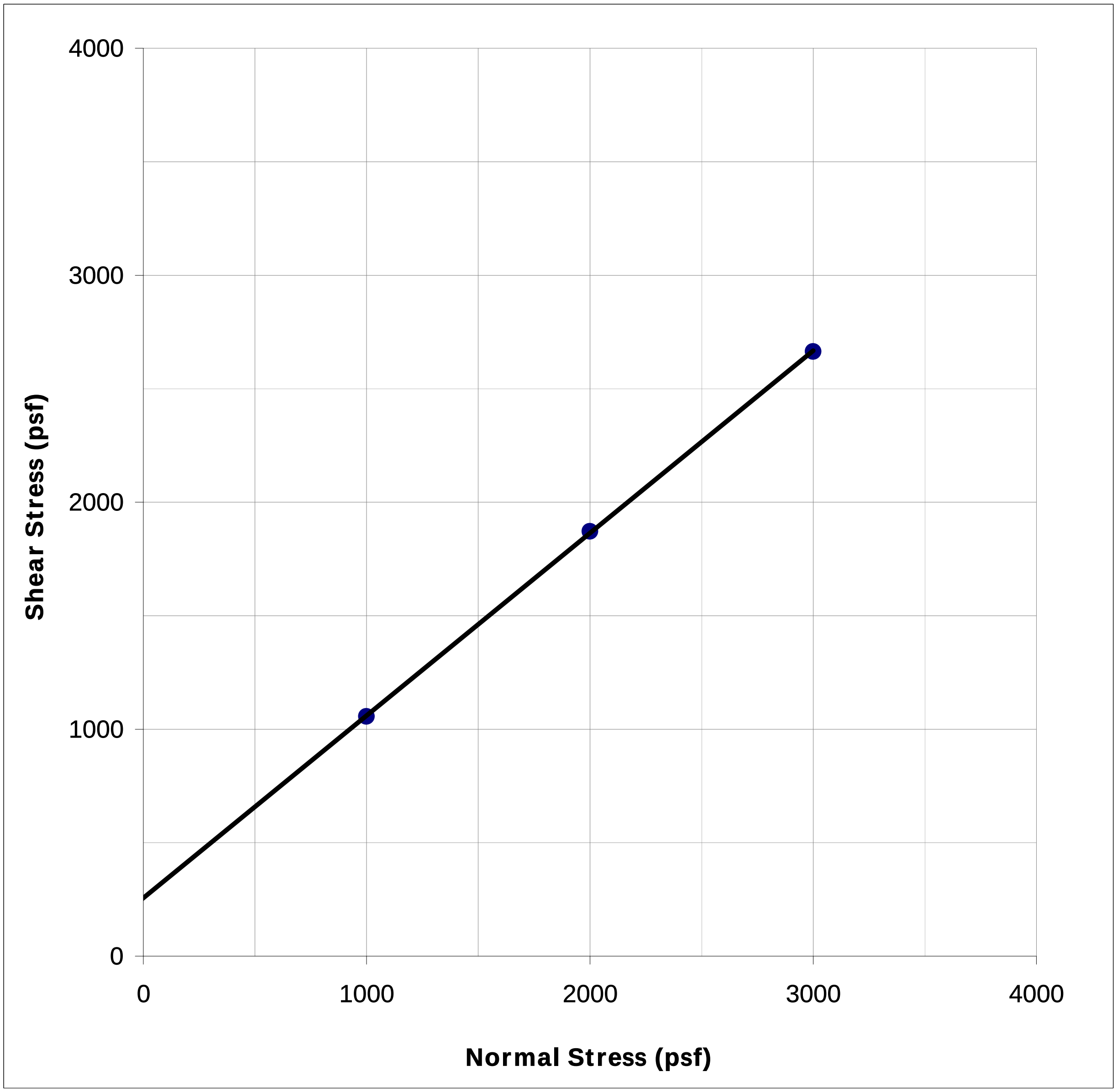


Shear Speed: 0.005 in. / sec.

Cohesion	304 psf
Internal Friction Angle	43 degrees

* Cohesion and angle of internal friction values are peak strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED	DIRECT SHEAR TEST RESULTS		
	SAMPLE: B-5, 46'-46.5'		
	SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)		
	BY: DLC	DATE:	10/09
	PROJECT NO.: 168-H09.1	PLATE NO.	19a



Shear Speed: 0.005 in. / sec.

Cohesion	256 psf
Internal Friction Angle	39 degrees

* Cohesion and angle of internal friction values are ultimate strength values from submerged sample.

HILLTOP GEOTECHNICAL INCORPORATED

DIRECT SHEAR TEST RESULTS			
SAMPLE: B-5, 46'-46.5'			
SOIL DESCRIPTION: Weathered Granitic Basement Rock (Kcc)			
BY:	DLC	DATE:	10/09
PROJECT NO.:	168-H09.1	PLATE NO.	19b