NATURAL RESOURCES

Slope Stability Analysis of the Bluffs along the Washington State Capitol Campus, Olympia, Washington

by Wendy J. Gerstel

WASHINGTON
DIVISION OF GEOLOGY
AND EARTH RESOURCES

Open File Report 96-3
April 1996

*Work performed under
Department of General Administration
Contract #FY93-077(4)*

WASHINGTON STATE DEPARTMENT OF
Natural Resources
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INTRODUCTION

This report presents the findings of a geotechnical investigation by the Department of Natural Resources (DNR) Division of Geology and Earth Resources (DGER) into the stability of the bluffs surrounding the Capitol Campus. The report has been submitted by DGER to the Department of General Administration (GA) Engineering and Architectural Services Division under contract #FY93-077(4) (Gerstel, 1996). It builds on previous geotechnical investigations by Dames & Moore (1965), Geolabs-Washington (1973), The Portico Group and The SWA Group (1992), and Shannon and Wilson, Inc. (1986), with the addition of recent borehole information, updated detailed geologic and geomorphic mapping, airphoto analysis, and slope stability modeling. This report addresses the stability of the natural bluff slopes and not the stability of the filled ravine underlying the Capitol Campus Conservatory/Greenhouse building complex, which will be discussed in a separate report.

INITIATION AND SCOPE OF WORK

This project was initiated by GA in their effort to carry out plans for the development of the Capitol Campus Master Plan and Heritage Park, including the design of access from the Campus to Capitol Lake along the proposed Capitol Trail. Consideration of the geologic conditions of the bluffs is essential to developing the aesthetics of the park and insuring the safety of its users. As a consequence, GA requested information on the stability of the natural bluffs, the location of thick soil accumulations and construction waste that might be unstable, and the location of springs and seeps that might also contribute to slope instability. Detailed geomorphic mapping and slope stability modeling of the north- and west-facing bluffs bordering the west Capitol Campus were performed to accomplish these goals. The investigation of the Capitol Campus bluffs consisted of a detailed examination of airphotos covering the years from 1965 through 1995, documentation of on-the-ground observations with construction of field-developed cross-sections, and the drilling of five boreholes at or near the bluff's edge. The purpose of the drilling program was to gain a better understanding of the subsurface stratigraphy and ground-water and geotechnical conditions. Soil parameters were developed using the information acquired through field observations, drilling, and soils testing done for this and previous studies. These parameters were then used in computer-aided slope stability modeling.

LOCATION AND SITE DESCRIPTION

The bluffs being evaluated in this report form the major portion of the north and west boundaries of the West Capitol Campus in Olympia (Plate 1). These bluffs make up the steepest part of the east side of Capitol Lake and fall within designated "Landslide Hazard Areas" and "Seismic Hazard Areas" under the City of Olympia's Critical Areas Ordinance. Wetlands have been identified in an area at the base of the slope between the Temple of Justice and the GA building. The study area includes the slopes extending from the northern edge of the Capitol Campus, around the north side of the Conservatory/Greenhouse complex, westward toward the steam plant, and south along Capitol Lake to the southern boundary of the Capitol Campus, just south of the State Library.

At the base of the north-facing slopes is a flat surface ranging from about 50 to 200 ft wide and supporting several sets of railroad tracks, a gravel road access to the steam plant, and a foot path. This surface is underlain by fill emplaced during the latter part of the last century and early part of this century (Plate 1 and Fig. 1). The elevation of the upper surface of the bluffs, on which the Capitol Campus is built, ranges from approximately 100 ft above mean sea level just west of the greenhouse to about 125 ft near the Governor's mansion.

Slope gradients within the described reach of the bluffs fall generally within the range of 70% to 100% (35°–50°), with some sections exceeding 170% (~65°). There is abundant evidence of repeated historic soil slips and small translational and/or rotational slope failures. Many of the unstable areas correspond to sites where construction material and organic debris have been sidecast from the top of the bluff. This is particularly evident along the northwest corner of the Campus (labelked "northwest point" on Plate 1 and Fig. 2).

Vegetation along the bluffs includes a ground cover of salal, Oregon grape, and swordfern (particularly on the west-facing bluff), with horsetails, grasses, and other hydrophilic plants in areas with springs and seeps. Snowberries, vine maple, salmon berries, and other shrubs contribute to the understory, while big leaf maple, Douglas fir, red alder, and some oak provide the upper canopy. The largest trees are generally the Douglas fir, reaching up to 3 ft in diameter and occurring in clusters primarily just south of the steam plant and as isolated trees elsewhere on the bluff. Some of the big leaf maples reach diameters of 2 to 3 ft.

REGIONAL GEOLOGY

The sediments and bedrock outcrops in the Olympia area record the advance and retreat (at least twice) of, and erosion and deposition by, the Puget lobe of the Cordilleran ice sheet. The last episode of glaciation occurred during the Vashon Stade of the Fraser Glaciation, approximately 20,000 to 10,000 years ago. The large-scale geomorphic features visible in today's landscape result from erosion and deposition by the ice and a complex fluvial system with associated lakes that intermittently occupied the Puget lowland area during that time. The channel walls of Percival Creek (about mi west of the Campus and across Capitol Lake) and a small drainage to the south expose nonglacial deposits of fine sands and silts correlated to the pre-Vashon deposits of the Kitsap Formation.

Thorson (1980) and Booth (1994) propose that during the later stages of Puget Lowland glaciation, subglacial meltwater streams cut channels into the earlier glacial and nonglacial deposits, forming Budd Inlet and other local waterways, including the lower Deschutes River valley. As the ice melted from the region, these channels and numerous outwash depressions (kettles) were filled by many interconnecting lakes (collectively known in the Olympia area as Lake Russell) in which were deposited a thick blanket of fine, laminated silts and sands and associated low-energy fluvial deposits. The surface morphology of these sediments has since been modified to some extent by Holocene processes, leaving them exposed primarily on upland surfaces, such as the bluffs north of Priest Point Park(along the east shore of Budd Inlet orth of the Campus),, and in dissected stream channels, such as Percival Creek and the lower reaches of the Deschutes River.

Bedrock exposures in the Olympia area are Eocene Crescent Basalt. However, there are no known outcrops in the vicinity of the Capitol Campus. The closest exposure is approximately 1.5 mi to the south at Tumwater Falls. Bedrock is thought to lie several hundred feet below the surface beneath the Campus. A boring drilled about 1 mi to the north of the Campus reached a depth of 495 ft and did not penetrate bedrock.

SITE HISTORY AND AIRPHOTO ANALYSIS

Historic airphotos show multiple slope failures over the past 30 years, allowing estimates of timing and frequency of failures and rates of revegetation.

The following is a list of DNR photos at a scale of 1:12,400 used in the airphoto analysis:

- 1965: KMT-65-29B-(22-24)
- 1972: MT-72 3-29A-(31, 32)
- 1978: NW-78 28A-(38, 39)
- 1981: SP-81 5-29-(32, 33)
- 1985: SP-85 13-029-(136-138)
- 1989: SP-89 30 29-(264, 265)
- 1995: 152-869 1312 (1-1, 1-2) and (3-3, 3-4)

The airphoto analysis, along with field observations, interviews with long-time Capitol Campus employees, and a search of historical records, hav identified slope failures in several places along the bluffs (Plate 1 and Fig. 2). The two largest occurred just north of the Temple of Justice and west of the GA building, respectively. Both involved the failure of native soils but may have been initiated by heavy rainfall and inadequate drainage systems (Ritchie and Cashman, 1959), possibly coupled with the disposal of fill or sidecast (construction debris and organic material) from the edge of the bluff onto the steep, loose soils of the slope (Washington Department of Transportation [WDOT], 1988). The failure near the GA building occurred in 1986 and was mitigated by a retaining wall (WDOT, 1988; GeoEngineers, 1988). The failure in front of the Temple of Justice occurred in the winter of 1958–59 and required modification of the adjacent parking area. A buttress and drainage system were proposed and designed for this area, but never constructed (Ritchie and Cashman, 1959).

Field observations and airphotos show that localized soil slips, translational failures, and small rotational failures have occurred along the bluffs in an area west of a private apartment building to the north of the GA building and in the area between the Temple of Justice and the north side of the steam plant. In 1990, both the north and west sides of the northwest point of the bluff failed in a large debris slide that buried the railroad crossing at the base of the slope. This failure was almost certainly initiated by repeated dumping of waste material, predominantly large blocks of concrete, over the edge of the bluff and onto the slope below (Allen, 1990). It occurred even though dumping of material over the bluff edge had been stopped by the early 1980s with the realization of the potential hazards (Nick Cockrell, GA, oral commun., 1995). A significant quantity of the unstable waste material is still draped on the bluff slopes.

From the steam plant southward for approximately 120 ft along the west-facing bluffs, there is little evidence of debris slides. There has, however, been persistent soil creep and small-scale slumping, especially along the lower part of the slope within about 15 to 25 ft of the lake (Fig. 3). Airphotos show stressed vegetation and toppled trees in the area of active slope movement, particularly since 1985. The upper part of the slope shows evidence of at least one small rotational slump. South of that, just west of the Governor's mansion, is an area of larger rotational failures and debris slumps and slides (Fig. 2). Both ground observations and airphoto review suggest that these failures have been active in the past 30 years.

South and west of the John L. O'Brien Building, the bluff slopes are now stable, but the gradient is unusually uniform and appears to have been modified at some time in the past (Fig. 4). The 'healing' designation in this area on Figure 2 denotes areas where vegetation had been disturbed, but it was unclear from the airphotos whether landsliding had actually occurred. Field observations show evidence of recent dumping of organic waste, which could eventually destabilize a portion of the slope. South of this area, west of the state library, are some additional small debris slide scars that appear in airphotos to be relatively recent (<20 years) by their cover of young vegetation.

Although mitigation measures have been proposed for some areas of the bluff in the past, such as a drainage system northeast of the Temple of Justice (Ritchie and Cashman, 1959; Jordan/Avent and Associates, 1972?), the only reach of the bluff to have received any constructed stabilization is the area to the west of the GA building. As mentioned previously, a large section of this portion of the bluff failed in 1986. Washington Department of Transportation (WDOT) (1988), in investigating this failure, estimated it to be approximately 100 ft in length and 70 ft in height and concluded from their investigation that the remaining slope was marginally stable to unstable. GeoEngineers (1988) subsequently designed and built the retaining wall. Some hints of the potential instability of this area may have already appeared by 1972 (Fig. 2). Surface erosion is visible in the airphotos of that year but seems to have healed over by 1981 (as viewed in the 1981 photo series).

Possible correlations between precipitation and landslide activity along the Capitol bluffs were investigated. Records of precipitation from the Olympia Airport for the years 1949 to 1993 (Fig. 5) were compared to the information gathered from the 1965 through 1995 airphoto coverage. Figure 2 shows that periods of high landslide activity were concentrated in 1965 to 1972 and 1981 to 1995 (particularly 1981 to 1985). This corresponds to the generally higher precipitation from 1968 to 1972 and 1980 to 1984 shown in Figure 5. Likewise, low landslide activity seems to correspond to the lower precipitation recorded between 1972 and 1980. Correlating the slide activity of the late 1980s to the precipitation record is more difficult. In spite of a lower-than-average recorded precipitation for these years (average being approximately 50 in. per year), there is a general increase in landslide activity. This lack of correlation may be due to human influence, such as increased surface runoff caused by paving, poor drainage from the campus, plugged storm drains, or the effects of sidecast of organic and construction debris. The 1995 airphotos most likely chronicle the landslides resulting from the severe storms of 1990, recorded in the extreme monthly precipitation for that year (Fig. 5). Most of these landslides were centered around the northwest point. The largest covered the access road to the steam plant, the railroad tracks, and almost reached Capitol Lake. This slide was the subject of the investigation by Allen (1990).

SITE GEOLOGY AND RESULTS OF THE DRILLING INVESTIGATION

The slopes adjacent to the Capitol Campus expose a sequence of glaciofluvial and glaciolacustrine sediments ranging from coarse sandy gravels and cobbles to fine sands and silts. The complex history of erosion and deposition of the glacial deposits, in particular the Vashon recessional fluvial and lacustrine deposits, is evident in the complex stratigraphy encountered in the borings drilled along the bluffs and elsewhere on the Capitol Campus (Appendix A). Cross sections derived from field observations and drill hole data suggest little lateral continuity in the uppermost units (Appendix B).

As described below, a sequence of laminated silts exposed in the lower portions of the bluffs on the north side of the Capitol Campus and in several of the borings is denser than the surface silts attributed to the recessional lake deposits. These probably have their origin in a proglacial lake associated with the onset of the Vashon glaciation, or they may have been deposited by slightly earlier nonglacial low-energy streams. The silts contribute to the instability of the bluffs in that they perch water.

Correlation of the stratigraphy among the five holes drilled to investigate the native soils of the bluff is difficult, even though they are separated by only 250 to 500 ft. Only one or two of the stratigraphic units encountered in those borings can be correlated across the short distance between holes and to the bluff exposures. The most continuous of these are the medium-dense laminated silts of variable thickness with blow counts ranging from 20 to 30 blows per foot (BPF) and an underlying dense, coarse gravelly unit. The top of the silts is encountered at about 52 ft above sea level (a.s.l.) in borings DH-5 and DH-6 and at about 90 ft a.s.l. in boring DH-14 (Appendix A). The silts are exposed in several places along the bluffs, as can be seen in cross sections FF' and GG' (Plate 1, Fig. 2, Appendix B). Correlating between the borings and the bluff exposures is tentative as the upper contact of the silts is exposed in the bluffs at approximately 65 to 70 ft, or about 35 ft below the parking lot surface.

Very little water was encountered during any of the drilling. Open stand pipe piezometers were installed in borings DH-1 and DH-10 (drilled next to DH-5 by WDOT and located as DH-5 on Plate 1 and Fig. 2) in an attempt to determine the regional ground-water table and locate any perched water. DH-1 was completed with a piezometer extending to a depth of 103 ft. DH-10 was completed with two piezometers, one extending to 109 ft, the other to 80 ft. Water levels in DH-1 from mid-1993 through 1995 have read consistently at about 101 to 102 ft below the surface (or about 7 ft a.s.l.), probably reflecting the regional ground-water table controlled by Capitol Lake. The deeper piezometer in DH-10 is apparently also reading the regional ground-water table at about 100 ft below the surface (or about 10 ft a.s.l.). None of the borings encountered any significant perched ground water during drilling. In DH-6 and DH-14, damp to wet samples were recovered from depths of 34 ft and 14 ft, respectively. These correspond to zones of iron staining, suggesting a fluctuating localized, possibly perched, water table at these depths.

Borehole DH-1, drilled in 1992, was also completed as a slope inclinometer. Repeated monitoring of this inclinometer has not shown any movement to date (Appendix C). Based on this information, we decided not to complete subsequent holes with inclinometer casing. The lack of movement indicated by the data from DH-1 confirms field observations suggesting that slope instability is primarily a result of shallow, translational failures.

SITE CONDITIONS

Since the retreat of the Puget lobe approximately 13,000 years ago, the slopes of the Capitol Campus bluffs have been modified by landsliding, stream erosion and surface runoff, and more recently artificial loading of the slopes with construction and organic waste material. The west-facing slopes have also been subject to undercutting at the toe by the Deschutes River (visible in Fig. 6 during draw-down of Capitol Lake in the summer of 1994) and more recently (since the creation of Capitol Lake in 1959) to erosion and undercutting by wave action and high water during flood events. Most of the slide debris around the northwest point and on the north-facing slopes contains large amounts of concrete pieces and other construction waste, suggesting that sidecast material has been a major contributor to instability of the slopes. This is borne out by several previous geotechnical investigations referenced in this report. In addition, development and construction of the Capitol Campus facilities have modified surface and ground-water conditions (Ritchie and Cashman, 1959), also affecting slope stability. Furthermore, the thick, dense silt unit encountered at about 60 to 75 ft elevation, which is described in the previous section, contributes to the instability of the bluff slopes by perching water and maintaining a steep slope gradient.

Field studies carried out from 1992 to 1995 included detailed mapping of historic, active, and potential failures. The cross sections (Appendix B) show that the general profile of the bluffs is concave at the top of the slope and convex and hummocky on lower parts of the slopes. The upper slopes commonly expose areas of fresh soil or thin soil mantle (2 to 4 ft thick). The lower slopes are mantled by failed soil or slide debris (4 to 10 ft thick or thicker).

The north-facing bluff, located between the old ravine fill under the Conservatory/Greenhouse and the northwest point, maintains a slope gradient of 70% to 100% (35° to 50°) or more in areas where it is not mantled with slumped soil. In some of the fresh scarps on this slope, medium-dense laminated silts with blow counts of 15 to 25 BPF are exposed for about 30 to 40 ft vertically in the lower third of the slope (Fig. 7). This unit apparently perches water, as small seeps are visible in places at the contact with the overlying poorly sorted loose sands and pea gravels (Appendix B, Sections FF' and GG').

Much of the slope is now mantled by slumped soil that readily becomes saturated, either by surface runoff from heavy rains and parking lot runoff, and/or seepage from the perched water above the dense laminated silts. This material, when saturated, is easily remobilized downslope. The soil mantle is damp to wet throughout most of the year.

Wet, boggy areas and seeps also occur at the base of the bluffs along the entire stretch from just north of the GA building to the slopes adjacent to the Temple of Justice (Plate 1). These are attributable to water emanating from along stratigraphic contacts, from storm water drains terminating and discharging at the edge of the bluffs, and/or from pre-existing natural drainages buried by fill (such as in the areas of the GA building and the Conservatory/Greenhouse).

In the west-facing bluffs east of the steam plant, stratified gravels and cobbles of Vashon advance outwash are exposed. This unit maintains a steep slope gradient where it was excavated for the construction of the steam plant in the early 1920s. Archival photographs show finer sediments, exposed during the construction of the storage tank in the 1970s(?), at the base of the slope just to the south. Some of the excavated material from both projects was probably used as fill along the west side of the steam plant.

In the slopes south of the storage tank, from lake level to about 30 ft up the slope, gravelly medium-coarse sands have been exposed by erosion and soil creep. These sands were probably deposited or reworked by an ancestral Deschutes River into one of the abandoned subglacial meltwater channels and were subsequently dissected by the meandering present-day Deschutes River prior to the existence of Capitol Lake. This portion of the bluff slope has a markedly convex shape in profile compared to the other slope profiles (Section LL′ in Plate 1, Fig. 2, and Appendix B). Persistent slope movement is visible in airphotos, particularly since 1985. Above this area on the slope is a small (<20 ft wide) dormant(?) rotational failure.

South of the steam plant, the mechanism of failure is slightly different from that described for the north-facing bluff slopes. On the slopes adjacent to the Governor's mansion are two large slump-earthflows with steep headwalls and hummocky slide debris at the base. These failures formed debris fans that extend out into Capitol Lake approximately 20 ft beyond the rest of the shoreline (Plate 1 and Fig. 2). Springs and seeps are visible in the headwall areas as well as at the base of the slope in the slide debris. Slope movement in this area has probably been sporadic with different portions moving at different times, making it difficult to estimate the age of movement.

SLOPE STABILITY MODELING

Models of Slope Failure

Field observations combined with borehole data suggest three likely mechanisms for slope failure along the bluffs of the Capitol Campus (Fig. 8). Figure 8A illustrates a simple, thin translational failure of an approximately 3- to 6-ft-thick mantle of sidecast material and/or remobilized native soil or colluvium. Figure 8B illustrates a small rotational slump in native soils, common on the upper slopes west of the Governor's mansion and the mechanism of the 1986 failure near the GA building. Locally these slumps transform into slump-earthflows as the soils attain residual strengths and develop excess porewater pressures. Such features are visible at the base of the slope west of the Governor's mansion. Figure 8C illustrates a combination of the processes depicted in 8A and 8B, in which failures are caused or enlarged by both the addition of sidecast material and the mobilization of native material by small rotational failures. This is the most likely mechanism causing the instability of the north-facing slopes along the Campus bluffs.

To evaluate the stability of the bluffs, field observations, borehole data, and soil test results were applied to three different slope stability modeling programs. Detailed stability modeling of the bluff slope at each cross-section was beyond the scope of this project. Section GG′ was selected as representative of slope conditions, particularly for the north-facing slopes. Section GG′ also shows the best correlation between bluff exposures and borehole data.

Level I Stability Analysis (LISA)

A reasonable distribution of *in situ* shear strengths for the soils mantling the bluff slopes was back-calculated using DLISA, the Deterministic Level I Stability Analysis software developed by the U.S. Forest Service Intermountain Research Station, Moscow, Idaho. DLISA calculates a factor of safety using the infinite slope model for a single set of input values. For these analyses, a factor of safety of 1.00 was assumed, and the failure surface was assigned to the soil mantle/in-place soil contact. The analyses looked at soil thicknesses ranging from 2 to 10 ft, and ground-water depths of several inches to full saturation. A range of shear strengths with ϕ's of 20°–27° was determined by the back calculations. Shear strengths for the soil mantle in this model are considered to be residual and therefore more likely to fall within the lower end of that range. The Level One stability analysis does not consider the effects of stratigraphy or ground-water conditions within the slope underlying the soil mantle.

With the range of soil and slope parameters determined in the DLISA back analysis, the program LISA, which uses a probabilistic (rather than deterministic) Monte Carlo simulation, was used to model the slope at two different conditions of ground-water saturation; half saturation (ground-water ratio of 0.50) and full saturation (ground-water ratio of 1.0). The results, presented in Appendix D, show that for the factor of safety range corresponding to the determined range of soil and slope parameters, the modeled stability conditions can vary from very stable to very unstable, depending on the water content of the soil. Elevated ground-water conditions result in a higher likelihood of slope failure. This has significant ramifications with respect to runoff and drainage from the Capitol Campus.

XSTABL Analysis

To evaluate the stability of the in-place native soils or sediment, soil parameters from the LISA analyses and laboratory testing (Dames & Moore, 1965; Geolabs, 1988; WDOT, 1988; and this report (Appendix E)) were applied to the slope stability modeling program XSTABL, developed by Sunil Sharma at the University of Idaho. XSTABL performs a two-dimensional limit-equilibrium analysis to compute the factor of safety for a layered slope using the modified Bishop or Janbu methods. Residual strengths were used to model the soil mantling the slope, and peak strengths were used to model the in-place sediments described earlier in this report. Several examples of the XSTABL analyses appear in Appendix F and are discussed below.

Models considered for the XSTABL analyses were set up to evaluate the factor of safety for the bluff slopes both at the soil mantle/native soil contact (Fig. 8A), and within the native soils (Fig. 8B). Five soil units were differentiated for the analyses as follows:

- Soil Unit 1 – soil mantle; contains Water Layer 1
- Soil Unit 2 – upper bluff unit, silt with gravel; contains Water Layer 2
- Soil Unit 3 – medium-dense to dense laminated silt
- Soil Unit 4 – basal bluff unit, gravels in sand; contains Water Layer 3
- Soil Unit 5 – fill from Capitol Lake dredgings; contains Water Layer 1

In the first round of analyses, XSTABL was allowed to generate random searches for circular failure surfaces, looking at slightly variable strength parameters and ground-water conditions for Soil Unit 1 (first two examples in Appendix F). In the next round of analyses, Soil Unit 1 was given higher (closer to peak) shear strengths and a failure circle was specified that would force the analysis into the native soils (next four examples in Appendix F). These runs were also evaluated under several different ground-water conditions.

Results of Slope Modeling

Slope stability modeling suggests that the bluffs are most likely to continue failing by the processes depicted in diagram A or C of Figure 8. With residual shear strengths for Soil Unit 1 of $\phi = 20°–23°$ or less and low cohesion values, the random-search XSTABL runs show that failures will occur most frequently at the soil mantle/native soil contact (Example 1 in Appendix F). These failures are particularly likely to occur during or shortly following periods of heavy rainfall and runoff with the resulting high water table in the soil mantle (Soil Unit 1). Using values for shear strength of $\phi = 24°–27°$, weighing the fact that some of Soil Unit 1 might demonstrate shear strengths closer to peak values, the generated critical failure surfaces commonly appear within the native soils (Example 2 in Appendix F). In both scenarios, a factor of safety of less than 1.0 is achieved under hydrologic conditions estimated for average to high local winter precipitation. Furthermore, the stability analyses show that only minimal increases in ground-water saturation are necessary to reduce the factor of safety or decrease the stability.

In XSTABL Examples 3–6 in Appendix F, a failure surface has been specified below the soil mantle/native soil contact (within the native soils) to assess the stability of the native soils. Hydrologic conditions are modeled to represent, respectively:

- Example 3 – periods of low precipitation,
- Example 4 – surface runoff affecting only the soil mantle,
- Example 5 – an increase in the thickness of the perched-water layer in Soil Unit 2 (increase in ground-water concentration with controlled surface runoff), and
- Example 6 – high winter precipitation affecting ground-water concentrations in both the soil mantle and the perched-water layer in Soil Unit 2.

Examples 3–5 illustrate conditions of low to moderate stability, with calculated factors of safety of 1.02. Example 6 shows an unstable situation, with a calculated factor of safety of less than 1.0.

From these analyses, we conclude that under present hydrologic conditions the Capitol Campus bluff slopes are moderately stable to unstable, the latter occurring during times of high ground water and/or high precipitation. The slope modeling suggests that infiltration of water into the soil mantle/sidecast by means of surface runoff and seepage from perched water layers is much more likely to result in slope instability than solely an increase in the thickness of the perched water table(s) within the native soil material (i.e., overlying the laminated silts). However, small rotational failures into the native soils, particularly in the upper portions of the slopes, are likely to occur following heavy rains and/or disturbance to the slopes such as by excavation and/or vegetation removal.

CONCLUSIONS

This investigation concludes that small failures are likely to continue along the steepest portions of the bluffs, especially in areas where a 3–10-ft-thick residual soil mantles the slope. This situation is most common along the north-facing bluff slopes. The soil mantle is easily saturated and subsequently remobilized by surface runoff and recharge from seeps and springs. Failures in the native, undisturbed soils are likely to occur less frequently, although they should not be discounted. As fresh material is exposed, it also becomes susceptible to erosion and saturation, and small rotational failures into this material are possible.

In the areas where there have been larger historic failures (rotational slumps transitional to slump-earthflows), such as adjacent to the Governor's mansion and off the northeast corner of the Temple of Justice parking lot, episodic slope instability is still likely. These soils are poorly drained, with at least a few water pipes/storm drains now discharging onto or into the slopes. Springs are numerous, and most flow year round.

Soils on the lower slopes in the area north of the Temple of Justice are typically saturated and likely to have high porewater pressures. The excavation for construction of Heritage Park facilities is likely to increase the potential for instability. As concluded in previous geotechnical studies of the area proposed for the Heritage Park access from the Capitol Campus (The Portico Group and The SWA Group, 1992; Dames & Moore, 1965), extensive site-specific geotechnical and ground-water investigations will be necessary prior to any construction or excavation on this slope.

The disposal, or sidecast, of organic material and construction waste over the edge of the bluff, particularly in the area of the northwest point, has exacerbated conditions of instability. The effectiveness of sidecast pull-back should be assessed on a site by site basis. Sidecast material should not be pulled back where it has become imbedded in the slope, acting somewhat as an armor, or where it will disturb well-established vegetation. However, in places along the bluff where tension cracks in the sidecast are visible at the bluff edge and no vegetation has established itself, or where large cement blocks are likely to further destabilize the slope and potentially cause injury or damage during a landslide event, the pull-back and/or removal of this material is advised. Locations where sidecast pull-back is recommended include the west-facing slope at the north end of the steam plant, west of the garage above the south end of the steam plant, and the north-facing side of the northwest point.

Storm-water and other drainage pipes discharging onto the bluff slopes should be investigated. In some cases, improvements can be made through the use of energy dissipators or half-pipe extensions at the discharge point, such as below the Governor's mansion. In other areas, such as near the Temple of Justice, more drastic measures might be needed to assess the routing of storm-water drainage from the Capitol Campus. No ponding of surface water should be allowed to occur within 50 ft of the top of the bluff.

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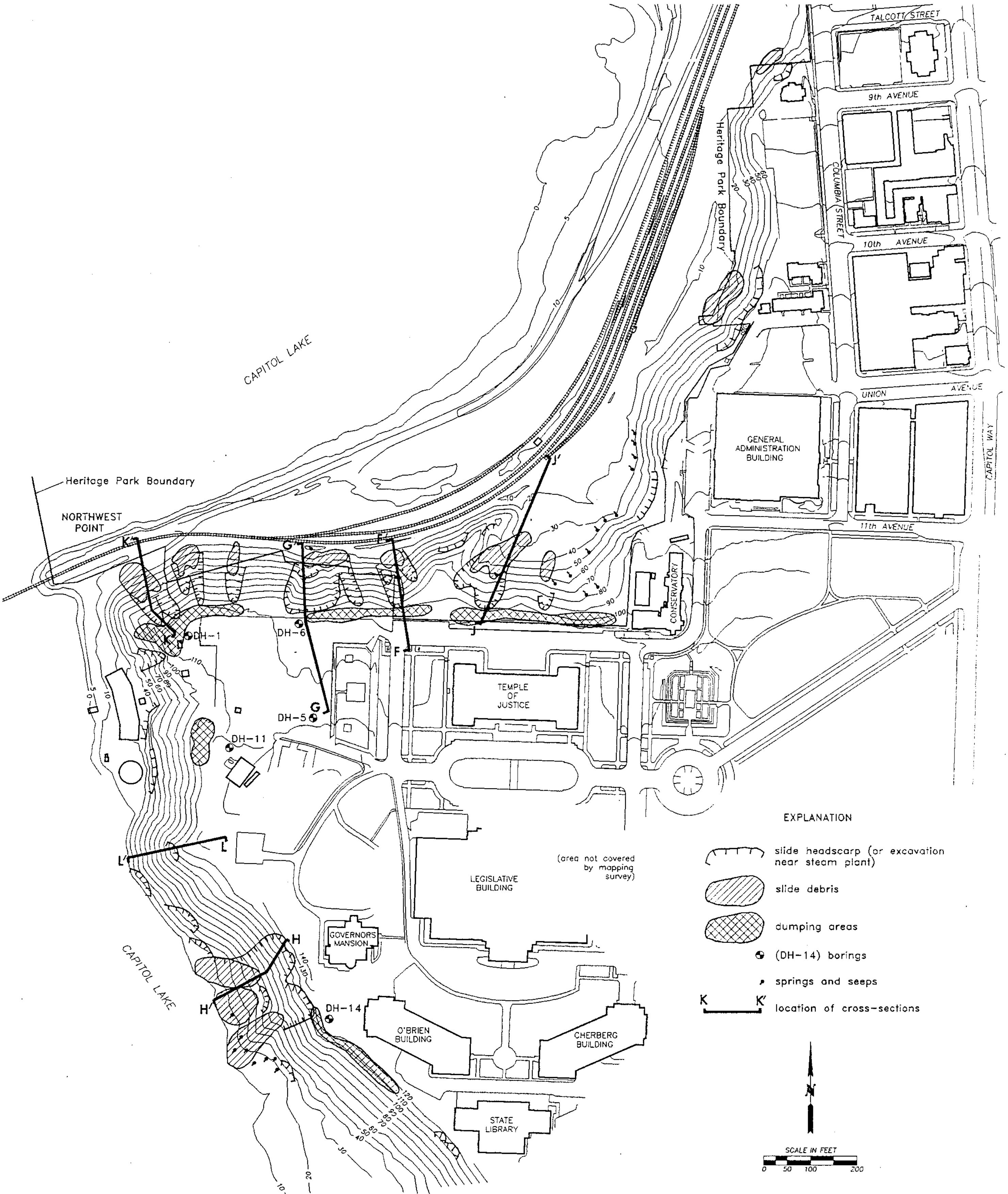


PLATE 1: Landslide and location map of the north- and west-facing bluffs of the Washington State Capitol Campus.

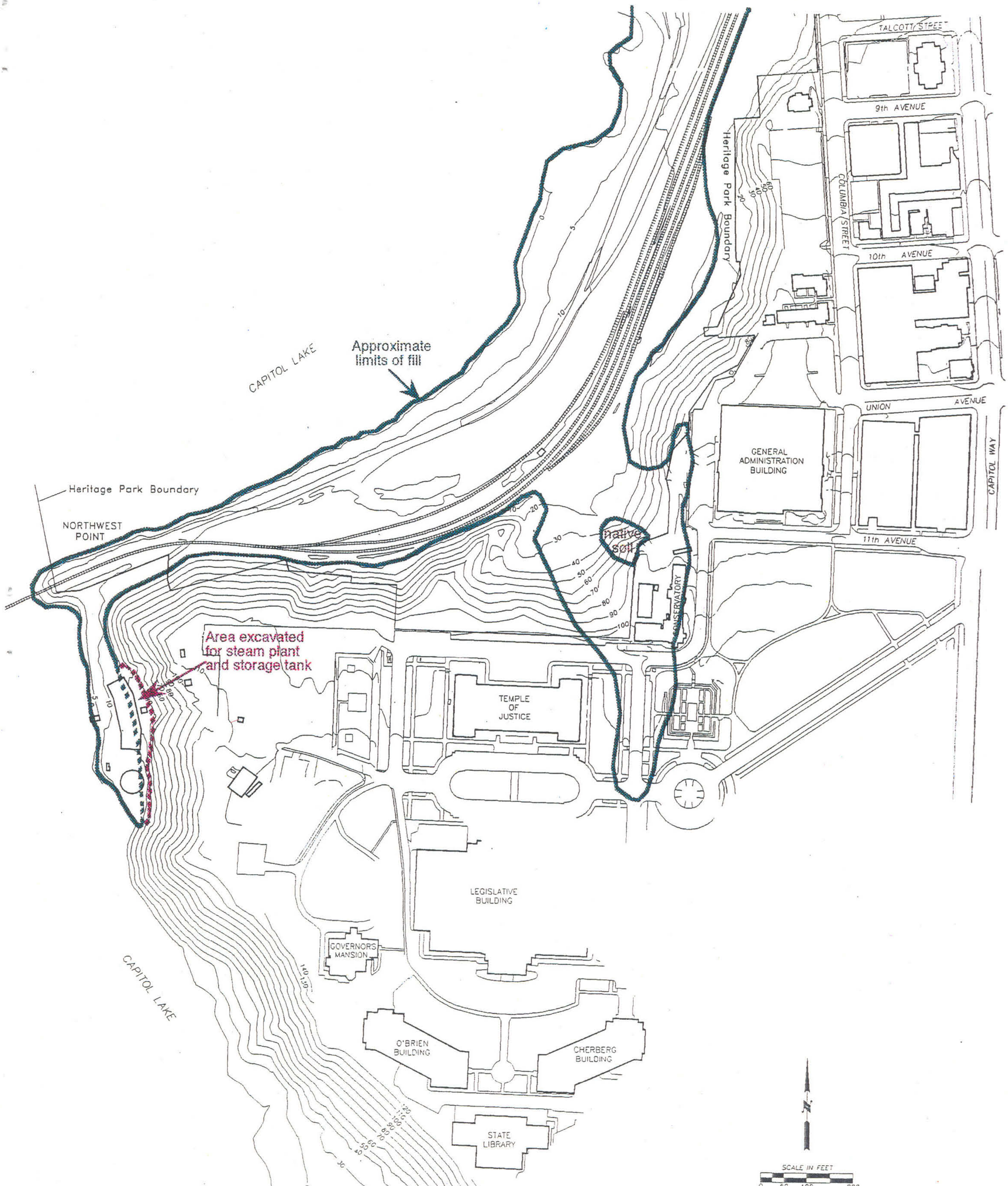


Figure 1. Approximate limits of fill emplaced during the late 1800's and early 1900's. Fill material generally consists of dredge spoils and/or construction waste. Material excavated from the bluffs for the construction of the steam plant in the early 1920's provided fill material for the plant foundation. Additional material was excavated in the 1970's for the larger replacement of the original storage tank.

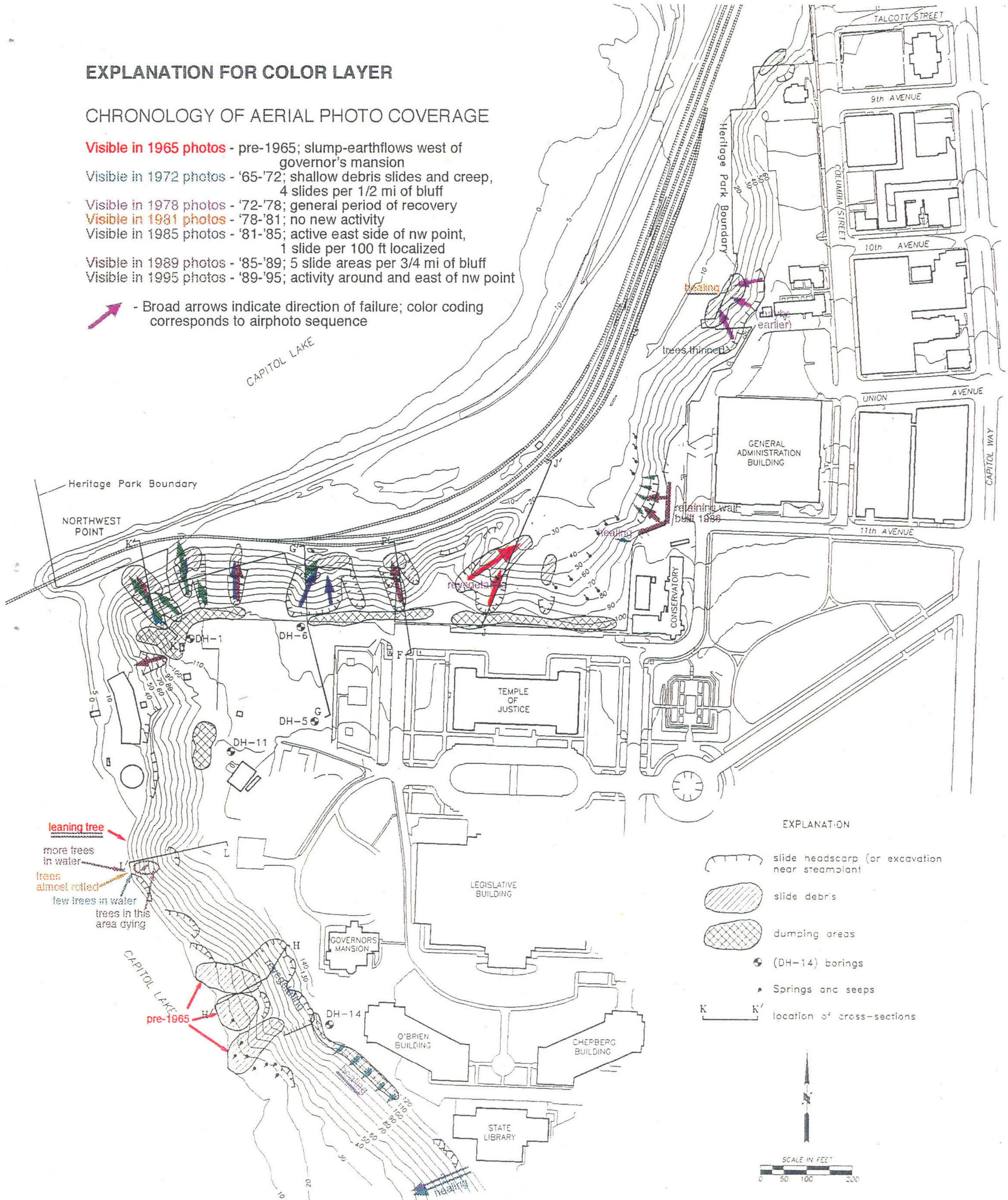


Figure 2. Thirty year chronology of landslide activity along the Capitol Campus bluffs, determined from airphoto coverage spanning the years 1965 through 1995.

Figure 3. View looking northeast from Capitol Lake to convex slope south of the steam plant. Approximate location of Section LL′. Note leaning trees along lower portion of slope.

Figure 4. View looking east-northeast from Capitol Lake to slope south and west of the O'Brien Building. Capitol dome is in the background. Note uniformity of slope and sparse vegetation. Left foreground with alder is underlain by debris slide material from slopes west of Governor's mansion. Boring DH-14 is located at top of slope to left of O'Brien Building.

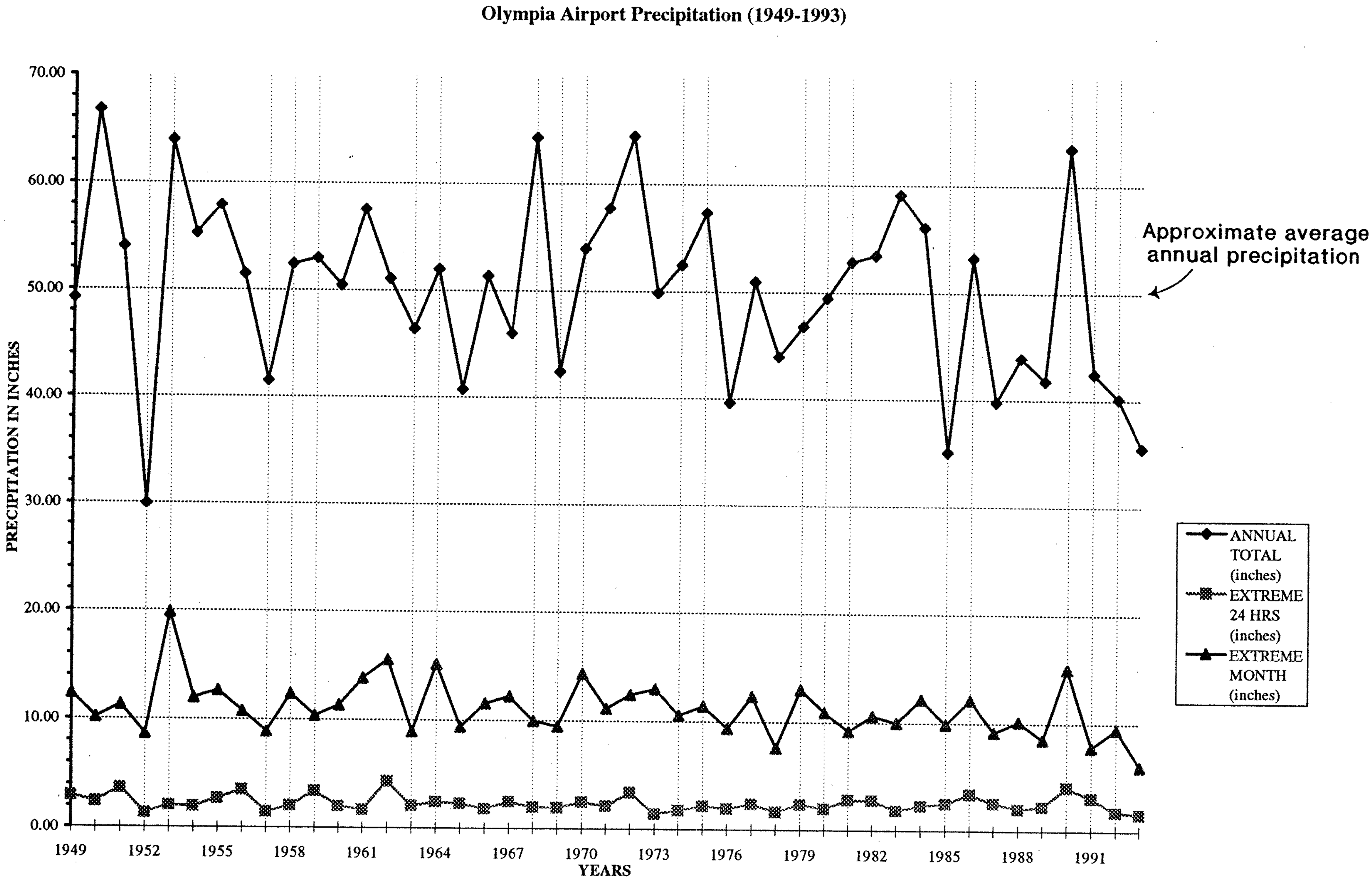


Figure 5. Record of precipitation showing annual total, 24-hour extreme, and monthly extreme at the Olympia Airport for the years 1949-1993.

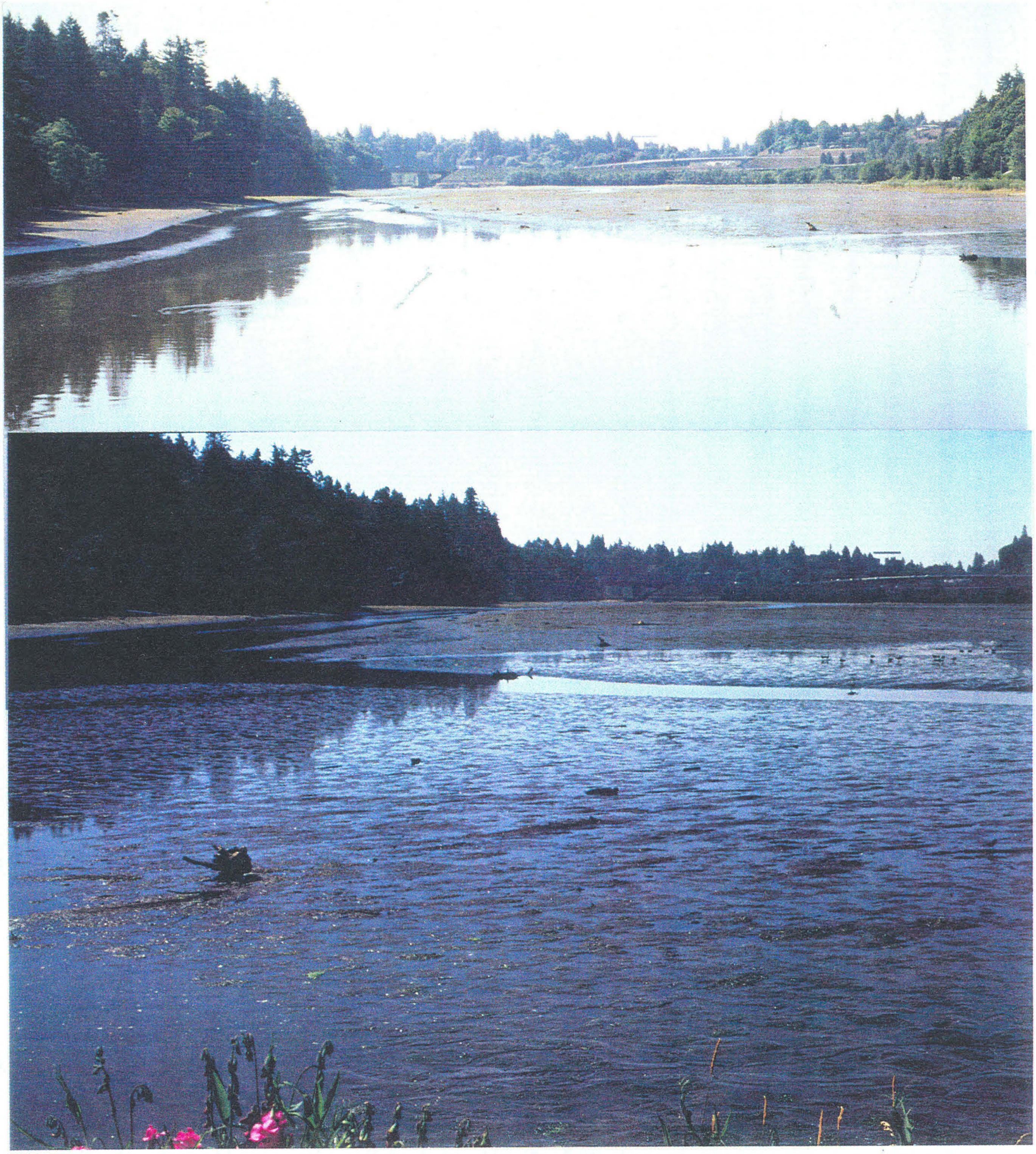
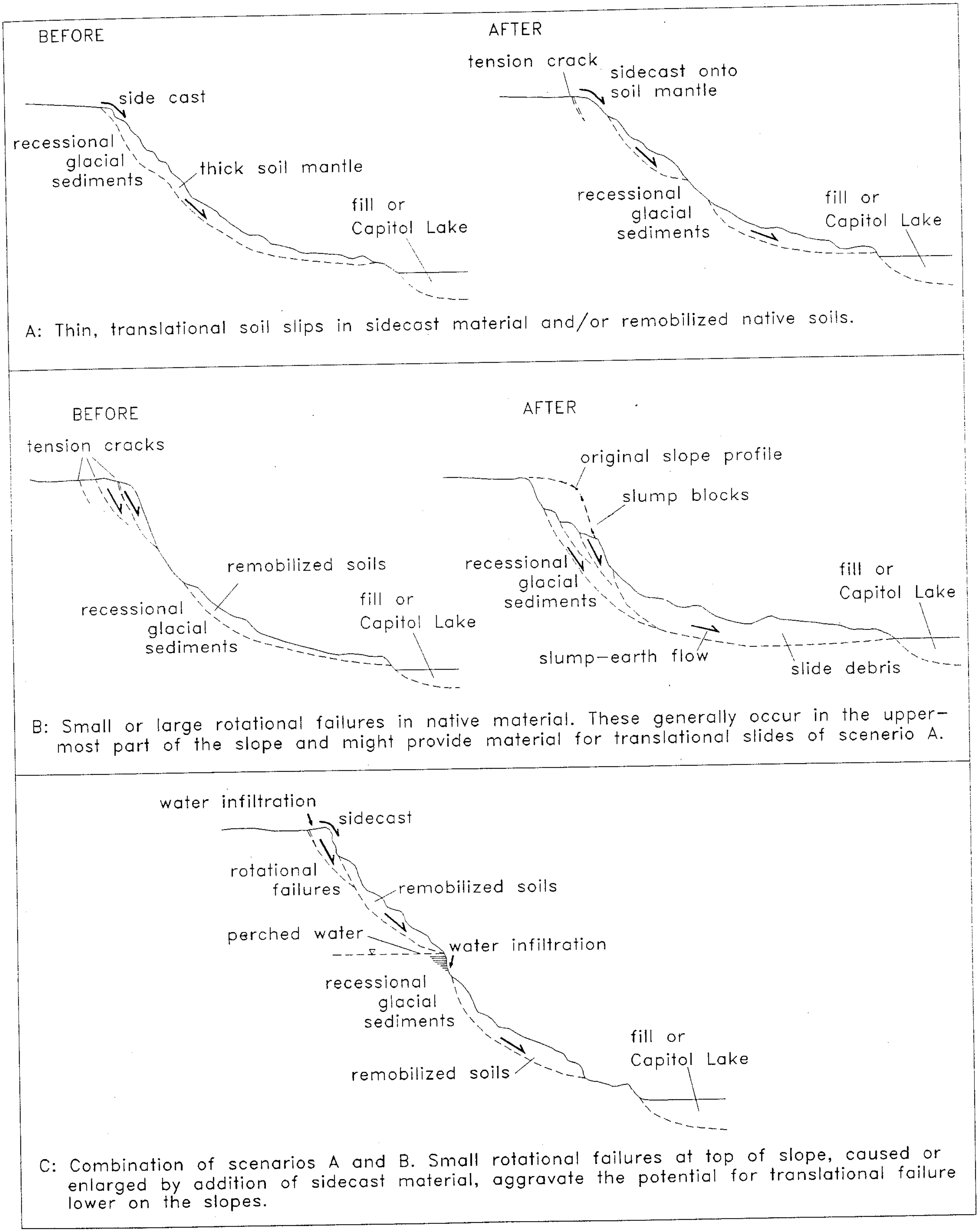


Figure 6. Views looking south of Deschutes River channel at base of west-facing Capitol Campus bluff slopes. Photos taken during drawdown of Capitol Lake in the summer of 1994. Percival Creek channel is visible entering from west in lower photo.

Figure 7a. View looking up slope along Section GG′. Note silts exposed midslope.

Figure 7b. View looking down slope along Section FF′.



A: Thin, translational soil slips in sidecast material and/or remobilized native soils.

B: Small or large rotational failures in native material. These generally occur in the uppermost part of the slope and might provide material for translational slides of scenerio A.

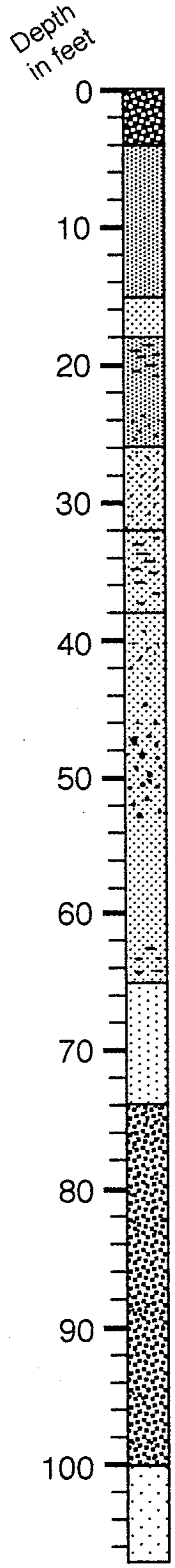
C: Combination of scenarios A and B. Small rotational failures at top of slope, caused or enlarged by addition of sidecast material, aggravate the potential for translational failure lower on the slopes.

Figure 8: Likely mechanisms of bluff failure on the Washington State Capitol Campus

APPENDIX A

BORING LOGS

BORING NUMBER: DH-1
PROJECT: Capitol Campus Bluff Stability Investigation
DATE OF DRILLING: October 24, 1994



Blows per foot

Ground Surface Elevation: approx. 110' a.s.l.

FILL: silty, sandy

6 — Brown sandy SILT

Brown fine SAND

13 — Brown clayey SILT

19

Brown sandy SILT

27

Brown silty SAND

19

Brown clayey SAND

33

Gray fine-medium clean SAND

27

37

Brown silty fine SAND with occasional GRAVEL

39

31

33

Brown silty fine SAND

30

Brown fine-medium clean SAND

50

50/4"

75/7" — GRAVEL with sand and silt

50/5"

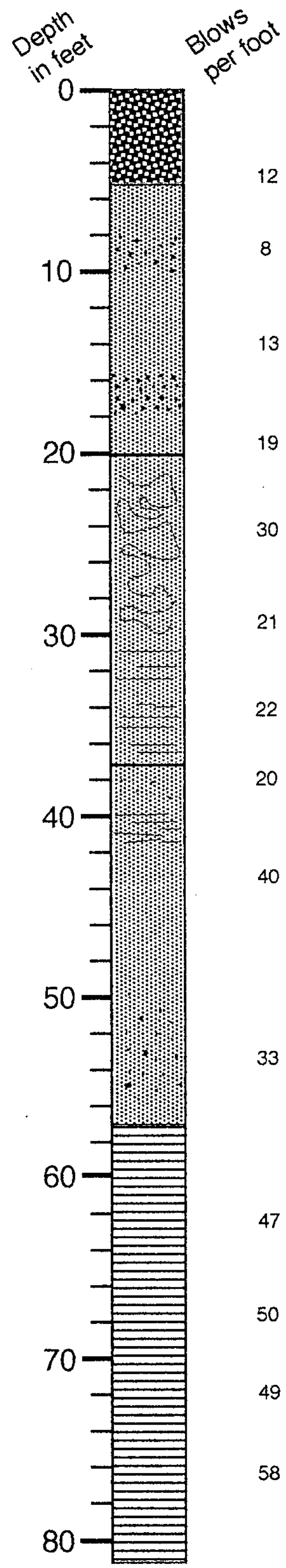
94/10"

Brown medium-coarse clean SAND

61/6"

Bottom of Hole 107.0 feet

BORING NUMBER: DH-5
PROJECT: Capitol Campus Bluff Stability Investigation
DATE OF DRILLING: December, 1994



Ground Surface Elevation: approx. 105' a.s.l.

FILL: mottled gray/tan clayey silt;silty clay

Brown/tan SILT with occasional pebbles, also tan with gray mottling slightly sandy SILT, scattered coarse sand and gravel lower 0.7'

Tan/brown mottled SILT

(zone of silty fine-med. SAND with Fe mottling)

Brown massive SILT with horiz. cemented iron-stained seams

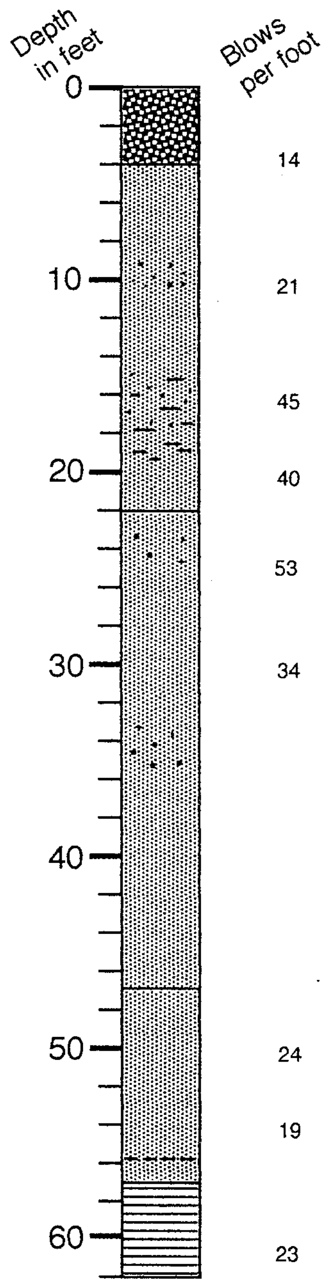
(some water in hole)

Brown SILT, silty sand, and sandy silt, some iron-stained sub-horizontal partings, occasional gravel (<0.5") above lower contact

Tan laminated SILT and silty fine SAND

Bottom of Hole 81.0 feet

BORING NUMBER: DH-6
PROJECT: Capitol Campus Bluff Stability Investigation
DATE OF DRILLING: December, 1994



Ground Surface Elevation: approx. 110' a.s.l.

FiILL: sand and gravel

Gray CLAY with gravel and cobbles, tan clayey SILT with occasional gravel.

(zone of pea gravel)

Clayey SILT with gravel.

Moist brown sandySILT and silty SAND with zones of heavy iron stain and some gravel.

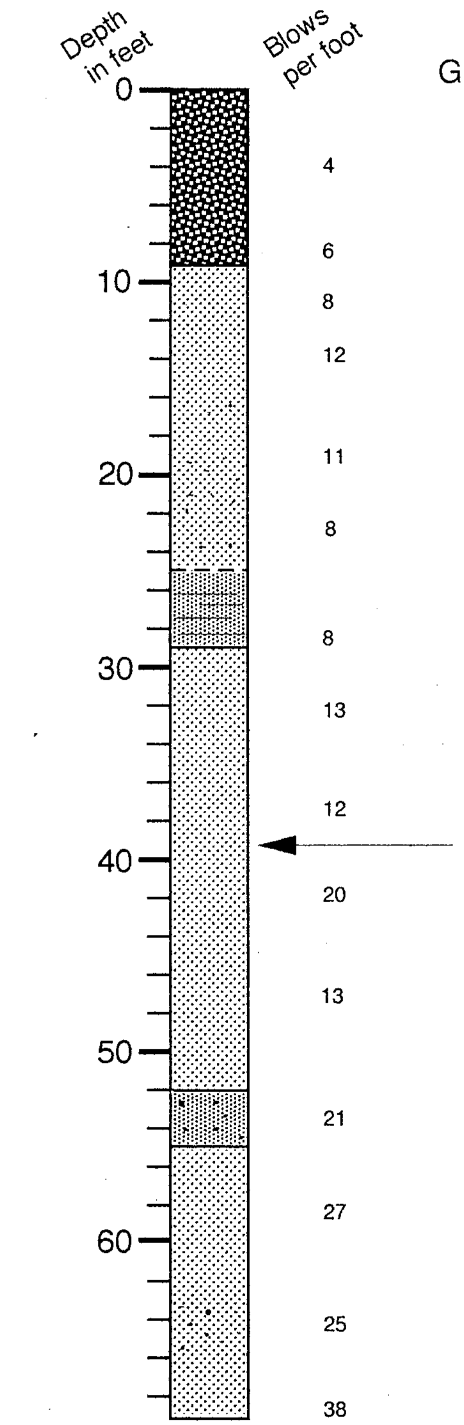
(moist-wet zone)

Tan sandySILT and tan and gray SILT

Tan laminated SILTS with some iron staining.

Bottom of Hole 62.0 feet

BORING NUMBER: DH-11
PROJECT: Capitol Campus Bluff Stability Investigation
DATE OF DRILLING: Janury, 1995



Bottom of Hole 69.5 feet

Ground Surface Elevation: approx. 110' a.s.l.

FILL: Black, organic, dry-damp silty sandy GRAVEL with brick fragments

Light brown silty fine SAND, some coarse sand with occasional rock fragments, some orange mottling, fairly massive

Wet-moist light brown interbedded sand and silt zone with horizontal and vertical contacts

bed of silty fine sand, some orange mottling

(orange oxidized zone)

Light brown massive fine-med. grained SAND grading downward to silty fine sand

mottling, 1/2" gravel clasts

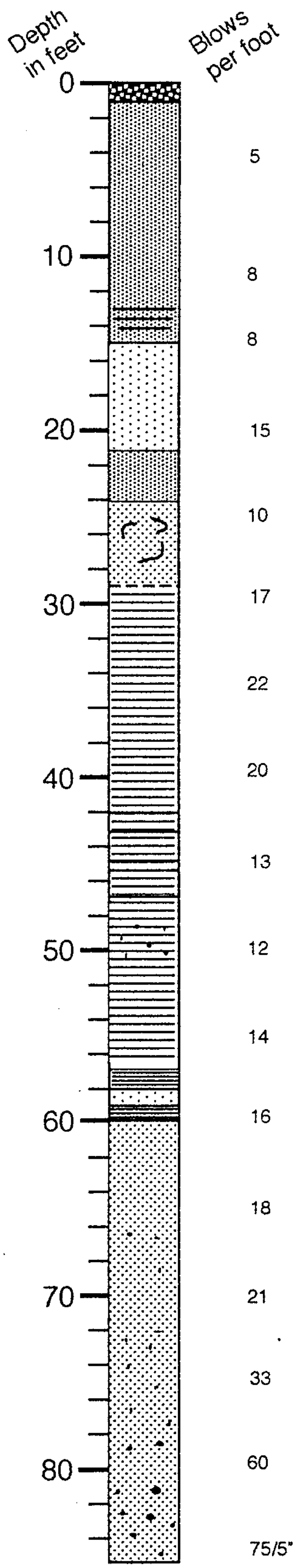
SILT with gravel, damp

Light brown damp massive silty FINE SAND

Boring terminated in clean damp salt and pepper med. grained SAND

Note: 1977 photo of excavation for new oil tank at base of slope south of steam plant exposes 8-10' of light-colored fine sands/silts (?)

BORING NUMBER: DH-14
PROJECT: Capitol Campus Bluff Stability Investigation
DATE OF DRILLING: July, 1995



Bottom of Hole 85.5 feet

Ground Surface Elevation: approx. 125' a.s.l.

FILL(?): fine sandy silt

Dry-damp, tan fine sandy SILT, silty SAND grading downward into bedded alternating moist sand and silt.

(thin zone of Iron staining)

Moist salt and pepper med-coarse SAND

Fine sandy SILT

Silty fine-med SAND with occasional roots

Tan dry-damp laminated SILT

(Iron stain along laminations, and iron crusts)

(occasional gravel <1cm)

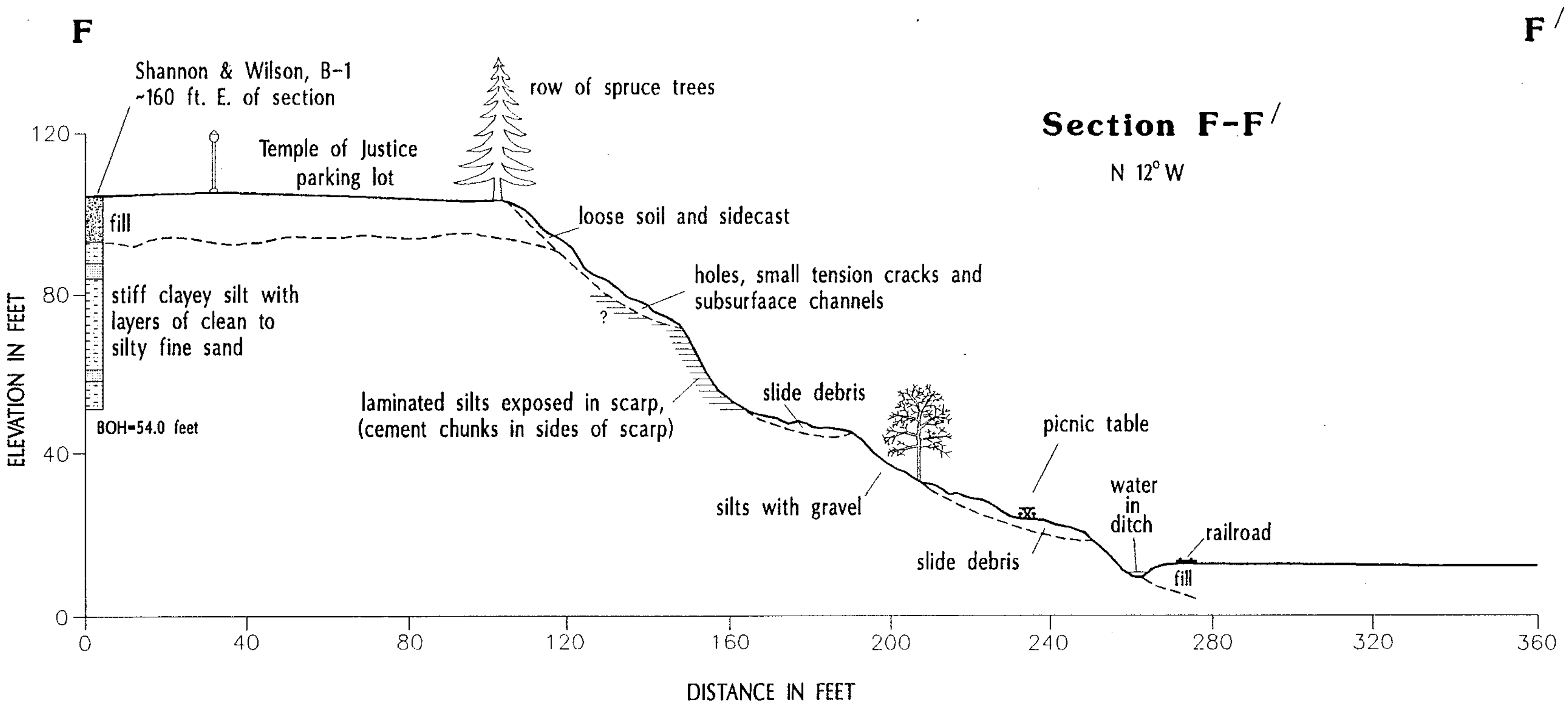
Damp laminated organic SILTS interbedded with med. SAND

Brown, salt and pepper fine-med. damp clean SAND coarsening with depth

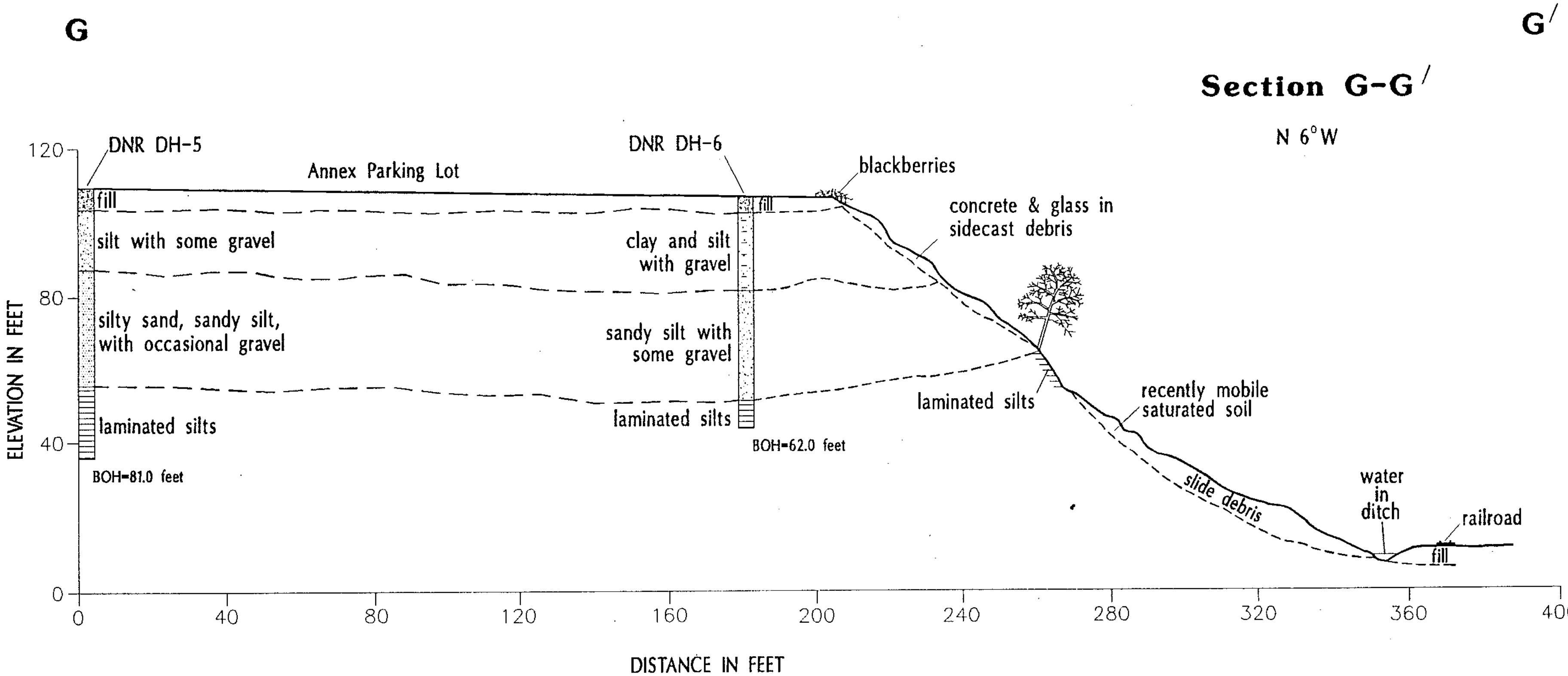
gravel <1cm increasing in size with depth to silty coarse SAND with gravel up to 3cm

APPENDIX B

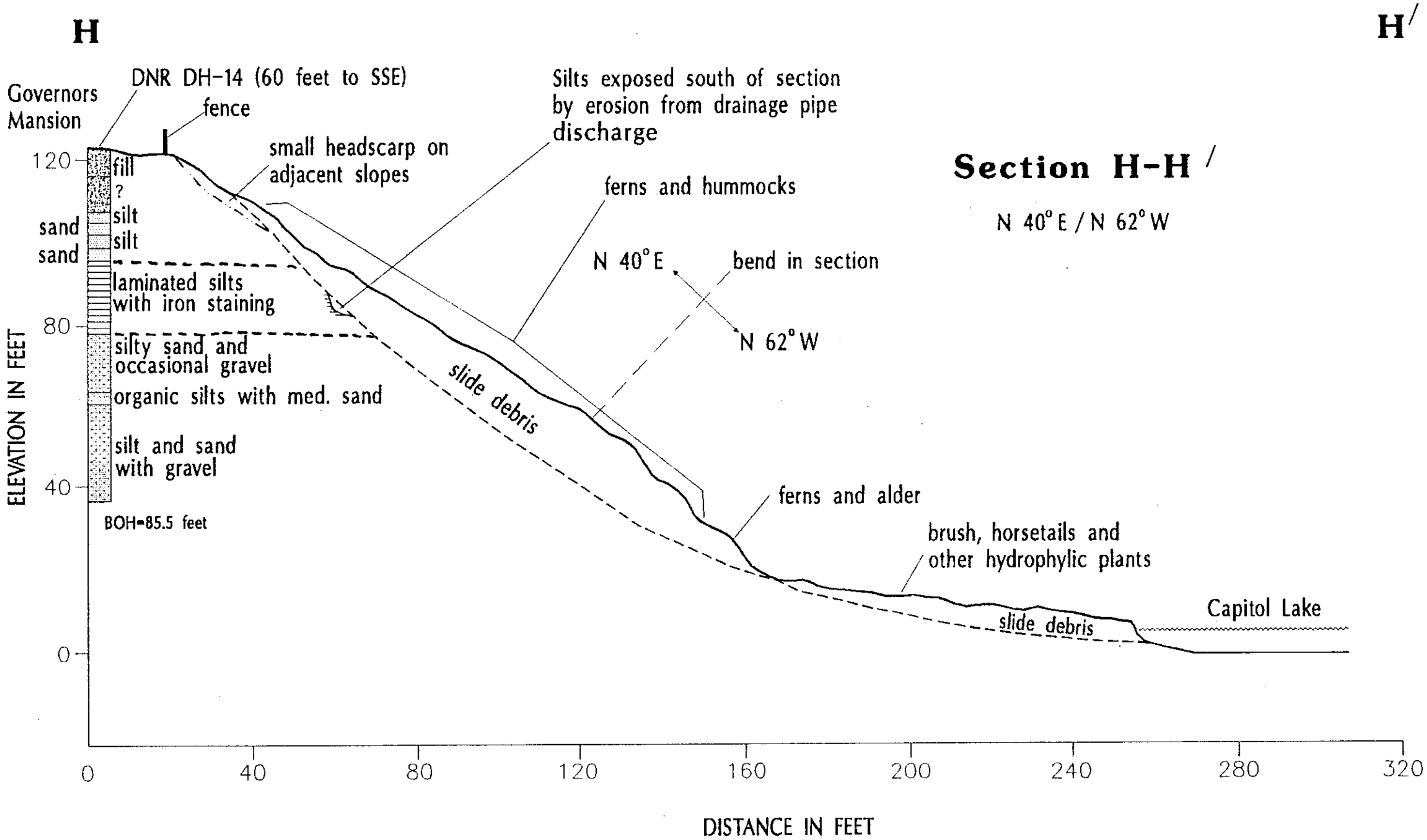
FIELD DEVELOPED CROSS-SECTIONS

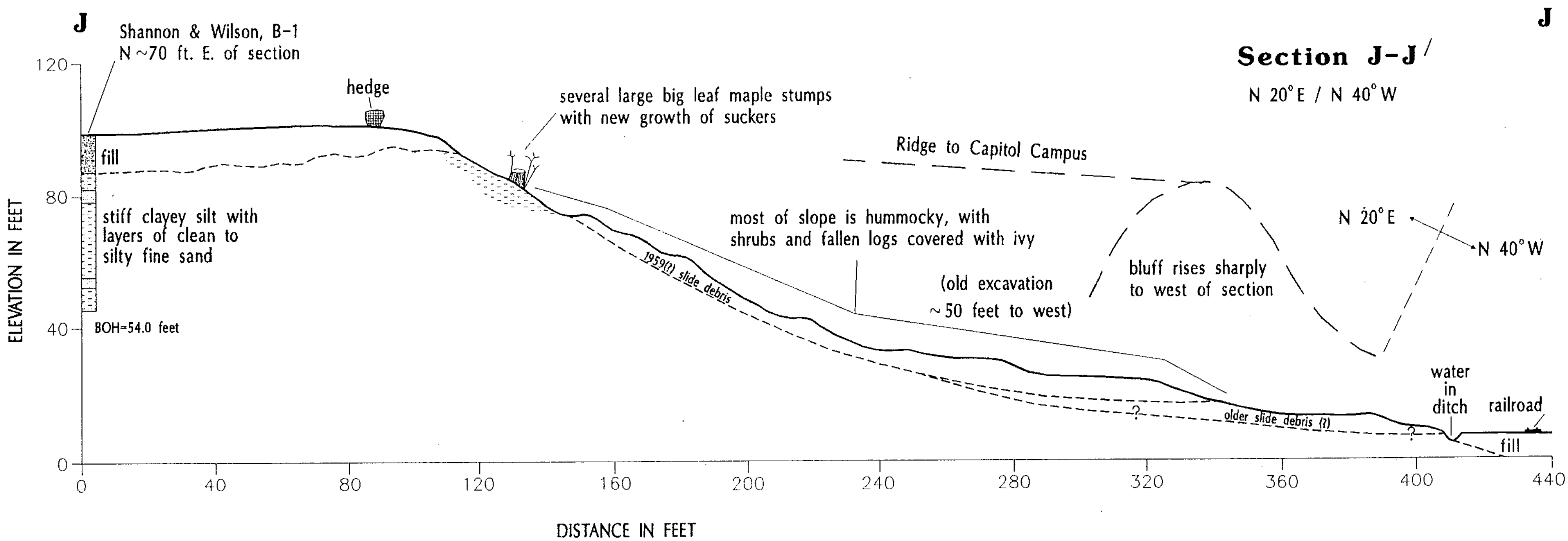


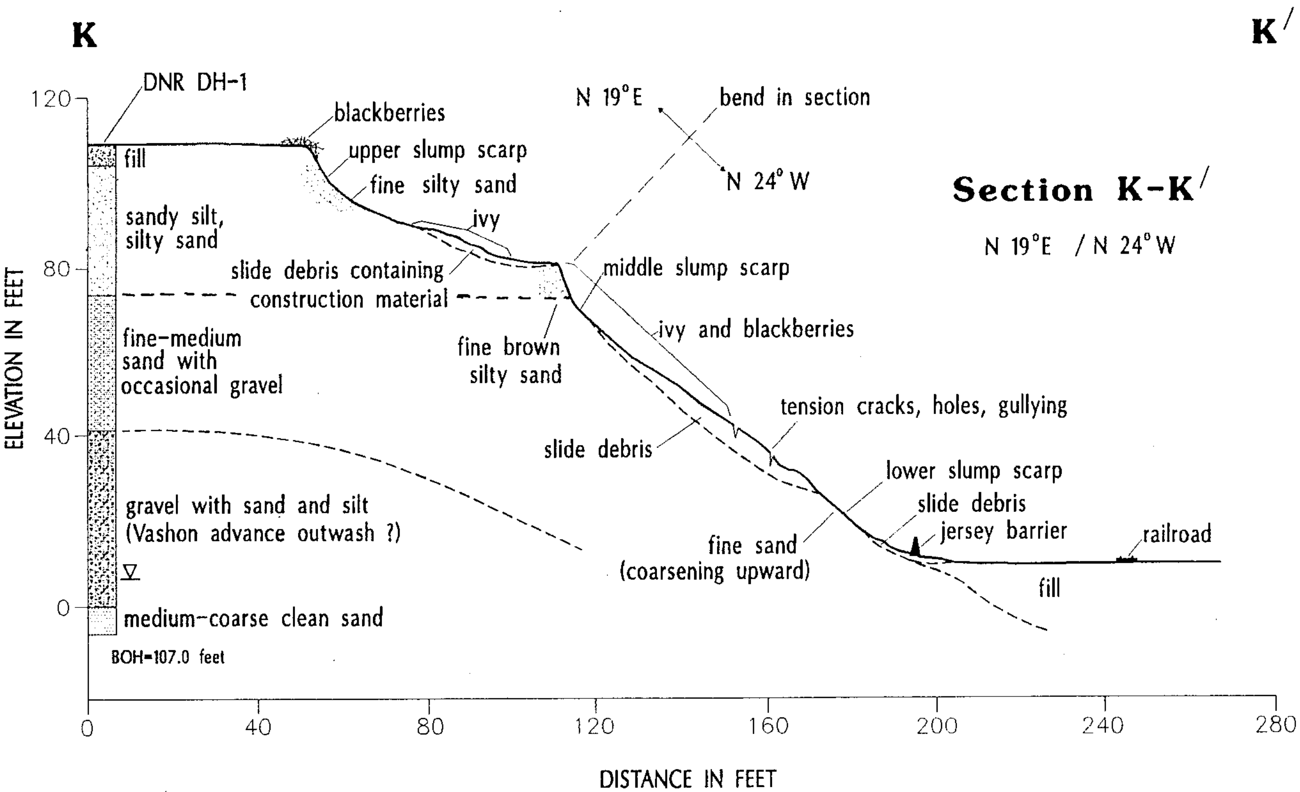
F
F/
Section F-F/
N 12° W
Shannon & Wilson, B-1
~160 ft. E. of section
row of spruce trees
Temple of Justice
parking lot
fill
loose soil and sidecast
stiff clayey silt with
layers of clean to
silty fine sand
holes, small tension cracks and
subsurfaace channels
?
BOH=54.0 feet
laminated silts exposed in scarp,
(cement chunks in sides of scarp)
slide debris
picnic table
silts with gravel
water
in
ditch
railroad
slide debris
fill
ELEVATION IN FEET
120
80
40
0
0
40
80
120
160
200
240
280
320
360
DISTANCE IN FEET

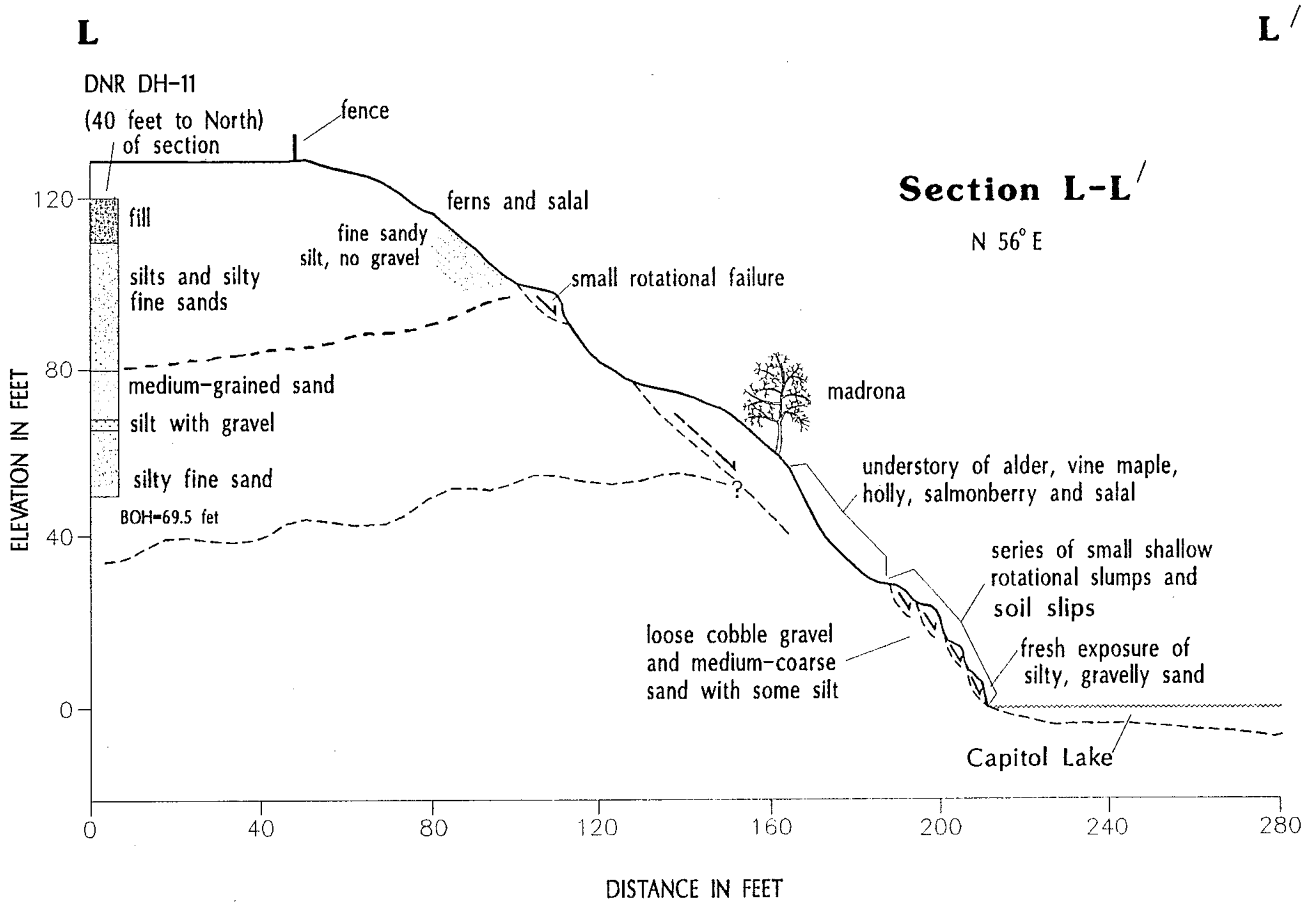


G
G'
Section G-G'
N 6°W
DNR DH-5
Annex Parking Lot
DNR DH-6
blackberries
concrete & glass in
sidecast debris
fill
silt with some gravel
clay and silt
with gravel
silty sand, sandy silt,
with occasional gravel
sandy silt with
some gravel
laminated silts
laminated silts
laminated silts
recently mobile
saturated soil
slide debris
water
in
ditch
railroad
fill
BOH=81.0 feet
BOH=62.0 feet
ELEVATION IN FEET
DISTANCE IN FEET
120
80
40
0
0
40
80
120
160
200
240
280
320
360
400


H
H/
Section H-H /
N 40° E / N 62° W
Governors Mansion
DNR DH-14 (60 feet to SSE)
fence
small headscarp on adjacent slopes
Silts exposed south of section by erosion from drainage pipe discharge
ferns and hummocks
N 40° E
bend in section
N 62° W
fill
?
silt
silt
sand
sand
laminated silts with iron staining
silty sand and occasional gravel
organic silts with med. sand
silt and sand with gravel
BOH=85.5 feet
slide debris
ferns and alder
brush, horsetails and other hydrophylic plants
Capitol Lake
slide debris
ELEVATION IN FEET
120
80
40
0
0
40
80
120
160
200
240
280
320
DISTANCE IN FEET


J
J′
Section J-J′
N 20° E / N 40° W
Shannon & Wilson, B-1
N ~70 ft. E. of section
hedge
several large big leaf maple stumps
with new growth of suckers
Ridge to Capitol Campus
fill
stiff clayey silt with
layers of clean to
silty fine sand
BOH=54.0 feet
most of slope is hummocky, with
shrubs and fallen logs covered with ivy
(old excavation
~50 feet to west)
bluff rises sharply
to west of section
N 20° E
N 40° W
1959(?) slide debris
older slide debris (?)
water
in
ditch
railroad
fill
ELEVATION IN FEET
DISTANCE IN FEET
120
80
40
0
0
40
80
120
160
200
240
280
320
360
400
440

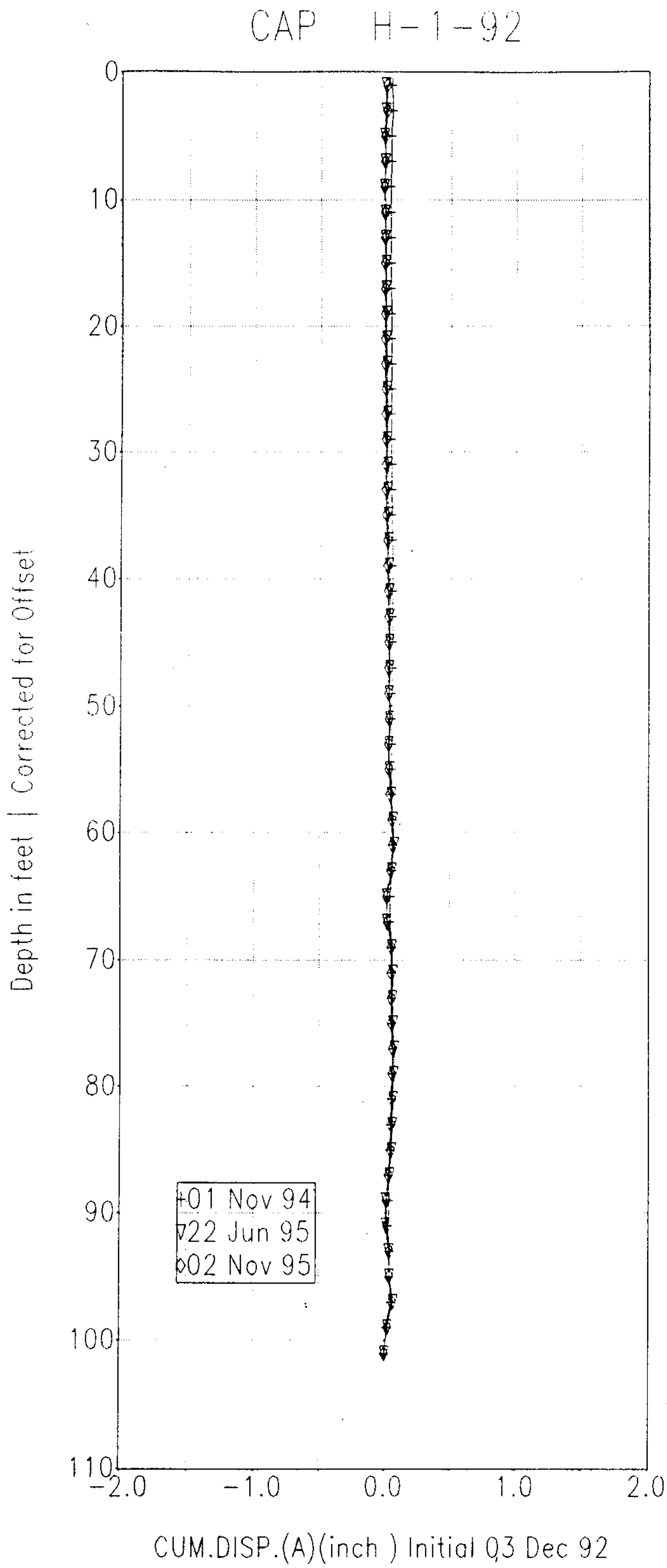

K
K'
Section K-K'
N 19°E / N 24°W
DNR DH-1
blackberries
upper slump scarp
fine silty sand
ivy
N 19°E
bend in section
N 24° W
fill
sandy silt,
silty sand
slide debris containing
construction material
middle slump scarp
fine brown
silty sand
ivy and blackberries
fine-medium
sand with
occasional gravel
tension cracks, holes, gullying
slide debris
lower slump scarp
slide debris
jersey barrier
railroad
gravel with sand and silt
(Vashon advance outwash ?)
fine sand
(coarsening upward)
fill
medium-coarse clean sand
BOH=107.0 feet
ELEVATION IN FEET
120
80
40
0
0
40
80
120
160
200
240
280
DISTANCE IN FEET

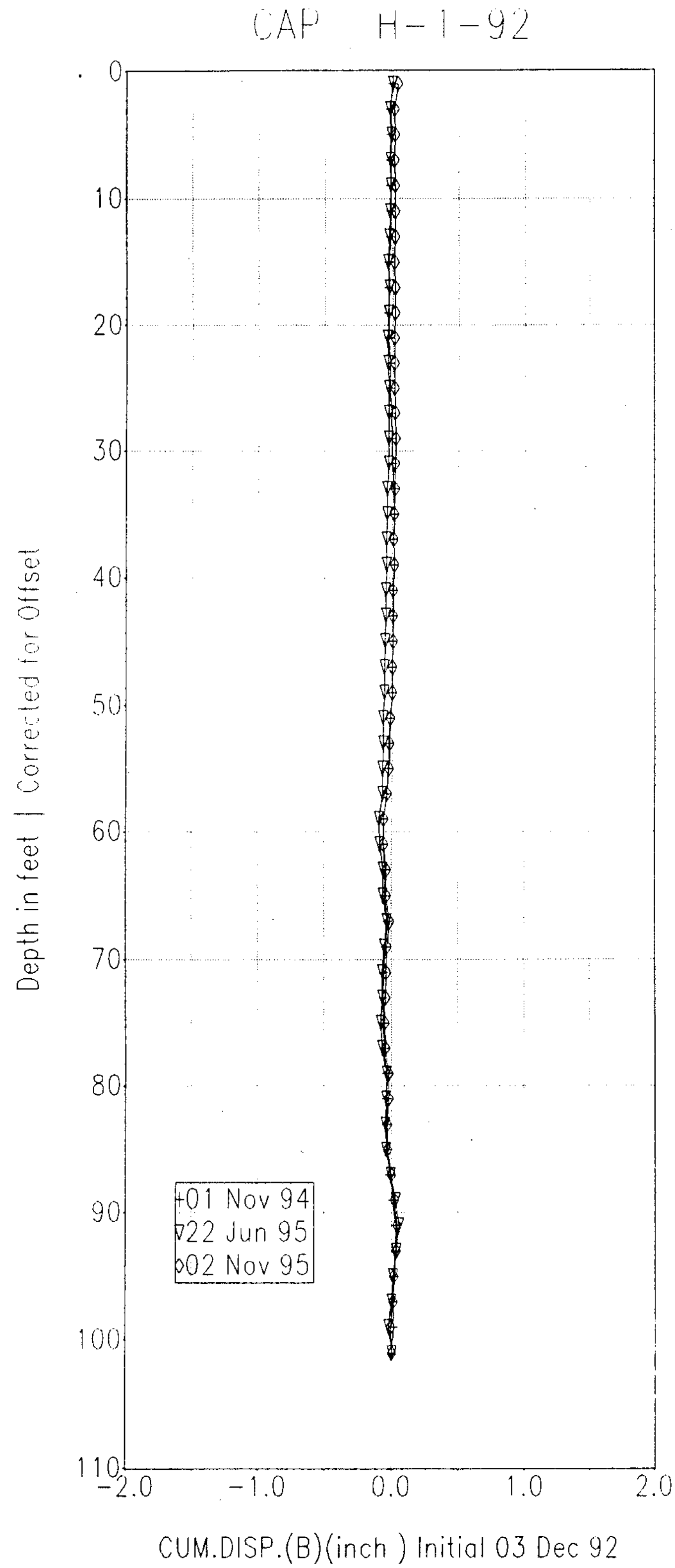


L
L/
Section L-L/
N 56° E
DNR DH-11
(40 feet to North) of section
fence
ferns and salal
fine sandy silt, no gravel
small rotational failure
fill
silts and silty fine sands
medium-grained sand
silt with gravel
silty fine sand
BOH=69.5 fet
madrona
understory of alder, vine maple, holly, salmonberry and salal
series of small shallow rotational slumps and soil slips
fresh exposure of silty, gravelly sand
loose cobble gravel and medium-coarse sand with some silt
Capitol Lake
ELEVATION IN FEET
120
80
40
0
0
40
80
120
160
200
240
280
DISTANCE IN FEET

APPENDIX C

INCLINOMETER DATA





Washington State
Department of Transportation

Capitol Campus

DNR Project # 728

A+= N332 deg.

APPENDIX D

RESULTS OF LEVEL ONE STABILITY ANALYSIS

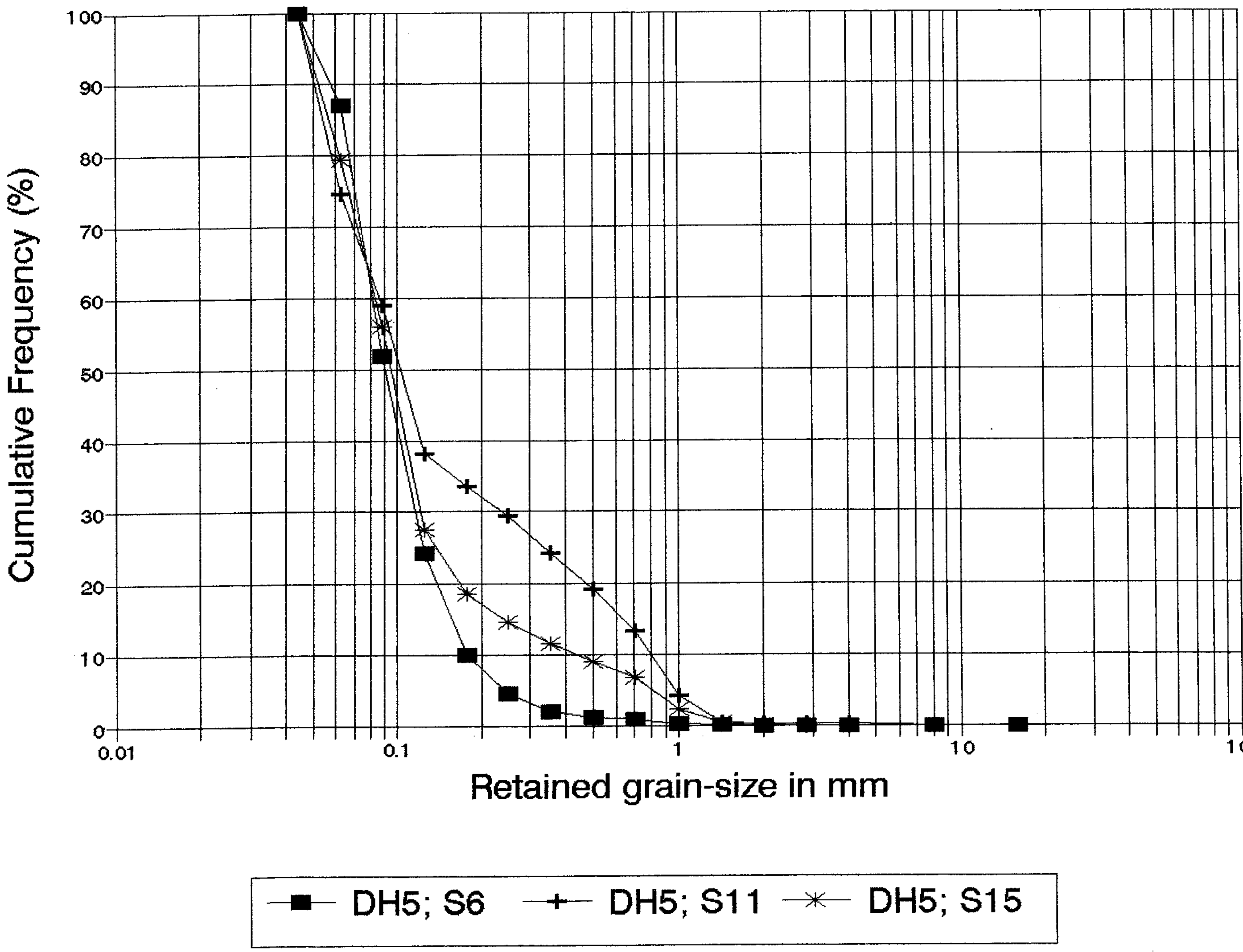
SOIL PARAMATERS USED IN LEVEL 1 STABILITY ANALYSIS (LISA)

	Minimum	Maximum	Mean
Soil depth (ft)	2	10	6
Ground surface slope (%)	70	108	90
Friction angle (deg)	20	28	24
Soil cohesion (psf)	100	150	125
Dry unit weight (pcf)	95 held constant for all runs		
Moist unit wt. (pcf)	115 held constant for all runs		
Saturated unit wt. (pcf)	120 held constant for all runs		
Moisture content (%)	20 held constant for all runs		
Groundwater ratio (Dw/D)	0.50		
FACTOR OF SAFETY	0.67	2.20	1.10
Groundwater ratio (Dw/D)	1.00		
FACTOR OF SAFETY	0.56	2.01	0.95

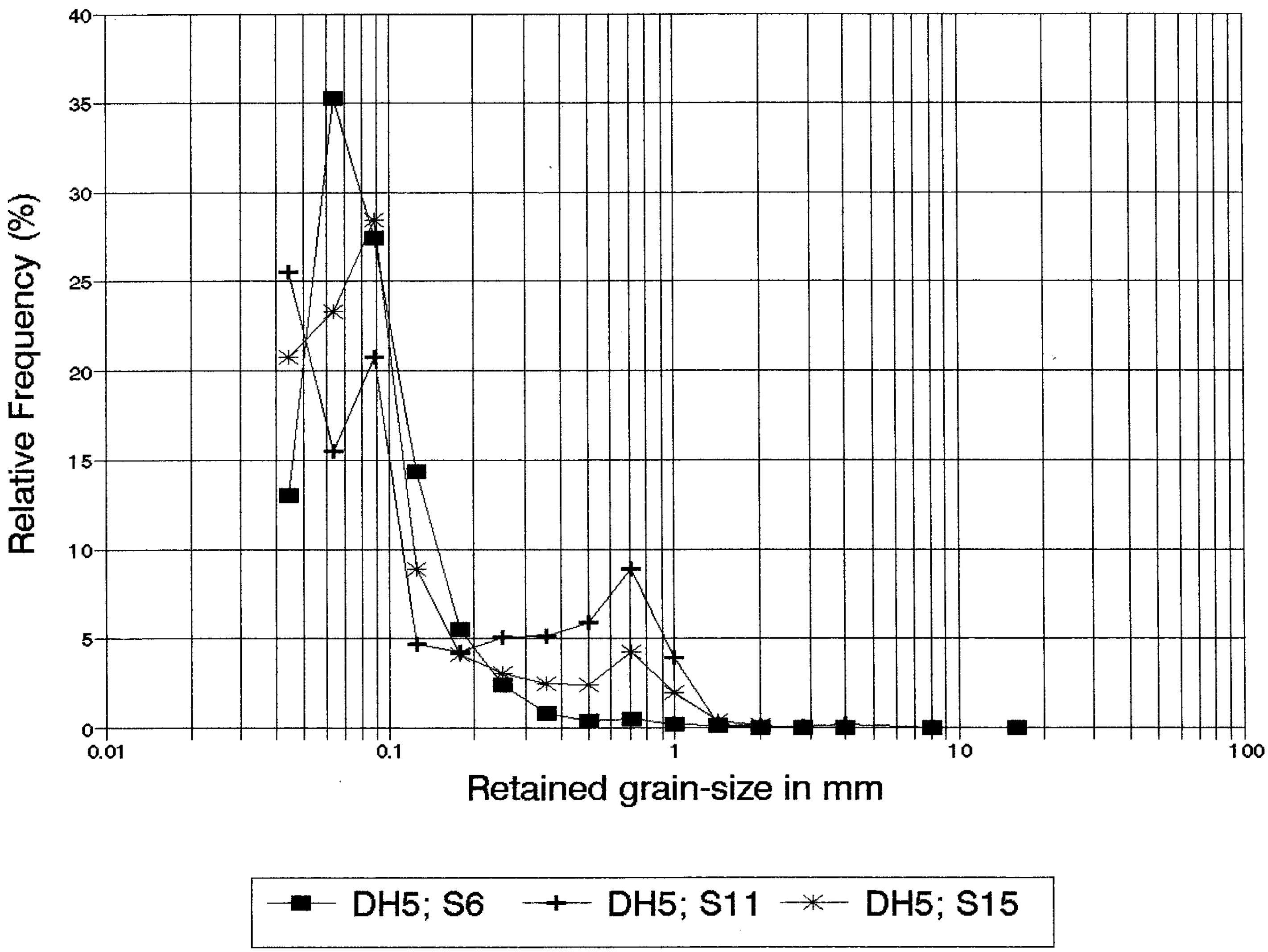
Note: Factor of safety calculations using the infinite slope method are fairly insensitive to the value of tree surcharge, particularly with soil depths greater than 5 feet. Because the soil mantle on the Capitol Campus bluff slopes averages about 5 feet, tree surcharge was considered negligible and given a value of zero for these calculations. With no local data available for root cohesion, a value of 100 psf was assigned for the calculations based on an estimate from studies in similar vegetation and soils.

APPENDIX E

LABRATORY RESULTS OF SOIL TESTING



Cumulative Frequency (%)
100
90
80
70
60
50
40
30
20
10
0
0.01
0.1
1
10
100
Retained grain-size in mm
DH5; S6
DH5; S11
DH5; S15



Relative Frequency (%)
40
35
30
25
20
15
10
5
0
0.01
0.1
1
10
100
Retained grain-size in mm
DH5; S6
DH5; S11
DH5; S15

SAMPL MBER: DH5; S6

midpoint phi	phi	weight retained	weight percent	cumulat percent	f*m
-4.5	-4.0	0	0.0	0.0	0
-3.5	-3.0	0.0	0.0	0.0	0
-2.5	-2.0	0.0	0.0	0.0	0
-1.75	-1.5	0.0	0.0	0.0	0
-1.25	-1.0	0.0	0.0	0.0	0
-0.75	-0.5	0.2	0.1	0.1	-0.0812
-0.25	0.0	0.4	0.2	0.3	-0.05413
0.25	0.5	1.0	0.5	0.8	0.123025
0.75	1.0	0.8	0.4	1.2	0.284189
1.25	1.5	1.7	0.8	2.0	1.039565
1.75	2.0	4.9	2.4	4.4	4.185326
2.25	2.5	11.3	5.5	10.0	12.45633
2.75	3.0	29.1	14.3	24.3	39.40751
3.25	3.5	55.8	27.5	51.8	89.30663
3.65	3.8	25.6	12.6	64.3	45.89218
3.9	4.0	46.0	22.6	87.0	88.28306
4.25	>4	26.5	13.0	100.0	55.36022
		203.2	100.0		

mean= 3.4

phi	stuff	stuff	stuff
-4.5	0	0	0
-3.5	0	0	0
-2.5	0	0	0
-1.75	0	0	0
-1.25	0	0	0
-0.75	1.830583372538	-7.52740819	30.95290548
-0.25	2.824942215988	-10.2037675	36.85628325
0.25	4.765863808098	-14.8314967	46.15601767
0.75	2.58524056665	-6.75271808	17.63828172
1.25	3.709715008139	-7.83501814	16.5477696
1.75	6.214923666414	-10.0186245	16.15029295
2.25	6.846018762337	-7.61295748	8.465814019
2.75	5.367689822855	-3.28517092	2.010613197
3.25	0.344862118188	-0.03863386	0.004328034
3.65	1.042676220675	0.300262634	0.086467541
3.9	6.55139474734	3.524473701	1.896071806
4.25	10.27089806252	9.120280502	8.098563138
	0.7	-1.5	6.7
	standard deviation	skewness	kurtosis

SAMPL MBER: DH5; S11

midpoint phi	phi	weight retained	weight percent	cumulat percent	f*m
-4.5	-4.0	0	0.0	0.0	0
-3.5	-3.0	0.0	0.0	0.0	0
-2.5	-2.0	2.0	0.2	0.2	-0.48453
-1.75	-1.5	0.5	0.0	0.2	-0.08051
-1.25	-1.0	0.6	0.1	0.3	-0.07219
-0.75	-0.5	1.7	0.2	0.5	-0.12407
-0.25	0.0	40.0	3.9	4.4	-0.97811
0.25	0.5	90.5	8.9	13.2	2.213907
0.75	1.0	60.8	6.0	19.2	4.462809
1.25	1.5	52.9	5.2	24.4	6.468956
1.75	2.0	51.6	5.1	29.4	8.842415
2.25	2.5	43.2	4.2	33.6	9.514394
2.75	3.0	48.0	4.7	38.3	12.93155
3.25	3.5	211.5	20.7	59.0	67.27396
3.65	3.8	9.4	0.9	60.0	3.34056
3.9	4.0	148.2	14.5	74.5	56.59068
4.25	>4	260.9	25.5	100.0	108.5204
		1021.6	100.0		

mean= 2.8

phi	stuff	stuff	stuff
-4.5	0	0	0
-3.5	0	0	0
-2.5	5.411764135323	-28.5968543	151.1115518
-1.75	0.945832931953	-4.28859747	19.4453668
-1.25	0.93990105011	-3.7917506	15.29668746
-0.75	2.066256727369	-7.30256845	25.80875125
-0.25	36.01952355959	-109.290507	331.6094628
0.25	56.87244224123	-144.126251	365.2450187
0.75	24.62266849185	-50.087479	101.8880447
1.25	12.18117565521	-18.6883828	28.67175234
1.75	5.404350717183	-5.58918976	5.780350656
2.25	1.206728203936	-0.6446365	0.344366039
2.75	0.005500703714	-0.00018813	6.43456E-06
3.25	4.49116551826	2.091976379	0.974438629
3.65	0.686056266152	0.593986214	0.514272137
3.9	18.06556332467	20.15752129	22.49172401
4.25	54.86187738771	80.4164358	117.874259
	1.5	-0.8	2.4
	standard deviation	skewness	kurtosis

SAMPL MBER: DH5; S15

midpoint phi	phi	weight retained	weight percent	cumulat percent	f*m
-4.5	-4.0	0	0.0	0.0	0
-3.5	-3.0	0.0	0.0	0.0	0
-2.5	-2.0	0.0	0.0	0.0	0
-1.75	-1.5	0.0	0.0	0.0	0
-1.25	-1.0	1.0	0.1	0.1	-0.15343
-0.75	-0.5	3.0	0.4	0.5	-0.28471
-0.25	0.0	15.4	2.0	2.5	-0.48781
0.25	0.5	33.5	4.2	6.7	1.058499
0.75	1.0	19.1	2.4	9.1	1.807926
1.25	1.5	19.6	2.5	11.6	3.101788
1.75	2.0	23.9	3.0	14.6	5.290281
2.25	2.5	32.2	4.1	18.7	9.173447
2.75	3.0	70.5	8.9	27.6	24.54667
3.25	3.5	224.5	28.4	56.0	92.32193
3.65	3.8	33.4	4.2	60.2	15.43561
3.9	4.0	150.7	19.1	79.3	74.36091
4.25	>4	163.5	20.7	100.0	87.93956
		790.3	100.0		

mean= 3.1

phi	stuff	stuff	stuff
-4.5	0	0	0
-3.5	0	0	0
-2.5	0	0	0
-1.75	0	0	0
-1.25	2.366705641807	-10.3924573	45.63439041
-0.75	5.747673231756	-22.3648106	87.02386746
-0.25	22.43839675462	-76.0910006	258.0327125
0.25	35.38985004118	-102.315837	295.8060171
0.75	13.78216505746	-32.9546291	78.79803894
1.25	8.874302478259	-16.7822541	31.73703545
1.75	5.850077562713	-8.13808289	11.32094275
2.25	3.237498619422	-2.88495715	2.570805044
2.75	1.365371317696	-0.53400606	0.20885342
3.25	0.33683928029	0.036679495	0.003994146
3.65	1.095176666624	0.557327918	0.283620367
3.9	10.98098747967	8.333396322	6.324157494
4.25	25.44337942625	28.21398949	31.28630005
	1.2	-1.5	4.5
	standard deviation	skewness	kurtosis

APPENDIX F

XSTABL ANALYSIS EXAMPLES

XSTABL File: CCBLFGGX   1-16-96   14:45

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****************************************
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```

EXAMPLE 1

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

SEGMENT BOUNDARY COORDINATES

9 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	63.0	30.0	60.0	5
2	30.0	60.0	54.0	73.0	1
3	54.0	73.0	92.0	88.0	1
4	92.0	88.0	114.0	105.0	1
5	114.0	105.0	124.0	116.0	3
6	124.0	116.0	138.0	130.0	1
7	138.0	130.0	166.0	152.0	1
8	166.0	152.0	180.0	158.0	1
9	180.0	158.0	224.0	158.0	2

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	52.0	30.0	60.0	4
2	30.0	60.0	60.0	66.0	4
3	60.0	66.0	80.0	76.0	4
4	80.0	76.0	96.0	86.0	4
5	96.0	86.0	114.0	105.0	3
6	114.0	105.0	124.0	116.0	3
7	124.0	116.0	140.0	126.0	2
8	140.0	126.0	158.0	140.0	2
9	158.0	140.0	180.0	158.0	2
10	124.0	116.0	144.0	112.0	3
11	144.0	112.0	184.0	106.0	3

12	184.0	106.0	224.0	104.0	3
13	96.0	86.0	144.0	83.0	4
14	144.0	83.0	224.0	83.0	4

ISOTROPIC Soil Parameters

5 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Constant (psf)	Water Surface No.
1	110.0	125.0	25.0	22.00	.000	.0	1
2	115.0	130.0	25.0	33.00	.000	.0	2
3	115.0	130.0	100.0	32.00	.000	.0	3
4	115.0	130.0	25.0	33.00	.000	.0	3
5	95.0	110.0	100.0	22.00	.000	.0	3

3 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 11 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	30.00	60.00
2	40.00	64.00
3	60.00	70.00
4	80.00	77.00
5	96.00	87.00
6	114.00	105.00
7	124.00	115.00
8	130.00	121.50
9	140.00	129.50
10	158.00	142.00
11	180.00	158.00

Water Surface No. 2 specified by 5 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)

1	124.00	116.00
2	126.00	116.00
3	144.00	115.00
4	184.00	112.00
5	224.00	112.00

Water Surface No. 3 specified by 6 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	60.00
2	30.00	61.00
3	60.00	66.00
4	104.00	69.00
5	144.00	70.00
6	224.00	70.00

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

400 trial surfaces will be generated and analyzed.

20 Surfaces initiate from each of 20 points equally spaced along the ground surface between x = 45.0 ft
and x = 135.0 ft

Each surface terminates between x = 120.0 ft
and x = 200.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

23.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -45.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

```
**************************************************************************
ERROR # 48
**************************************************************************
Negative effective stresses have been calculated at the base of a
slice.  This error is usually reported for cases where slices have
low self-weight and a relatively high "c" shear strength parameter.
This error can only be eliminated by reducing the "c" value.
**************************************************************************
```

USER SELECTED option to maintain strength greater than zero

Factors of safety have been calculated by the :

* * * * *   MODIFIED BISHOP METHOD   * * * * *

The most critical circular failure surface
is specified by 4 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	125.53	117.53
2	144.91	129.91
3	160.74	146.59
4	162.05	148.90

**** Modified BISHOP FOS = .536 ****

The following is a summary of the TEN most critical surfaces

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Driving Moment (ft-lb)
1.	.536	84.49	203.11	94.91	125.53	162.05	8.067E+05
2.	.558	80.33	206.14	99.48	125.53	160.89	7.193E+05
3.	.564	94.31	188.91	77.91	125.53	160.21	6.219E+05
4.	.602	48.98	275.41	173.38	130.26	173.40	1.771E+06
5.	.650	-7687.68	10887.52	13305.60	125.53	181.01	1.606E+08
6.	.705	121.94	145.67	28.37	125.53	149.53	1.636E+05
7.	.724	99.36	157.65	50.01	120.79	143.66	1.813E+05
8.	.735	103.53	152.25	43.37	120.79	142.74	1.480E+05
9.	.739	124.66	150.45	28.74	130.26	151.72	8.746E+04
10.	.748	-2248.91	3443.90	4085.80	130.26	178.46	3.105E+07

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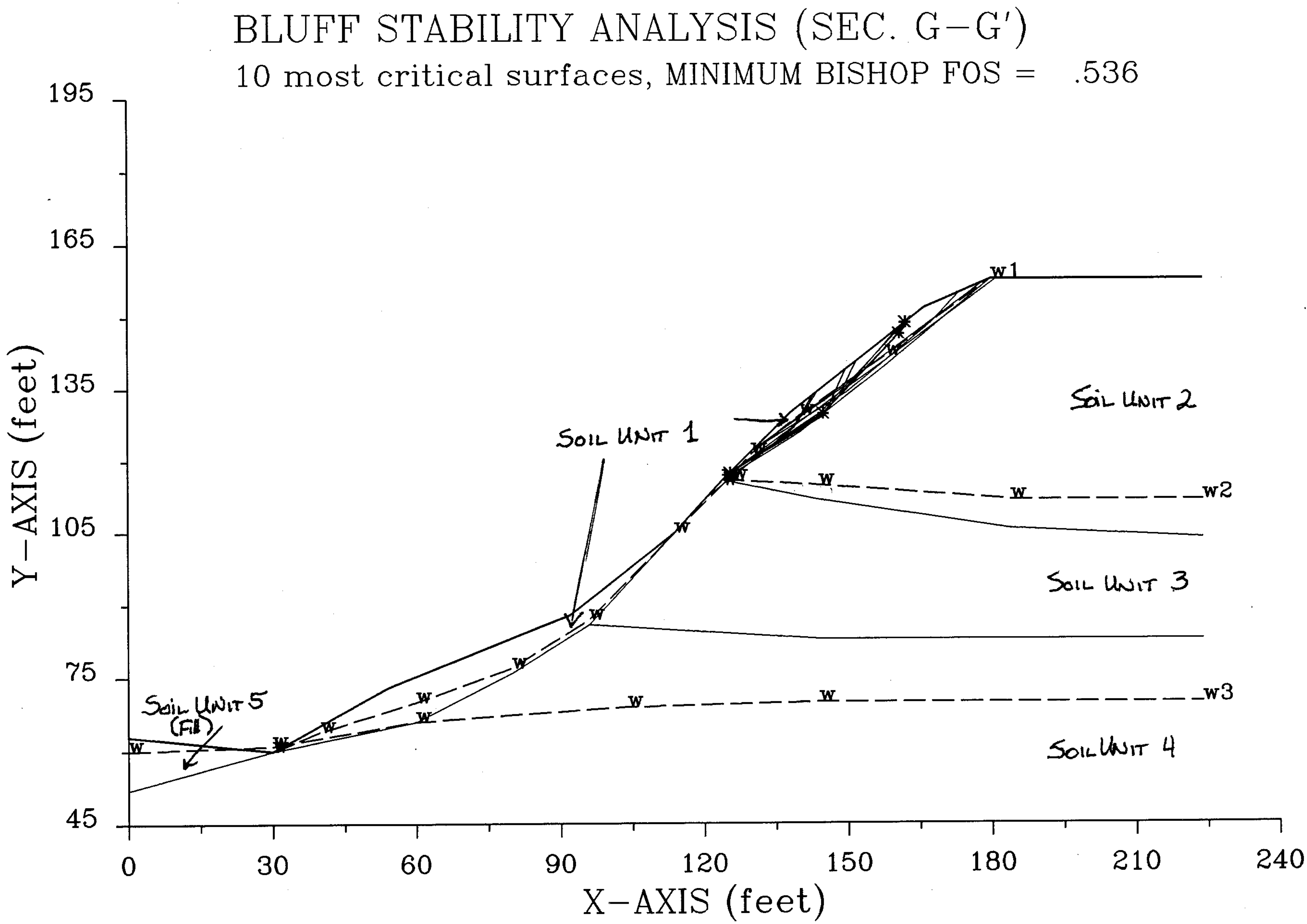

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**************************************
```

EXAMPLE 2

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

SEGMENT BOUNDARY COORDINATES

9 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	63.0	30.0	60.0	5
2	30.0	60.0	54.0	73.0	1
3	54.0	73.0	92.0	88.0	1
4	92.0	88.0	114.0	105.0	1
5	114.0	105.0	124.0	116.0	3
6	124.0	116.0	138.0	130.0	1
7	138.0	130.0	166.0	152.0	1
8	166.0	152.0	180.0	158.0	1
9	180.0	158.0	224.0	158.0	2

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	52.0	30.0	60.0	4
2	30.0	60.0	60.0	66.0	4
3	60.0	66.0	80.0	76.0	4
4	80.0	76.0	96.0	86.0	4
5	96.0	86.0	114.0	105.0	3
6	114.0	105.0	124.0	116.0	3
7	124.0	116.0	140.0	126.0	2
8	140.0	126.0	158.0	140.0	2
9	158.0	140.0	180.0	158.0	2
10	124.0	116.0	144.0	112.0	3
11	144.0	112.0	184.0	106.0	3

12	184.0	106.0	224.0	104.0	3
13	96.0	86.0	144.0	83.0	4
14	144.0	83.0	224.0	83.0	4

ISOTROPIC Soil Parameters

5 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	115.0	130.0	120.0	24.00	.000	.0	1
2	115.0	130.0	25.0	33.00	.000	.0	2
3	115.0	130.0	100.0	32.00	.000	.0	3
4	115.0	130.0	25.0	33.00	.000	.0	3
5	95.0	110.0	100.0	22.00	.000	.0	3

3 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 11 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	30.00	60.00
2	40.00	64.00
3	60.00	70.00
4	80.00	77.00
5	96.00	87.00
6	114.00	105.00
7	124.00	115.00
8	130.00	121.50
9	140.00	129.50
10	158.00	142.00
11	180.00	158.00

Water Surface No. 2 specified by 5 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)

1	124.00	116.00
2	126.00	116.00
3	144.00	115.00
4	184.00	112.00
5	224.00	112.00

Water Surface No. 3 specified by 6 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	60.00
2	30.00	61.00
3	60.00	66.00
4	104.00	69.00
5	144.00	70.00
6	224.00	70.00

A critical failure surface searching method, using a random technique for generating CIRCULAR surfaces has been specified.

400 trial surfaces will be generated and analyzed.

20 Surfaces initiate from each of 20 points equally spaced along the ground surface between x = 45.0 ft
and x = 135.0 ft

Each surface terminates between x = 120.0 ft
and x = 200.0 ft

Unless further limitations were imposed, the minimum elevation at which a surface extends is y = .0 ft

* * * * * DEFAULT SEGMENT LENGTH SELECTED BY XSTABL * * * * *

23.0 ft line segments define each trial failure surface.

ANGULAR RESTRICTIONS :

The first segment of each failure surface will be inclined within the angular range defined by :

Lower angular limit := -45.0 degrees
Upper angular limit := (slope angle - 5.0) degrees

```
*************************************************************************
ERROR # 48
*************************************************************************
Negative effective stresses have been calculated at the base of a
slice.  This error is usually reported for cases where slices have
low self-weight and a relatively high "c" shear strength parameter.
This error can only be eliminated by reducing the "c" value.
*************************************************************************
```

USER SELECTED option to maintain strength greater than zero

Factors of safety have been calculated by the :

* * * * *   MODIFIED BISHOP METHOD   * * * * *

The most critical circular failure surface
is specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	97.11	91.94
2	117.95	101.67
3	137.50	113.78
4	155.48	128.12
5	171.64	144.49
6	182.15	158.00

**** Modified BISHOP FOS = .939 ****

The following is a summary of the TEN most critical surfaces

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

	FOS (BISHOP)	Circle Center x-coord (ft)	Circle Center y-coord (ft)	Radius (ft)	Initial x-coord (ft)	Terminal x-coord (ft)	Driving Moment (ft-lb)
1.	.939	25.55	272.61	194.32	97.11	182.15	1.198E+07
2.	.941	65.20	203.47	116.00	97.11	169.38	6.154E+06
3.	.954	63.11	210.30	125.47	92.37	176.07	9.322E+06
4.	.955	66.46	225.30	132.27	106.58	179.98	7.378E+06
5.	.962	80.15	197.25	101.48	106.58	171.78	4.882E+06
6.	.963	63.92	214.88	129.75	92.37	180.44	1.085E+07
7.	.966	77.06	190.36	100.44	97.11	169.93	6.199E+06
8.	.969	51.71	250.08	153.97	120.79	172.51	3.126E+06

9.	.973	74.61	201.60	111.93	97.11	176.44	8.151E+06
10.	.976	28.01	237.36	160.99	97.11	162.43	4.495E+06

* * * END OF FILE * * *

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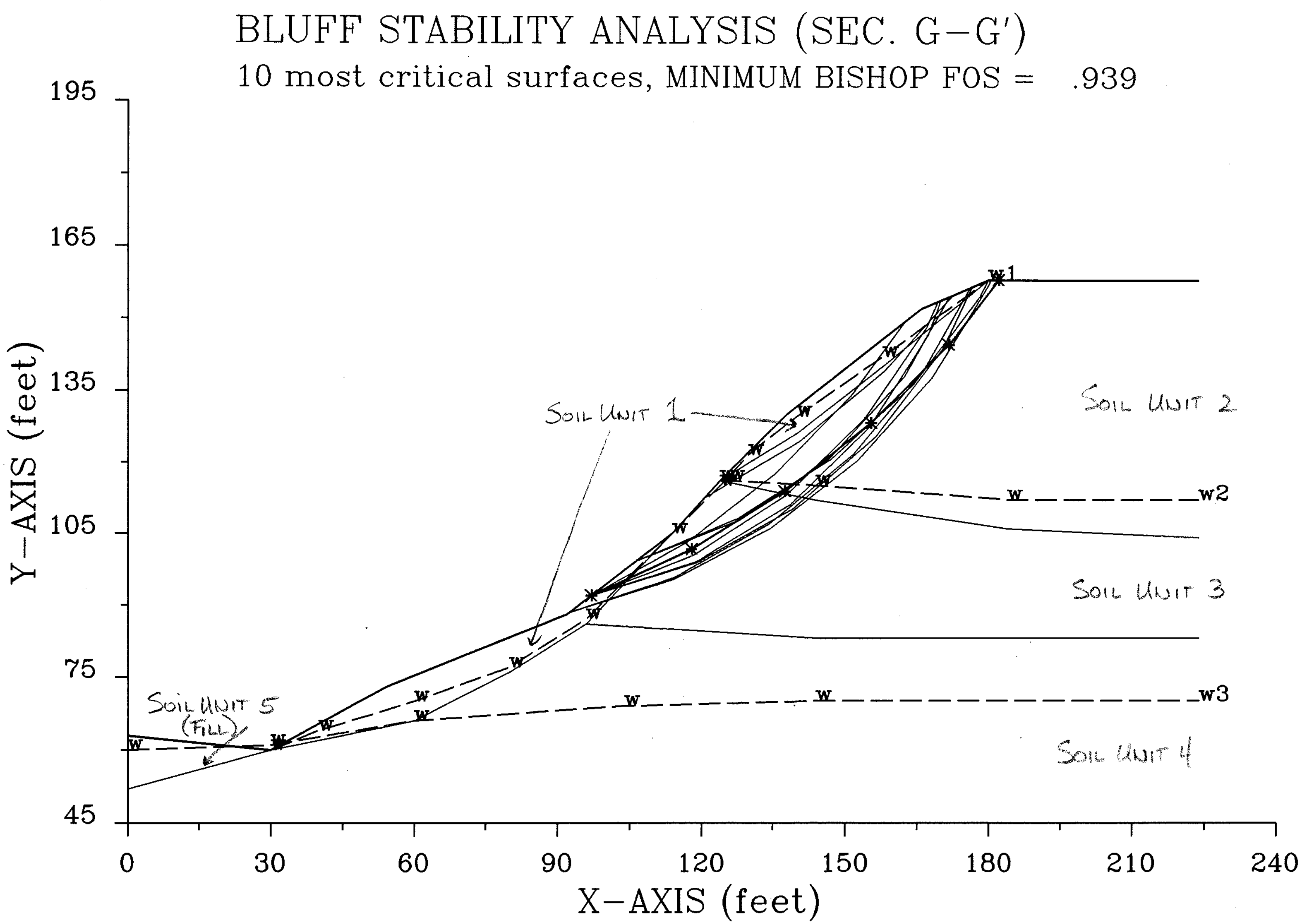

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****************************************
```

EXAMPLE 3

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

SEGMENT BOUNDARY COORDINATES

9 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	63.0	30.0	60.0	5
2	30.0	60.0	54.0	73.0	1
3	54.0	73.0	92.0	88.0	1
4	92.0	88.0	114.0	105.0	1
5	114.0	105.0	124.0	116.0	3
6	124.0	116.0	138.0	130.0	1
7	138.0	130.0	166.0	152.0	1
8	166.0	152.0	180.0	158.0	1
9	180.0	158.0	224.0	158.0	2

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	52.0	30.0	60.0	4
2	30.0	60.0	60.0	66.0	4
3	60.0	66.0	80.0	76.0	4
4	80.0	76.0	96.0	86.0	4
5	96.0	86.0	114.0	105.0	3
6	114.0	105.0	124.0	116.0	3
7	124.0	116.0	140.0	126.0	2
8	140.0	126.0	158.0	140.0	2
9	158.0	140.0	180.0	158.0	2
10	124.0	116.0	144.0	112.0	3
11	144.0	112.0	184.0	106.0	3

12	184.0	106.0	224.0	104.0	3
13	96.0	86.0	144.0	83.0	4
14	144.0	83.0	224.0	83.0	4

ISOTROPIC Soil Parameters

5 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	110.0	125.0	25.0	22.00	.000	.0	1
2	115.0	130.0	25.0	33.00	.000	.0	2
3	115.0	130.0	100.0	32.00	.000	.0	3
4	115.0	130.0	25.0	33.00	.000	.0	3
5	95.0	110.0	100.0	22.00	.000	.0	3

3 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 11 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	30.00	60.00
2	40.00	64.00
3	60.00	70.00
4	80.00	77.00
5	96.00	87.00
6	114.00	105.00
7	124.00	115.00
8	130.00	121.50
9	140.00	129.50
10	158.00	142.00
11	180.00	158.00

Water Surface No. 2 specified by 5 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)

1	124.00	116.00
2	126.00	116.00
3	144.00	115.00
4	184.00	112.00
5	224.00	112.00

Water Surface No. 3 specified by 6 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	60.00
2	30.00	61.00
3	60.00	66.00
4	104.00	69.00
5	144.00	70.00
6	224.00	70.00

Trial failure surface specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	125.00	117.00
2	129.00	118.00
3	133.00	119.00
4	148.00	126.00
5	160.00	135.00
6	183.00	158.00

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION :
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	125.50	117.13	.375	1.000	14.036	45.000	41.3
2	126.05	117.26	.788	.100	14.036	45.000	8.7
3	126.14	117.29	.856	.082	14.036	45.000	7.7
4	127.59	117.65	1.943	2.818	14.036	45.000	638.1
5	129.50	118.13	3.375	1.000	14.036	45.000	400.6
6	131.50	118.63	4.875	3.000	14.036	45.000	1730.2
7	135.50	120.17	7.333	5.000	25.017	45.000	4312.3
8	139.00	121.80	8.986	2.000	25.017	38.157	2112.4
9	144.00	124.13	10.581	8.000	25.017	38.157	9890.3
10	153.00	129.75	12.036	10.000	36.870	38.157	13919.8
11	159.00	134.25	12.250	2.000	36.870	38.157	2818.0
12	163.00	138.00	11.643	6.000	45.000	38.157	8006.1
13	173.00	148.00	7.000	14.000	45.000	23.199	11212.7
14	181.50	156.50	1.500	3.000	45.000	.000	517.5

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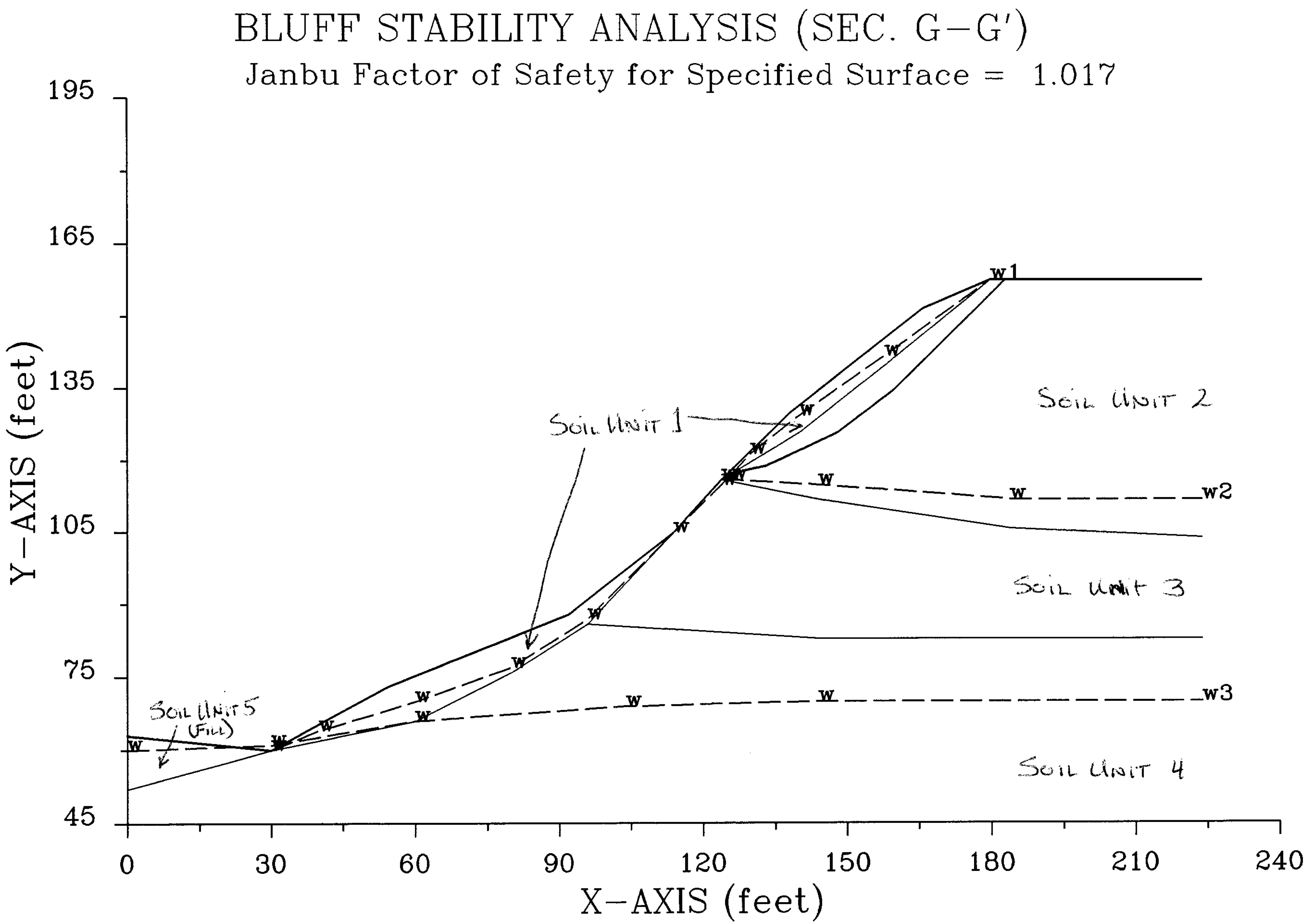

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	phi	c-value (psf)	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	31.6	22.00	25.0	.0	.0	.0	.00
2	68.9	33.00	25.0	.0	.0	.0	.00
3	75.5	33.00	25.0	.0	.0	.0	.00
4	188.8	33.00	25.0	.0	.0	.0	.00
5	338.3	33.00	25.0	.0	.0	.0	.00
6	489.4	33.00	25.0	.0	.0	.0	.00
7	649.9	33.00	25.0	.0	.0	.0	.00
8	797.9	33.00	25.0	.0	.0	.0	.00
9	935.5	33.00	25.0	.0	.0	.0	.00
10	917.5	33.00	25.0	.0	.0	.0	.00
11	928.9	33.00	25.0	.0	.0	.0	.00
12	787.7	33.00	25.0	.0	.0	.0	.00
13	466.7	33.00	25.0	.0	.0	.0	.00
14	88.5	33.00	25.0	.0	.0	.0	.00

For the single specified surface,
Corrected JANBU factor of safety = 1.017 (Fo factor =1.037)

Resisting Shear Strength = 317.72E+02 lb
Total Driving Shear Force = 323.95E+02 lb

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EXAMPLE 4

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

SEGMENT BOUNDARY COORDINATES

9 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	63.0	30.0	60.0	5
2	30.0	60.0	54.0	73.0	1
3	54.0	73.0	92.0	88.0	1
4	92.0	88.0	114.0	105.0	1
5	114.0	105.0	124.0	116.0	3
6	124.0	116.0	138.0	130.0	1
7	138.0	130.0	166.0	152.0	1
8	166.0	152.0	180.0	158.0	1
9	180.0	158.0	224.0	158.0	2

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	52.0	30.0	60.0	4
2	30.0	60.0	60.0	66.0	4
3	60.0	66.0	80.0	76.0	4
4	80.0	76.0	96.0	86.0	4
5	96.0	86.0	114.0	105.0	3
6	114.0	105.0	124.0	116.0	3
7	124.0	116.0	140.0	126.0	2
8	140.0	126.0	158.0	140.0	2
9	158.0	140.0	180.0	158.0	2
10	124.0	116.0	144.0	112.0	3
11	144.0	112.0	184.0	106.0	3

12	184.0	106.0	224.0	104.0	3
13	96.0	86.0	144.0	83.0	4
14	144.0	83.0	224.0	83.0	4

ISOTROPIC Soil Parameters

5 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	110.0	125.0	25.0	22.00	.000	.0	1
2	115.0	130.0	25.0	33.00	.000	.0	2
3	115.0	130.0	100.0	32.00	.000	.0	3
4	115.0	130.0	25.0	33.00	.000	.0	3
5	95.0	110.0	100.0	22.00	.000	.0	3

3 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 11 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	30.00	60.00
2	40.00	64.00
3	60.00	70.00
4	80.00	77.00
5	96.00	87.00
6	114.00	105.00
7	124.00	115.00
8	130.00	121.50
9	140.00	131.00
10	158.00	145.00
11	180.00	158.00

Water Surface No. 2 specified by 5 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)

1	124.00	116.00
2	126.00	116.00
3	144.00	115.00
4	184.00	112.00
5	224.00	112.00

Water Surface No. 3 specified by 6 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	60.00
2	30.00	61.00
3	60.00	66.00
4	104.00	69.00
5	144.00	70.00
6	224.00	70.00

Trial failure surface specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	125.00	117.00
2	129.00	118.00
3	133.00	119.00
4	148.00	126.00
5	160.00	135.00
6	183.00	158.00

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION :
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	125.50	117.13	.375	1.000	14.036	45.000	41.3
2	126.05	117.26	.788	.100	14.036	45.000	8.7
3	126.14	117.29	.856	.082	14.036	45.000	7.7
4	127.59	117.65	1.943	2.818	14.036	45.000	638.1
5	129.50	118.13	3.375	1.000	14.036	45.000	400.6
6	131.50	118.63	4.875	3.000	14.036	45.000	1740.4
7	135.50	120.17	7.333	5.000	25.017	45.000	4374.2
8	139.00	121.80	8.986	2.000	25.017	38.157	2152.9
9	144.00	124.13	10.581	8.000	25.017	38.157	10110.3
10	153.00	129.75	12.036	10.000	36.870	38.157	14307.3
11	159.00	134.25	12.250	2.000	36.870	38.157	2903.9
12	163.00	138.00	11.643	6.000	45.000	38.157	8214.7
13	173.00	148.00	7.000	14.000	45.000	23.199	11413.2
14	181.50	156.50	1.500	3.000	45.000	.000	517.5

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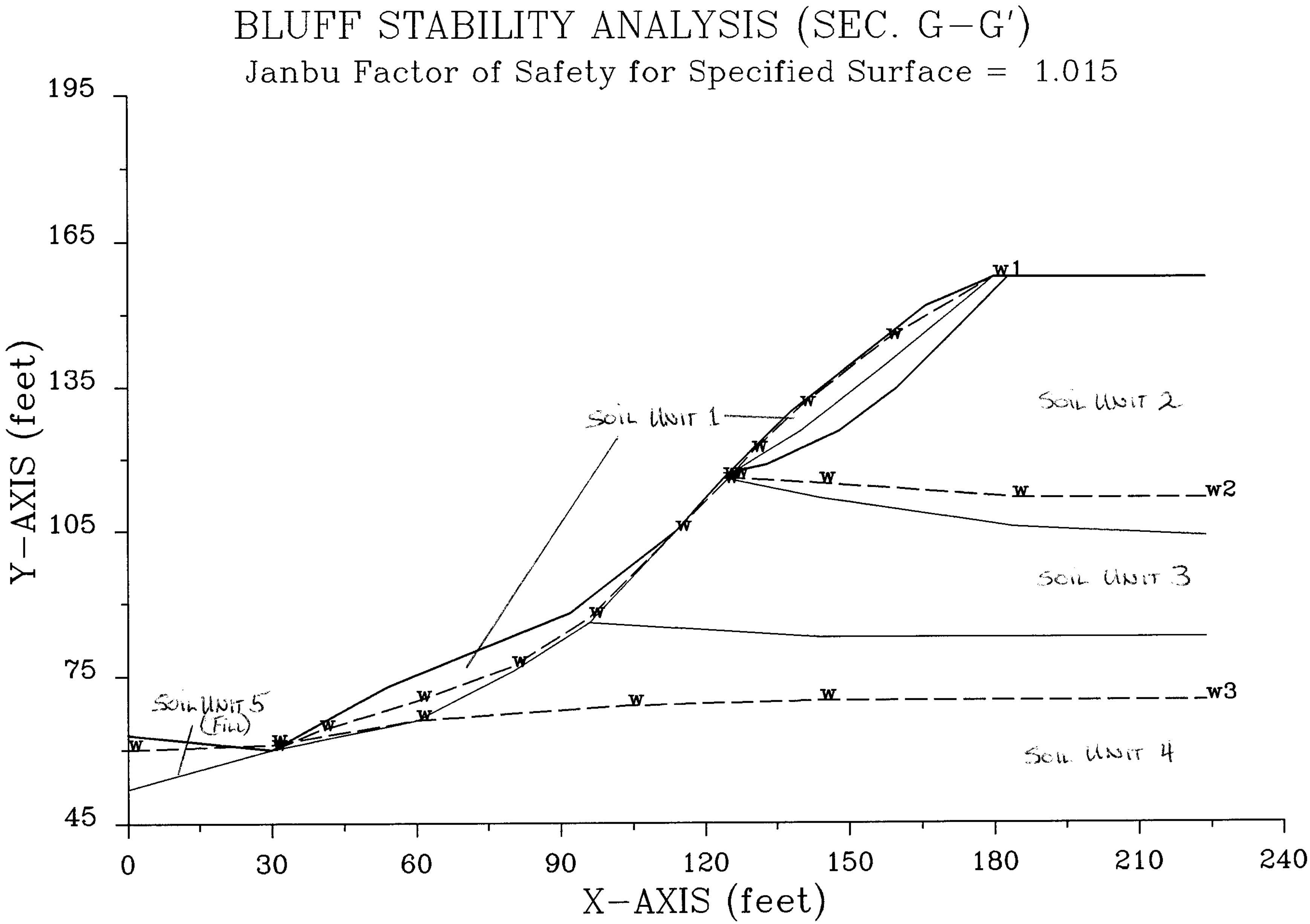

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	phi	c-value (psf)	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	31.6	22.00	25.0	.0	.0	.0	.00
2	68.9	33.00	25.0	.0	.0	.0	.00
3	75.5	33.00	25.0	.0	.0	.0	.00
4	188.8	33.00	25.0	.0	.0	.0	.00
5	338.2	33.00	25.0	.0	.0	.0	.00
6	492.2	33.00	25.0	.0	.0	.0	.00
7	659.0	33.00	25.0	.0	.0	.0	.00
8	813.0	33.00	25.0	.0	.0	.0	.00
9	956.0	33.00	25.0	.0	.0	.0	.00
10	942.8	33.00	25.0	.0	.0	.0	.00
11	956.9	33.00	25.0	.0	.0	.0	.00
12	807.9	33.00	25.0	.0	.0	.0	.00
13	474.8	33.00	25.0	.0	.0	.0	.00
14	88.4	33.00	25.0	.0	.0	.0	.00

For the single specified surface,
Corrected JANBU factor of safety = 1.015 (Fo factor =1.037)

Resisting Shear Strength = 324.16E+02 lb
Total Driving Shear Force = 331.22E+02 lb

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EXAMPLE 5

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

SEGMENT BOUNDARY COORDINATES

9 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	63.0	30.0	60.0	5
2	30.0	60.0	54.0	73.0	1
3	54.0	73.0	92.0	88.0	1
4	92.0	88.0	114.0	105.0	1
5	114.0	105.0	124.0	116.0	3
6	124.0	116.0	138.0	130.0	1
7	138.0	130.0	166.0	152.0	1
8	166.0	152.0	180.0	158.0	1
9	180.0	158.0	224.0	158.0	2

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	52.0	30.0	60.0	4
2	30.0	60.0	60.0	66.0	4
3	60.0	66.0	80.0	76.0	4
4	80.0	76.0	96.0	86.0	4
5	96.0	86.0	114.0	105.0	3
6	114.0	105.0	124.0	116.0	3
7	124.0	116.0	140.0	126.0	2
8	140.0	126.0	158.0	140.0	2
9	158.0	140.0	180.0	158.0	2
10	124.0	116.0	144.0	112.0	3
11	144.0	112.0	184.0	106.0	3

12	184.0	106.0	224.0	104.0	3
13	96.0	86.0	144.0	83.0	4
14	144.0	83.0	224.0	83.0	4

ISOTROPIC Soil Parameters

5 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	110.0	125.0	25.0	22.00	.000	.0	1
2	115.0	130.0	25.0	33.00	.000	.0	2
3	115.0	130.0	100.0	32.00	.000	.0	3
4	115.0	130.0	25.0	33.00	.000	.0	3
5	95.0	110.0	100.0	22.00	.000	.0	3

3 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 11 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	30.00	60.00
2	40.00	64.00
3	60.00	70.00
4	80.00	77.00
5	96.00	87.00
6	114.00	105.00
7	124.00	115.00
8	130.00	121.50
9	140.00	129.50
10	158.00	142.00
11	180.00	158.00

Water Surface No. 2 specified by 5 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)

1	125.00	117.00
2	126.00	118.00
3	144.00	118.00
4	184.00	118.00
5	224.00	118.00

Water Surface No. 3 specified by 6 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	60.00
2	30.00	61.00
3	60.00	66.00
4	104.00	69.00
5	144.00	70.00
6	224.00	70.00

Trial failure surface specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	125.00	117.00
2	129.00	118.00
3	133.00	119.00
4	148.00	126.00
5	160.00	135.00
6	183.00	158.00

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION :
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	125.50	117.13	.375	1.000	14.036	45.000	41.3
2	126.05	117.26	.788	.100	14.036	45.000	8.7
3	126.14	117.29	.856	.082	14.036	45.000	7.8
4	126.69	117.42	1.268	1.018	14.036	45.000	150.9
5	128.10	117.78	2.325	1.800	14.036	45.000	497.3
6	129.50	118.13	3.375	1.000	14.036	45.000	400.6
7	131.50	118.63	4.875	3.000	14.036	45.000	1730.2
8	135.50	120.17	7.333	5.000	25.017	45.000	4312.3
9	139.00	121.80	8.986	2.000	25.017	38.157	2112.4
10	144.00	124.13	10.581	8.000	25.017	38.157	9890.3
11	153.00	129.75	12.036	10.000	36.870	38.157	13919.8
12	159.00	134.25	12.250	2.000	36.870	38.157	2818.0
13	163.00	138.00	11.643	6.000	45.000	38.157	8006.1
14	173.00	148.00	7.000	14.000	45.000	23.199	11212.7
15	181.50	156.50	1.500	3.000	45.000	.000	517.5

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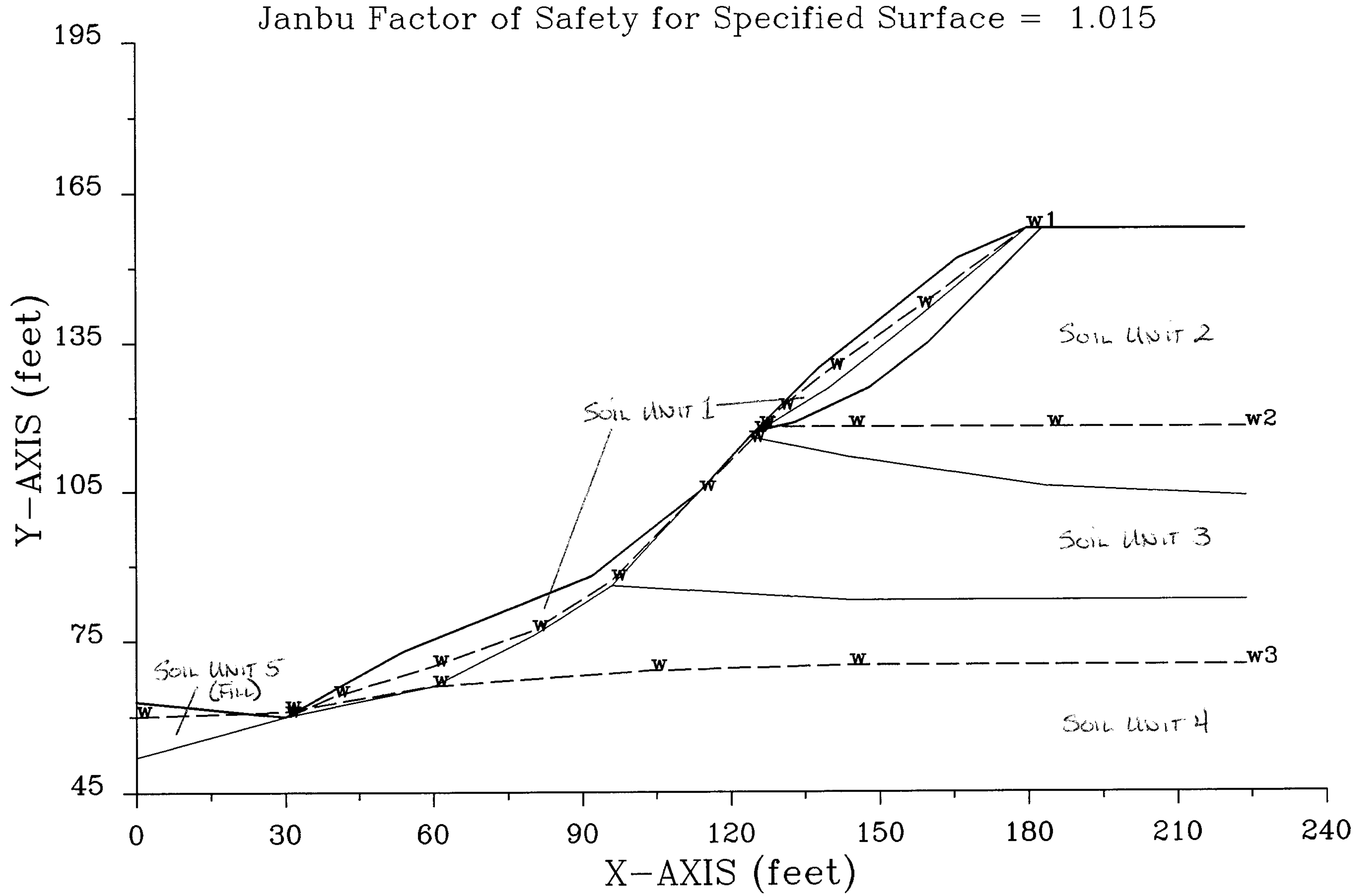
BLUFF STABILITY ANALYSIS (SEC. G-G')



SLICE INFORMATION ... continued :

Slice	Sigma (psf)	phi	c-value (psf)	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	31.6	22.00	25.0	.0	.0	.0	.00
2	29.7	33.00	25.0	4.7	.0	.0	.00
3	37.9	33.00	25.0	3.8	.0	.0	.00
4	90.7	33.00	25.0	37.8	.0	.0	.00
5	219.5	33.00	25.0	26.0	.0	.0	.00
6	338.2	33.00	25.0	.0	.0	.0	.00
7	489.3	33.00	25.0	.0	.0	.0	.00
8	649.7	33.00	25.0	.0	.0	.0	.00
9	797.6	33.00	25.0	.0	.0	.0	.00
10	935.2	33.00	25.0	.0	.0	.0	.00
11	917.1	33.00	25.0	.0	.0	.0	.00
12	928.4	33.00	25.0	.0	.0	.0	.00
13	787.2	33.00	25.0	.0	.0	.0	.00
14	466.4	33.00	25.0	.0	.0	.0	.00
15	88.4	33.00	25.0	.0	.0	.0	.00

For the single specified surface,
Corrected JANBU factor of safety = 1.015 (Fo factor =1.037)

Resisting Shear Strength = 317.24E+02 lb
Total Driving Shear Force = 323.92E+02 lb

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EXAMPLE 6

Problem Description : BLUFF STABILITY ANALYSIS (SEC. G-G')

SEGMENT BOUNDARY COORDINATES

9 SURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	63.0	30.0	60.0	5
2	30.0	60.0	54.0	73.0	1
3	54.0	73.0	92.0	88.0	1
4	92.0	88.0	114.0	105.0	1
5	114.0	105.0	124.0	116.0	3
6	124.0	116.0	138.0	130.0	1
7	138.0	130.0	166.0	152.0	1
8	166.0	152.0	180.0	158.0	1
9	180.0	158.0	224.0	158.0	2

14 SUBSURFACE boundary segments

Segment No.	x-left (ft)	y-left (ft)	x-right (ft)	y-right (ft)	Soil Unit Below Segment
1	.0	52.0	30.0	60.0	4
2	30.0	60.0	60.0	66.0	4
3	60.0	66.0	80.0	76.0	4
4	80.0	76.0	96.0	86.0	4
5	96.0	86.0	114.0	105.0	3
6	114.0	105.0	124.0	116.0	3
7	124.0	116.0	140.0	126.0	2
8	140.0	126.0	158.0	140.0	2
9	158.0	140.0	180.0	158.0	2
10	124.0	116.0	144.0	112.0	3
11	144.0	112.0	184.0	106.0	3

12	184.0	106.0	224.0	104.0	3
13	96.0	86.0	144.0	83.0	4
14	144.0	83.0	224.0	83.0	4

ISOTROPIC Soil Parameters

5 type(s) of soil

Soil Unit No.	Unit Weight Moist (pcf)	Unit Weight Sat. (pcf)	Cohesion Intercept (psf)	Friction Angle (deg)	Pore Pressure Parameter Ru	Pore Pressure Constant (psf)	Water Surface No.
1	110.0	125.0	25.0	22.00	.000	.0	1
2	115.0	130.0	25.0	33.00	.000	.0	2
3	115.0	130.0	100.0	32.00	.000	.0	3
4	115.0	130.0	25.0	33.00	.000	.0	3
5	95.0	110.0	100.0	22.00	.000	.0	3

3 Water surface(s) have been specified

Unit weight of water = 62.40 (pcf)

Water Surface No. 1 specified by 11 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	30.00	60.00
2	40.00	66.00
3	60.00	73.00
4	80.00	81.00
5	96.00	89.00
6	114.00	105.00
7	124.00	115.00
8	130.00	121.50
9	140.00	130.00
10	158.00	144.00
11	180.00	158.00

Water Surface No. 2 specified by 5 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)

1	125.00	117.00
2	126.00	118.00
3	144.00	124.00
4	184.00	128.00
5	224.00	129.00

Water Surface No. 3 specified by 6 coordinate points

****
PHREATIC SURFACE,
****

Point No.	x-water (ft)	y-water (ft)
1	.00	60.00
2	30.00	61.00
3	60.00	66.00
4	104.00	69.00
5	144.00	70.00
6	224.00	70.00

Trial failure surface specified by 6 coordinate points

Point No.	x-surf (ft)	y-surf (ft)
1	125.00	117.00
2	129.00	118.00
3	133.00	119.00
4	148.00	126.00
5	160.00	135.00
6	183.00	158.00

****
SUMMARY OF INDIVIDUAL SLICE INFORMATION :
****

Slice	x-base (ft)	y-base (ft)	height (ft)	width (ft)	alpha	beta	weight (lb)
1	125.50	117.13	.375	1.000	14.036	45.000	41.3
2	126.05	117.26	.788	.100	14.036	45.000	8.7
3	126.14	117.29	.856	.082	14.036	45.000	7.8
4	127.38	117.59	1.782	2.390	14.036	45.000	512.8
5	128.79	117.95	2.839	.429	14.036	45.000	150.1
6	129.50	118.13	3.375	1.000	14.036	45.000	416.3
7	131.50	118.63	4.875	3.000	14.036	45.000	1788.0
8	135.50	120.17	7.333	5.000	25.017	45.000	4407.9
9	139.00	121.80	8.986	2.000	25.017	38.157	2141.9
10	141.50	122.97	9.783	3.000	25.017	38.157	3480.5
11	145.50	124.83	11.060	5.000	25.017	38.157	6518.8
12	153.00	129.75	12.036	10.000	36.870	38.157	14157.3
13	159.00	134.25	12.250	2.000	36.870	38.157	2875.2
14	163.00	138.00	11.643	6.000	45.000	38.157	8145.2
15	173.00	148.00	7.000	14.000	45.000	23.199	11346.4

16	181.50	156.50	1.500	3.000	45.000	.000	517.5

SLICE INFORMATION ... continued :

Slice	Sigma (psf)	phi	c-value (psf)	U-base (lb)	U-top (lb)	P-top (lb)	Delta
1	31.5	22.00	25.0	.0	.0	.0	.00
2	32.7	33.00	25.0	4.4	.0	.0	.00
3	39.3	33.00	25.0	3.6	.0	.0	.00
4	136.6	33.00	25.0	119.6	.0	.0	.00
5	247.0	33.00	25.0	24.4	.0	.0	.00
6	300.7	33.00	25.0	60.3	.0	.0	.00
7	446.5	33.00	25.0	209.8	.0	.0	.00
8	618.9	33.00	25.0	309.9	.0	.0	.00
9	782.9	33.00	25.0	66.1	.0	.0	.00
10	865.0	33.00	25.0	37.2	.0	.0	.00
11	982.9	33.00	25.0	.0	.0	.0	.00
12	927.8	33.00	25.0	.0	.0	.0	.00
13	942.3	33.00	25.0	.0	.0	.0	.00
14	795.8	33.00	25.0	.0	.0	.0	.00
15	468.9	33.00	25.0	.0	.0	.0	.00
16	87.6	33.00	25.0	.0	.0	.0	.00

For the single specified surface,
Corrected JANBU factor of safety = .999 (Fo factor =1.037)

Resisting Shear Strength = 316.50E+02 lb
Total Driving Shear Force = 328.40E+02 lb

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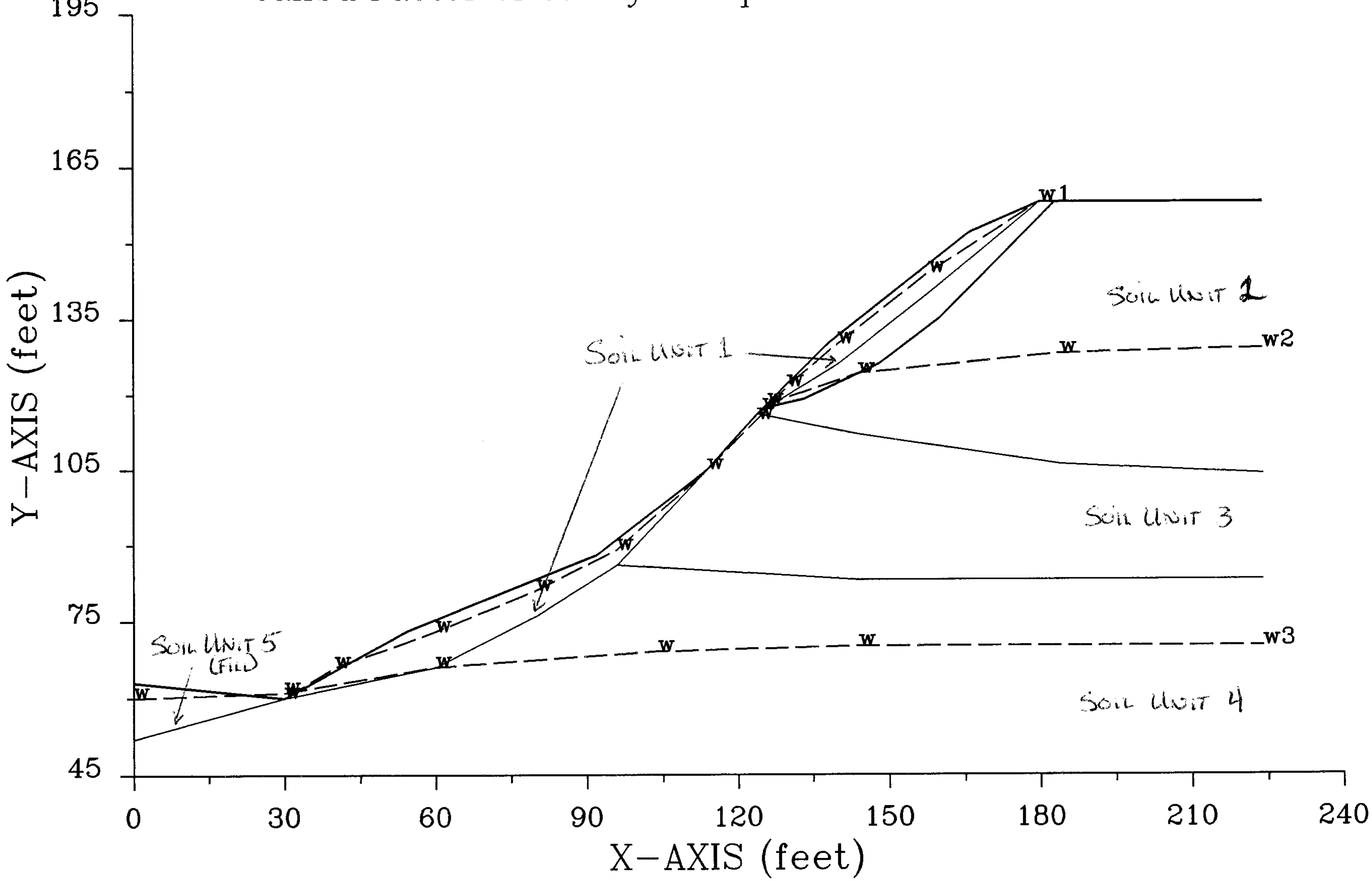
BLUFF STABILITY ANALYSIS (SEC. G-G')

Janbu Factor of Safety for Specified Surface =   .999



APPENDIX G

DOCUMENTATION OF LANDSLIDES/DEBRIS FLOWS RESULTING FROM THE FEBRUARY 5-8, 1996 STORM EVENT

APPENDIX G

Results of the February 5-8, 1996 storm

During the final compilation of this report Washington (as well as Oregon and Idaho) was hit with a severe storm that dropped over 8.0 in. of rain over a four day period from Monday evening Feb. 5 through Thursday afternoon Feb. 8, 1996. The highest rainfall during any 24-hour period of the storm occurred on Feb. 8 with 2.75 in. recorded at the Olympia Airport. Field reconnaissance along the Capitol Campus bluffs on Feb. 9 and 10, 1996 revealed several new landslides and debris flows ranging in size from approximately 2-5 yd^3 to 150-200 yd^3 of displaced material. The figure in Appendix G shows the location of these landslides along with notes on other areas of disturbance that resulted from the storm.

The largest slide occurred just to the southwest of the Governor's mansion. This one actually consisted of two debris flows separated by about 20 ft of undisturbed slope. Of the two flows, the larger, southernmost one is approx. 50 ft across and initiated at the top of the slope. The smaller one is approx. 30 ft across and initiated approx. 10-15 ft below the top of the bluff. Both slides reached Capitol Lake and deposited sediment and large organic debris into the water. The cause of these two slides is not yet certain, although they may be related to an abandoned sewer line located in the area.

A slide of approximately 50 yd^3 occurred on the slopes behind the north end of the steam plant. Here, two initiation areas merged into one debris flow, damaging a fence and overtopping a ~3-ft cement diversion structure near the northeast corner of the building, before spreading out as a fan onto the access road and finally reaching Capitol Lake. The remaining slope, especially the headscarp, is now critically over-steepened with tree roots overhanging the fresh slide scarps. Blocks of cement construction waste rest precariously on the slope above and between the two scarps. At the top of the slope are tension cracks, visible at the northwest edge of the Temple of Justice annex parking lot. Concerns regarding the stability of this area, referred to as the northwest point, have been discussed in the main text body of this report. These concerns have become more critical following the recent storm and slope activity.

A slide of approximately 5 yd^3 occurred on the north-facing slope of the northwest point. At the edge of the annex parking lot is a recently dumped pile of gravel and several large wooden wire spools. Apparently this area is still being used to dispose of construction waste. The jersey barrier, placed at the base of the slope following the landslide here in 1990, served well to contain the slide debris and keep it from flowing onto the access road and railroad tracks.

The new exposures created by the recent landsliding suggest that most of the slides initiated in the material overlying the thick sequence of laminated silts, or some comparable impermiable sediments in the bluff. With the new exposures caused by the landslides, this unit can now more confidently be traced along the entire length of the bluff, both north and west-facing slopes, with its upper contact at approximately 20 ft (along the north-facing bluff) to 30 ft (along the west-facing bluff) below the top of the bluff.

These recent landslides have offered insight into the typical/expected mechanisms of bluff failure and confirm the analysis in this report. The slides tend to occur as relatively small failures initiating on the upper slopes in the soil mantle and/or partially into the native material, transforming into debris flows as they progress downslope. Organic debris is often mobilized with the slide material from the upper slopes to the surface below. The fine-grained saturated material from the dewatering slide fans out once it hits the level ground at the base of the slope, leaving behind a goopy mess.

The mass-wasting events following the February 5-8 storm also confirm the approach that mapping of previously unstable slopes is a good, but not infallible, indicator of areas of future slope instability.

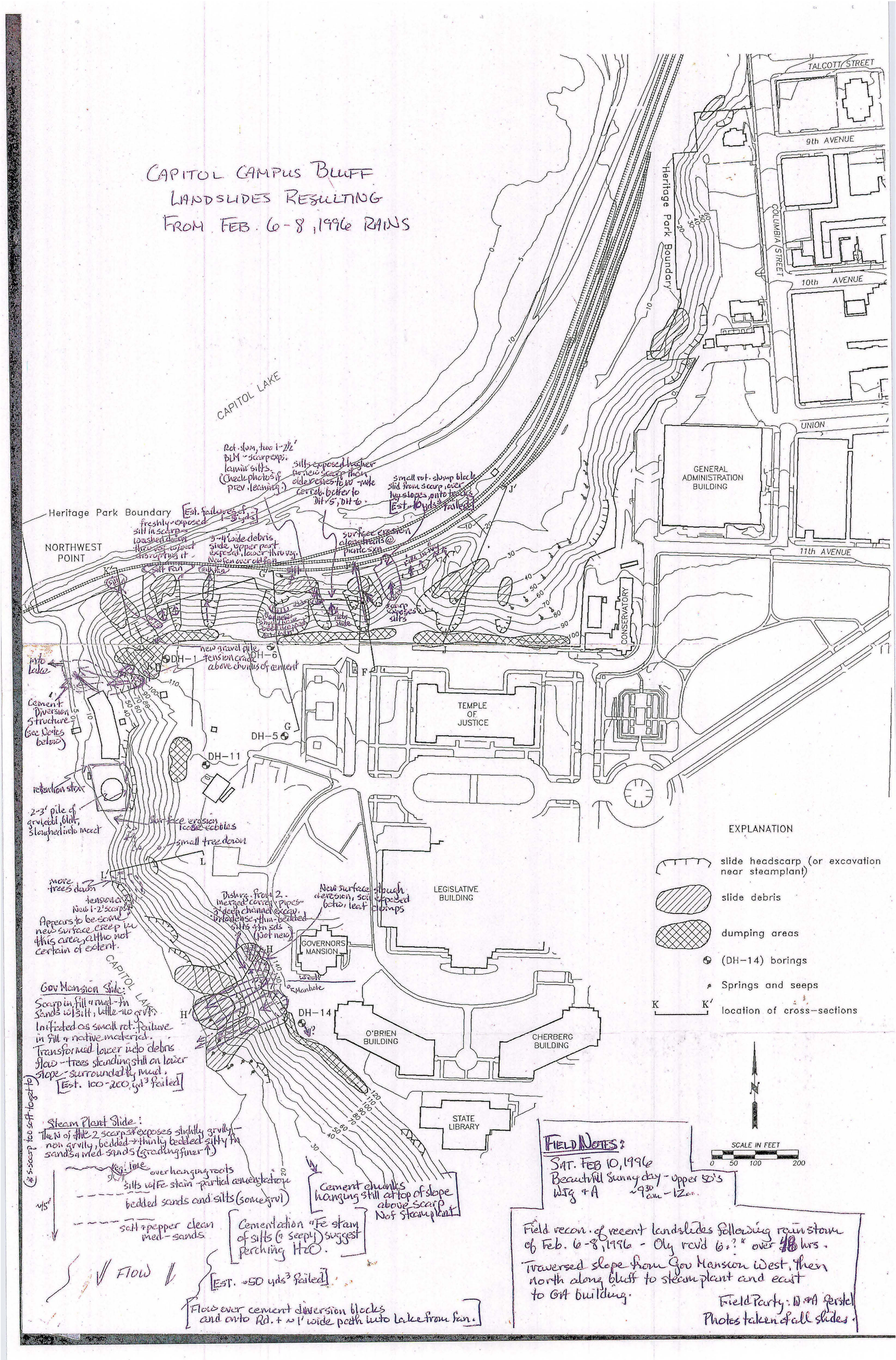

CAPITOL CAMPUS BLUFF
LANDSLIDES RESULTING
FROM FEB. 6-8, 1996 RAINS
TALCOTT STREET
9th AVENUE
Heritage Park Boundary
COLUMBIA STREET
10th AVENUE
UNION
GENERAL ADMINISTRATION BUILDING
11th AVENUE
CAPITOL LAKE
NORTHWEST POINT
Heritage Park Boundary
CONSERVATORY
TEMPLE OF JUSTICE
LEGISLATIVE BUILDING
GOVERNORS MANSION
O'BRIEN BUILDING
CHERBERG BUILDING
STATE LIBRARY
DH-1
DH-6
DH-5
DH-11
DH-14
EXPLANATION
slide headscarp (or excavation near steamplant)
slide debris
dumping areas
(DH-14) borings
Springs and seeps
location of cross-sections
SCALE IN FEET
0 50 100 200
new gravel pile
tension crack
above chunks of cement
small tree down
Gov Mansion Slide:
Scarp in fill & med-fn sands w/silt, little-no grvls.
Initiated as small rot. failure in fill & native material.
Transformed lower into debris flow - trees standing still on lower slope - surrounded by mud.
[Est. 100-200 yd³ failed]
Steam Plant Slide:
The N of the 2 scarps exposes slightly grvlly - non grvlly, bedded → thinly bedded silty fn sands & med sands (grading finer ↑)
overhanging roots
silts w/Fe stain - partial cementation
bedded sands and silts (some grvl)
salt & pepper clean med-sands
Cementation & Fe stain of silts (& seeps) suggest perching H2O.
Cement chunks hanging still at top of slope above scarp N of Steamplant
FLOW
[EST. ~50 yds³ failed]
Flow over cement diversion blocks and onto Rd. + ~1' wide path into Lake from fan.
FIELD NOTES:
SAT. FEB 10, 1996
Beautiful Sunny day - upper 50's
WJG + A ~9:30 am - 12
Field recon. of recent landslides following rainstorm of Feb. 6-8, 1996 - Oly rcv'd 6.?" over 48 hrs.
Traversed slope from Gov Mansion West, then north along bluff to steam plant and east to GA building.
Field Party: W & A Gerstel
Photos taken of all slides.

Figure 1. This debris slide is located on the slope north of the west end of the Temple of Justice building. It is the eastern-most slide occurring on the Capitol Campus bluffs as a result of the February, 1996 storm. The slide initiated in the loose sandy material overlying the dense laminated silt unit. It incorporated approximately 10-12 yds^3 of material from the upper portions of the slope, including a 1′ diameter tree, which then overrode the vegetation on the lower portions of the slope, and was deposited onto two lines of railroad tracks.

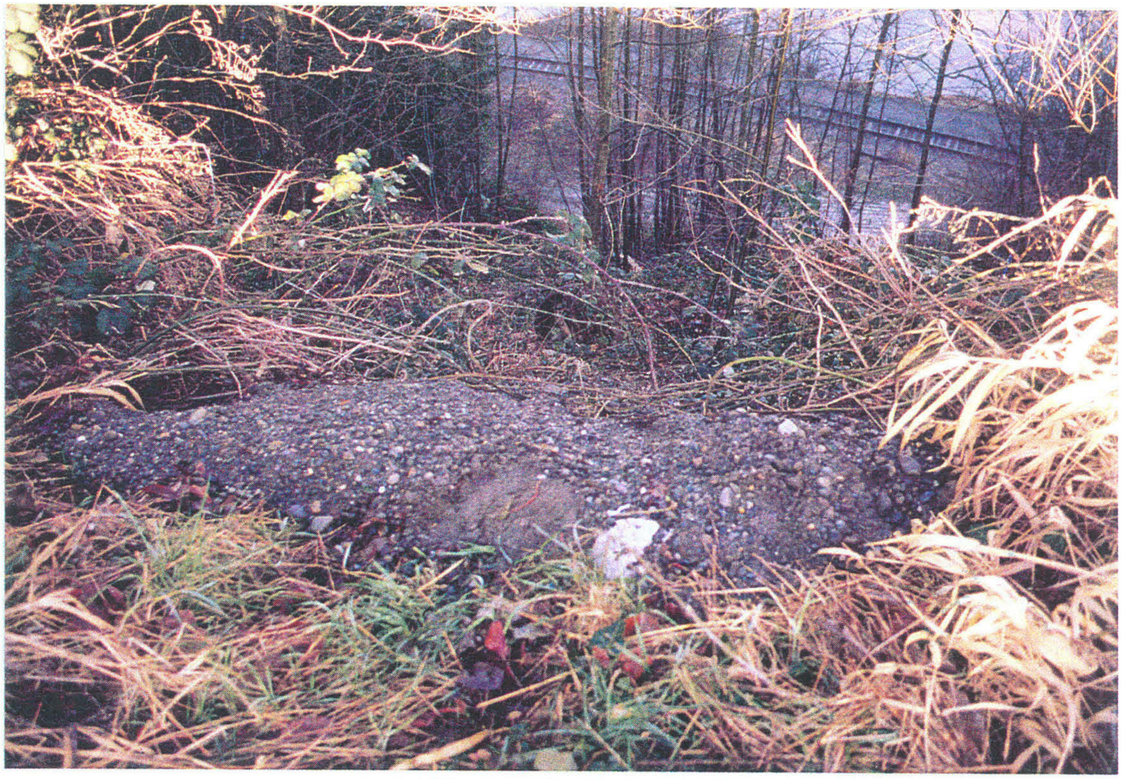


Figure 2. This debris slide is located on the north-facing slope of the northwest point of the Capitol Campus. The extreme precipitation associated with the February, 1996 storm, combined with sidecast construction waste, **above**, created the conditions of instability. The slide initiated at or just above the dense laminated silt unit and incorporated approximately 5 yds^3 of material. The jersey barrier at the base of the slope, **right**, served to contain the larger vegetation debris and coarse slope material. A fan of fine sediment flowed through the gap between sections of the cement barrier and onto the powerplant access road.

Figure 3. This debris slide is located at the north end of the steam plant and occurred as a result of the extreme precipitation associated with the Feb., 1996 storm, combined with loading of the slope with side-cast cement construction debris **(visible in Figure 4)**. The slide incorporated approximately 50 yds^3 of material. It initiated from two separate headwall areas (top center of photo and to left of center, behind trees) **(also visible in Figure 4)** in interbedded sands and silts (some laminated). Slide debris was deposited on the steam plant access road, and fine sediment from the slide run-out reached Capitol Lake.

Figure 4. These are views of the upper portions of the debris slide that occurred at the north end of the steam plant during the Feb., 1996 storm **(also see Figure 3)**. Two areas of initiation are visible **(below)**. Chunks of cement construction waste are still perched at the top of the scarp **(right**, view is looking down on the slide area with Capitol Lake behind the trees in the background). A tension crack exists in the lower right corner of the photo. The arrow in the lower photo points to the location of the cement construction waste.

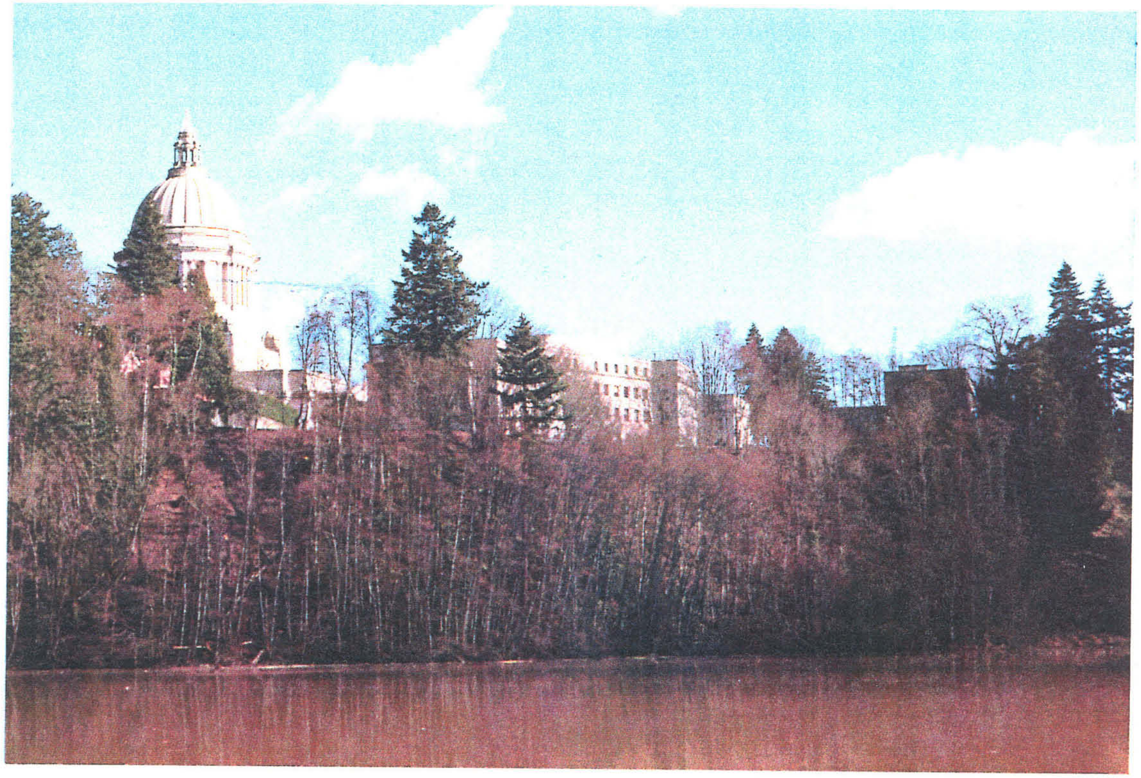


Figure 5. **Above**, view across Capitol Lake to debris slides located south of the Governor's Mansion, behind the O'Brien Building. **Below**, view is looking down larger slide path from just south of the retaining wall behind the Governor's Mansion. The headscarp of the smaller slide lies just to the north, out of view of the photo; however, the deposition area of the smaller slide is visible in the center of the photo. Note slide material in Capitol Lake. These two slides initiated in the unconsolidated sandy material overlying the dense laminated silts.