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WEST BENCH/SAGE MESA AREA GEOLOGICAL HAZARDS REVIEW

PB 5847 0101

KLOHN LEONOFF

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Our File: PB 5847 0101
WP 621

August 10, 1992

Regional District of Okanagan-Similkameen
101 Martin Street
Penticton, British Columbia
V2A 5J9

Andrew Swetlishoff

West Bench/Sage Mesa Geological Hazards Review

Dear Sir:

Enclosed are 20 copies of the final report "West Bench/Sage Mesa Geological Hazards Review". We request that all draft reports be destroyed or returned to Klohn Leonoff Ltd.

We have enjoyed being of service to the Regional District of Okanagan-Similkameen on this interesting project. If you have any questions regarding this report or related matters, we would be pleased to be of assistance.

Yours very truly,

KLOHN LEONOFF LTD.

H.R. (Rod) Smith, P.Eng.
Project Manager

HRS/dls

Regional District of Okanagan-Similkameen

WEST BENCH/SAGE MESA AREA GEOLOGICAL HAZARDS REVIEW

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AUGUST 1992

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SUMMARY

This report, prepared for the Regional District of Okanagan-Similkameen, is a review of the geological hazards of the West Bench/Sage Mesa area. The terms of reference were supplied by the Regional District in their call for proposal (October 1991).

West Bench/Sage Mesa is located to the northwest of Penticton. The area is generally composed of dry lacustrine silt bluffs which are bounded on the east by steep scarps down to Okanagan Lake and on the west by kettled outwash sands and gravels. The high steep bluffs is a location which provides a spectacular view of Penticton and Okanagan Valley and so is desirable for residential development. West Bench currently consists of 385 houses with a population of about 1,100 people and Sage Mesa currently consists of 73 houses with a population of about 225 people.

The silt bluffs of the study area were deposited into glacial Lake Penticton during retreat of the last phase of glaciation. When the lake level lowered to the current elevation, extensive silt erosion probably occurred, from surface slumping to large landslides and subsurface and surface erosion. The gravels west of the silt also had to drain as the lake level lowered which may have resulted in additional landslides and gully development.

Following deglaciation and lake level lowering, the geologic activity in the study area probably decreased significantly. However, there is evidence for an ongoing hazard of landslides, mass wasting, sinkholes (subsurface erosion) and gully erosion in the study area. These geological processes can be hazardous, and can cause loss of life and major property damage.

Twelve major landslides have been reported in the region. The majority of these slides occurred after irrigation began and before the use of sprinklers. The cause of these slides is therefore believed to be high groundwater pressures. Remnants of only one slide were identified in the West Bench Sage Mesa study area and that slide is very old. Under natural conditions, landslides are apparently rare in this area.

Development pressures led to a geotechnical study of the area in the mid-70s. A report entitled "Geological Hazards and Urban Development of the Silt Deposits in the Penticton Area" (Nyland and Miller, 1977) recommended restrictions in development by creating zones of development. A resurfacing of development pressures since the late 1980s led to this study for evaluation of possible further development.

This study indicates that the use of septic fields for house wastewater disposal significantly increases the groundwater levels in the silt bluffs and therefore significantly increases the probability of a landslide. Less significant is the increased groundwater from septic fields installed in the sands and gravels to the west of the silts. To reduce the risk associated with landslide hazard, we recommend that all further development be restricted within a set back distance from the bluff toe of 2.2 times the height of the silt bluff plus 10 m. In addition, we recommend that development be restricted a distance from the slope toe 1.8 times the height of the silt bluff plus 10 m for slide runout. We also recommend that no further development proceed in the remainder of the study area or in the catchment for the study area without suitable measures to control the increase of groundwater levels.

As a result of groundwater flow causing subsurface erosion, sinkholes have developed over a large portion of the study area. Sinkholes occur above large subsurface erosion pipes which carry water off site. Recent sinkhole development has apparently doubled compared to the average sinkhole development since glacial times. The air photo analyses carried out for this study indicates that all sinkholes occur within 40 m of another sinkhole or a bluff edge. To reduce the risk associated with subsurface erosion, a setback of 40 m from any past or existing sinkhole or gully edge is recommended. Development-induced trigger mechanisms such as broken pipes, leaking swimming pools and ornamental ponds, and uncontrolled concentration of precipitation run-off can increase the likelihood of sinkhole development.

Erosion in the gullies occur whenever there is an adequate supply of water for free flow. On application of even moderate quantities of water, subsurface erosion in the valley floor begins with piping and sinkhole development. Common sources of water include high precipitation or snowmelt, discharge of road runoff into a gully and discharge of groundwater from bedrock and gravel into the gullies. Continued gully erosion could lead to wider and deeper gullies further eroding the land suitable for development in the study area. Gully erosion is best controlled by collecting runoff from the site and transmitting the water to Okanagan Lake level and by reducing groundwater entering the gullies from the bedrock and sand and gravel units to the west.

Drawing D-1007 presents development zones based upon the above criteria for landslides, subsurface erosion and gully erosion. Also included is a matrix which suggests an administrative decision for types of development applications in each zone.

For some of the zones, development is recommended only with implementation of mitigative measures. The Regional District requires that such mitigative measures be practical, be enforceable at the time of construction and not require ongoing policing. Recommended measures meeting these criteria include:

- restriction of development in the study area and study area catchment to limit the quantity of water entering the silts and gullies;
- installation of septic sewers, storm sewers, road curbs and gutters and roof and driveway runoff collection to carry water to Okanagan Lake level;
- improvement of water system distribution and maintenance requirements;
- collection of groundwater from the sands and gravels downstream of Madeline Lake and use as irrigation or transport to Okanagan Lake level;
- restriction on construction of swimming pools and ornamental pools; and

- restriction on construction of swimming pools and ornamental pools; and

- distribution of information to the residents of West Bench and Sage Mesa regarding the potential hazards and associated risks along with methods for mitigating the potential trigger mechanisms.

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1. INTRODUCTION

1.1 General

The Regional District of Okanagan-Similkameen requested the services of Klohn Leonoff Ltd. to carry out a review of the geological hazards of the West Bench/Sage Mesa area based on current practice in hazard mapping. The Terms of Reference are included as Appendix I.

The purpose of the study was to determine criteria for development, taking into account identified geological conditions and associated risks.

This report describes the work carried out in the study, presents an interpretation of geological conditions, identifies geological hazards and evaluates the probability of the hazards. The report also includes a guide to administrative decisions, introduces bench marks for acceptable risk levels and suggests a matrix format for application of the study results to bylaw preparation.

1.2 Scope of Work

The scope of work carried out in this study is briefly described below:

- A review was made of all previous studies and the rationale behind the hazard zones of the Nyland and Miller Report (1977) was examined. The site was visited to review existing hazard boundaries as defined by Nyland and Miller (1977).

- Effects of development to date were reviewed using air photo interpretation, field investigation and interviews with residents and agencies operating within the area. The study area was evaluated both analytically and probabilistically for identified hazards.

- Benchmarks for administration were outlined to determine levels of acceptable risk.

- Practical and enforceable mitigative measures to reduce identified hazards were designated and a matrix and hazard boundaries recommended for ongoing administrative controls.

1.3 Site Description

This study was carried out on the West Bench and Sage Mesa developments of the Regional District of Okanagan-Similkameen. The study area is located on the west side of the Okanagan Valley west and northwest of Penticton, British Columbia. As of 1991, West Bench consists of 358 houses with a population of 1,100 and one school with 221 ha (545 acres), of which 130 ha (315 acres) is irrigated land. Sage Mesa consisted of 73 houses with a population of approximately 225 and covers an area of approximately 19 ha (47 acres).

Between West Bench and Sage Mesa is an undeveloped tract of land covering 19 ha (47 acres). An application to rezone the tract for golf course use is currently underway. Above Sage Mesa to the west is Pine Hills Golf Course consisting of 28 ha (70 acres).

A development is underway east of West Bench on Penticton Indian Reservation No. 1 land. This development will consist of 75 houses. To the west of West Bench is the Hsula Highlands development consisting of 87 houses.

The study area is located at latitude 49° 30.5′ north longitude and 119° 37.5′ west longitude and covers the area shown on Drawing A-1001 and Drawing B-1002. The area generally comprises a dry silt bench which is bounded on the east by steep scarps down to Okanagan Lake and Okanagan River and on the west by kettled outwash sands and gravels, Blue Mountain and Nkwala Mountain.

West Bench was developed in the late 1950s under the Veterans Land Act as affordable property for veterans of the Canadian Armed Forces. Sage Mesa was developed in the late 1960s by a developer.

The West Bench Irrigation District supplies domestic and irrigation water to the residents by pumping water from Okanagan Lake. Irrigation water is supplied at a maximum of 6 gallons/minute/irrigated acre. The West Bench Irrigation District is owned privately and managed by the residents of West Bench.

The Sage Mesa Irrigation District supplies domestic and irrigation water to the residents of Sage Mesa, the Pine Hills Golf Course and Hsula Highlands by pumping water from Okanagan Lake. The Sage Mesa Irrigation District is a private utility presently under control of the British Columbia Ministry of Environment, Lands and Parks, through the Water Rights Branch.

Sewage is disposed of through individual septic fields provided by the residents on their individual properties. Storm drainage is controlled through ditches and some curbed roads where the run-off is diverted through culverts into gullies. Other storm drainage, including water collected on driveways and roofs, is disposed of by individual residents by various means.

2. DATA ACQUISITION

2.1 Data and Report Review

2.1.1 General Review

The initial stages of the study included an extensive data and report review. The object of the review was to put together as complete an information database as possible in the time available. The majority of the work for this task was completed prior to starting the other tasks of the project, although data and report collection continued throughout the entire length of the project.

Air photo flight lines for the area were reviewed and four sets of air photos were ordered from Maps B.C. of the British Columbia Ministry of Environment, Lands and Parks, Survey and Resource Mapping Branch, in Victoria. The air photos sets reviewed were from 1951 (which predates most of the development in the area), 1966, 1985 and 1990 (which was the latest set available for the area).

All groundwater well logs available for the West Bench/Sage Mesa area were ordered from the Water Investigation Branch of the Department of Environment, Water Resources Division, in Victoria. A total of 22 well logs were received and reviewed.

Seismic hazard calculations were ordered from Energy, Mines and Resources Canada, through the Geological Survey of Canada, at the Pacific Geoscience Centre in Sidney, British Columbia, for the West Bench/Sage Mesa area.

Rainfall data was ordered from the Atmospheric Environment Service of Environment Canada. Other rainfall and climatic data was obtained from the Rainfall Frequency Atlas of Canada (1985) and the Canadian Climate Normals (1980).

The most current maps of the site were ordered from Maps British Columbia of the British Columbia Ministry of Environment, Lands and Parks, Survey and Resource

Mapping Branch, in Victoria. The maps purchased were the 1:20,000 scale Terrain Resource Information Management (TRIM) series.

A literature review was carried out to obtain pertinent articles on geology, geotechnical properties, hazards, and mitigative measures relating to geologic conditions at the site and to other similar geologic terrains to the Okanagan Valley. Reports on hazard assessment and classification were also reviewed. A list of references is compiled for this report.

Previous studies were carried out on the West Bench/Sage Mesa area. These reports are particularly relevant for this geological hazards review. These reports are listed in Section 2.1.2.

2.1.2 Key Reports

Wright, A.S.C. and C.C. Kelly, "Soil Erosion in the Penticton Series. West Bench Irrigation District, Penticton, British Columbia", Soil Survey Branch, Department of Agriculture, Kelowna, British Columbia, June 1959.

Runka, G.G., "Soil Stability Ratings - South Okanagan", September 1971.

Nyland, D. and G.E. Miller, "Geological Hazards and Urban Development of Silt Deposits in the Penticton Area", British Columbia Ministry of Highways and Public Works, Geotechnical and Materials Branch, 1977.

Evans, S.G. and R.G. Buchanan, "Geotechnical Problems Associated with Silt Deposits in the Thompson Valley, British Columbia", British Columbia Ministry of Highways and Public Works, Geotechnical and Materials Branch, 1977.

Wilson, G., "Terrain Analysis for part of Lot 137, Plan 68395 C.L.S.R. Being Part of Penticton I.R. No. 1", Prepared for Redwing Resorts Ltd., Gordon Wilson and Associates Inc., 1991.

2.1.3 Rationale of the Nyland and Miller Report

The present basis for decisions regarding subdivision of new or existing lots in the West Bench/Sage Mesa area is the report "Geological Hazards and Urban Development of Silt Deposits in the Penticton Area" (Nyland and Miller, 1977). The report was prepared for the Ministry of Transportation and Highways, Geotechnical and Materials Branch, after an extensive field and laboratory investigation of the study area.

The Nyland and Miller (1977) report concluded that urban development in the West Bench/Sage Mesa area is subject to two types of hazards:

(i) piping, caving and collapse of the silt; and

(ii) landslides along the steep silt slopes.

These phenomena were considered natural and would occur sporadically without development. The study determined that the main triggering mechanism for failures is water, and that urban development would increase water inputs well beyond the natural supply of the area. Consequently, development would increase the occurrence of failures.

The report by Nyland and Miller (1977) recommended that hazardous areas be delineated and the addition of water reduced. A zone map was prepared covering the study area. The map contained three zones:

- **Red Zone:** The red zone covered areas where the hazard was so great that no further building should be allowed.
- **Orange Zone:** The orange zone covered areas where no further development was allowed unless water controls were implemented in all developed areas of West Bench (including the green zone).

  Water controls were to include storm and sanitary sewer systems, curb and gutter street design, sprinkling controls, dole valves on outside water services, collection of roof and driveway run-off and conveyance to storm sewer systems, plus maximum safeguards against damage from breakage of water and sewer lines.

- **Green Zones:** The green zone covered areas where the hazard was judged sufficiently low to allow subdivision to the 1/2 acre minimum lot size with no additional controls on water input to the soils (unless development is to take place in the orange zone).

2.2 Air Photo Interpretation

2.2.1 General Air Photo Interpretation

An air photo interpretation was carried out on four stereo sets of air photos. Air photos reviewed include the 1:31,680 scale 1951 series, the 1:31,680 scale 1965 series, the 1:15,000 scale 1985 colour series and the 1:12,500 scale 1990 series. A total of forty photos of the study area from four sets spanning time from predevelopment to the present were reviewed.

Photos were compared to determine if any development of gullies, sinkholes, or slides had occurred over the period of record. All sinkholes visible were mapped and plotted and a review made of the occurrence of a sinkhole in relation to another sinkhole or bluff edge (see Appendix II). Photos were also used to assist in the field mapping and interpretation of the geology.

2.2.2 Air Photo Observations

Air photo interpretation revealed the following observations:

- the distribution of sinkholes evident on the air photos reveal that all sinkholes occur within less than 40 m of another sinkhole or bluff edge (see Appendix II);
- sinkholes generally occur in a dendritic pattern and individually near bluff edges;
- gullies appear to be associated with coalescing of sinkholes;
- no major landslides, development of sinkholes or gully advancement is obvious over the period of record;
- ravelling of the natural slopes can be observed;

- north facing slopes have a higher incidence of ravelling than do south facing slopes;
- an ancient landslide exists at the mouth of the gully in which Sage Mesa Drive connects Sage Mesa with the Highway 97; and
- the various geologic units can be delineated on the air photo.

2.3 Field Investigations

2.3.1 Geology Mapping

A field mapping program was carried out between March 6, 1992, and March 20, 1992. A total of 235 outcrops were mapped in and around the study area. Outcrops were both man-made and natural, and consisted of varved lacustrine silt, colluvial silt, sands and gravels, and bedrock. Outcrops were also observed for structure to determine depositional environment; piping, sinkholes and collapse features; slope angles and slope failures; and any jointing or lineations that were present.

A map was prepared including outcrop information as well as geologic information confirmed in other reports (Drawing B-1003). Sections were drawn (Drawing BX-1004) to assist in interpreting the geology. Air photos were used in conjunction with the other geology information to prepare a geology map.

An ancient landslide at the mouth of the gully in which Sage Mesa Drive connects Sage Mesa with the Highway 97 was mapped. A shear surface was observed (see Photo 1) and the landslide included on the geology map.

Photo 1 - Photo of Failure Plane of Ancient Slide

2.3.2 Geophysics

On March 13 and 14, 1992, a small program of dipole-dipole apparent resistivity was carried out at the Pine Hills Golf course, in West Bench.

The objective was to assess the effectiveness of the resistivity method in mapping possible ground water flow and voids which would indicate subsurface erosion within the silt formation.

The resistivity survey consisted of three lines totalling 800 m in length. This survey consists of passing a current through the ground between two probes and measuring the potential across two other probes. The ease with which the ground passes or does not pass the current is the resistivity of the material. If the different material types over which the survey is performed have a large difference in resistivity then the results of the survey can be interpreted.

The results from the survey performed show two areas of very high resistivity which could be interpreted as bedrock, dry granular material or possibly open voids (see Appendix III).

More work would need to be performed to verify the source of the anomaly if this information is to be correlated to geology. These results appear promising for the use of resistivity surveys as a tool in distinguishing voids in the silt.

2.4 Interviews

2.4.1 Discussions with Residents

A general information meeting was held at the offices of the Regional District of Okanagan-Similkameen for interested residents on the evening of Tuesday, March 10, 1992. Approximately 30 residents attended. Residents were informed of the geological hazards review under way and asked for comments and input. The following concerns were raised:

- Residents were concerned that the Redwing Resort currently under construction on the Penticton Indian Reservation Land between West Bench and the bluff edge might prevent subdivision of land in the West Bench area, as the new houses may be more exposed to potential slope failures.
- Concerns were raised that small individual properties would be missed in the scope of the overall study. Many residents requested that the guidelines be written so that they could be applied to individual cases rather than as broad, general lines on a map.

Residents were also requested to provide the study with any reports for geotechnical investigations carried out on their individual properties. A number of reports were supplied for review (see the list of references for reports provided).

A number of discussions were held with individual residents at their request. These discussions covered the same issues raised during the information meeting and details of topics brought up at the meeting.

2.4.2 Discussions with Agencies

Agencies operating in the West Bench/Sage Mesa area were interviewed for information pertaining to the study. Those interviewed include:

- the Regional District of Okanagan-Similkameen;
- Ministry of Transportation and Highways, Thompson-Okanagan Regional office;
- Ministry of Transportation and Highways, Geotechnical and Materials Engineering office;
- West Bench Irrigation District;
- Sage Mesa Irrigation District, through Water Rights Branch in Victoria; and
- British Columbia Gas local office.

3. GEOLOGY

3.1 Regional Geology

The Okanagan Valley is a major physiographic feature that trends generally north/south through the Interior Plateau of south central British Columbia and the Columbia Plateau of north central Washington State, where it joins the Columbia River System.

From Vernon to the U.S. - Canada Boundary, the Okanagan Valley consists of a main trench and parallel valleys cut deeply into the surface of the plateau. South of Vernon, no major valley joins the Okanagan in Canada, and the watershed divides are abnormally close to the main valley for such a major valley system. Minor tributary streams flow from the plateau surface in narrow valleys with steep gradients to join the Okanagan Valley.

Several sequences of glaciation are thought to have occurred during the Pleistocene Epoch. The Okanagan Valley acted as an important channel for the movement of ice. During glacial advance, the Okanagan Valley was deeply incised, with the valley bottom ranging from 4 km to 22 km in width. The Fraser ice sheet was the last glacial stage to advance through this region with deglaciation occurring between 11,000 years and 9,000 years ago (Fulton, 1975). During the period of final deglaciation, most of the unconsolidated sediments that are found in and around the Okanagan Valley were deposited. Extreme climatic changes, according to Nasmith (1962), account for the Fraser ice sheet apparently wasting away through down-wasting rather than by retreat. As the rapid down-wasting occurred, the unconsolidated sediments were laid down.

An expanded interpretation of the origin of the surficial deposits and resultant topography have been reported by Nasmith (1962). A summary of the sediment origin and deposition environment as described by Nasmith follows:

Glacial Occupation

During the stage of glacial occupation the main ice lobe occupied the Okanagan Valley. Morainal ridges consisting of sorted and unsorted material were deposited at the edge of the ice lobe. Kame terraces consisting of stratified drift were deposited by meltwater streams flowing along the edge of the ice.

Glacial Retreat

During the stage of glacial retreat the ice lobe occupied the central part of the valley and large streams and lakes were formed by the melting ice of the main lobe. Outwash terraces consisting of stratified drift, including fine sand to coarse gravel, were deposited by meltwater streams. These are similar to kame terraces, although in kame terraces the gradient is controlled by the adjacent ice. Where outwash was deposited over glacial ice, kettled outwash resulted when the buried ice melted and subsequent depressions, known as kettles, formed.

During the retreat of the Okanagan ice lobe, the valley was blocked by ice near the present day location of Okanagan Falls. This blockage caused the formation of glacial Lake Penticton. Glacial lake sediments consisting of thick deposits of silt, clay and sand accumulated in the calm water. Much of the Okanagan Valley from Okanagan Falls north to Vernon is flanked by bluffs consisting of glacial lake sediments.

Late Glacial

During the late stages of ice retreat, raised alluvial fans and deltas were deposited by local streams grading into a lake water level higher than present.

Postglacial

Recent sediments include floodplain sediments of sand, silt and swamp deposits. One example of this is the Okanagan River floodplain between Okanagan and Skaha Lakes. Alluvial fans, deltas and stream channels created by present-day streams are graded to present day base level. Erosion of the lacustrine silt bluffs results in colluvial silt deposits.

3.2 Land Form Development

3.2.1 Glacial Occupation

The local geology interpretation is based on the extensive work of Nasmith (1962), the work of Nyland and Miller (1977) and the field program for this study. The interpretation follows Nasmith with minor enhancements where more details are available.

During the early stages of the glacial recession, the highland areas that surrounded the Okanagan Valley were ice-free while the ice still occupied the main valley. The ice at the south end of the valley down-wasted earlier than the ice in the North. As melting occurred, the Marron Valley, a parallel valley located 14 km to the west, acted as a channel for the meltwater to move away. The water flowed south then west to the Similkameen Valley. Over time the ice tongue blocking the Shingle Creek Valley melted down to allow the flow of water to return to the Okanagan Valley down Shingle Creek. At about the same time as the Shingle Creek Valley opened up meltwater began to follow the course of Trout Creek and was diverted into the Trout Creek - Penticton Diversion, the valley between Blue Mountain and Nkwala Mountain.

Kame terraces are visible on the eastern flank of Blue Mountain above West Bench at El. 520 m. These kame terraces were deposited when the ice lobe filled the main valley to an elevation of 550 m and meltwater was flowing through the Trout Creek - Penticton Diversion. The water deposited sediments along the ice-rock contact to form the kame terraces.

3.2.2 Glacial Retreat

During the initial stages of Lake Penticton the ice down-wasted further, so that meltwater flowing south through the Trout Creek - Penticton Diversion and east down Shingle Creek deposited sands and gravels into the ice-marginal valley. The resulting outwash terraces and kettled outwash were formed throughout the area on the west side of West Bench. These silty sand and gravel deposits are exposed between elevation 450 m and 500 m and in outcrops below 450 m and are easily recognized by the kettle topography. The eastern edge of the kettled outwash deposit dips steeply to the east.

When the ice lobe had down-wasted to below 450 m, the meltwater started to flow down the main valley and stopped flowing through the Trout Creek - Penticton Diversion and Shingle Creek. Shingle Creek continued to act as a drainage creek for the watershed. The level of Lake Penticton was controlled to the south by a dam formed from outwash deposits and buried ice.

The lacustrine silts, clays and sands were deposited within the waters of Lake Penticton close to the ice margin and on top of the ice lobe. Silt is evident as a surficial mantle up to El. 450 m, but most evident in the thick silt benches left along the valley edge at El. 400 m.

The lacustrine silt is most easily identified by the varving. Varving is horizontal layering caused by changes in the depositional rates of the sediments. The silt is varved most probably as a result of seasonal fluctuations, climatic changes, or variations in flow as the lake level declined. Varves range in thickness from 2 cm to 3 cm up to approximately 1 m, with the thickest varves found on the lower slopes. The clay varves indicate that there were periods of calm water that allowed the clay to settle out.

Where silt was deposited over the ice lobe, the ice became insulated by the silt. When the ice support of the silt was removed, slumping and differential settlement of the silt occurred. Evidence of this are broad synclinal sags and normal faults first noted in the Okanagan Valley by Flint (1935).

At the north end of Sage Mesa, the silt bluffs are interbedded with some fine to coarse sand deposits. There may have been a meltwater channel formed by the ice lobe and the east side of Nkwala Mountain which juts east into the Okanagan Valley. The interbedded silt and sand may be a small delta formed as the meltwater, flowing through the channel, entered the deeper, wider channel south of Nkwala Mountain.

3.2.3 Late Glacial

The late glacial period was geologically a very active time. As the level of Lake Penticton dropped, the lacustrine silt deposits were drained rapidly. If lake level decline exceeded the ability of the silt to drain the excess pore pressures would have resulted in dramatic slope failures all along the edge of the lacustrine silt deposit.

The relatively rapid lowering of Lake Penticton, and a climate at the end of the glacial period with rainfall much greater than today, probably caused the major gullies along West Bench to form. The excess pore water, the high rainfall run-off, and drainage from the gravels to the west may have combined to erode through the silts as the lake level fell.

Any deltas formed by the debris eroding from the gullies or by slope failures have been washed away by the flow of the Okanagan River or by wave action on Okanagan Lake. This erosion activity is evident even today: where landslides occur into Okanagan Lake, the toe is completely eroded away in only a few years. Estimating the date of gully formation, the incidence of landslides along the silt bluffs or the rate of cliff erosion is therefore not possible.

The ancient slide that created the slide remnants observed in Sage Mesa most probably predates the forming of the gully that flows through the slide. The slide at the mouth of the gully probably caused the gully to form there.

The outwash and lacustrine silt insulated the ice lobe in the early stages of melting. As the climate continued to warm, the buried ice gradually melted slowly removing the ice support of the overlying materials. The overlying materials then settled into the resulting void.

The outwash collapsing into the voids created kettles. Where there was a thin veneer of silt over the outwash, a kettle now occurs in the silt. Where the silt partially covered the ice below, differential settlement and slumping occurred in the silt.

3.2.4 Postglacial

While Lake Penticton existed, Shingle Creek flowed to the higher lake level depositing an alluvial fan on to the area south of West Bench. When the level of Lake Penticton dropped, the base level of Shingle Creek also dropped. A gully on the raised alluvial fan indicates a temporary drainage course followed by the creek. In its present course, Shingle Creek follows a narrow channel that it has eroded through the alluvial fan.

According to Nasmith (1962), Penticton, Ellis and Shingle Creeks have built alluvial fans graded to the present lake level. These fans are sufficiently extensive to coalesce and divide the formerly continuous lake into two lakes. The City of Penticton is built upon the coalescing fans.

The present Okanagan River follows a sinuous course between the fronts of the fans from Okanagan Lake to Skaha Lake. The base of the silt bluffs in the southern portion of the study area is in the floodplain of the Okanagan River. The air photos clearly illustrate that the course of the Okanagan River has meandered back and forth, at times eroding into the base of the silt bluffs and at other times leaving swamps next to the silt bluffs.

Slides probably have been an ongoing process since the recession of Lake Penticton to its present level. As outlined in Section 3.2.3, the lake and river can remove the toe of a slide in only a few years, so any evidence of old slides is difficult, if not impossible, to find. Therefore, the forming of gullies may have occurred in the late glacial period, or may have occurred postglacially. This is also true for the ancient slide at Sage Mesa. The slide may have occurred postglacially, and thus the gully behind it could also have formed postglacially.

If the gullies are not late glacial features, they could have formed in the postglacial period. There was an increase in rainfall at the end of the glacial period due to the change in climate and the gullies may have been formed by increased run-off during this period. Water flowing down to lake level, both as surface water and through the gravels, would have caused rapid erosion of the silts.

At least three of the gullies in the silt bluffs have bedrock exposed in the base at the upstream ends. The exposed bedrock in the gullies indicates that the headward advance of the gully is stopped. Sand and gravel outwash deposits exposed in some of the gullies has also slowed or stopped the headward progression of the gully.

Some of the gullies may have been formed by the coalescing of sinkholes in the silt. The dendritic pattern of sinkholes visible on the air photos is very likely the present expression of pipes caused by erosion from internal drainage. The pipes have collapsed and formed lines of sinkholes. As erosion of the pipes continued, gullies formed. Once the gully started to form, the water flowing along the drainage path would continue to advance the gully headward.

The visible sinkholes are less developed than the sinkholes that have formed gullies. Water entering the silts through joints or cracks would flow internally causing erosion where the gradients were high. Once the erosion starts, the eroded pipe acts as a conduit to collect and carry more water. Once they start to erode, subsurface, subhorizontal pipes intersect and draw more water from other surface areas through joints and cracks. The piping is therefore expected to be an ongoing process, concentrating flow into existing pipes. The ground eventually collapses into the pipe, creating sinkholes.

The lacustrine silt contains extensive near-vertical jointing. The causes of the jointing may be both the internal properties of the silt and external forces. Jointing may be caused by shrinkage from desiccation, stress relief, differential settlement and wet-dry cycles. The stress relief joints and wet-dry cycle joints should primarily affect the bluff faces of the silt.

The colluvial silt is postglacial. Colluvial silt forms when the lacustrine silt erodes. The colluvial silt is found in gullies, depressions, and on the slopes below the bluffs. This colluvial silt could be a direct erosion deposit, or it could be blown by wind into gullies and kettles. As an erosion product of the lacustrine silt, the colluvial silt is similar in composition to the lacustrine silt.

The erosion of silt from the bluff edges, through toppling, small planer slides, and small circular slides, is known as ravelling. Ravelling is a process that would probably have been continuous since the draw-down of Lake Penticton. Where the Okanagan River and waves from Okanagan Lake have eroded away the colluvial silt that has ravelled down, the ravelling will continue actively. Once the ravelled material has reached the top of the slope, new ravelling will not occur until this colluvial material moves away, exposing the bluff once again. The colluvial material is highest on slopes that have not had active river or lake erosion at the toe for the longest the period of time. Photo 2 shows the silt bluffs of West Bench. The colluvial slopes reach the top of the bluff at the point on the slope furthest from Okanagan Lake and very little colluvium at the point nearest Okanagan Lake.

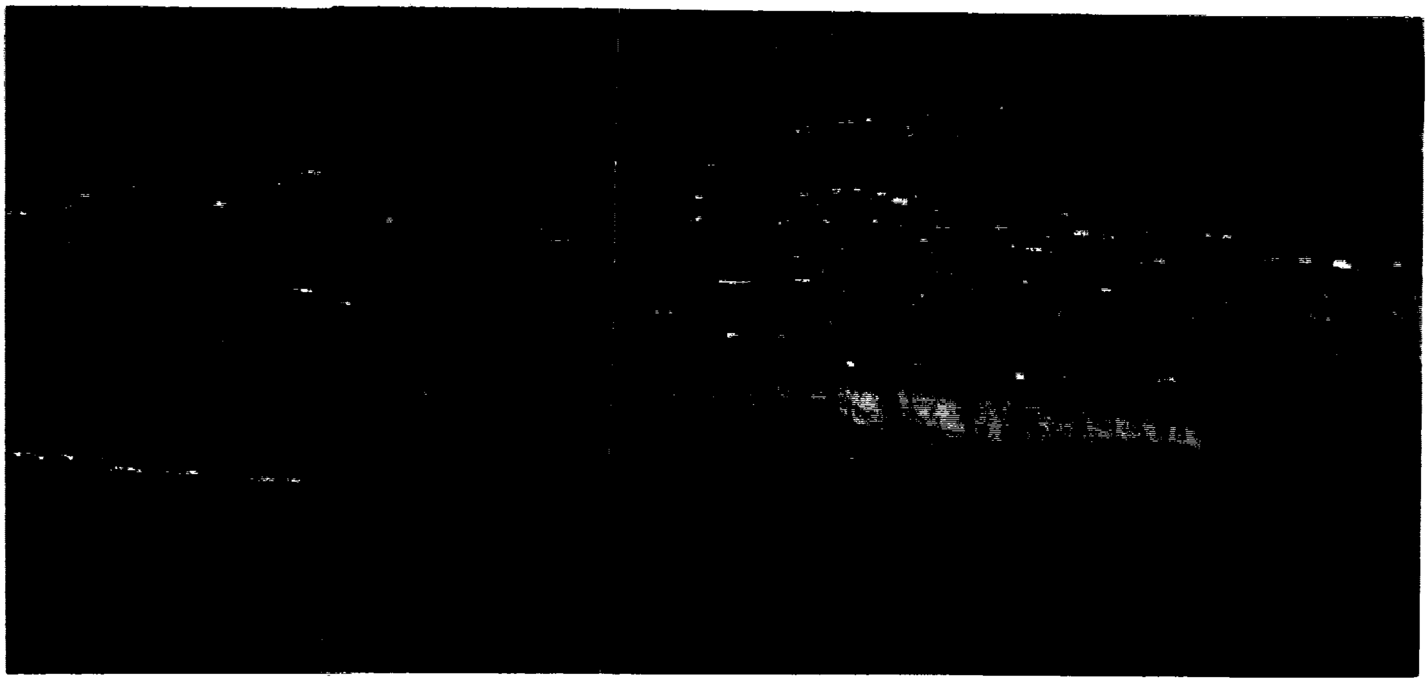


Photo 2 - Photo of Ravelling Slope in West Bench

Other than erosion from the river and lake, the colluvial slopes would also move to flatter angles through erosion of the colluvial material. The colluvial slopes can fail as a result of shallow planer and circular failures of the colluvial material itself.

3.2.5 Current Environment

The current active erosion processes include:

- ravelling;
- long-term slope adjustments;
- piping and sinkhole formation;
- gully formation; and
- landslides.

The current active processes visible are the slope ravelling and adjustments. Photo 2 shows current ravelling and Photo 3 shows a recent circular failure in the colluvial material. The process of ravelling will continue until the slopes have been covered with colluvium to the crest.

Photo 3 - Photo of Failure of Colluvium Talus Slope in Sage Mesa

Man-made cuts in the silt slopes are evident at the entrance to West Bench Drive at Highway 97. As shown on Photo 2, the silt slopes were cut back to allow the road to be placed at the base. With construction of Highway 97, a berm was created between the cliff toe and Okanagan Lake which prevents the lake from removing material at the toe of the slope. Similarly, the Okanagan River is presently controlled by a weir, and flows in a lined channel built away from the bluff edge. These man-made alterations at West Bench and Sage Mesa prevent further river and lake erosion of the colluvial slopes.

Field reconnaissance shows that the colluvial silt in the gully bottoms are very prone to piping. Sinkholes and horizontal pipes were evident in the base of many of the gullies in the colluvial silt. Piping is also active in the lacustrine silt. Signs of recent activity were observed at a few sinkholes in lacustrine silt.

On February 3, 1992, a water main break at a house on Hyslop Drive in Sage Mesa caused a sinkhole 12 ft deep to appear next to the house where the break occurred. The sinkhole ran under the carport and across the front lawn to the nearby cliff (Penticton Herald, February 4, 1992).

Other sinkholes have resulted from domestic water leaks throughout the West Bench and Sage Mesa area. Additionally, a number of small sinkholes have occurred where roof and road drainage has been diverted directly on to the silt. Other known examples of erosion caused by cultural development are:

- In December 1958, during construction of a house on Lot 132, Hyslop Drive, a large cave-in occurred about 60 m from the site of the house. The shaft was 4 m in diameter and about 6 m deep. At the bottom of the shaft two fairly large tunnels were exposed, both about 1.4 m high and 0.75 m wide (Wright and Kelly, 1959).

- A house in Sage Mesa was reported damaged, apparently as a result of a cave-in initiated by septic discharge from a lot above. The house reverted to a mortgage company which spent $15,000 repairing the damage (Nyland and Miller, 1977).

- In March 1974 a water main burst on Sage Mesa Drive resulting in the development of two large sinkholes eight to ten feet in diameter. These required approximately 15 cubic metres of granular fill to refill (Nyland and Miller, 1977).

- On October 29, 1976, a cave-in occurred on Lot 14 in the Sage Mesa area. The resulting hole was approximately 3 m in diameter and 2 m deep. A pipe apparently had formed up- and down-gradient from the caved-in structure (Nyland and Miller, 1977).

- The owner of Lot 102, Jonathan Drive, West Bench, reported that his lot was susceptible to subsidence with the addition of water. He stated that when he left a tap running for less than 24 hrs, a depression approximately 1.2 m in diameter and 0.3 m deep resulted. The owner reported a similar occurrence on a neighbouring lot (Nyland and Miller, 1977).

- In the last week of June, 1982, excessive rainfall initiated a serious soil erosion problem at 54 Solana Crescent in Sage Mesa. A ravine adjacent to the property developed a large sinkhole 5 m to 10 m downslope of where a culvert empties into the ravine. The sinkhole appeared in an area of existing sinkholes which had been backfilled by the property owner (MOTH memorandum, December 7, 1982).

- In August 1986 a large sinkhole (1.8 m x 1.5 m x 5 m deep) occurred at the top of Sage Mesa Drive, 3 m off the pavement on the east side of the road. A horizontal pipe was observed extending in the up- and down-hill directions from the base of the pipe. The triggering mechanism for the sinkhole was attributed to a leaking water line recently installed to service fire hydrants (MOTH memorandum, No. 2M5-30-26, August 22, 1986).

Major landslides of the silt bluffs of the Okanagan Valley have occurred recently. Nyland and Miller (1977) studied ten major slides that have occurred over the last 60 years in the Okanagan Valley in silt material similar to that of the study area. The slides were studied to determine existing slide profiles, to estimate the position of the toe of the slide prior to failure, and to determine postfailure angles. One additional slide has been documented that occurred since the Nyland and Miller (1977) report in silt material similar to the study area. The Summerland slide of 1984. An additional slide also occurred at the Summerland Research Station in December 1987. Figure 1 is a summary of these slides.

Of the slides studied by Nyland and Miller, seven of ten were located adjacent to irrigated land. The study showed that many of the landslides occurred after irrigation began and before the use of sprinklers for irrigation.

	SLIDE	H	COT. I_1	COT. I_2	COT. I_3	DATE OF OCCURRENCE
S-2	Chute Creek	120	1.2	2.3	2.5	1947, west 150′ into lake
S-4		159	1.0	1.8	2.2	1951
S-5	Johnson Creek	191	1.7	2.2	2.2	1951 (July)
S-6	Randolph Creek	230	0.6	1.4	1.4	1936
S-7	North Marina	182	1.0	1.4	1.5	1930 approx.
S-8	Mid. Marina	178	1.0	1.6	1.9	
S-9	South Marina	152	0.8	1.6	1.7	
S-10	Skaha Lake	252	1.3	1.7	1.7	
S-11	Research Stn.	124	0.8	1.4	1.4	1969 (Aug) with a minor slide same year also Dec. 1971 and 1974 and 1987
S-12	O.K. Lake	140	1.0	1.4	1.7	1975 (March)
-	Lakeshore Drive Summerland	-	-	-	-	1983 Dec ($60,000\ m^3$)
NOTE: COT. I_3 = L_3/H						

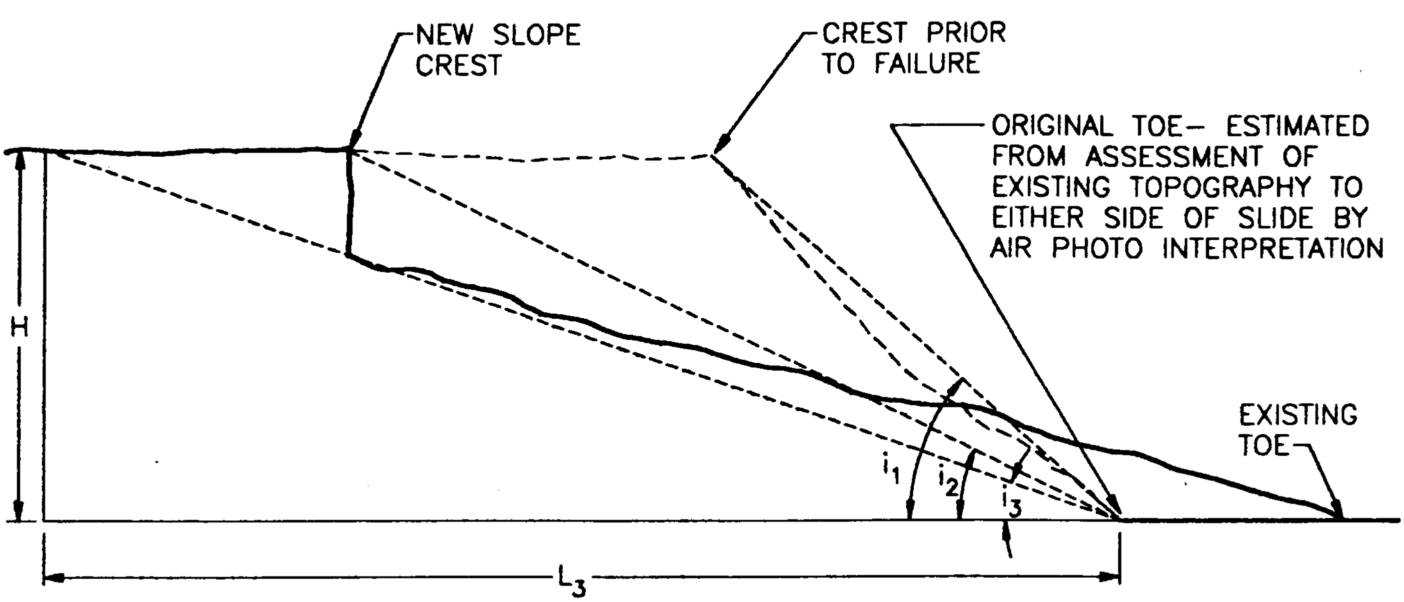


Figure 1 - Review of Existing Slides (after Nyland and Miller, 1977)

3.3 Engineering Parameters

3.3.1 General

There are five geological units within the West Bench/Sage Mesa area. The units, from youngest to oldest, are:

- colluvial silt;
- glacio-lacustrine silt;
- glacio-fluvial kettled outwash;
- glacial till; and
- bedrock.

The bedrock exists as a lower bound for the sedimentary geology. From the exposures on the upper slopes the bedrock surface dips steeply to unknown depths in the Okanagan Valley. The bedrock is generally exposed at elevations above 500 m to 550 m.

Drill logs from Nyland and Miller (1977) show a till above the bedrock in some of the drill locations (Holes 2 and 5). This till unit was also observed in one of the gullies. This till is comprised of gravelly till material. This material is likely a recessional till left behind from one of the previous glacial stages that advanced through the region.

The kettled outwash deposits, as described in Section 3.2.3, are comprised of silty sand and gravel. These units are located on the west side of the study area, exposed as a large terrace from El. 450 m to 500 m and in outcrops in the gullies below El. 450 m.

Lacustrine silt consists of silt and small amounts of clay and sand. Random boulders and gravel pockets are attributed to material dropped from melting ice rafts. The silt is visible as a blanket over the kettled outwash between El. 400 m and 450 m, and as the dominant silt bluffs at El. 400 m. The lacustrine silt is distinguished primarily by its varved structure.

The youngest unit is the colluvial silt. This silt is the erosion product of the lacustrine silt, and is recognized by its lack of structure and lack of varves. The material is found in gullies, in depressions, and on the slopes below the bluffs. The colluvial silt is also recognized by its almost uniform slope angle of approximately 40° where it rests against the bluff.

3.3.2 Hydrogeology

The top few metres of the bedrock is heavily fractured, probably from stress relief and weathering. This upper layer of bedrock is expected to have a relatively high hydraulic conductivity because of the fractures. The fractured bedrock would be less pervious than the gravel but more pervious than the silt.

The glacial till would have a relatively low hydraulic conductivity, although it is most likely discontinuous and would not affect the flow of groundwater significantly.

The outwash deposits have a relatively high hydraulic conductivity relative to the other units. The coarse nature of this unit (sand and gravel) allows water to pass through with relative ease. Infiltration into the outwash deposits could ultimately come into contact with the silt where the outwash pinches out.

The hydraulic conductivity of the lacustrine silt is relatively low because the material is fine grained, although the joints and varves in the silt would most likely make this unit anisotropic, with the preferential flow directions down along the joints and outward along the varves. The relatively low hydraulic conductivity of the lacustrine silt will cause it to act as an aquitard above the outwash and fractured bedrock.

3.3.3 Material Properties

The following is a summary of laboratory analysis and field observations from both the reports on the West Bench/Sage Mesa area and the field investigation for this report. Grain-size analysis (Nyland and Miller, 1977) of the lacustrine silt indicates a clay content of 8% to 17%; a silt content of 80% to 87%; and a sand content of 0% to 2%. The varved nature of the deposit indicates that sorting of the material occurred and that much finer and coarser layers can be expected.

Index tests summarized in the Nyland and Miller Report (1977) show that the liquid limits of samples collected were grouped around the "A" line and ranged from 21% to 39%. Plastic limits ranged from 13% to 31%. Plastic indices varied from 1.1% to 14%. Natural moisture contents ranged from 0.9% to 7.9%.

Density testing by standard Proctor method from Nyland and Miller (1977) yielded maximum dry densities ranging from 1557 kg/m^3 to 1734 kg/m^3 (97 lb/ft^3 to 108 lb/ft^3) with optimum moisture contents ranging from 17% to 24%.

Microscopic analysis (Quigley, 1976) showed both lacustrine and colluvial silts have an open, porus structure.

Mineralogical data (Quigley, 1976) indicated the presence of abundant quartz, moderate feldspar and minor clay minerals. X-ray diffraction traces on the clay fraction indicate a dominance of montmorillonite clay.

All samples tested by Quigley (1976) appeared to be above the critical void ratio. Small amounts of soluble precipitates or evaporates were also found.

Both the lacustrine and colluvial samples tested by Quigley (1976) showed varying degrees of sudden decrease in void ratio when flooded under load in the consolidometer.

Direct shear tests were performed by Sobkowicz and Coulter (1992) using undrained direct shear test procedures on samples with natural moisture content. For silt samples with moisture contents significantly below the plastic limit, peak strength parameters are 30 kPa for cohesion and 35° for angle of friction. For silt samples with moisture content at or near the plastic limit, peak shear strength parameters are 30 kPa for cohesion and 30° for angle of friction. Tests were also performed for materials of higher plasticity. The following strength parameters were reported:

Clayey Silt, Peak Strength	Cohesion - 35 kPa Angle of Friction - 22°
Silty Clay, Peak Strength	Cohesion - 35 kPa Angle of Friction - 17°
Silty Clay, Residual Strength	Cohesion - 10 kPa Angle of Friction - 10°

As the direct shear tests were carried out in an undrained state, these strength parameters would be appropriate for dynamic slope stability analysis provided the slope is not saturated, but would not necessarily be the appropriate strength parameters for long-term stability analysis.

Reports by Wright and Kelly (1965), Nyland and Miller (1977), and Evans and Buchanan (1977) noted that the silt has a high strength in the air dry state but that in the wet state the strength is low. Work has been done by Nyland and Miller (1977) and Quigley (1976) to try to quantify both the lacustrine and colluvial silts. It appears that wetting of the silt leads to collapse of the soil structure and corresponding loss of strength of the material.

The lacustrine silt deposit exhibits intensive vertical joint patterns at the bluff edge. Factors that may have caused this jointing include shrinkage, stress relief, differential settlement, and seasonal wet-dry cycles. Jointing due to differential settlement and shrinkage most likely continue through the entire deposit while jointing caused by stress release and wet-dry cycles most likely affect only the material near the surface or bluff faces.

4. HYDROLOGY

4.1 General Water Balance

A conceptual water balance was created to account for all sources and sinks of water in the study area. The general sources of water entering the site include precipitation, domestic water and off-site water flowing on to the site. See Appendix IV for water balance.

Precipitation sources for water include rainfall and snow melt. Precipitation can occur directly on the site in the catchment basin or it can be concentrated on roads and roofs and then added to the system. Of the rainfall and snow melt, some of the water becomes run-off, some infiltrates into the ground and the remainder leaves by evapotranspiration.

Domestic water includes water added through septic fields and irrigation water applied to the site. Septic field water enters the system through infiltration and leaves by evapotranspiration. Irrigation water can become run-off, infiltration or evapotranspiration.

Sinks for water on the site include evapotranspiration of water from the system and groundwater and surface water flowing off the site. If the volume of water entering the system is greater than or less than the volume leaving the system, then the remainder of the water is accounted for as increased or decreased storage.

Water infiltrating in the silts will move slowly because of the low hydraulic conductivity of this material. During the winter, flow in the unsaturated zone will most likely be downward, while in the summer, flow may turn upward because of the high evapotranspiration rate. If the net flow for the year is positive, there will be a raising of the water table.

Water concentrated on roofs and roadways, or by other means, entering the silts can flow along joints causing internal erosion and increasing the flow rate. If this water does not have a place to exit the silt, then it will collect at the water table, raising the water table.

Water flowing on to the site as groundwater or infiltrating on the site into the outwash will move through the outwash sands and gravels or the fractured bedrock. The water flowing along these high hydraulic conductivity units must either flow out as surface water in the gullies or as groundwater discharging to the lake. If not, the excess water will build behind the silts and any trapped water will raise the water table in the silts.

4.2 Climate

Climatic conditions for the West Bench/Sage Mesa area are consistent with a mid-latitude, semi-desert type, with warm summers and cool winters. Climatic records from the Penticton Airport for the period of 1945 to 1985 (Hogg and Carr, 1985) show that the area has a mean monthly temperature of 8.9°C and a mean annual precipitation of 282.9 mm, of which 76.0 mm is snowfall, and that the average annual precipitation occurs over 100 days. The mean lake evaporation, calculated from pan evaporation data at Penticton Airport, is 845 mm, the majority of which occurs in the months of April through September (see Table 1). Based on the 10-year period from 1981 to 1991, mean annual precipitation is 355 mm. Lake level fluctuations are minimal.

The maximum monthly rainfall on record is 86.1 mm in August 1976, while the maximum three-month rainfall is 193.5 mm, occurring April through June 1948. The 1:1000 probability per annum monthly rainfall was calculated to be 130 mm, using a log normal distribution, while the 1:500 probability per annum three-month rainfall is calculated to be 230 mm.

4.3 Madeline Lake Catchment

The Madeline Lake catchment is located west of the West Bench/Sage Mesa area on the slopes of Blue Mountain and Mount Nkwala. The catchment area is approximately 13.5 km^2 and ranges in elevation from 500 m to 1360 m. The valley bottom areas of the catchment are vegetated with scrub grass and bushes while the higher portions of the catchment are treed. Several small lakes are located on the upper slopes of Blue Mountain. There is no discernible surface outlet from Madeline Lake, although the water in Madeline Lake is not stagnant, indicating significant groundwater inflow and outflow.

There are two Water Survey of Canada stream flow gauges west of this area:

- Shingle Creek above Kaleden Diversion (08NM037), drainage area of 44.8 km^2; and
- Shatford Creek near Penticton (08NM037), drainage area of 100 km^2.

Data for Shingle Creek consists of 20 years of manual daily readings during the summer months. The Shatford Creek data consists of 25 years of continuous records throughout the year. The Shingle Creek catchment ranges from El. 900 m to El. 2100 m and the Shatford Creek catchment ranges from El. 700 m to El. 2100 m, the majority of which is above El. 1000 m. Thus it is expected that these catchments would experience more precipitation and more snowfall than the Madeline Lake catchment and, therefore, somewhat higher run-off.

Mean monthly recorded discharge data from Shingle Creek and Shatford Creek were used to estimate the water yield from the Madeline Lake catchment. The recorded discharge data were prorated by drainage area and also reduced by 50% (to account for the reduced precipitation at the lower elevation Madeline Lake catchment). The resulting Madeline Lake catchment yield is 0.01 m^3/s (100 gpm) or less for the months of January through March and July through December. The yield for May and June is approximately 0.1 m^3/s (1000 gpm) and consists of rainfall and melting of the snow pack.

4.4 Developed Area Water Balance

All of the domestic and irrigation water for the area is supplied by the West Bench or Sage Mesa irrigation districts by pumping water from Okanagan Lake. The area is not serviced by sanitary sewers and therefore sanitary waste is disposed of in septic fields. Ditches and culverts collect surface run-off, but do not take it out of the area.

The Red Wing development will be different from the other developments in the West Bench/Sage Mesa watershed, as we understand that septic sewer will be connected directly to the City of Penticton sewer system, and all roads, driveways and roofs will have storm water collected and delivered to lake level in storm sewers. Red Wing will provide their own water supply.

Current water consumption per household in the study area is approximately 200 gallons/day based on winter water use and 431 occupied dwellings. To accommodate future demographic changes a discharge of 375 gallons/house/day which is the B.C. Health Act design standard for a four bedroom house, has been adopted in this study.

Table 1 is a water balance for West Bench based on mean monthly conditions. The pumped water supplied to the area is based on the mean of nine years of pumping records. These records demonstrate that water use significantly increases for the months of June to September. The mean precipitation is based on records from Penticton Airport and include rain and snow for the 10-year period from 1981 to 1991. The evaporation information is based on pan evaporation data from the Penticton Airport.

Table 1 can be used as a basis for calculating net input into the silt annually. The calculations assume that good irrigation practices are being followed and that during dry months, when evaporation is high, water is available for evaporation. Results show between 100 mm and 200 mm net evaporation. The actual evapotranspiration that takes place is lower as a rate for pan evaporation rather than for evapotranspiration has been used.

Table 1 - West Bench - Mean Monthly Water Balance

WEST BENCH - MEAN MONTHLY WATER BALANCE						
10-YEAR AVERAGE	PUMPED WATER		PRECIPITATION	TOTAL INPUT	EVAPORATION	WATER INPUT MINUS EVAPORATION
Month	m^3	mm	mm	mm	mm	mm
January	9706	4	40	44	4	40
February	9293	4	25	29	0	29
March	11451	5	21	26	0	26
April	46804	21	26	47	102	(55)
May	64727	29	36	65	128	(63)
June	100957	46	35	81	159	(78)
July	151235	68	26	94	174	(80)
August	104216	47	34	81	136	(55)
September	95192	43	23	66	91	(25)
October	51825	23	19	42	54	(12)
November	10932	5	30	35	0	35
December	10024	5	39	44	0	44
Total	666362	300	354	654	848	(194)

4.5 Watershed Water Balance

A water balance was performed for the entire watershed to estimate the water movement through the area. Table 1 shows the water balance based on average precipitation data from 1981 to 1991 and average water consumption based on 1983 to 1992.

A rainfall equivalent of approximately 43 mm of water is currently expected to flow through the silt in an average year (200 gallons/day/household). Compared to the water balance calculated for predevelopment conditions (Appendix IV) where the rainfall equivalent flow through silt is 20 mm of water, this is an increase of 114%. With the design domestic water usage of 375 gallons/day/household, the calculated flow through the silt increases to 59 mm, an increase of 193% over predevelopment.

An analysis of various housing densities in West Bench compared to overall background water balances was carried out. Results are in Appendix IV. A summary of the calculations is presented in Table 2.

Table 2 - Summary of Infiltration into Silt Compared to Average Lot Size
(based on 375 gallons/day/household)

HOUSES IN WEST BENCH	AVERAGE LOT SIZE ACRES/HOUSE	FLOW INTO SILT (RAINFALL EQUIVALENT)
0	N/A	20 mm/yr
358	1.14	59 mm/yr
388	1.05	62 mm/yr
410	1.00	64mm/yr
545	0.75	78 mm/yr
825	0.50	104 mm/yr

5. SEISMICITY

Seismic hazard calculations were carried out by Energy, Mines and Resources Canada, through the Geological Survey of Canada, at the Pacific Geoscience Centre in Sidney, British Columbia. Table 3 summarizes the seismic hazard calculation for the West Bench/Sage Mesa area.

Table 3 - Seismic Hazard Calculation Summaries

Probability of exceedance per annum	1:100	1:200	1:475	1:1000
Probability of exceedance in 50 years	40%	22%	10%	5%
Peak Ground Acceleration (G)	0.029	0.040	0.060	0.083
Peak Ground Velocity (m/sec)	0.038	0.052	0.075	0.099

The corresponding zoning based on the National Building Code of Canada (NBCC, 1990) applied to this data:

Acceleration Zone:	1
Zonal Acceleration:	0.05 G
Velocity Zone:	1
Zonal Velocity:	0.05 m/sec

To put these numbers in perspective, there are seven zones established by the NBCC. These zones are numbered 0 to 6, with 0 the lowest and 6 the highest. Zone 1 indicates that there is a probability of ground motion due to a seismic event but the peak ground acceleration and velocity used for building design (the event with a probability of 10% in 50 years) are relatively low.

From a deterministic point of view, the maximum credible earthquake (MCE) for the study area is expected to be in the order of magnitude 6.5. This earthquake could produce a peak ground acceleration in the order of 0.35 G and peak ground velocity in the order of 0.35 m/sec. As an upper-bound earthquake, no probability can be assigned, though it could occur tomorrow or several tens of thousands of years from now.

6. HAZARD ASSESSMENT

6.1 General

Geological hazards can include a variety of natural events, listed as follows:

- flood water;
- stream erosion;
- debris flows;
- mass wasting;
- piping and subsurface erosion;
- subsidence;
- faulting;
- volcanism;
- snow avalanche;
- rock falls; and
- major landslides.

In order for any natural event to occur, there must be both prevailing conditions and a triggering event. The study area was assessed to verify if prevailing conditions existed for each of the possible events listed above. Geology, geomorphology and climate rule out a number of the potential events and leave:

- mass wasting; including
  - landslides;
  - ravelling of slopes;
  - long term adjustments;
- piping and subsurface erosion; including
  - new subsurface erosion;
  - sinkholes formed by existing pipes; and
- gully erosion.

6.2 Mass Wasting

6.2.1 Description

Historical records for the Okanagan Valley from south of Penticton to north of Summerland indicate 10 landslides have occurred over the past 60 years (Nyland and Miller, 1977). As described in Section 3.2.5, all of these slides occurred in silt from the same depositional environment as the silt bluffs of West Bench/Sage Mesa area.

Field investigations described in Section 2.3.1 show geologic evidence of a landslide having occurred at the mouth of the gully where Sage Mesa Drive connects with Highway 97. This ancient landslide is also visible on all air photos of the area.

Landslides are defined as large-scale failures of the silt bluffs. Landslides occur very rapidly, resulting when the silt bluff material breaks away and moves out to a lower angle of repose at the base of the bluff. Typical slides are 50 m to 400 m in width and result in a final slope angle from the new toe of about 18° to 20° (see Figure 2).

Factors causing a steep slope would be high internal strength, erosion at the toe of the slope, or a weak underlying material. Factors causing slope failure include gravity, water pressure, changes in strength due to saturation, and seismic acceleration acting on the silt. Both reduction in forces resisting failure and increases in driving forces causing failure can cause the slope to move.

Landslides can result in property loss, as well as loss of life. A slide in Summerland in 1970 destroyed three houses located below the slide and killed one person.

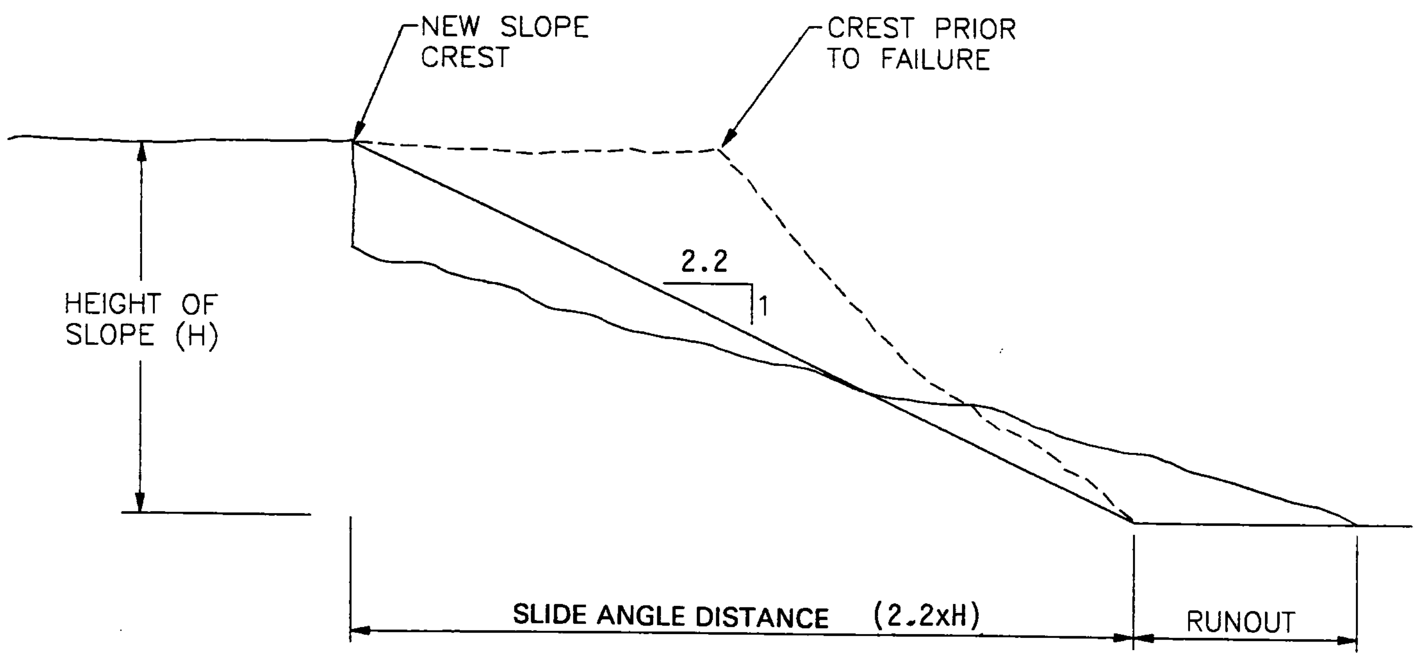


Figure 2 Typical Landslide Section

The angle from the toe of the slope prior to failure to the furthest point at the top of the slope where the landslide occurred is called the slide angle. The slide angle can be expressed as a ratio of the horizontal distance back from the preslide toe in relation to the height of the slope. Houses and property behind the slide angle would not be affected while houses and property within this zone would. A line established to define the hazard zone is known as the setback.

Similarly, run-out is the distance the slide moves out from the preslide toe, stated as a ratio to the slope height (Figure 2).

Ravelling and long-term adjustments are special cases of the landslide. Ravelling is defined as small scale failure of the silt bluffs from toppling failures, shallow circular failures and small block failures.

The process of ravelling is ongoing in the study area. Ravelling is seen to varying degrees at the face of all silt bluffs. The product of ravelling is the colluvial slope seen next to the steep lacustrine silt faces. Photo 2 shows a slope on the east side of West Bench varying from no colluvium to colluvium at the top of the slope.

Long-term slope adjustments, that is, small movements in the colluvial slopes, are visible throughout the study area. Long-term adjustments occur as the colluvial slopes move to shallower, more stable slopes.

6.2.2 Triggering Mechanisms

A review of the 10 recent landslides in the Penticton area of the Okanagan Valley studied by Nyland and Miller (1977) indicated that 7 of the 10 landslides occurred after open ditch irrigation and before sprinkler irrigation. On one of the remaining slides, seepage was seen on the bluff face prior to failure. A high groundwater level is considered the trigger for each of these slides.

A simplified analysis using simple circular and block failure methods indicates that a rise in groundwater levels of about 1 m can result in a 3% to 6% reduction in the factor of safety.

A second triggering mechanism is earthquakes. As Penticton is not located adjacent to a major tectonic boundary, the maximum credible size of earthquake is limited. The earthquake-induced ground motions may, however, cause enough displacement within the silt bluffs to break or crack the slope-forming materials. Once the desiccated silt has been broken, its resistance to movement will be lowered, so that late or postearthquake failure could occur. The size of such a failure block will depend on the current groundwater conditions and the size of the earthquake. Smaller earthquakes would likely cause small scale block and toppling failures. Larger scale failures are possible with larger earthquakes when prevalent conditions are near failure (i.e., high water table).

6.2.3 Prevailing Conditions

Prevailing conditions which may lead to a landslide include:

- geometry;
- material strength; and
- groundwater.

Previous landslides in the silt bluffs of the region occurred on steep slopes. The slopes along West Bench and Sage Mesa, as described in the geology section, are steep and, therefore, no significant difference is believed to exist between the study site and the known location of slides.

The failures were probably across varves in the upper reaches of the slide and possibly along weaker materials at the base of the slide. As the dip of the bedding is not documented in detail at previous slides, but is known to be subhorizontal in all silt bluffs, we anticipate that the geometry at West Bench and Sage Mesa is similar to the sites where slides have occurred.

Predevelopment conditions allowed the Okanagan Lake and Okanagan River to erode away ravelled material at the toe of the silt bluffs. Highway 97, at the base of the slope, now acts as a protective berm at the toe of the slope. Continued ravelling and long-term adjustments will, with time, improve the prevailing conditions.

The material strengths of the silts and clays in the silt bluffs in the Okanagan Valley are expected to be very similar. All are expected to contain material which will have low strengths in the horizontal direction when wet and have very high dry strengths. The study site is therefore expected to be similar in this regard to sites where slides have occurred.

Groundwater conditions are believed to have been the trigger mechanism for most of the documented slides in the silt bluffs. The majority of the slides were triggered by open ditch irrigation.

Factors which contribute to prevailing groundwater conditions at the site include long-term climatic conditions which influences the quantity of precipitation entering the silts, both from the top and from the gravels to the west, domestic sewage disposal, and the collection and management of storm water run-off.

Adding water to the general water balance for the watershed will change the prevailing conditions such that a smaller triggering event is needed. As shown in Section 4.5, the calculated current infiltration through the silt is 114% greater than predevelopment conditions. The housing density has the potential to increase the infiltration up to 193% greater than predevelopment by a change in demographics. This increased infiltration raises the water table so that a smaller triggering event, such as higher than average rainfall, is required to induce a landslide. The seepage analysis indicates that water infiltrating into silt from the surface will raise the water table more than water added to the gravel to the west.

Landslides have probably occurred in the Okanagan Valley since glacial melting. The frequency of these events was probably much greater during lowering of Lake Penticton and the wetter conditions prevalent at that time. Recently, however, a number of landslides have occurred as the result of irrigation practices. Those irrigation practices have been changed. The hazards, however, still exist in the study area, awaiting adequate water to trigger the event. Potential sources of water include rainfall directly onto the site, rainfall moving to the site from the catchment upstream, and pumping of water to the site for irrigation and household use. The major change to the water balance of the area is the additional irrigation and household use water.

6.3 Subsurface Erosion

6.3.1 Description

Subsurface erosion in glacial lake deposits of British Columbia occurs in the south Thompson Valley, the Okanagan Valley and the Kootenay River Valley. All of these materials were deposited in glacial lakes during the late stages of glaciation. They are typically varved silt and clay bluffs along the valley walls in a relatively dry climate.

The subsurface erosion may be composed of two mechanisms, piping and sinkholes. The first, piping, is the result of a series of events. High groundwater gradients may cause material to be eroded away, leaving an open void. Removal of this material shortens the flow and concentrates more flow to the void. Consequently, the hydraulic gradient at the exit is even higher, and erosion at the head of the void or pipe is more intense. The pipe advances at an increasing rate toward the source of the water.

Once the pipe has reached a source of water, much higher flow rates are possible, so that the flow of water along the pipe can mobilize silts along the pathway, thereby enlarging the size of the cavity.

In the study area, an additional component is the existence of fractures which can act as pathways for the pipes to develop even without high hydraulic gradients. The fractures can also act as small courses along the pipe pathway, collecting water to the main pipes.

Sinkholes are the result of a collapse of a pipe roof when the strength of the silt material is inadequate to maintain the roof. Sinkholes are therefore a surface expression of relatively large scale pipes.

The pipe exits are not always observable as they may be covered by failure of roof materials or movement of talus slopes.

6.3.2 Triggering Mechanisms

Trigger mechanisms for piping involves supplying water to the erodible silts. Triggers therefore can include two broad categories:

- an increase in the supply of water to an area; and
- a change in catchment conditions leading to concentration of water to a smaller area.

Natural cycling of water supplied to the gravel west of the study area can be expected. The site geology and geometry suggests that increased groundwater supplied from the gravels will result in a small increase in water levels in the gravel, combined with a significant increase in discharge to the gullies. This discharge to the gullies will result in gully-widening with time. Only small incremental increase to groundwater levels is expected in the varved silts which may slightly enhance the piping potential near the bluff toes.

Natural cycles of precipitation onto the site is also expected, with extreme events promoting additional piping activity, as has occurred in the past. Colluvial activity, particularly related to leaking of water lines and swimming pools, will continue to be a significant trigger mechanism. The increase in water infiltration from septic drain fields and irrigation will probably not act as a trigger but may reduce the necessary precipitation intensity required to initiate internal erosion.

Driveways, compacted silt fill, and roof and road drainage are the most notable changes to catchment conditions which may serve to concentrate water which can lead to internal erosion. Additionally, as new erosion progresses, and new natural catchments are added to existing drainage paths, erosion potential increase.

6.3.3 Prevailing Conditions

Prevailing conditions which may lead to subsurface erosion include:

- erodible materials;
- adequate supply of water; and
- hydraulic conditions.

The glacial lake silts at the site have demonstrated that they are erodible. Many pipes and sinkholes have been mapped. As described in this report, laboratory work confirms the erodibility of the silts. A simple practical test is to drop water on the desiccated silt and observe silts eroding from the block. This can also be observed in the field. After a light rainfall, the bluffs look like flowing wax after the silts mobilize.

The timing of pipe formation is not known. Many of the gullies leading back to the gravel may have eroded during drawdown of glacial Lake Penticton. However, "recent" erosion around some sinkholes at the site implies that the process is ongoing. The presence of erodible materials is therefore considered certain at the study site.

A supply of water is necessary both for headward migration of a pipe and for erosion along a developed pipe. Once a pipe is established and begins migrating towards the "source" of water, a larger and larger catchment may be included. Termination of any pipe will probably only occur where one pipe extends and "captures" the water source of a second pipe. The potential sources of water at the study site include:

- groundwater in gravels to the west of the silt bluffs migrating into the gullies and into the silts;
- groundwater moving from the bedrock beneath the site into the silts. This volume is considered to be relatively small and stable;
- precipitation onto and migrating through the silts;
- precipitation onto roofs and roads being concentrated and redirected;
- the septic field discharge from residences;
- irrigation of orchards and yards;

- leakage from water supply pipes; and
- leakage from swimming and ornamental pools.

Any incremental increase in prevailing conditions can be expected to reduce the necessary size of event which triggers initiation of piping.

Most of the existing gullies are believed to have developed from subsurface erosion and collapse rather than as surface erosion.

All of the major gullies terminate at bedrock or at the gravel contact. The major source of water leading to this gully development is believed to be the gravel and the top of bedrock. As erosion has exposed the gravel in the gullies, drainage of the gravel into the gullies is possible. The resulting reduced head in the gravels is expected to reduce the erosion rate of the silt bluffs.

Most of the mapped sinkholes can be attributed to natural climatic conditions which periodically reach a threshold value which has renewed erosion. This natural condition is expected to continue. Additional water is now made available from Okanagan Lake for irrigation or household uses.

Some additional water from roofs or roads which previously fell directly on the ground and either infiltrated or evaporated is now concentrated in time and space. As a result, the quantity available for evapotranspiration may be reduced.

The hydraulic conditions which may have led to piping at this site include the following. The quantity of water infiltrating into the silts might exceed the ability of the silts to discharge at low gradients. The gradients would therefore increase until piping commenced. The ability of the silt to discharge is dependent on the hydraulic conductivities. This type of piping phenomenon would therefore occur where mass permeabilities are low, which would be where fracture flow did not occur. This piping phenomenon might therefore be prevalent in colluvial silts.

Water infiltrating into fractures would tend to travel at higher velocities, causing erosion and transportation of silts. This type of erosion would follow joint patterns. Both of the above conditions may have existed at the study site since the draining of glacial Lake Penticton.

6.4 Gully Erosion

6.4.1 Description

The gully erosion may result from two processes. The first is internal and surface erosion of the colluvial silt material form the gully bases. Sinkholes and pipes in the gullies show current internal erosion in bases of all gullies. One gully shows some surface erosion as well. Water flows along the gully bases from the bedrock and gravel outcrops.

The second process is mass wasting of the silt slopes. When the erosion of the base removes the colluvial silt talus or support for the talus, the slopes regress. This regression could include small slope failures in the colluvial material, ravelling and even small- to large-scale landslides of the silt bluffs above.

6.4.2 Triggering Mechanisms

The triggering mechanism for gully erosion involves supplying water to the gullies. There are two sources of increase in water supply:

- climatic conditions, such as spring run-off or wet periods; and
- irrigation and septic fields, through increased development.

As discussed in Section 6.3.2, natural cycling of water supplied to the gravels and bedrock west of the study area can be expected. The site geology and geometry suggests that increased groundwater supplied from the gravels will result in small increases in the water levels in the gravel combined with a significant increase in discharge to the gullies. This discharge to the gullies will result in widening of the gullies with time. This cycling in natural climatic conditions through high spring run-off or extreme wet periods acts as the triggering mechanism for the erosion of the gully bases and, consequently, the continued mass wasting of the gully side slopes.

The increased water supply can also result from increased water input from development. At present all houses on the gravels dispose of waste water through septic fields. This discharge from septic fields and increased infiltration from irrigation acts as the triggering mechanism for the erosion of gully bases and the subsequent mass wasting of the gully side slopes.

6.4.3 Prevailing Conditions

Prevailing conditions which may lead to gully erosion include:

- erodible materials;
- hydraulic conditions; and
- adequate supply of water.

As discussed in Section 6.3.3, and by Nyland and Miller (1977), the colluvial silt has demonstrated that it is erodible. Evidence during the field investigation showed active erosion to varying degrees of the colluvial silts in the bases of all gullies. Actual changes in erosion conditions were observed in the gully between Hyslop Drive in West Bench and the proposed golf course between the February 1992 and March 1992 site visits.

All of the major gullies terminate at bedrock or at the gravel contact. The major source of water leading to this gully development is believed to be the gravel or the near-surface bedrock. As erosion has exposed the gravel in the gullies, drainage of the gravel into the gullies is possible.

As the silt bluffs are the same along the gully side slopes as they are along the eastern silt bluffs, they are expected to have the same potential for erosion. The erosion of the gully bases and toe of the colluvial talus slopes would increase the likelihood of mass wasting events occurring.

7. RISK ASSESSMENT

7.1 General

In the practice of assessing risk there are numerous uncertainties associated with assigning "a number". There are the geotechnical uncertainties in assigning a probability due to the short historical time-frame used to predict the long-term process. There are also the uncertainties caused by incomplete information regarding the site. Geotechnical engineering requires the prediction of the varying geologic conditions at a site from surface and limited subsurface investigations. These would include the spatial variation of material properties such as permeability, porosity, fracture location and density, and the temporal variation of rainfall and evapotranspiration. In addition, the parameter distributions must also include the inherent uncertainty in establishing parameter values in a geologic environment. The calculation of probability is sensitive to many of these parameters so that the result calculated in the low probability range is usually highly dependent on the input uncertainty. For this reason, geologic hazards are often assessed deterministically (assignment of single value conservative numbers) or by assigning probability based on evidence of past performance. In this study, we have established the risk based on a combination of these methodologies to establish the best available answer.

Probability is expressed as a number from 0 to 1 with "0" meaning no occurrence and "1" meaning 100% chance of occurrence in one year. Typically, probability of occurrence used as a threshold for acceptability is in the order of 0.005 to 0.0001. As such small numbers are difficult to relate to, most people will refer to the inverse of probability known as the "return period".

A probability of 0.005 is the same as 1/200, commonly stated as a 1-in-200 chance per annum. This does not mean that an event will only occur once every 200 years. In fact, the event could occur twice in a single year, or not for 1,000 years. What once-in-200-years indicates is that there is a 1/200 (0.005) chance of an event occurring in any single year.

Once a probability of occurrence is established, the mode of failure is then evaluated in reference to the consequences of the occurrence. Two criteria impact the consequences of a hazard. First, the predictability of an event controls the warning that could be given prior to the event occurring. An event that happened without warning would have more severe consequences than an event that would allow days or even hours of warning. Second, the type of damage ranging from minor property damage through major property damage to loss of life is considered. When the two criteria are put together, a risk category can be assigned.

7.2 Mass Wasting

7.2.1 Geometric - Slide Debris Angle

A geometric analyses was carried out to relate slide angle and run-out, and to examine the maximum setback criteria. The basic assumption in the analyses is that the volume of material missing from the top of the preslide profile equals the volume of material added to the bottom of the preslide profile. Based on a stable slide debris slope and a preslide profile, the slide angle can be calculated. Field measurements of the stable slide debris slope angle range between 3:1 and 4:1. Figure 4, calculated using the more conservative stable angle of 4:1 indicates a slide angle of 2.2:1 (horizontal: vertical) from the existing slope toe for a slope with no talus and a slide angle of 2.6:1 for a slope with all talus.

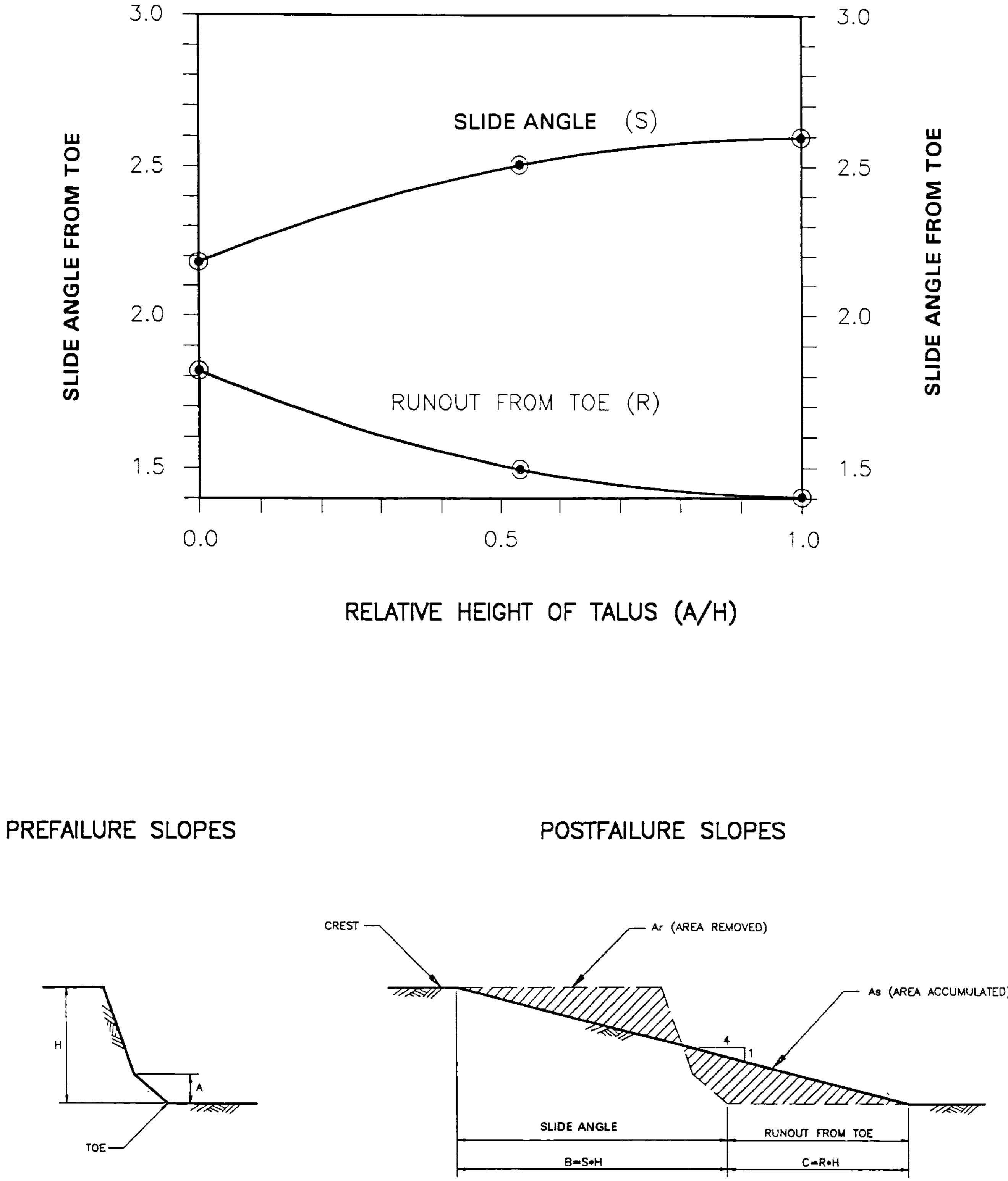


Figure 3 - Geometric Slide Angle Assessment

7.2.2 Geometric - Historic Slides

By reviewing case histories of the landslides studied by Nyland and Miller (1977) and using the post failure angle I_2 calculated, a maximum slide angle was estimated, (see Figure 1). The angle I_2 was used rather than I_3 used by Nyland and Miller, as I_2 reflects the slide angle which would have resulted in immediate property damage.

The Chute Creek slide as described by Nyland and Miller failed into the lake, causing much more mobility of the silt than other comparable slides. For this reason, this study does not include that slide.

In addition Wilson (1991) suggests that the Chute Creek Slide does not apply as the slide was caused by seepage from Koosi Creek, possible irrigation water from the silt bench above and was over an old channel of Koosi Creek.

Wilson also discounted two additional slides (S-4 and S-5 on Figure 1) on the east side of Okanagan Lake because of heavy irrigation, creeks and large amounts of groundwater in these locations. He concluded that groundwater on the west side is much less and that the resulting maximum slide angle is about 1.7:1. He therefore concludes that a safe setback at West Bench - Sage Mesa is 1.75:1 if water controls are used and 2.0:1 if effluent disposal is done on each lot.

Based on the remaining nine slides from Nyland and Miller (1977) and the additional slide in Summerland, the maximum overall slide angle for all relevant historic slides in the region is 2.2:1 (horizontal: vertical). All investigators concur that high groundwater levels are the primary cause of landslides.

7.2.3 Probability - Slope Morphology

Reviewing the existing slopes qualitatively can give insights into the probability of landslides. Steep bluffs occur in the silt when the toe of the slope has been eroded away. Along the bluffs, between West Bench and Sage Mesa, where the lake shore was adjacent to the slope prior to highway construction, there are steep slopes with little or no talus. Further south along West Bench where swampy deposits lay along the toe, the talus approaches the top of the slope at a slope angle of 1.2:1. Generally, the talus is higher on the slope, further away from the lake. This talus erosion to a slope angle of 1.2:1 most probably occurred over the order of 500 years to 1,000 years.

There is evidence of one ancient failure in the study area. Under natural predevelopment conditions landslides can occur in the study area. Based on the observation that one landslide is evident in the study area, landslides may have a return period of 2,000 years to 20,000 years in the study area under predevelopment conditions.

After development, landslides occurred rapidly, in the region mostly associated with increased water infiltration due to open ditch irrigation for orchards. At present we believe there is more water infiltrating through the silt bluffs than there was prior to development. This conclusion is based on our calculation of increased infiltration from the residential septic fields.

7.2.4 Probability - Development Impact

The impact of development on the probability of landslides, as discussed in Section 7.1 is difficult to assess. However, an indication of the relative impact on the probability has been estimated as described below. The nine slides from Nyland and Miller (1977), occurred under the prevailing conditions of open ditch irrigation, so that absolute probability of failure is not directly applicable to conditions in the study area. However, these slides have been used to establish the relationship between slides with different slide angles which may be controlled at least in part by the distribution of material properties.

Using a simple wedge failure mechanism, a number of translational limit equilibrium slope stability analyses have been performed to calculate the groundwater gradient emanating at the slope toe necessary to initiate failure. Ground strength parameters and permeabilities were selected which in our judgment are representative of the glacial lake sediments, and which result in failure with a five year wet period with a probability of exceedance of 1:14000 per annum. A five year wet period was selected as evidence from many geologic environments indicate that long periods of higher than average precipitation are one of the most common natural conditions leading to landslides (see Patton, 1984).

Various infiltration rates were used to calculate water table gradients. Infiltration conditions considered included predevelopment, present estimated infiltration conditions, maximum infiltration expected from present housing density and from present housing density plus 30 extra houses (388 houses), and maximum infiltration for 1-acre/house average lot size and 0.75-acre/house average lot size. The gradient probabilities were compared with gradient required for failure, so that a probability of failure could be estimated for each housing density condition.

A probability curve for a five year wet period induced slide under present conditions was created by combining the probability that infiltration rates which will cause failure would be exceeded with the distribution calculated from historic events, which includes variations in geometry and triggering mechanisms. Results are shown on Figure 4 and Appendix II.

Although the results of the probability study are not precise, they demonstrate the sensitivity of probabilities to development. A sixty-fold increase in likelihood of failure was calculated between predevelopment and present. If infiltration rates increased to the maximum expected from the present housing density, there would be a further five-fold increase in the probability of failure. An additional 30 houses added to the present housing density will increase the probability of failure by an additional 50%, which works out to approximately a 1.7% increase in probability of failure per additional household.

Similarly, slope failure may be initiated by earthquake ground motions. Small ground motions may result in significant strength loss of the desiccated silt. The peak ground acceleration would then be the appropriate input parameter to a pseudo-static limit equilibrium analyses. Based on this analysis a less than extreme climatic event may be combined with earthquake ground motion to initiate failure. This increase in probability is considered insignificant compared to the calculated probability illustrated on Figure 4.

7.2.5 Mass Wasting - Summary

The risk for mass wasting has been assessed by evaluating the historical and morphological evidence in the study area and in the region as well as by calculating the influence of development on stability. Following is a summary of the findings:

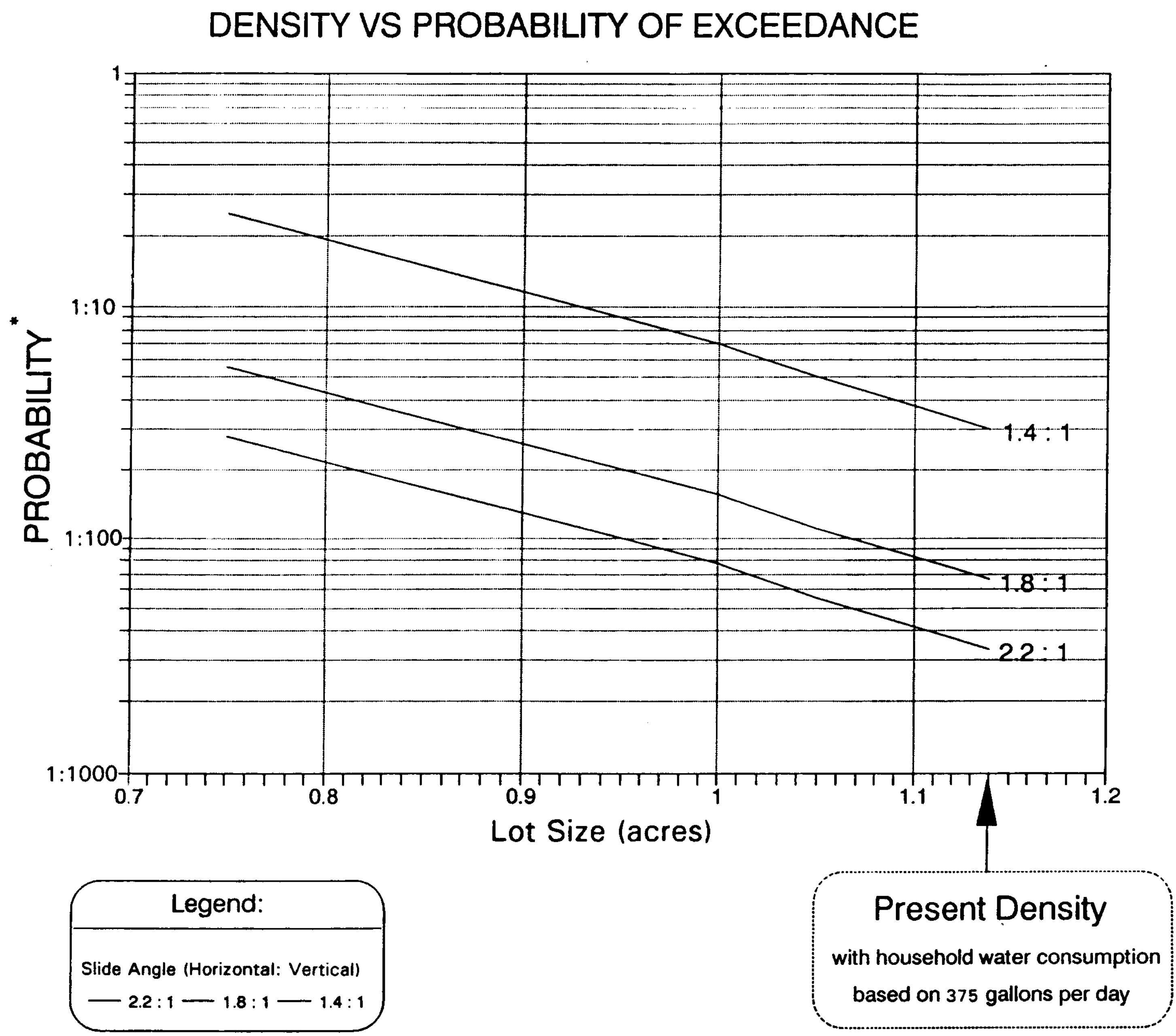
Methodology	Slide Angle
Geometric - Slide Debris Angle equal to 4:1	2.2:1 to 2.6:1
Geometric - Historic Slides	2.2:1
Probability - Slope Morphology	Not Applicable
Probability - Development Impact (1:500 Probability)	
(Current Density, Design Sewer Loads)	2.4:1

7.3 Subsurface Erosion

Natural Conditions

The probability of sinkhole occurrence has been calculated from mapped sinkholes in West Bench and Sage Mesa. All sinkholes distinguishable on the air photos were drawn on the geology plan, Drawing B-1003. The minimum distance between any sinkhole and the nearest sinkhole or bluff edge was found and plotted (see Appendix II). the mapped sinkholes were assumed to develop at a constant rate over periods of 2,000, 5,000 and 10,000 years.

This sheet presents information derived from the results of calculations using estimated values for many of the input parameters, each of which can vary over a wide range. Consequently, the information on the sheet is for illustration purposes only, and is not reliable for all conditions. The information on this sheet must not be used for design and must not be interpreted in any absolute manner.



* Probability of Exceeding a Slide Angle

Figure 4 - Landslide Probability Analysis

The data also indicate that under natural conditions, development of a new sinkhole has a probability of about 1/10 per annum. A probability of 1:200 per annum has a minimum distance of 32.5 m from any other sinkhole or gully edge. The distances range up to 40 m.

Developed Areas

In developed areas we have not predicted the probability of a sinkhole occurring, but where run-off is concentrated, hoses left running or pipes are broken, sinkholes and piping can and will form.

There have been eight large sinkholes reported in the last 34 years. This works out to a probability of 1-in-4.25 per annum chance of sinkholes caused by development. Minor sinkholes caused by development and some major sinkholes have not been recorded, with these included in the calculations, the probability would become more than 1-in-4 per annum of failure. This represents a doubling of sinkhole development from the calculated predevelopment probability.

8. GUIDE TO ADMINISTRATIVE DECISIONS

8.1 General

This section has been prepared for the Regional District for consideration when preparing by-laws. The engineer can identify and quantify risks. Society must decide what is acceptable. Today, in the Province of British Columbia, there is guidance from the provincial government and courts for what is considered acceptable risk.

8.2 Risk Acceptability

In setting a guideline for acceptability of risk there are few general standards. The Regional District of Fraser-Cheam is one of the pioneers in applying hazard acceptability thresholds for local government approval. The following is a summary of standards based on precedent, from Cave (1991).

The first guideline is derived from the Provincially sponsored flood-proofing program, which provides financial support for protective measures and regulatory control over many forms of development. The design event for this program has a probability of 1:200. Floods greater than this are regarded as too costly to protect against, too unlikely, or both; lesser floods are seen as too frequent and, therefore, too costly if not protected against.

The second guideline is inferred from Provincial policy on subdivision approval in hazardous areas where advice is given to geotechnical engineers "...to think in terms of a 10% probability in 50 years..." (probability of 1:475 per annum). This varies with the hazard.

The third guideline derives from the British Columbia Supreme Court decision of the Honourable Mr. Justice Berger (1973) which found a site exposed to a very low probability of landslide occurrence (probability of 1:10 000 per annum) to be unsuitable for development. The 1:10 000 probability is assigned to an event that, although possible at any time, has not occurred within the last 10,000 years (since the retreat of the last glaciers). In this sense, the 1:10 000 standard has absolute significance in that such hazards have not occurred under present climatic conditions. In this case, the hazard potential was massive and destructive and could occur with little or no warning. The case involved a development that would have formed the nucleus for a new community. The risk during the lifetime of the new community was deemed to be unacceptably high.

8.3 Hazard Rating

Risk type is broken down into three categories for this project:

- Low Hazard - Events that allowed a reasonable warning or that were ongoing and where the consequences of the event were minor in nature.
- Medium Hazard - Events that give no warning but would not generally result in loss of life, or in events that are predictable but could result in major property damage.
- High Hazard - Events where loss of life is possible and where little or no warning of the event would be possible.

To eliminate subjectivity, the types of hazard present can be assigned a number for the predictability (warning) and for the consequences. The proper risk type can be assigned from the resulting total. This is shown on Table 4.

Predictability		Consequences	
0	Predictable	0	No Damage
1	Partially Predictable	1	Minor Property Damage
2	Not Predictable	2	Major Property Damage
		3	Loss of Life

Although all hazards do have the potential for loss of life, only those hazards where loss of life is significant are considered. The resulting sum is used to assign the hazard category.

0-1 LOW HAZARD
2-3 MEDIUM HAZARD
4-5 HIGH HAZARD

Table 4 - Hazard Assessment

	PREDICTABILITY	CONSEQUENCES	TOTAL	HAZARD RATING
Major Landslide	2	3	5	HIGH
Run-out from Landslide	2	3	5	HIGH
Ravelling	1	2	3	MEDIUM
Long Term Adjustments	0	1	1	LOW
Sinkholes	1	2	3	MEDIUM
Gully Erosion	1	2	3	MEDIUM

8.4 Mitigative Measures

8.4.1 Hazard Avoidance

The obvious approach to reducing risk due to a hazard is to simply avoid the risk. This can be achieved by building in areas where the risk is reduced. The decision matrix in the next section defines zones of hazard, for example, by setback from slopes and sinkholes. In this way a simple decision can be reached according to the acceptably of a hazard. Development can be avoided in areas where the risk is unacceptably high. According to Cave (1991) "...it is worth noting that the Municipal Act encourages the Development Permit regulations to implement such risk avoidance policies even to the point of allowing the permit to over-ride the use and density variations in the zoning bylaw."

8.4.2 Hazard Reduction

General

When development has already occurred hazard avoidance would not be a possibility. If the risk of hazard can be reduced to acceptable limits, a method of hazard reduction may be chosen as an alternative to not developing. Hazard reduction is not a preference to hazard avoidance and should only be used when the method of reduction is long term and "relatively" maintenance free.

Mass Wasting

To reduce the risk of landslides, the prevailing conditions must be improved. Slope stability can be improved by changing slope geometry, by slope reinforcement, by ground improvement or by reducing the groundwater levels. At this site, the only practical method is to reduce groundwater levels by reducing the quantity of water entering the silts.

In the following discussion is a list of water sources and practical and enforceable measures to reduce impact from these sources. The sources are not equal in importance.

To reduce infiltration, a septic sewer system carrying waste water to Okanagan Lake level can be implemented in any new development. Curb and gutter street design with storm sewers and collection of roof and driveway run-off with conveyance to the storm sewer system which would deliver the water to the Okanagan Lake level would also reduce the net input to the water balance.

Water could be removed from the Madeline Lake Valley. At present, this water flows from the valley directly into the gravel. If this water was removed and piped to Okanagan Lake level, the net water balance would be improved. Alternatively, irrigation water could be supplied from groundwater developed around the Madeline Lake Valley.

Watering entering the system from water supply pipes can be reduced by improving the water line maintenance and/or by installing all future water lines in utility culverts reducing the likelihood of infiltration to the silt and improving the ability to identify and repair leaks.

Subsurface Erosion

To reduce the risk of subsurface erosion and sinkhole development, the total quantity of water entering the silts must be reduced and in particular any concentration of water must be collected and removed to Okanagan Lake level by suitable means (i.e., storm sewers, lined ditches, culverts, etc.).

Storm water can be collected using curbs and gutters and carried in lined ditches or culverts down to the base of the silt bluffs at lake level. Because roads presently concentrate water on to the silt bluffs, active piping occurs where the water contacts the silt. This piping induced by concentration of water on roads will only continue and worsen with time if it is not controlled.

Roof storm drainage can be collected and dispersed to avoid concentration. Water collected from driveways and roofs can be removed in storm sewers off the silt to lake level.

Swimming pools and ornamental ponds which are susceptible to leakage are not desirable in the development area. Pool or pond leakage could create serious subsurface erosion problems very quickly.

Dry land landscaping is beneficial, particularly for residents living near the edge of bluffs, a zone of higher hazard. Irrigation water added for lawns and gardening can be detrimental to geologic stability.

A process of educating all residents of the potential hazards and their associated risks, along with methods of mitigating these problems as described above, could go a long way to reduce the occurrence of subsurface erosion caused by development. Only with the residents' understanding of the hazards and commitment to work together can subsurface erosion be reduced.

Gully Erosion

To reduce erosion of the gully bases and the consequential mass wasting of the gully side slopes, the water entering the gullies must be reduced.

To reduce the water entering the gullies, new development could include septic sewers to remove domestic sewage to lake level.

To effectively reduce the water entering the gullies, existing houses could be provided with septic sewage to lake level. Providing storm sewers and curb and gutter collection of road drainage would also reduce the water entering the gravels, and then on to the gullies.

Finally, use of groundwater from the Madeline Lake Valley for use as irrigation or domestic water or removal of the water down to Okanagan Lake level in lined ditches or culverts, would reduce the water available to the gullies.

8.4.3 Waivers

As Cave (1991) states,

> One of the most common arguments relating to development applications in hazardous areas is whether approval can be granted in return for some form of waiver of the right to sue the regulatory authority in the event that damage or death occurs. This is usually coupled with some form of indemnity to protect the regulatory authority against suits launched by others. Such waivers are known as 'save-harmless' covenants and, if linked to the land use restrictions, can be registered as legal incumbrances against the title of the property pursuant to Section 215 of the Land Title Act.

It should be noted that these covenants are in the nature of private agreements between the landowner and the government. Thus third parties, such as visitors to the property, will be exposed involuntarily to the hazards while not being party to the agreement. Their statutory rights to protection cannot really be transferred by these agreements.

Nevertheless, these covenants do serve a valuable function as an instrument on title, in informing prospective purchasers of known hazards. They may also have value, in some cases, as an attempt to recognize and assign the residual liability after all reasonable remedial and protective measures have been undertaken. They do not, however, provide an alternative to implementation of the requirements of the Municipal Act and the Land Title Act by elected officials, planners, building inspectors and approving officers. The duties of each are rather clearly spelled out in the statutes, and no private agreements or covenants can over-ride these obligations.

9. DECISION MATRIX

9.1 Hazard Zones

In order to put the hazard probabilities into a form that can be effectively used by the Regional District, a study area zone plan has been created which is referenced with a decision matrix. This plan is prepared in consultation with the Regional District.

The first hazard zone includes the area of potential landslide and run-out. The setback required for adequate safety, based on the back analysis of the past failures, is an angle of 2.2:1. This is confirmed by the theoretical analysis and the probability analysis. As the back analysis predicts the edge of failure, occupied residential structures should be setback an additional 10 m to act as a safety factor which would keep the structure serviceable in the event of a landslide. From the theoretical analysis, the run-out should be 1.8:1 from the toe plus 10 m. Figure 5 illustrates the setback and run-out definition and Drawing D-1005 is a plan showing the setback and run-out.

The second hazard zone is delineated by the sinkhole hazard. A setback distance of 40 m from the edge of any present or previous sinkhole or gully edge, the maximum measured distance, has been selected. The sinkhole hazard line is shown on Drawing D-1006, the Sinkhole Hazard Plan.

The third zone is the area that will affect the landslide prevailing conditions. In this zone, increased water input through domestic water disposal in septic fields will increase the probability of landslides occurring. This zone includes all silt bluffs in the study area shown on Drawing B-1003, Geology Plan.

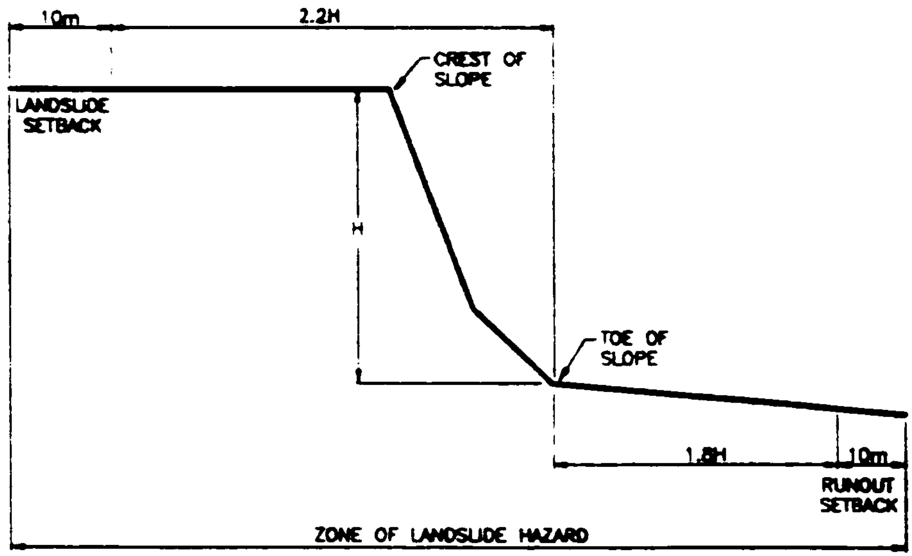


Figure 5 - Setback and Run-out Section

The fourth and fifth zones are defined as all gravel or bedrock outcrops in or above the study area. Increased water input through domestic water disposal in septic fields and through irrigation in this zone will increase gully erosion. This area, including gravel and bedrock both inside and outside of the study area, can be seen on Drawing B-1003, Geology Plan.

The five zones defined above are combined together on Drawing D-1007, the study Area Zone Plan. Where the zones overlap, the zone of higher hazard is used to define the hazard on the Area Zone Plan.

9.1.1 Matrix Development

As a final step in putting this information in a form that is easily usable by the regional district, the type of application and the type of hazard are put together in a matrix which is designed to produce the appropriate response. To simplify the process, the matrix is based on three types of applications.

- Subdivision of an existing lot into parcels greater than one acre. - Subdivision of an existing lot into smaller parcels allows a greater number of persons to be exposed to an existing risk, and may imply a greater contribution to groundwater infiltration in this study area.

- Subdivision of an existing lot into parcels between 0.5 acre and 1 acre. Subdividing existing lots also means that more water will be directly added to the ground through septic fields and there will be a greater concentration of water from driveways and roofs. As water is the single greatest problem in stability of the silt bluffs, lot size is one of the few ways that the Regional District can directly affect the amount of water directed into the ground.

- Creation of a new community. - The Berger decision (1973) that new communities should not be exposed to high hazard areas is clear. For medium and low hazard, the risk accepted should still be low.

The decision matrix is composed of a series of applications that would be received by the Regional District as described above. The application is compared against the probability of each particular event. The probability of each event is found in its associated drawing. With these two pieces of information, the matrices below are used to find the appropriate response.

The type of response to applications will depend on what zone is being considered and the kind of remedial measures available. Responses are rated on a scale of "a" to "e".

a - Permit approved without conditions.

b - Permit approved only with a covenant registered on the property title clearly defining the hazards present.

c - Permit approved only with installation of septic sewers and storm sewers.

d - Permit approved only with irrigation or domestic water drawn from groundwater.

e - Permit not approved.

9.1.2 Decision Matrix

This decision matrix, Table 5, is to be used with Drawing D-1007 for deciding responses to permit applications in the West Bench/Sage Mesa area.

Table 5 - Decision Matrix

ZONE	NEW COMMUNITY	SUBDIVISION OF EXISTING LOT TO > 0.5 ACRE	SUBDIVISION OF EXISTING LOT TO > 1.0 ACRE
1. Landslide Hazard	e	e	e
2. Sinkhole Hazard	e	e	e
3. Silt Bluff	e	c	c
4. Gravel or Bedrock in Study Area	c	c	d
5. Gravel or Bedrock Outside Study Area	c	c	d

NOTE: To be used with Drawing D-1007.

10. CONCLUSIONS AND RECOMMENDATIONS

10.1 Conclusions

Based on the field investigations and reviews of this study of the geological hazards of the West Bench/Sage Mesa area, the following are conclusions of this study:

1. West Bench/Sage Mesa is situated on lacustrine silt bluffs to the east and on kettled outwash sands and gravels and bedrock to the west.

2. The dry climate, high evapotranspiration rates, and natural drainage of the sands and gravels are responsible for the slow erosion rate of the silt bluffs.

3. At least one slide has occurred in the lacustrine silt of the study area in the past.

4. Sinkholes are prevalent throughout the study area in the silt bluffs and the colluvial silt.

5. The principal geological hazards, elements of the erosion process, are gully erosion, subsurface erosion (piping and sinkholes) and mass wasting (landslides).

6. The key trigger for gully erosion is most probably from water derived from the sands and gravels and bedrock located west of the silt deposits.

7. The key trigger for sinkholes on the silt bluffs is increased supplies of concentrated water on the silt.

   Concentration of water can result from extreme precipitation events; collected run-off from sources such as roofs, roads and driveways; leaking swimming pools; and broken water supply lines.

8. Increased water infiltration in the silts will facilitate requirements for a landslide.

   During open ditch irrigation in the Okanagan Valley the occurrence of failures increased dramatically over predevelopment conditions. Under present housing density, the potential for infiltration through septic fields also increases the likelihood of failure.

9. The study area has been subdivided into five zones as shown on Drawing D-1007:

   - Zone 1 - Land within the area of landslide and run-out potential, defined as a setback angle of 2.2:1 from the toe plus 10 m and a run-out distance of 1.8 times the slide height plus 10 m.

   - Zone 2 - Land within the area of potential sinkholes, defined as the area within a distance of 40 m from past or existing sinkholes or gully edge.

   - Zone 3 - Land on the lacustrine silt unit, but not within Zone 1 or Zone 2.

   - Zone 4 and Zone 5 - Land within the catchment on the kettled outwash sands and gravels or the bedrock.

10.2 Recommendations

The following are recommendations of this study:

1. Adopt Drawing D-1007, the Study Area Zone Plan, as the updated geological hazards map.

2. Adopt the geological hazards decision matrix presented as Table 5 and on Drawing D-1007.

3. To facilitate future property development, plan for installation of suitable measures to control infiltration of water to the silt bluffs. These measures would include development restrictions, installation of septic sewers, storm sewers, curbs and gutters, improvement of water distribution systems, interception of groundwater near Madeline Lake and restriction of pools.

4. Inform residents of West Bench and Sage Mesa of the potential hazards and the associated risks that they expose themselves to, along with methods for mitigating the potential trigger mechanisms.

KLOHN LEONOFF LTD.

R.C. (Bob) Gill, P. Eng.
Project Engineer

H.R. (Rod) Smith, P. Eng.
Project Manager

PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
H. RODNEY SMITH

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GLOSSARY

Bedrock - The solid, undisturbed rock in place either at the ground surface or beneath surficial deposits of soil.

Caving - Failure of a cavern or pipe roof.

Collapse of Internal Soil Structure - Sudden increase in volume of soil due to failure of the bonding agents maintaining the soil structure.

Collapsible Soil - Low density soil which collapses, when wetted for the first time since deposition, in a process termed hydrocompaction, resulting in ground subsidence and cracking.

Colluvial - Slope wash and gravity carried material deposited on and at the base of slopes.

Consolidation Test - A test in which the specimen is laterally confined in a ring and is compressed between porous plates under load.

Engineering Geology - The application of geologic data, principles, and interpretation to naturally occurring earth materials so taht geological factors affecting planning, design, construction, and maintenance of civil engineering works are properly recognized and utilized.

Geologic Hazard - A naturally occurring or man-made geologic condition or phenomenon that may present a potential danger to life and property.

Glacio-lacustrine - Deposition of materials derived from deglaciation as lake sediments.

Ground Wastewater Disposal System - (commonly called septic or septic disposal system) - disposal to the ground of domestic waste water.

Groundwater - Subsurface water within the zone of saturation that is free to move through a soil mass under the influence of gravity.

Groundwater Table - (Water table) - elevations at which the pressure in the water is zero, with respect to the atmospheric pressure or level below which the soil or rock is saturated.

Hydraulic Gradient - The loss of hydraulic head (water pressure) per unit distance of flow.

Hydro-Compaction - Densification of a soil by saturation with water causing rearrangement of soil grain structure in a more compact form.

Joints - Breaks or discontinuities, general planar, in a soil or rock mass.

Joint Set - A number of joints with the same orientation.

Joint System - A number of joint sets within a formation.

Kettle - A depression in a ground caused by the burial and subsequent melting out of an isolated block of glacial ice.

Lacustrine - Referring to lake deposited sediments.

Loess - A uniform silty wind-deposited material having an open structure and relatively high cohesion due to cementation of clay or calcareous material at individual soil grain contacts.

Mass Wasting - The natural movement of materials downslope from small scale ravelling to large scale landslides.

Meltwater Channels - Water course formed by water derived from melting glacial ice (commonly inactive at present).

Perched Water Table - A water table usually of limited area maintained above the normal water table by the presence of a relatively impervious layer.

Piezometer - An instrument for measuring the elevation of the water table (sometimes a small diameter well).

Piping - Subsurface mechanical erosion in which particles of soil are dislodged from their natural position and entrained in a flow of water to form a conduit.

Runoff - Flow of excess surface water (i.e., flow of water that has not infiltrated or evaporated).

Seepage - (Or seepage flow) - the infiltration and subsurface flow of water derived from natural sources and activities of man.

Silt - (Also inorganic silt or rock flour) - material passing the No. 200 (74 - micron) U.S. standard sieve that is non-plastic or very slightly plastic.

Slope Failure - Downslope ovement of soil and rock under the influence of gravity, commonly termed landsliding (including planar and rotational slides, flows, falls, spreads, and raveling).

Solifluction - The slow downslope flow of masses of soil rock debris which are saturated with water and not confined to definite channels.

Subsidence - The downward settling or sinking of the ground.

Varves - Layers of fine sediments graded from coarse below to fine above deposited annually in a lacustrine (lake) environment.

APPENDIX I

TERMS OF REFERENCE

Regional District of Okanagan-Similkameen

101 Martin Street, Penticton, B.C. V2A 5J9 Fax: 492-0063 Telephone: 492-0237

TERMS OF REFERENCE

PROPOSAL CALL (OCTOBER, 1991)

FOR A STUDY OF GEOLOGICAL CONDITIONS WITH RESPECT TO DEVELOPMENT IN THE WEST BENCH/SAGE MESA AREA, ELECTORAL AREA 'F'

Background

Development pressures led to a geotechnical study of the area in the mid seventies. A report entitled "Geological Hazards and Urban Development of Silt Deposits in the Penticton Area" recommended restrictions on development by creating green, orange and red zones which effectively impacted further development.

A resurfacing of development pressures since the late eighties requires that previous studies be reviewed in relation to possible further development.

Purpose

To determine criteria for development, taking into account identified geological conditions and associated risks.

Scope of Work

1. Review all previous studies.

2. Examine and update the rationale behind the hazard zones (green, orange, red) referred to in the 1977 report entitled "Geological Hazards and Urban Development of Silt Deposits in the Penticton Area".

3. Re-visit hazard zone boundaries, confirm or modify same and determine which areas can be further subdivided.

4. Determine the effects of development to date, utilizing such methods as air photo interpretation; survey of residents; contact with agencies operating within the area; and limited site investigation.

5. Analyze margin of safety for development within the zones with respect to such issues as: slope stability, piping, drainage, and related phenomena.

6. Establish bench marks for risks to allow administrators to decide on acceptable risk levels.

7. Identify practical and enforceable measures required for geotechnical stability of the entire area.

8. Produce in a matrix format specific criteria versus lot size for each zone, without the requirement for ongoing administrative controls.

Proposal Submission

If you are interested in this assignment, please submit twelve (12) copies of your proposal in writing by 3:00 p.m. local time, November 1, 1991 to:

Mr. Andrew Swetlishoff
A/Director of Development Services
Regional District of Okanagan-Similkameen
101 Martin Street
Penticton, B.C.
V2A 5J9

complete with the following information:

A. The consultant shall confirm all members of his project team and submit a resume for each member.

B. A graphic work plan and a methodology are required. This should include a clear description of the tasks proposed to carry out the various aspects of the work and to fulfil the objectives. The work plan should clearly show the level of effort planned for all project team members on each task. A timetable/schedule for the completion of all tasks is also required. (A preliminary indication of when meetings will be required with Regional District and B.C. Ministry of Transportation and Highways staff and the timing of interim and final reports is attached.)

C. Description of recent experience of the Company in related work.

D. A list of sub-consultants or sub-contractors and their qualifications, if planned to be engaged in this study.

E. Suggested revisions to the terms of reference, if any.

F. Proof of professional liability (errors and omissions) insurance coverage.

G. A schedule of hourly rates for all personnel who might be utilized on the project must be provided. The hourly rates quoted shall be firm for a period of one (1) year from the date of your proposal.

H. The percentage mark-up for disbursements arising from the assignment should be indicated. The estimated value of disbursements shall be listed separately, but included within the consultant's upset limit fee to complete the engineering assignment.

I. A total upset fee to complete the engineering assignment as outlined in the foregoing terms of reference, including all disbursements.

Payment

The method of payment will be based on actual time at the hourly rates provided by the consultant to the upset amount, in accordance with job progress. Progress billings will be made in accordance with the work plan.

Preliminary Time Schedule

- Proposals to close November 8, 1991.
- Contract to commence by December 1, 1991.
- Review meetings to be held on or about the first day of each month at the office of the Regional District of Okanagan-Similkameen.
- Draft report to be completed by February 28, 1992.
- Final report to be completed by March 31, 1992.

NOTE: Please be advised that funding for this assignment is subject to the receipt of grants from the Ministry of Transportation and Highways and the Ministry of Municipal Affairs, Recreation and Culture, which have been applied for by the Regional District of Okanagan-Similkameen.

APPENDIX II

SINKHOLE DISTRIBUTION
AND
LANDSLIDE PROBABILITY ANALYSIS

APPENDIX II

TABLE OF CONTENTS

PAGE

Data Base - distance to sinkhole or gully edge

sinkhole/gully #	distance to sinkhole or gully edge (e)
1	5 e
2	20
3	25
4	27
5	22
6	22
7	30
8	25
9	25
10	25 e
11	27
12	25
13	25
14	15 e
15	12
16	12
17	20
18	25
19	20
20	25
21	22
22	20 e
23	2 e
24	25
25	17
26	30
27	17
28	15
29	15
30	32
31	25
32	25
33	30
34	25 e
35	20
36	20
37	12
38	22
39	12
40	22
41	20
42	20
43	15
44	15
45	30 e
46	20
47	20
48	20
49	12
50	25 e
51	12

Distance equal to:

dist (m)	all	gully
0	1	1
2	2	2
5	4	4
7	5	5
10	13	11
12	33	11
15	35	14
17	37	13
20	73	14
22	51	5
25	35	8
27	21	1
30	14	3
32	6	0
35	4	1
37	1	0
40	1	1
	336	94

52	15	
53	12	
54	12	
55	10	e
56	27	
57	22	
58	15	
59	15	
60	27	
61	22	
62	15	e
63	22	
64	12	e
65	20	e
66	10	e
67	25	
68	15	
69	15	
70	20	
71	20	
72	20	
73	25	e
74	15	e
75	12	e
76	17	e
77	22	e
78	17	e
79	20	e
80	27	
81	10	e
82	17	
83	17	
84	25	
85	27	
86	15	
87	15	
88	22	
89	17	
90	20	e
91	17	
92	17	
93	17	
94	20	
95	20	
96	20	
97	20	
98	20	
99	20	
100	17	e
101	27	
102	25	
103	30	

This sheet presents information derived from the results of calculations using estimated values for many of the input parameters, each of which can vary over a wide range. Consequently, the information on the sheet is for illustration purposes only, and is not reliable for all conditions. The information on this sheet must not be used for design and must not be interpreted in any absolute manner.

104	22 e
105	15 e
106	20 e
107	40 e
108	12 e
109	27
110	20
111	20
112	20
113	22
114	22
115	30
116	22
117	22
118	20
119	20
120	27
121	25
122	17
123	17
124	22
125	22
126	27
127	20
128	20
129	7 e
130	25
131	12
132	12
133	22
134	15 e
135	17 e
136	17
137	22
138	20
139	27
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This sheet presents information derived from the results of calculations using estimated values for many of the input parameters, each of which can vary over a wide range. Consequently, the information on the sheet is for illustration purposes only, and is not reliable for all conditions. The information on this sheet must not be used for design and must not be interpreted in any absolute manner.

156	20	
157	20	
158	25	
159	27	
160	22	
161	20	
162	20	
163	30	
164	25	
165	20	e
166	20	
167	17	
168	25	
169	17	
170	17	
171	10	e
172	20	
173	17	e
174	22	
175	22	
176	22	
177	15	
178	12	
179	12	
180	15	e
181	15	
182	15	
183	17	e
184	20	e
185	27	
186	7	e
187	10	e
188	22	
189	22	
190	15	e
191	20	
192	27	
193	30	
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195	30	e
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197	25	
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This sheet presents information derived from the results of calculations using estimated values for many of the input parameters, each of which can vary over a wide range. Consequently, the information on the sheet is for illustration purposes only, and is not reliable for all conditions. The information on this sheet must not be used for design and must not be interpreted in any absolute manner.

208	22
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224	15 e
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226	32
227	30
228	20 e
229	30 e
230	15 e
231	15 e
232	15 e
233	25 e
234	20 e
235	22
236	10
237	10
238	25 e
239	5 e
240	17 e
241	35
242	7 e
243	10 e
244	27 e
245	10 e
246	22 e
247	20 e
248	17
249	17
250	20
251	17 e
252	22
253	17
254	12 e
255	22
256	22
257	30
258	25 e
259	22 e

This sheet presents information derived from the results of calculations using estimated values for many of the input parameters, each of which can vary over a wide range. Consequently, the information on the sheet is for illustration purposes only, and is not reliable for all conditions. The information on this sheet must not be used for design and must not be interpreted in any absolute manner.

260	32	
261	10	e
262	12	
263	12	
264	12	
265	15	
266	12	
267	12	
268	12	
269	25	
270	15	
271	15	
272	22	
273	22	
274	20	
275	20	
276	17	e
277	20	
278	7	e
279	20	
280	5	e
281	20	
282	20	
283	20	
284	20	
285	22	
286	12	e
287	20	
288	20	
289	17	e
290	25	
291	12	e
292	32	
293	12	e
294	20	
295	10	e
296	20	
297	0	e
298	12	e
299	22	
300	22	
301	20	
302	20	
303	17	e
304	17	
305	17	
306	15	e
307	30	
308	15	e
309	20.	e
310	35	e
311	10	e

312	25
313	7 e
314	22
315	15 e
316	22
317	20 e
318	12 e
319	22 e
320	25 e
321	2 e
322	22
323	22
324	25
325	17 e
326	20 e
327	22
328	22
329	35
330	32
331	12 e
332	37
333	35
334	5 e
335	12 e
336	20 e

Distance (m)	336/5000	336/2000	336/10000
D	0.0672	0.168	0.0336
0	0.0672	0.168	0.0336
2.5	0.067	0.1675	0.0335
5	0.0666	0.1665	0.0333
7.5	0.0658	0.1645	0.0329
10	0.0648	0.162	0.0324
12.5	0.0622	0.1555	0.0311
15	0.0556	0.139	0.0278
17.5	0.0486	0.1215	0.0243
20	0.0412	0.103	0.0206
22.5	0.0266	0.0665	0.0133
25	0.0164	0.041	0.0082
27.5	0.0094	0.0235	0.0047
30	0.0052	0.013	0.0026
32.5	0.0024	0.006	0.0012
35	0.0012	0.003	0.0006
37.5	0.0004	0.001	0.0002
40	0.0002	0.0005	0.0001

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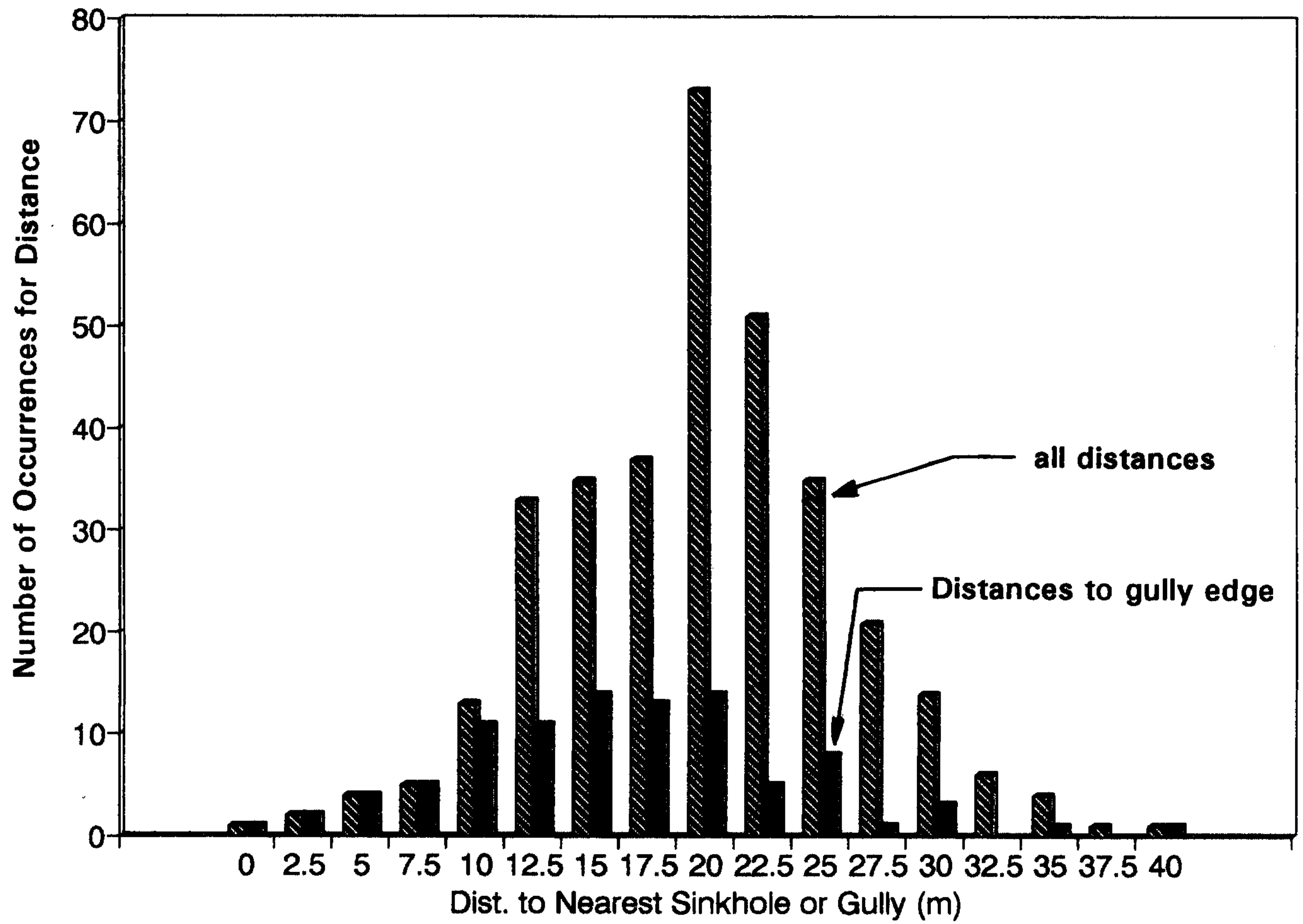
DISTANCE (m) VS. OCCURRENCE

Frequency Distribution



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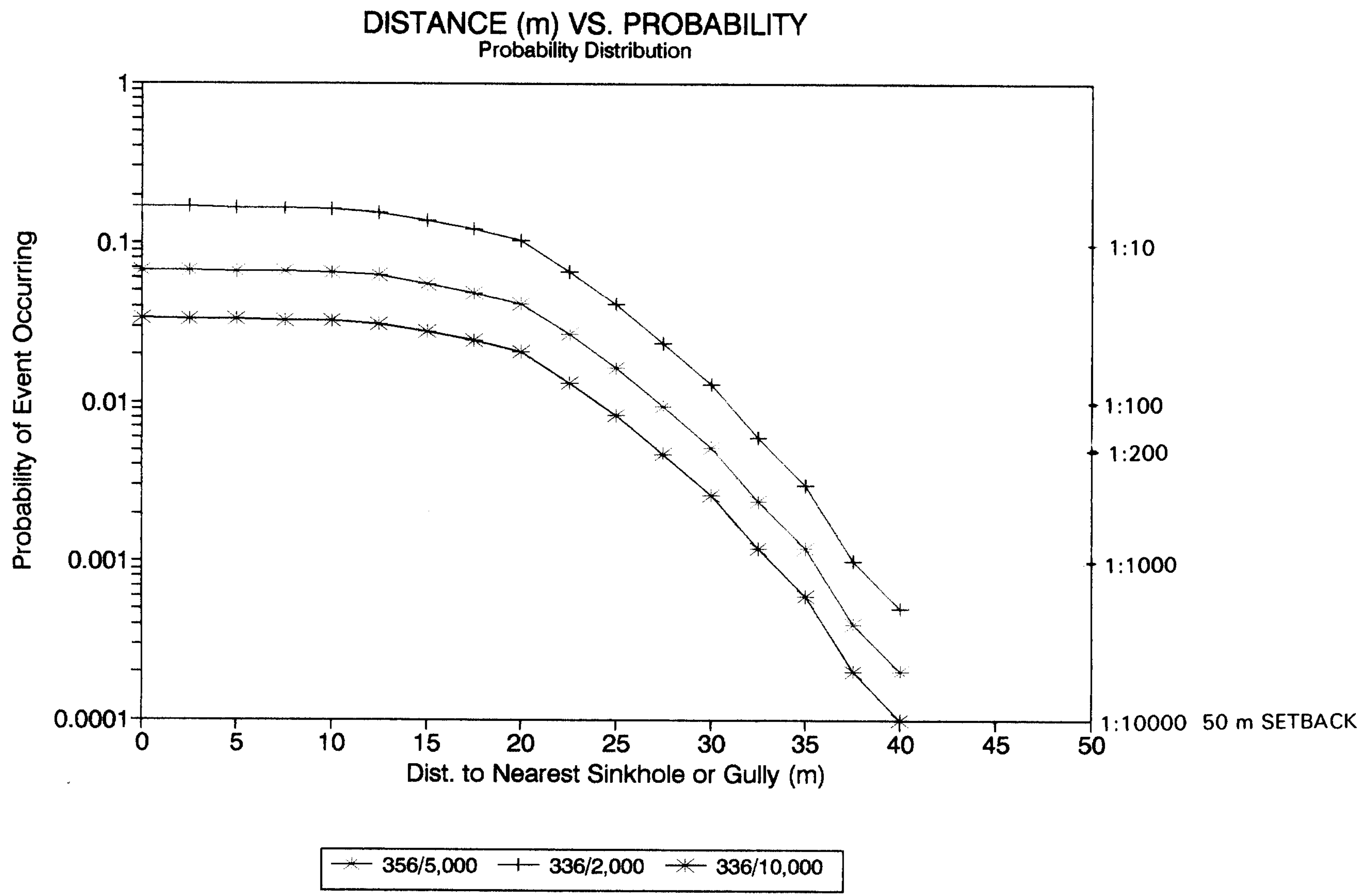

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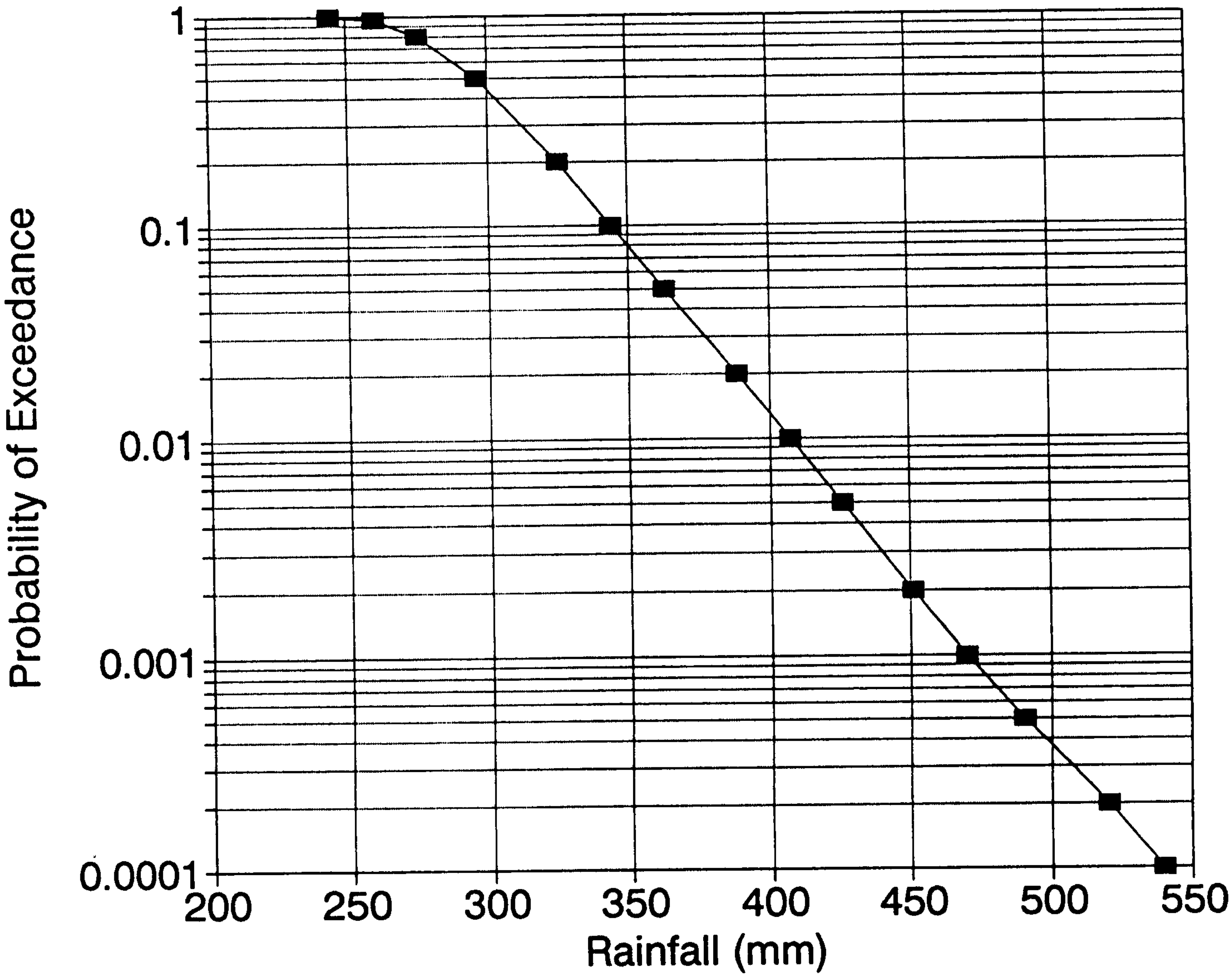
5-YEAR RAINFALL AVERAGE



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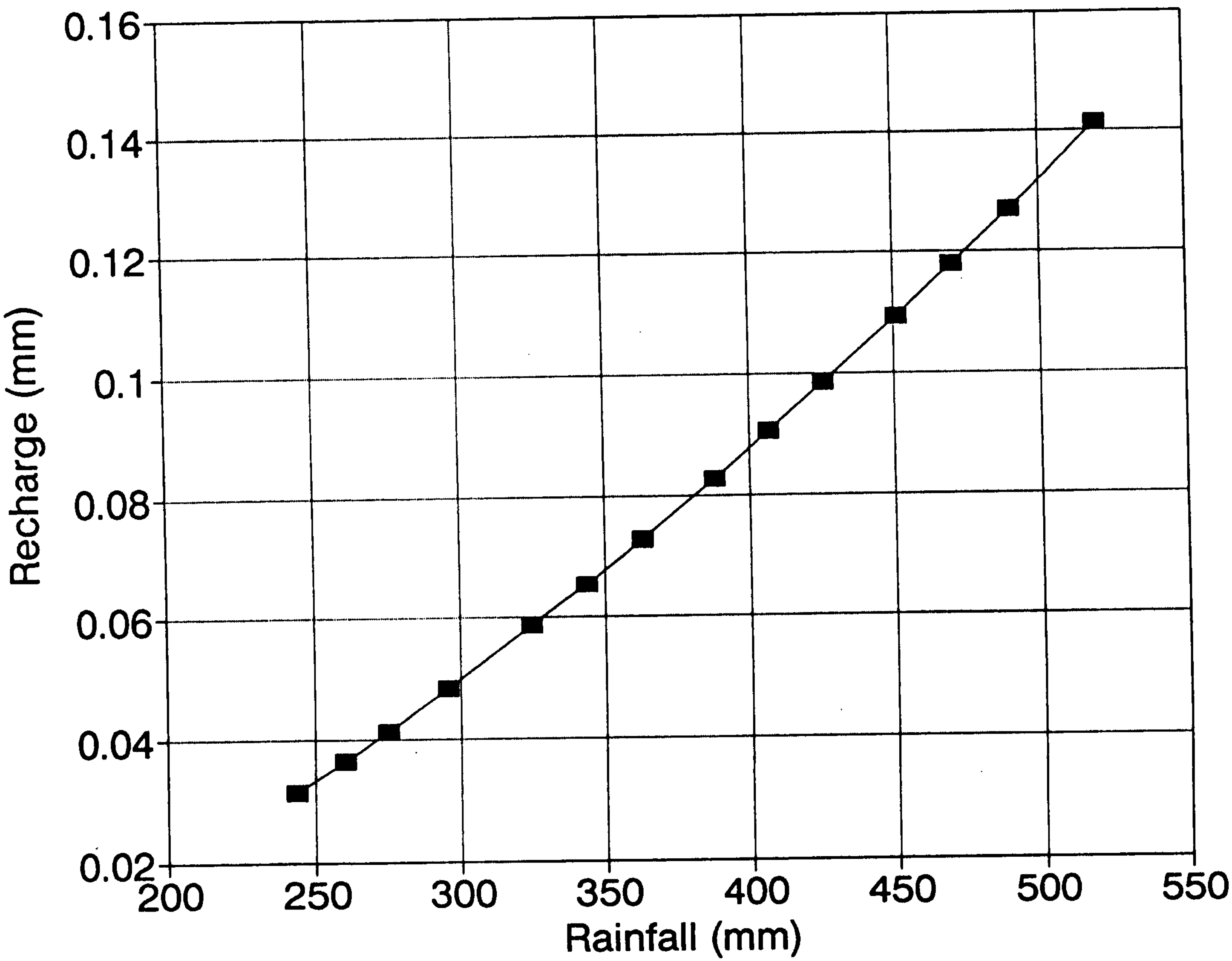
RECHARGE CURVE



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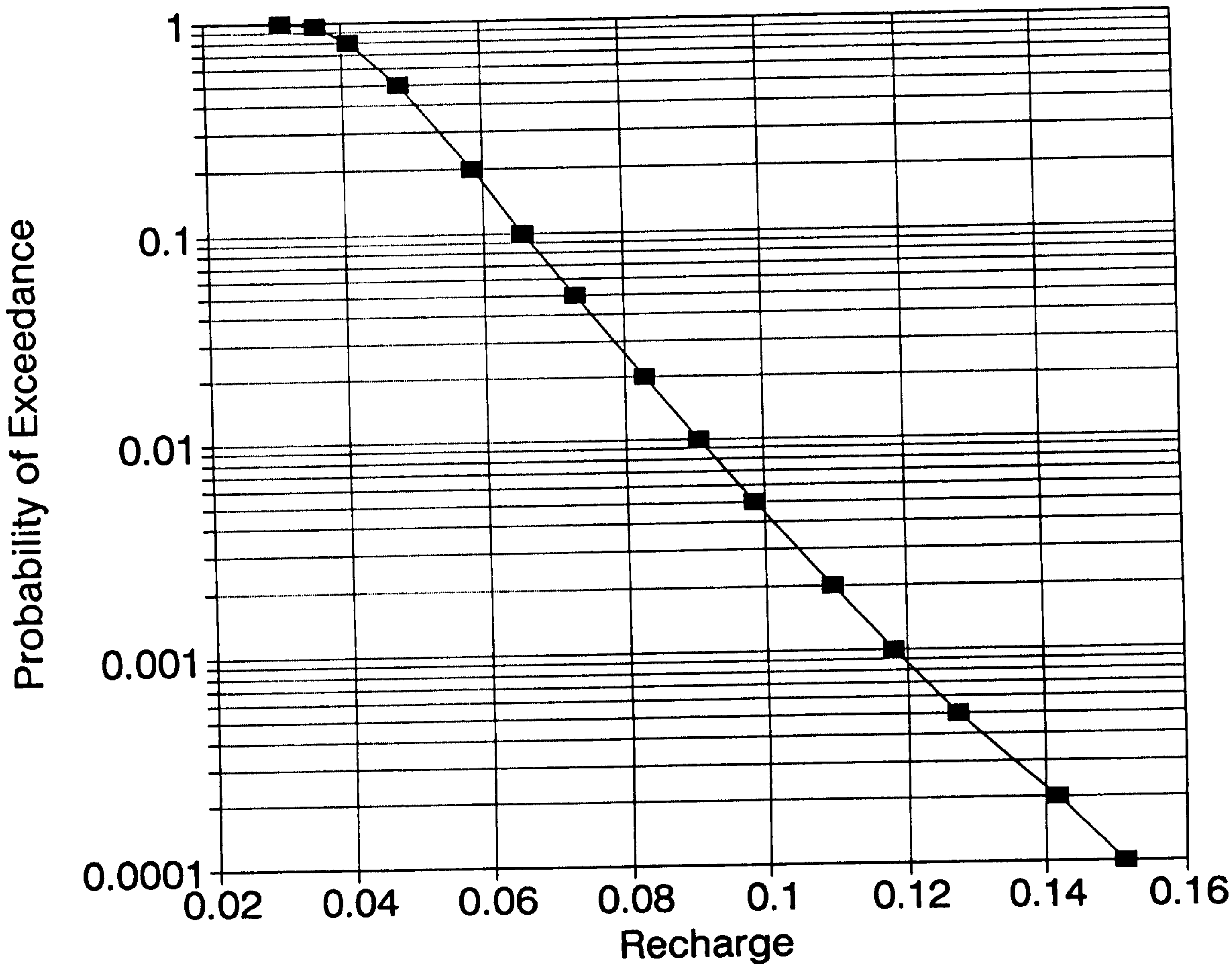
RECHARGE BASED ON 5-YEAR RAIN AVERAGE



RECHARGE VS. GRADIENT

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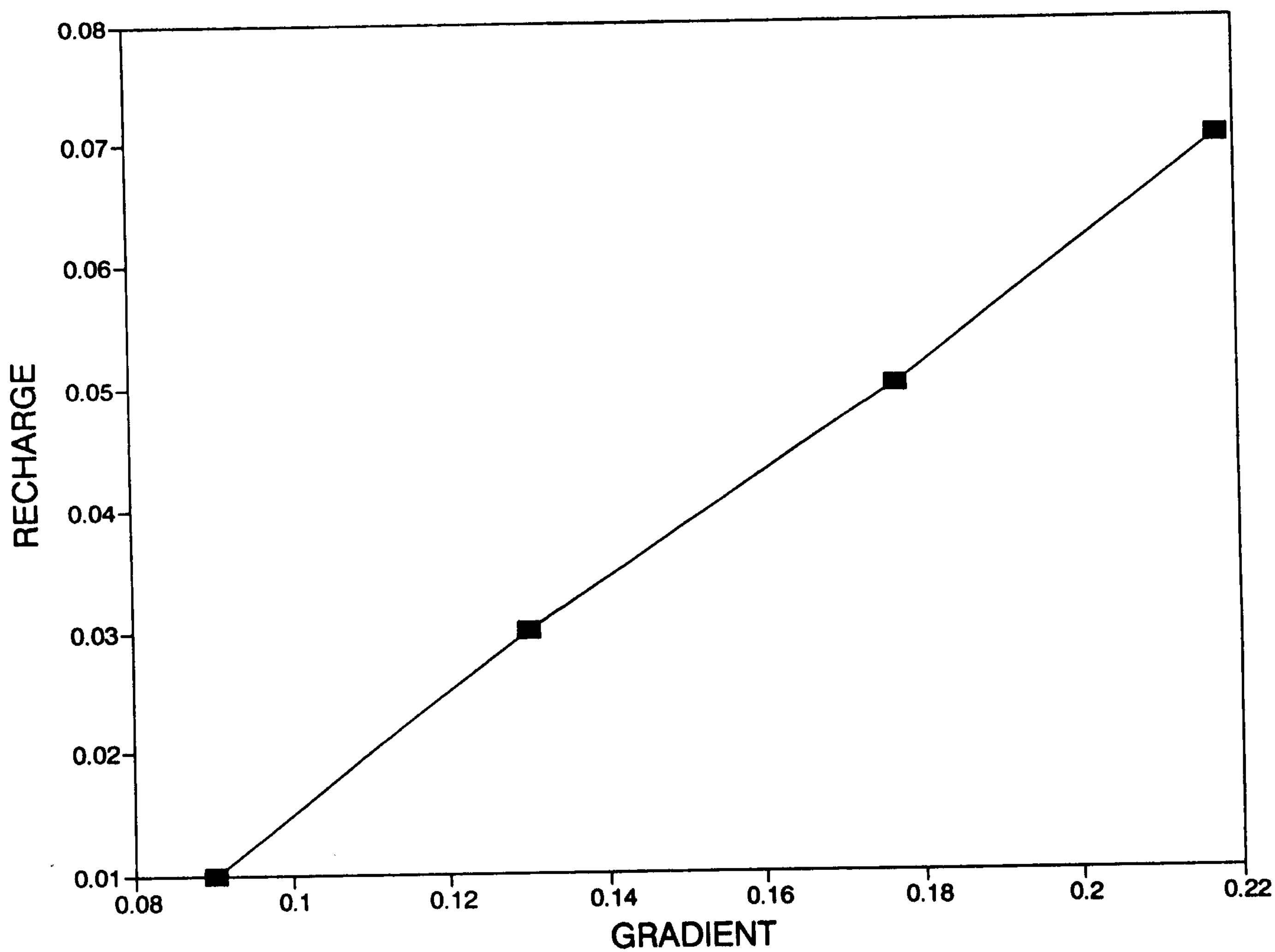

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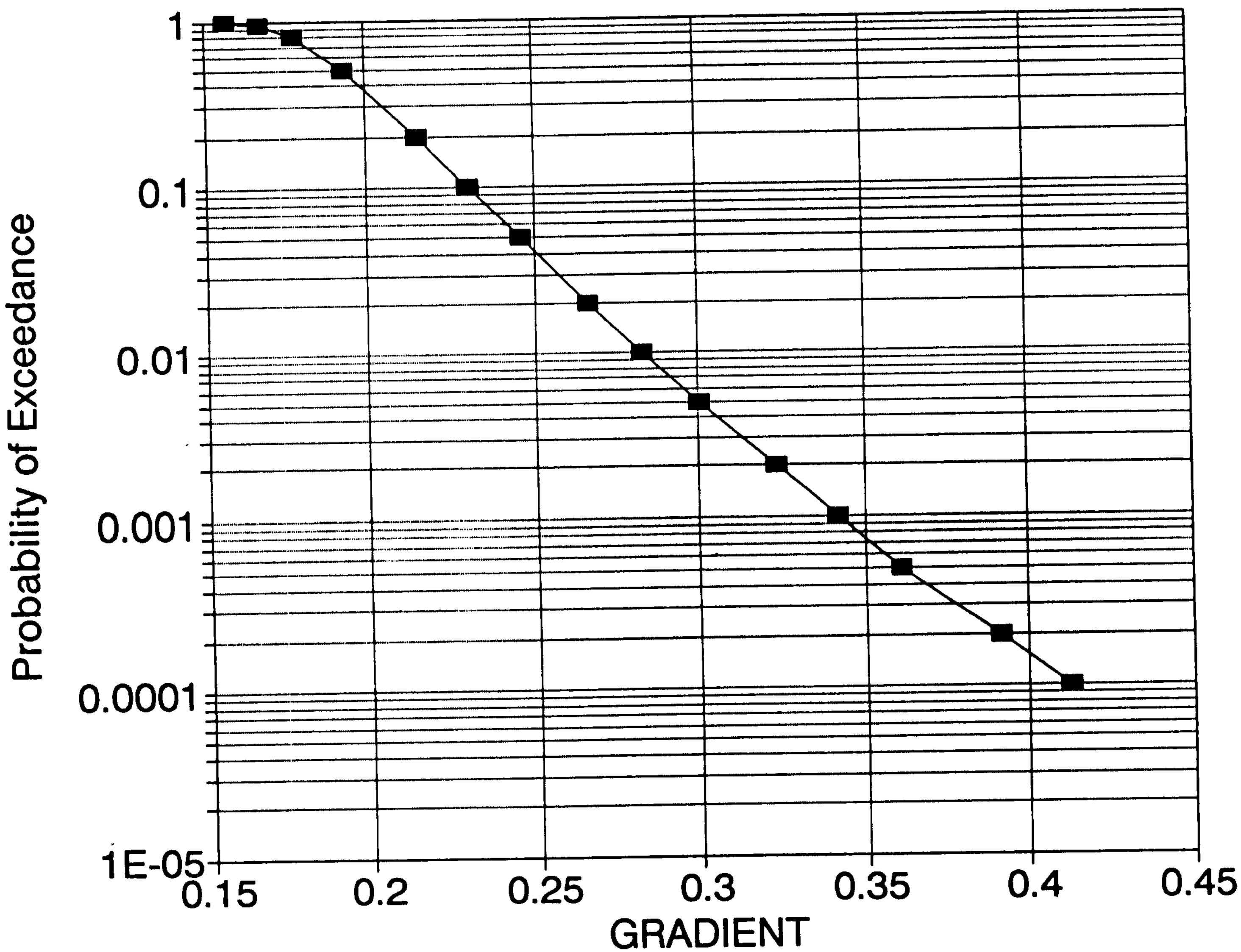
GRADIENT BASED ON 5-YEAR RAIN AVERAGE



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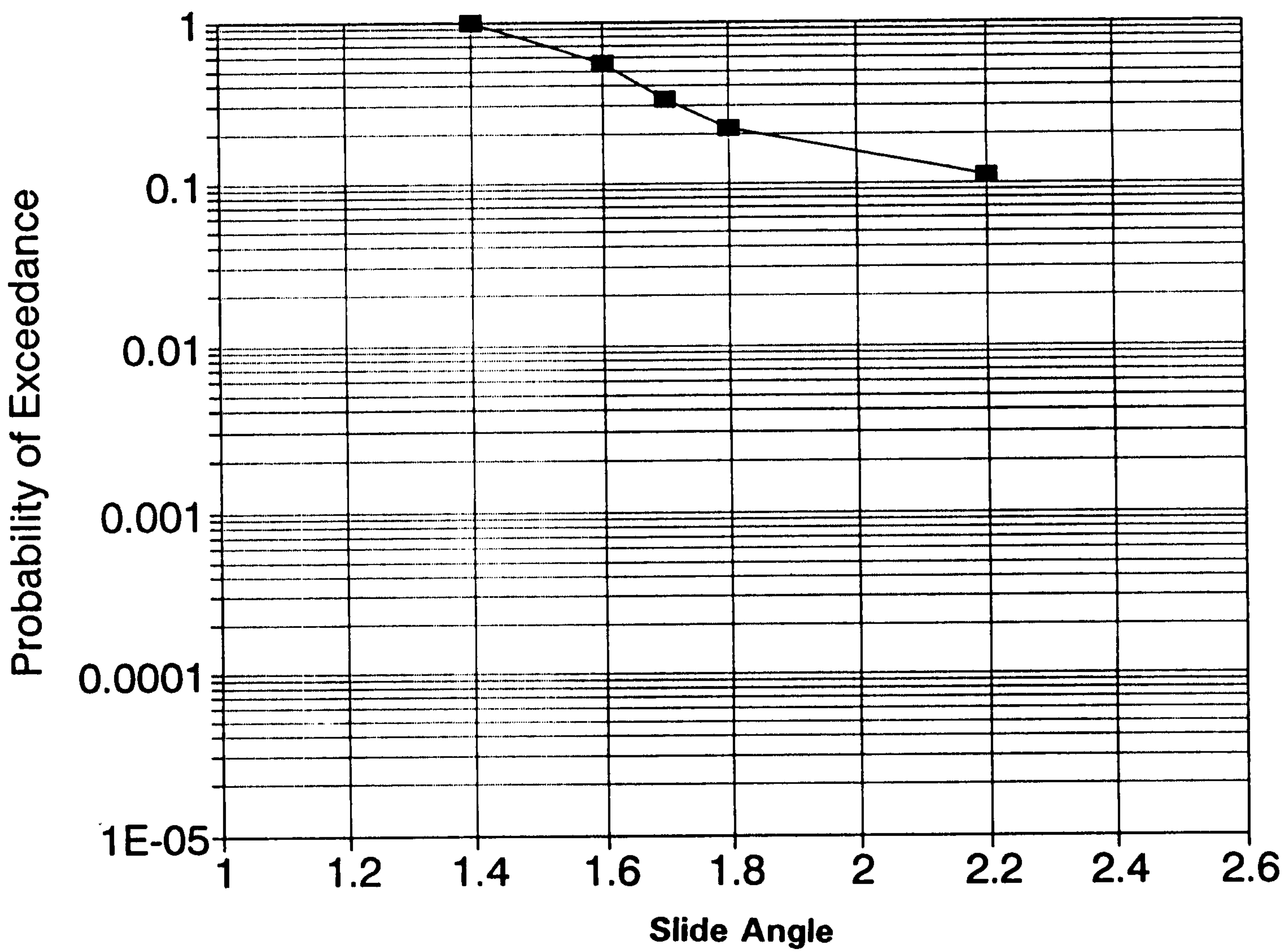
SLIDE ANGLE VS PROBABILITY OF EXCEEDANCE
Based on Precedent



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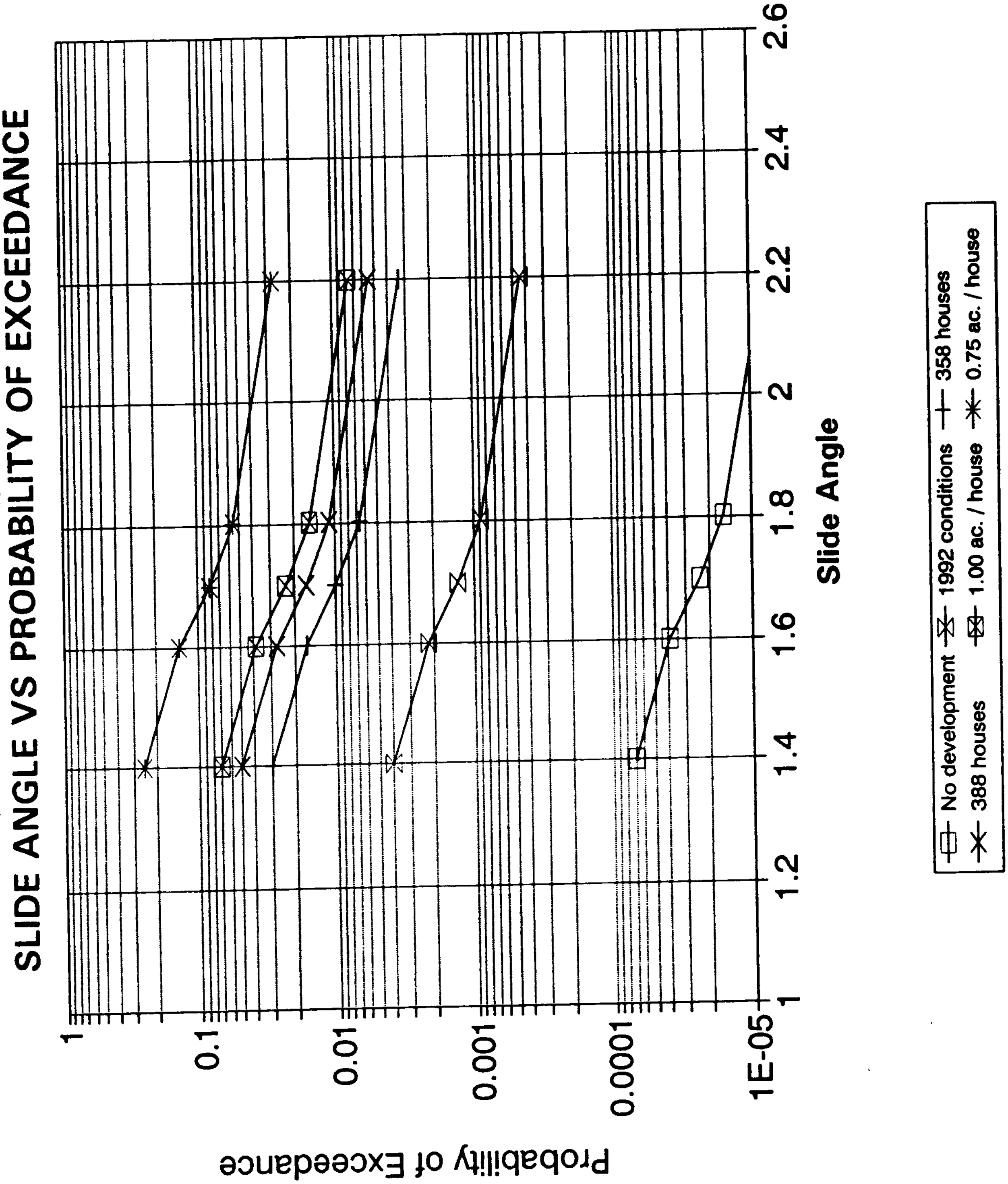

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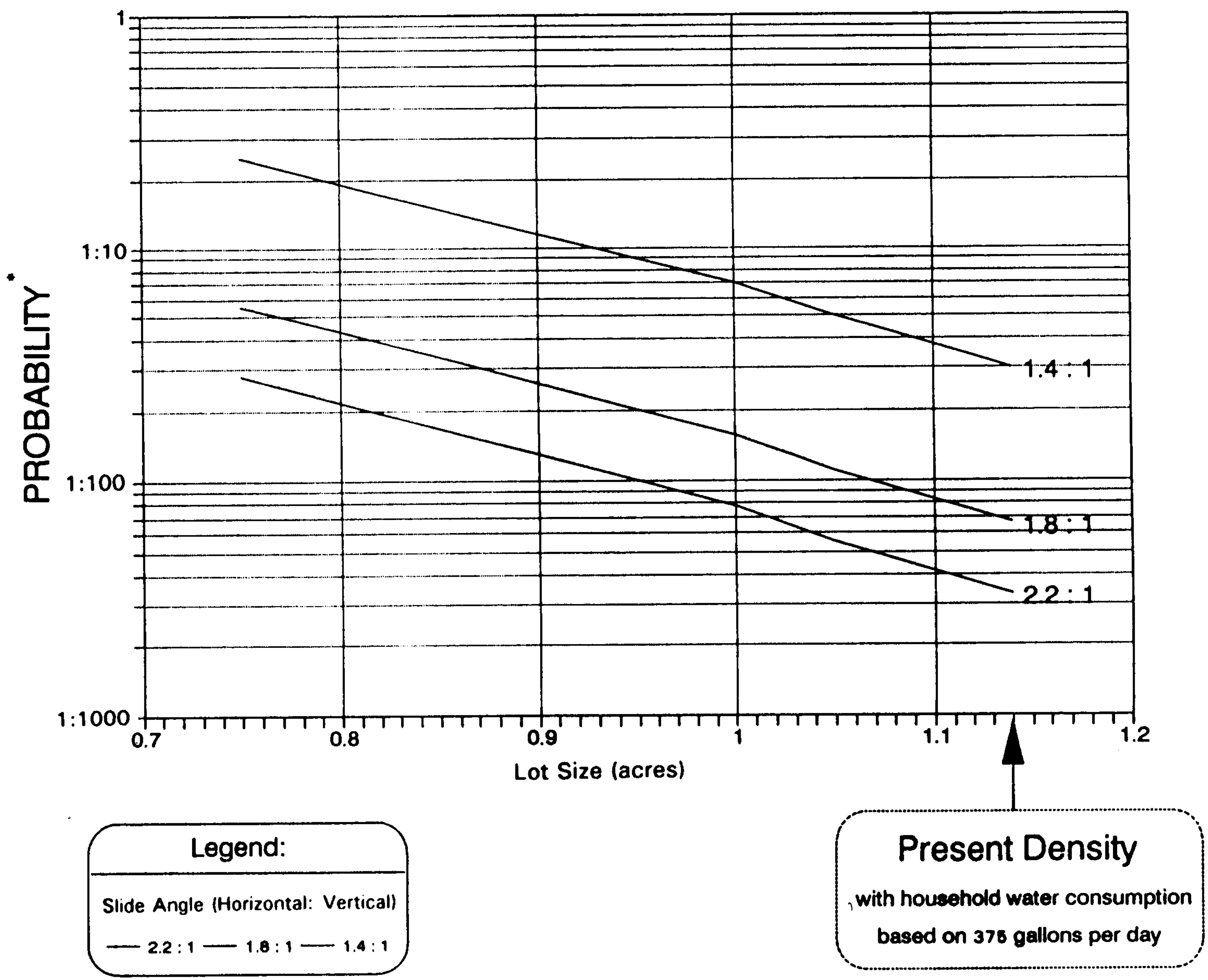
DENSITY VS PROBABILITY OF EXCEEDANCE



* Probability of Exceeding a Slide Angle

APPENDIX II

SINKHOLE DISTRIBUTION AND LANDSLIDE PROBABILITY ANALYSIS

APPENDIX II

TABLE OF CONTENTS

PAGE

Data Base - distance to sinkhole or gully edge

sinkhole/gully #	distance to sinkhole or gully edge (e)
1	5 e
2	20
3	25
4	27
5	22
6	22
7	30
8	25
9	25
10	25 e
11	27
12	25
13	25
14	15 e
15	12
16	12
17	20
18	25
19	20
20	25
21	22
22	20 e
23	2 e
24	25
25	17
26	30
27	17
28	15
29	15
30	32
31	25
32	25
33	30
34	25 e
35	20
36	20
37	12
38	22
39	12
40	22
41	20
42	20
43	15
44	15
45	30 e
46	20
47	20
48	20
49	12
50	25 e
51	12

Distance equal to:

dist (m)	all	gully
0	1	1
2	2	2
5	4	4
7	5	5
10	13	11
12	33	11
15	35	14
17	37	13
20	73	14
22	51	5
25	35	8
27	21	1
30	14	3
32	6	0
35	4	1
37	1	0
40	1	1
	336	94

This sheet presents information derived from the results of calculations using estimated values for many of the input parameters, each of which can vary over a wide range. Consequently, the information on the sheet is for illustration purposes only, and is not reliable for all conditions. The information on this sheet must not be used for design and must not be interpreted in any absolute manner.

52	15
53	12
54	12
55	10 e
56	27
57	22
58	15
59	15
60	27
61	22
62	15 e
63	22
64	12 e
65	20 e
66	10 e
67	25
68	15
69	15
70	20
71	20
72	20
73	25 e
74	15 e
75	12 e
76	17 e
77	22 e
78	17 e
79	20 e
80	27
81	10 e
82	17
83	17
84	25
85	27
86	15
87	15
88	22
89	17
90	20 e
91	17
92	17
93	17
94	20
95	20
96	20
97	20
98	20
99	20
100	17 e
101	27
102	25
103	30

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104	22 e
105	15 e
106	20 e
107	40 e
108	12 e
109	27
110	20
111	20
112	20
113	22
114	22
115	30
116	22
117	22
118	20
119	20
120	27
121	25
122	17
123	17
124	22
125	22
126	27
127	20
128	20
129	7 e
130	25
131	12
132	12
133	22
134	15 e
135	17 e
136	17
137	22
138	20
139	27
140	20
141	27
142	25
143	25
144	25
145	15
146	15
147	20
148	20
149	22
150	22
151	22
152	17
153	17
154	17
155	22

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156	20
157	20
158	25
159	27
160	22
161	20
162	20
163	30
164	25
165	20 e
166	20
167	17
168	25
169	17
170	17
171	10 e
172	20
173	17 e
174	22
175	22
176	22
177	15
178	12
179	12
180	15 e
181	15
182	15
183	17 e
184	20 e
185	27
186	7 e
187	10 e
188	22
189	22
190	15 e
191	20
192	27
193	30
194	30
195	30 e
196	27
197	25
198	20
199	25
200	20
201	32
202	10 e
203	17
204	17
205	20
206	22
207	20

208	22
209	22
210	17 e
211	27
212	12
213	12
214	27
215	27
216	20
217	15
218	15
219	20
220	12
221	12
222	22
223	27
224	15 e
225	20
226	32
227	30
228	20 e
229	30 e
230	15 e
231	15 e
232	15 e
233	25 e
234	20 e
235	22
236	10
237	10
238	25 e
239	5 e
240	17 e
241	35
242	7 e
243	10 e
244	27 e
245	10 e
246	22 e
247	20 e
248	17
249	17
250	20
251	17 e
252	22
253	17
254	12 e
255	22
256	22
257	30
258	25 e
259	22 e

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260	32
261	10 e
262	12
263	12
264	12
265	15
266	12
267	12
268	12
269	25
270	15
271	15
272	22
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274	20
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276	17 e
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278	7 e
279	20
280	5 e
281	20
282	20
283	20
284	20
285	22
286	12 e
287	20
288	20
289	17 e
290	25
291	12 e
292	32
293	12 e
294	20
295	10 e
296	20
297	0 e
298	12 e
299	22
300	22
301	20
302	20
303	17 e
304	17
305	17
306	15 e
307	30
308	15 e
309	20. e
310	35 e
311	10 e

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312	25
313	7 e
314	22
315	15 e
316	22
317	20 e
318	12 e
319	22 e
320	25 e
321	2 e
322	22
323	22
324	25
325	17 e
326	20 e
327	22
328	22
329	35
330	32
331	12 e
332	37
333	35
334	5 e
335	12 e
336	20 e

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Distance (m)	336/5000	336/2000	336/10000
D	0.0672	0.168	0.0336
0	0.0672	0.168	0.0336
2.5	0.067	0.1675	0.0335
5	0.0666	0.1665	0.0333
7.5	0.0658	0.1645	0.0329
10	0.0648	0.162	0.0324
12.5	0.0622	0.1555	0.0311
15	0.0556	0.139	0.0278
17.5	0.0486	0.1215	0.0243
20	0.0412	0.103	0.0206
22.5	0.0266	0.0665	0.0133
25	0.0164	0.041	0.0082
27.5	0.0094	0.0235	0.0047
30	0.0052	0.013	0.0026
32.5	0.0024	0.006	0.0012
35	0.0012	0.003	0.0006
37.5	0.0004	0.001	0.0002
40	0.0002	0.0005	0.0001

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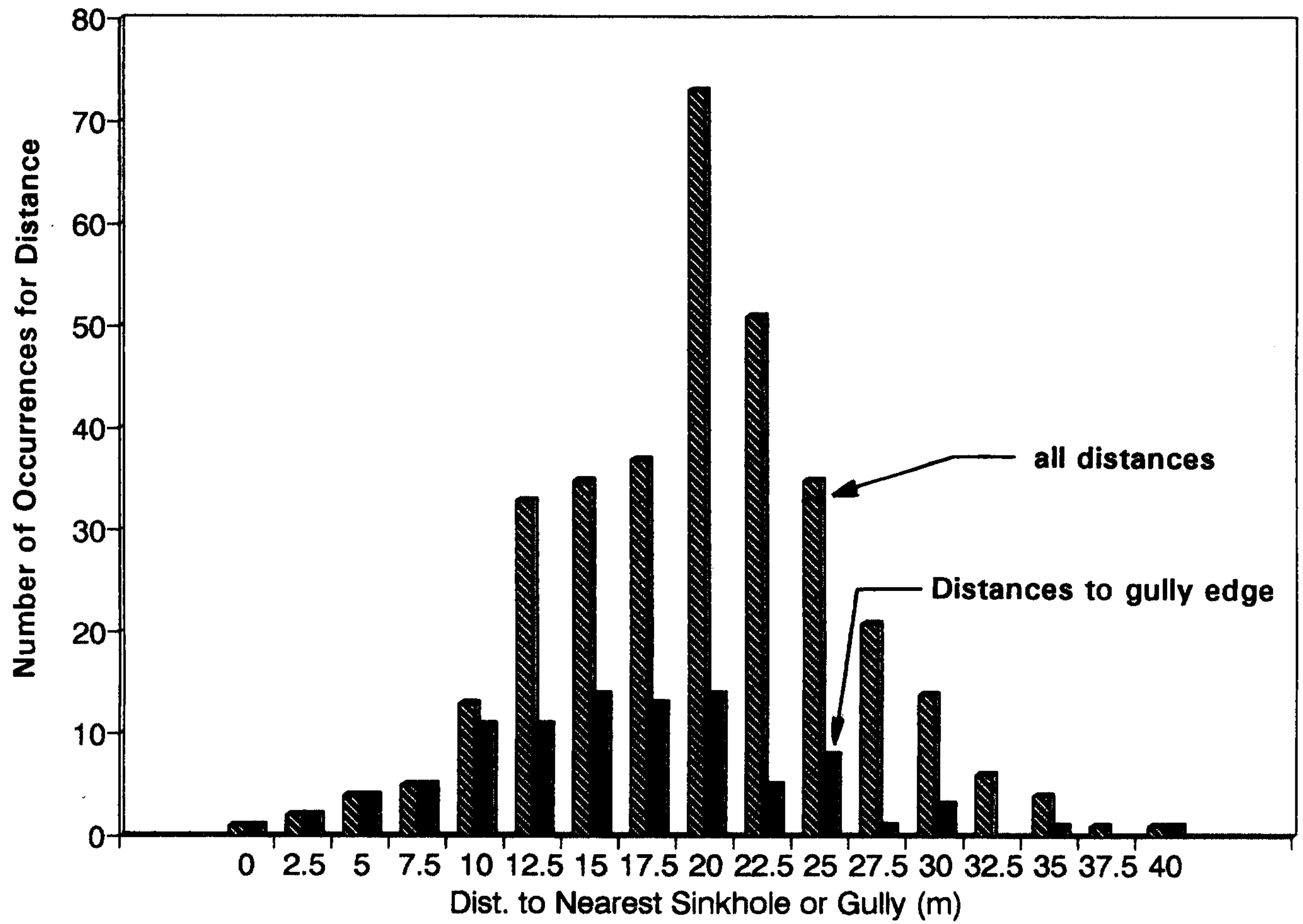
DISTANCE (m) VS. OCCURRENCE

Frequency Distribution



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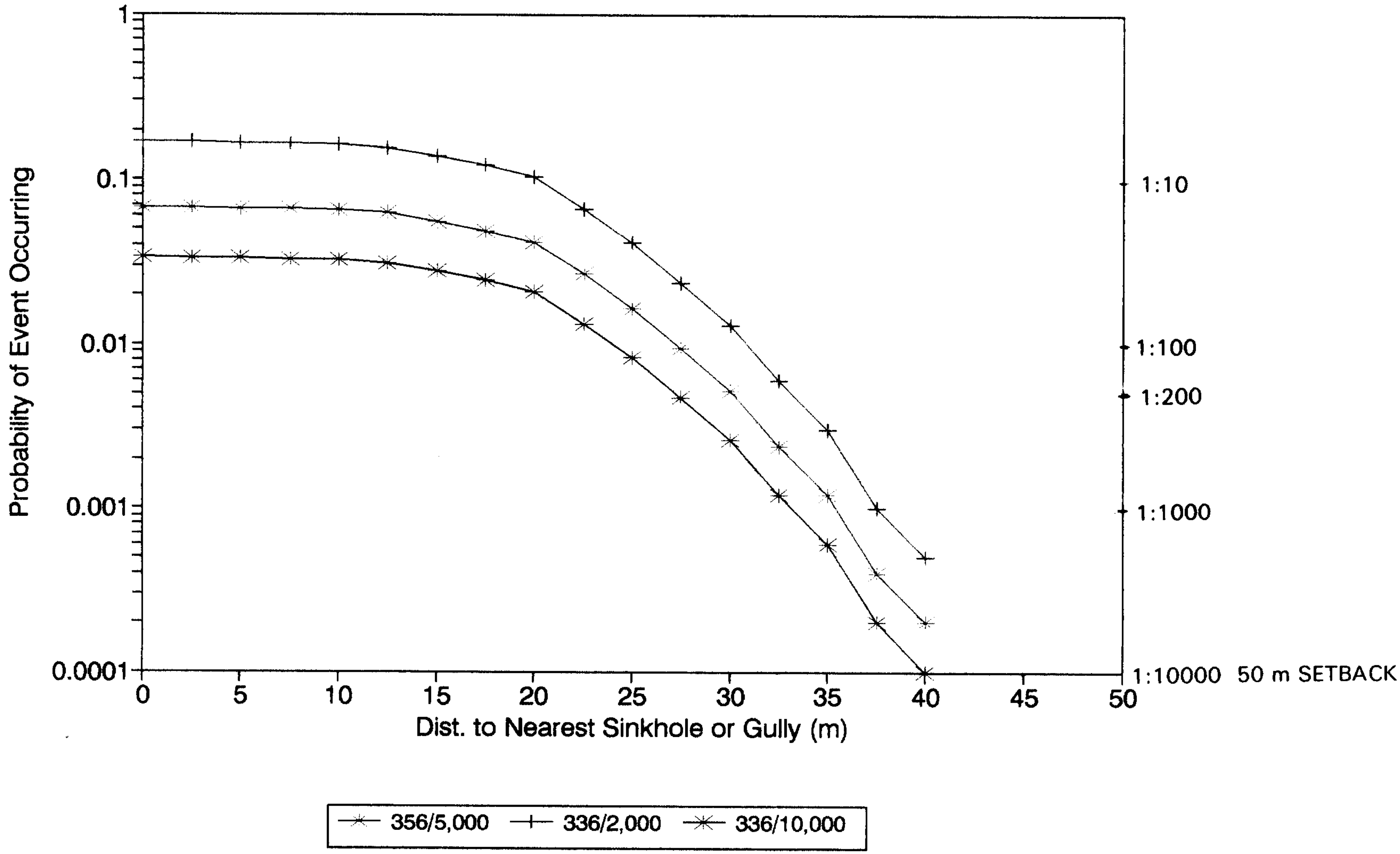
DISTANCE (m) VS. PROBABILITY

Probability Distribution



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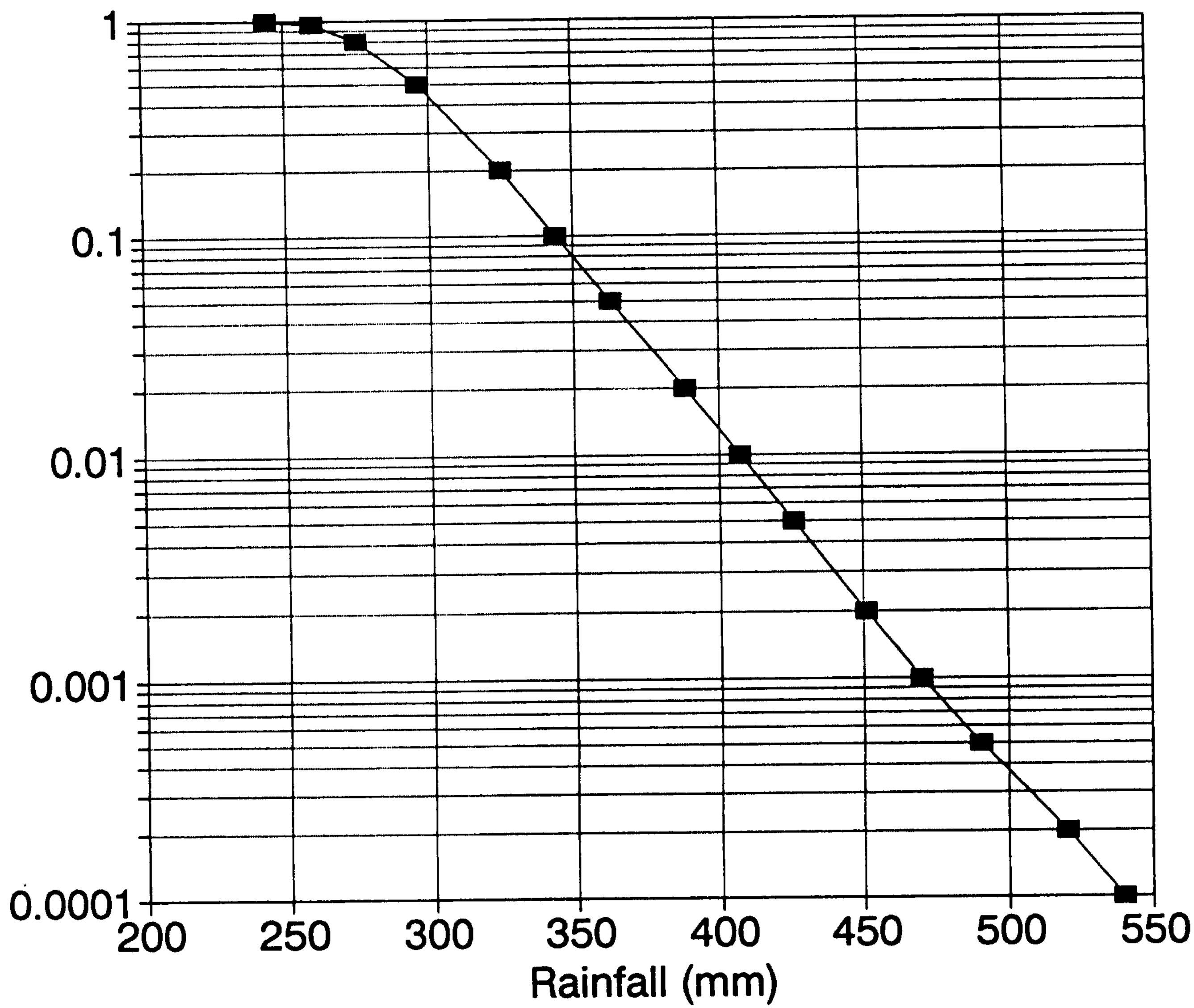
5-YEAR RAINFALL AVERAGE



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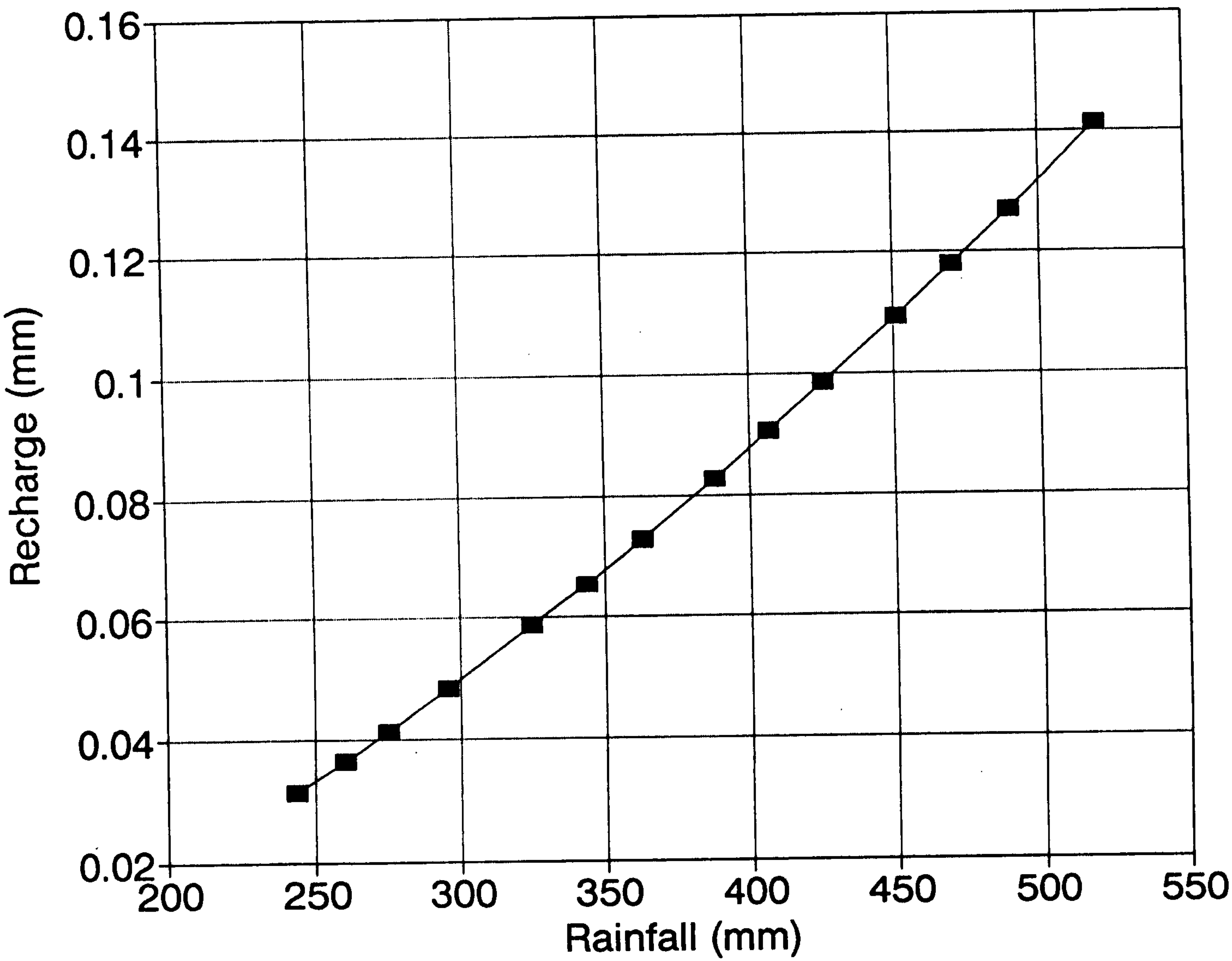
RECHARGE CURVE



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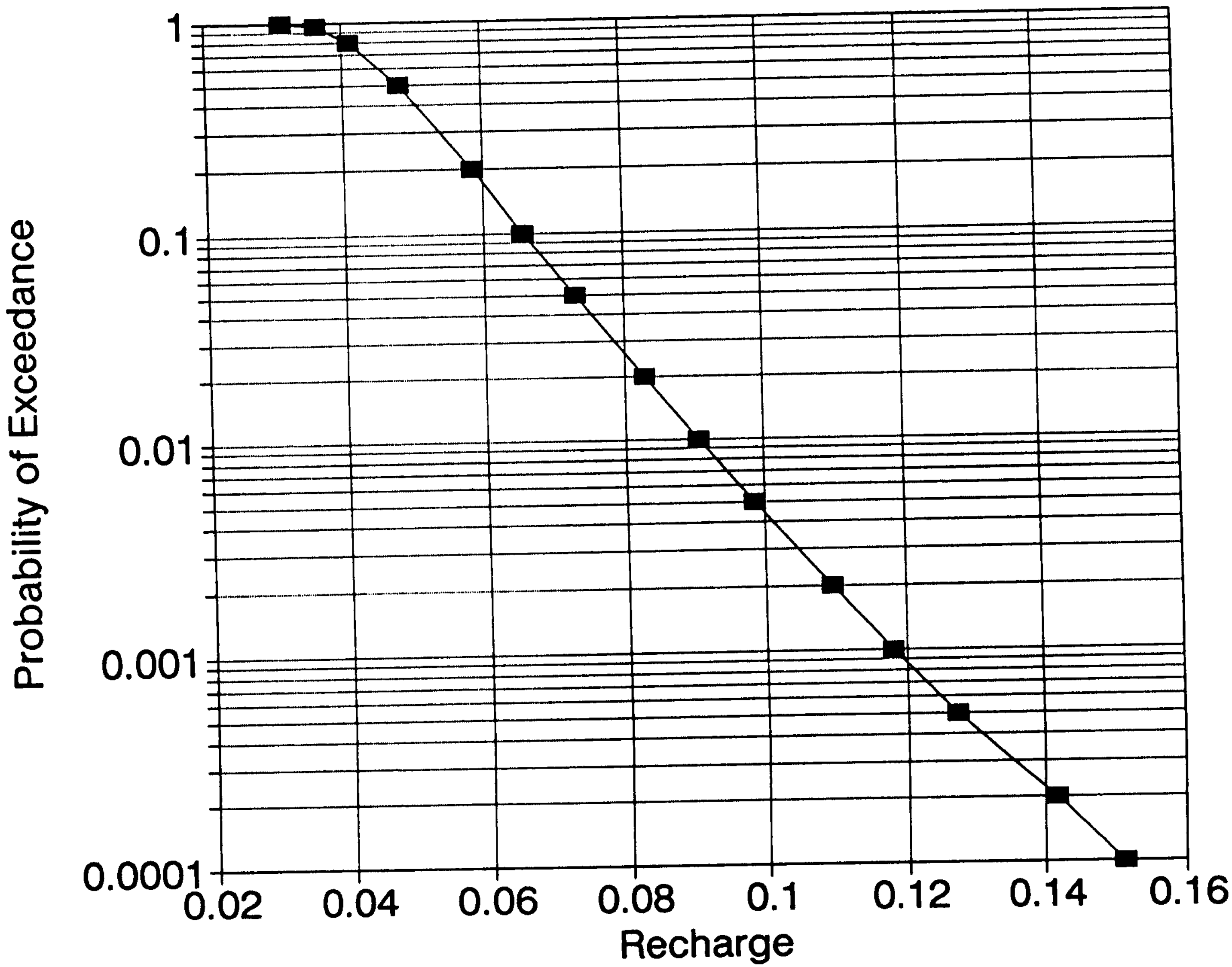
RECHARGE BASED ON 5-YEAR RAIN AVERAGE



RECHARGE VS. GRADIENT

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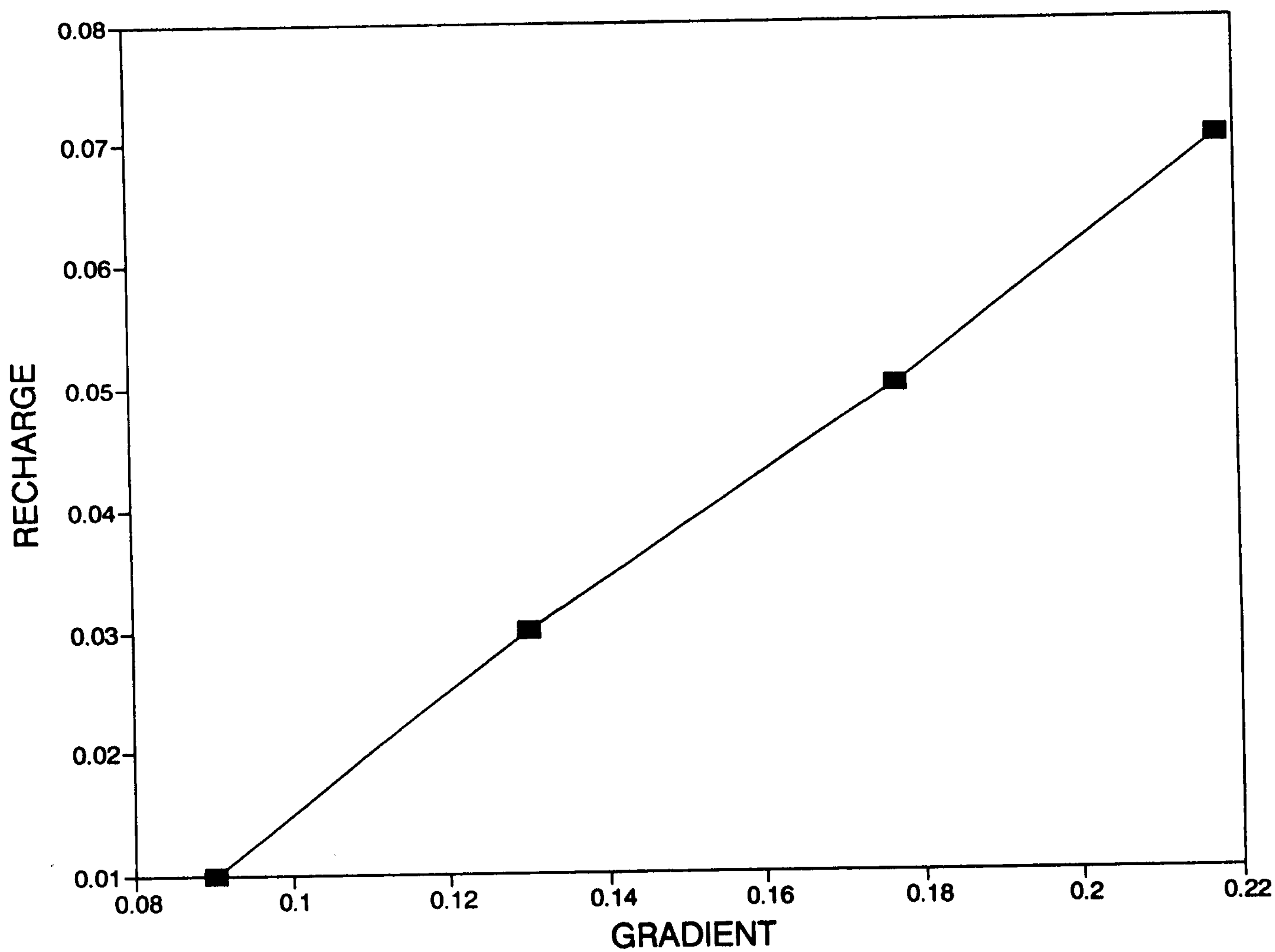

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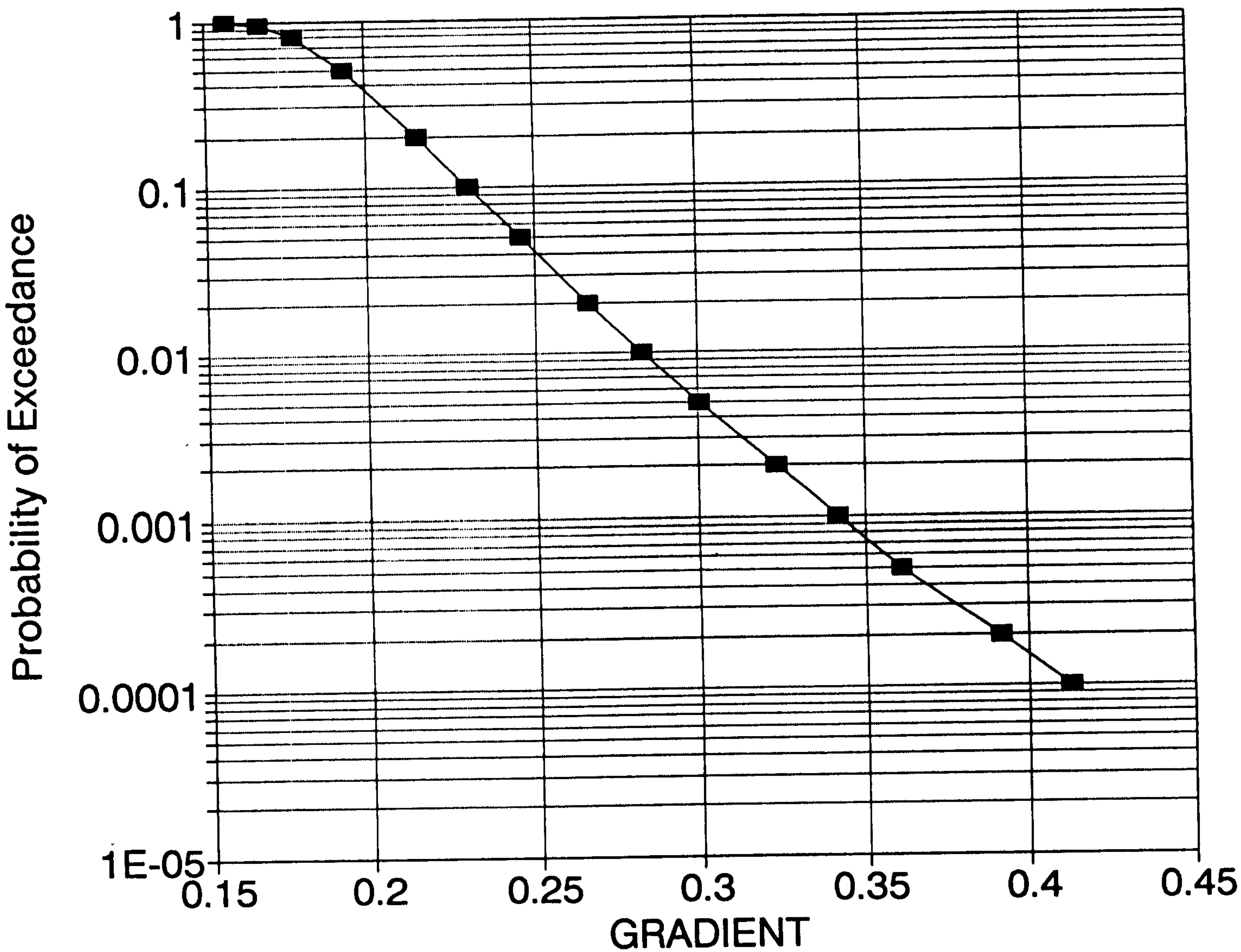
GRADIENT BASED ON 5-YEAR RAIN AVERAGE



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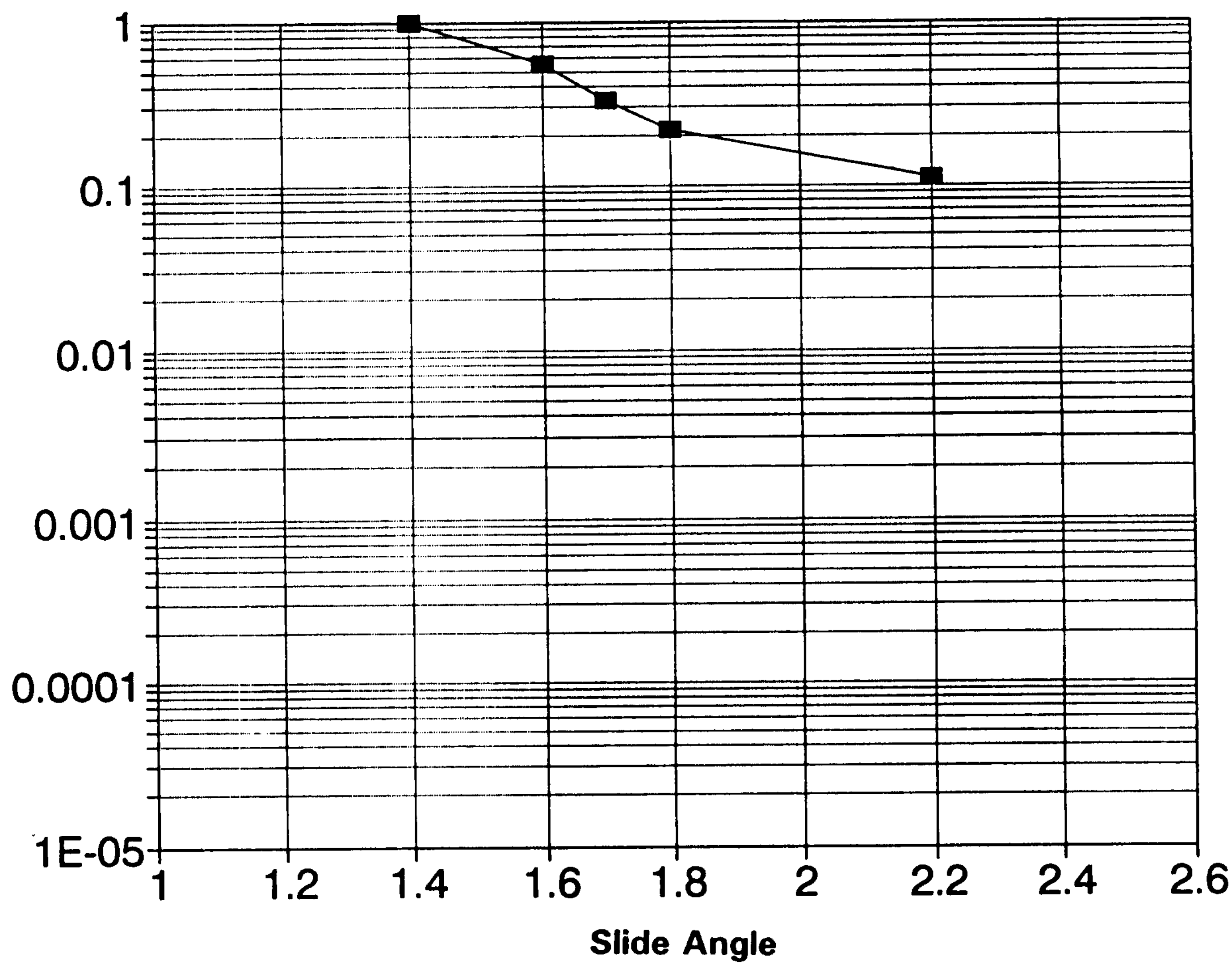
SLIDE ANGLE VS PROBABILITY OF EXCEEDANCE
Based on Precedent



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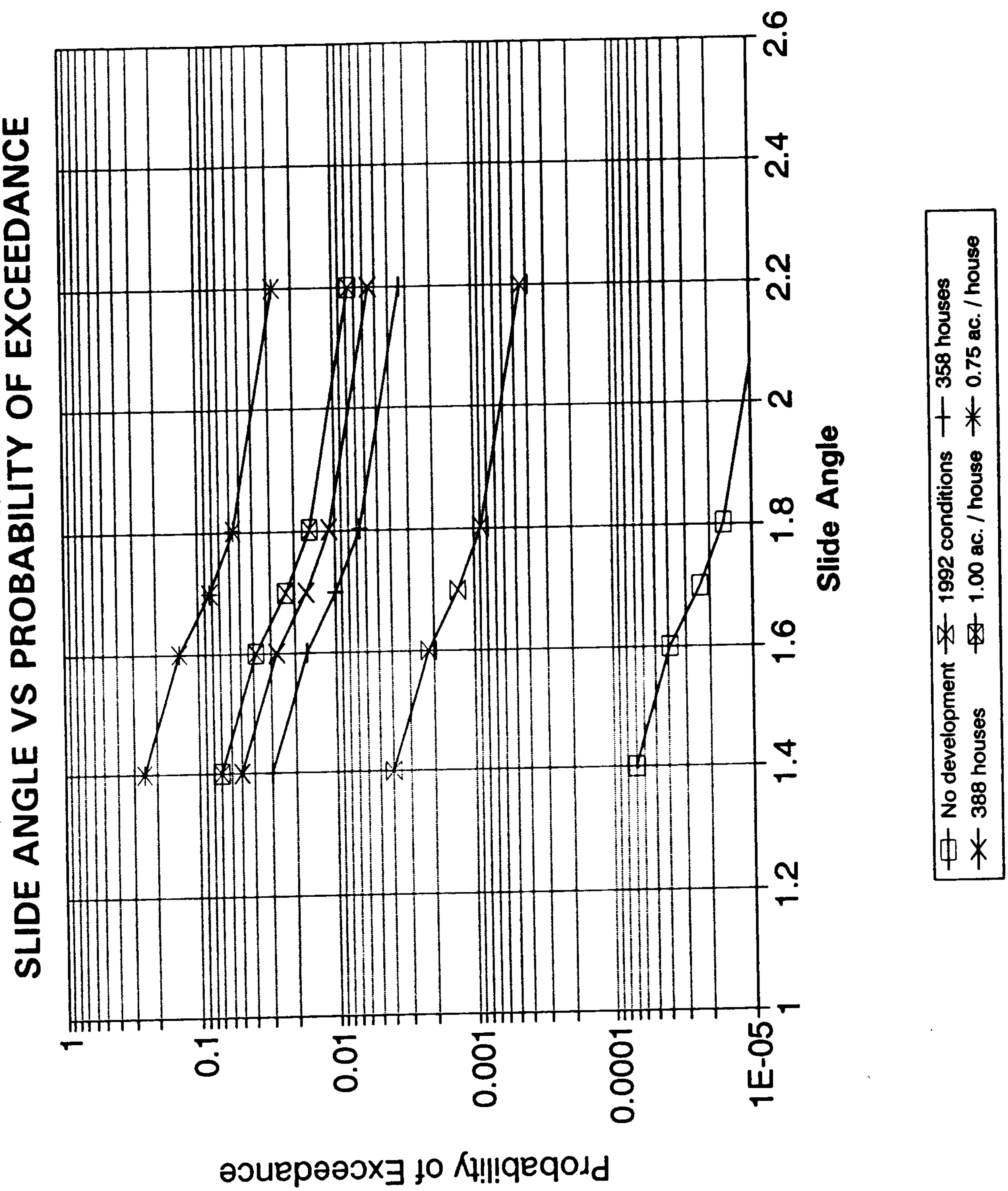

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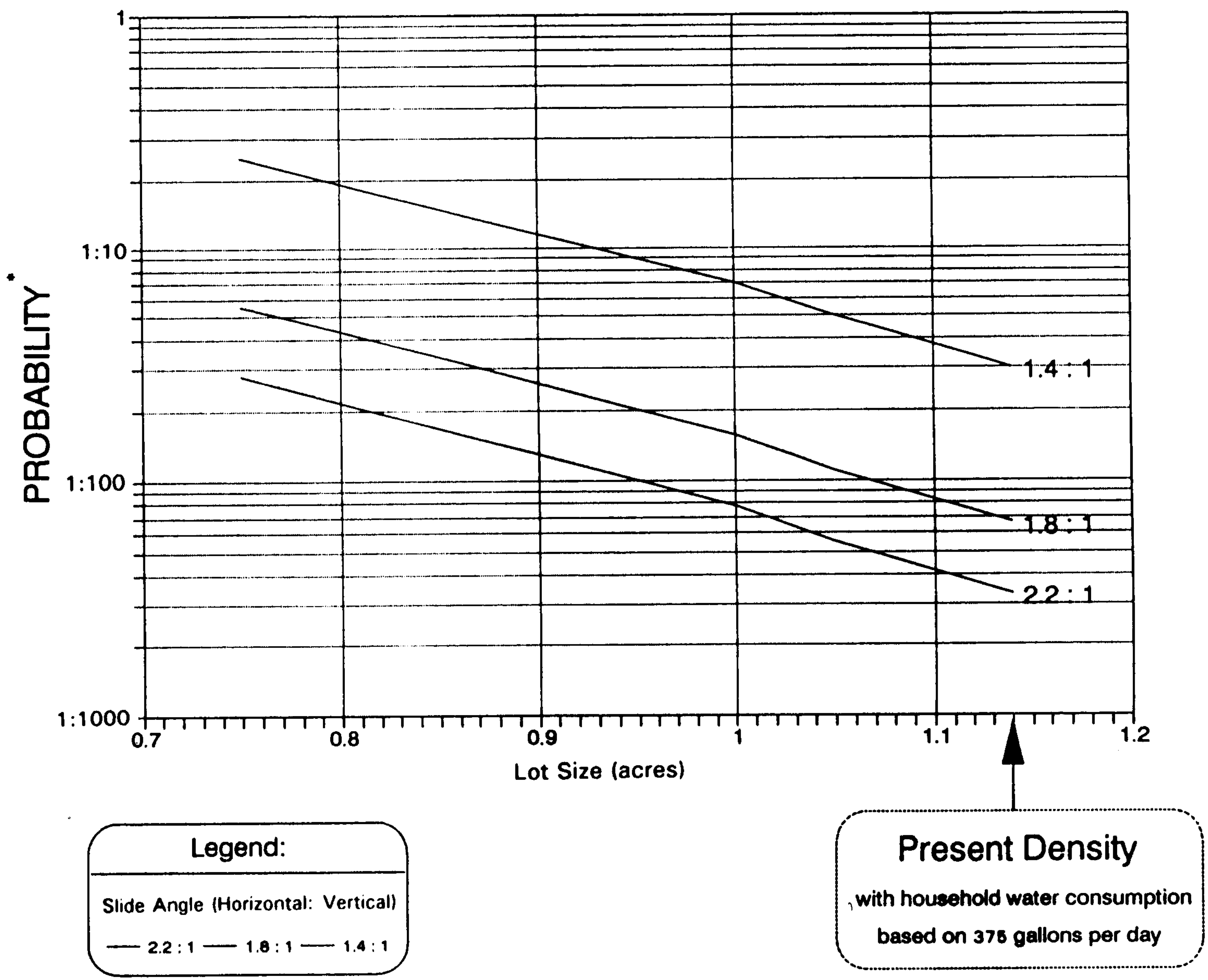
DENSITY VS PROBABILITY OF EXCEEDANCE



* Probability of Exceeding a Slide Angle

APPENDIX III

GEOPHYSICS

Geophysical Dipole-Dipole Resistivity Investigation

Introduction

On march 13 and 14 1992, a small program of dipole-dipole apparent resistivity was carried out at the Pine Hills Golf course, on the West Bench in Penticton, B.C..
The objective was to assess the effectiveness of the resistivity method in an area prone to sinkhole development in mapping out possible ground water flow and voids which would indicate pipes or caved areas within the silt formation.
The resistivity survey consisted of 3 lines totalling 800 metres of dipole-dipole profiling with a 7 separation coverage.

Instrumentation and Survey Procedure

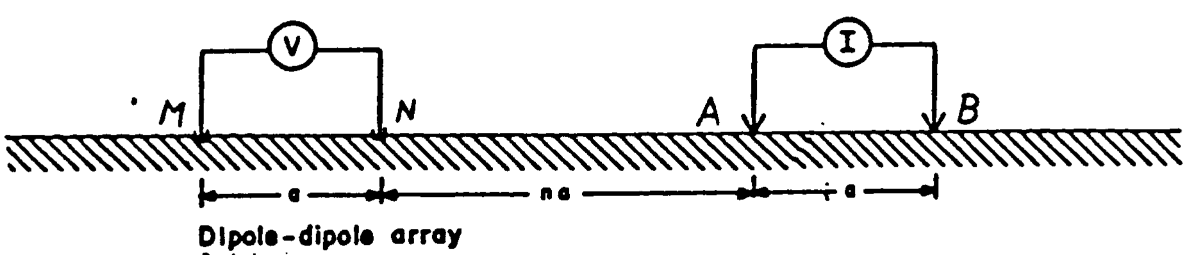
Instrumentation

The resistivity survey was carried out using an ABEM SAS 300B resistivitimeter with stainless steel electrodes and one 100 metre, 26 conductor cable.

Dipole-dipole survey

The 'a-na-a' dipole-dipole array is defined as having 4 collinear electrodes with 2 current electrodes on one end and 2 potential electrodes on the other. The current electrodes are separated by a distance 'a', which is also the separation between potential electrodes. The distance between the near electrodes (one current and one potential) is 'na', where n represen ts the number of separations.
The dipole-dipole configuration allows for definition of both horizontal and vertical locations of discreet resistivity anomalies (sinkholes and zones of piping).
An 'a' spacing of 10 metres was employed with 'n' values ranging from 1 to 7 .
The dipole-dipole survey was carried out over three North-South trending line with a 20 m spacing between lines and 10 m between stations along the surveyed lines.

Fig, 1 Schematic diagram of dipole-dipole electrodes configuration.



Data processing

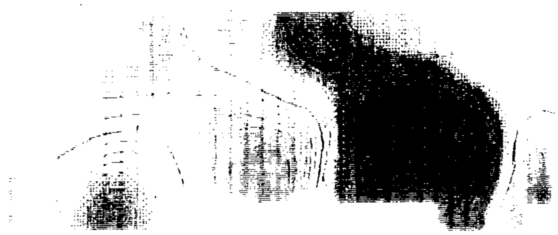
The dipole-dipole data was reduced and resistivity values plotted for each line in a 2D "pseudosection" to give a simultaneous display of both horizontal and vertical variations in apparent resistivity. The conventional presentation places each value measured at the intersection of two 45-degree lines through the centre of the dipoles. Each horizontal data line is associated with a specific value of n and, by implication, with a given "effective depth of investigation".
The plotted data were then gridded using a 5 m grid cell; the resulting gridded data were assigned colours in a logarithmic distribution. The 3 resulting false colour pseudosections are presented in Appendix.
The resistivity data was also plotted in plan for each one of the seven "n" separations, gridded using a 5 m grid cell and contoured to create an apparent resistivity colour map for each pseudo "n" level.

Interpretation

Vertical pseudosections and level "n=1" resistivity map indicate most significantly that colluvium and reworked (collapsed silt) can be easily discerned from the lacustrine silt by a much higher recorded resistivity values. Resistivity values calculated using the resistivity interpretation program RESIXP range between 150 to 400 ohm/m for the colluvium and reworked silt and 20 to 40 ohm/m for the lacustrine silt.
A high resistivity anomaly on maps for levels "n=3" to "n=7" could be associated with an open void (developing sinkhole) with an easterly dipping pipe at level "n=7".
A second high resistivity anomaly on maps for levels "n=4" to "n=7" could indicate another large void. This anomaly is in line with a serie of sinkhole, directly East and West of the surveyed area.

Conclusions

Resistivity can be used to detect and map with considerable accuracy, the discontinuity between colluvial silt and in place lacustrine silt on the silt benches in the Penticton area. It also clear from the results that actively developing sinkholes are readily detectable with the dipole-dipole resistivity method and that this geophysical method holds considerable promise as a tool to locate and map otherwise undetectable zones along which sinkhole activity may develop.



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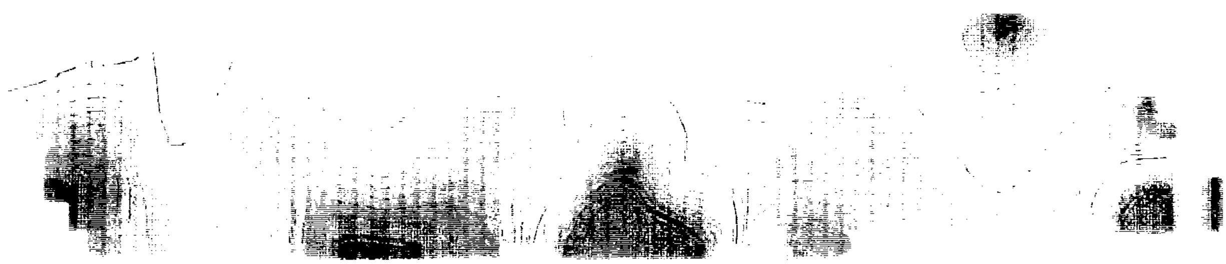

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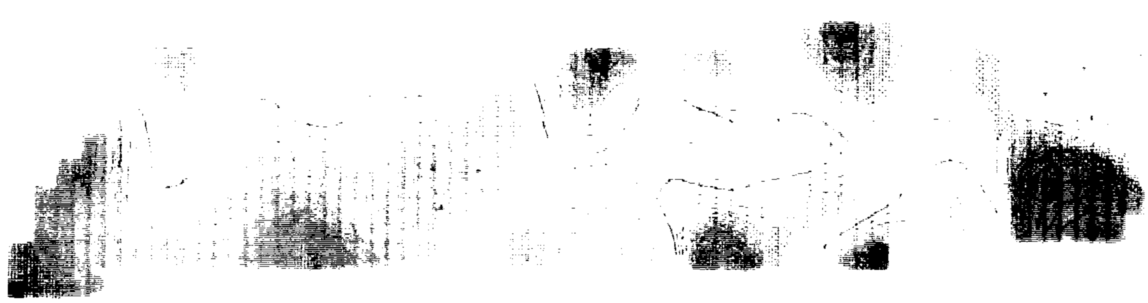


Survey Line 1

SCALE

KLOHN LEONOFF LTD.

PROJECT: WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW

TITLE: DIPOLE–DIPOLE RESISTIVITY SURVEY PSEUDO – SECTIONS

CLIENT: REGIONAL DISTRICT OF OKANAGAN–SIMILKAMEEN

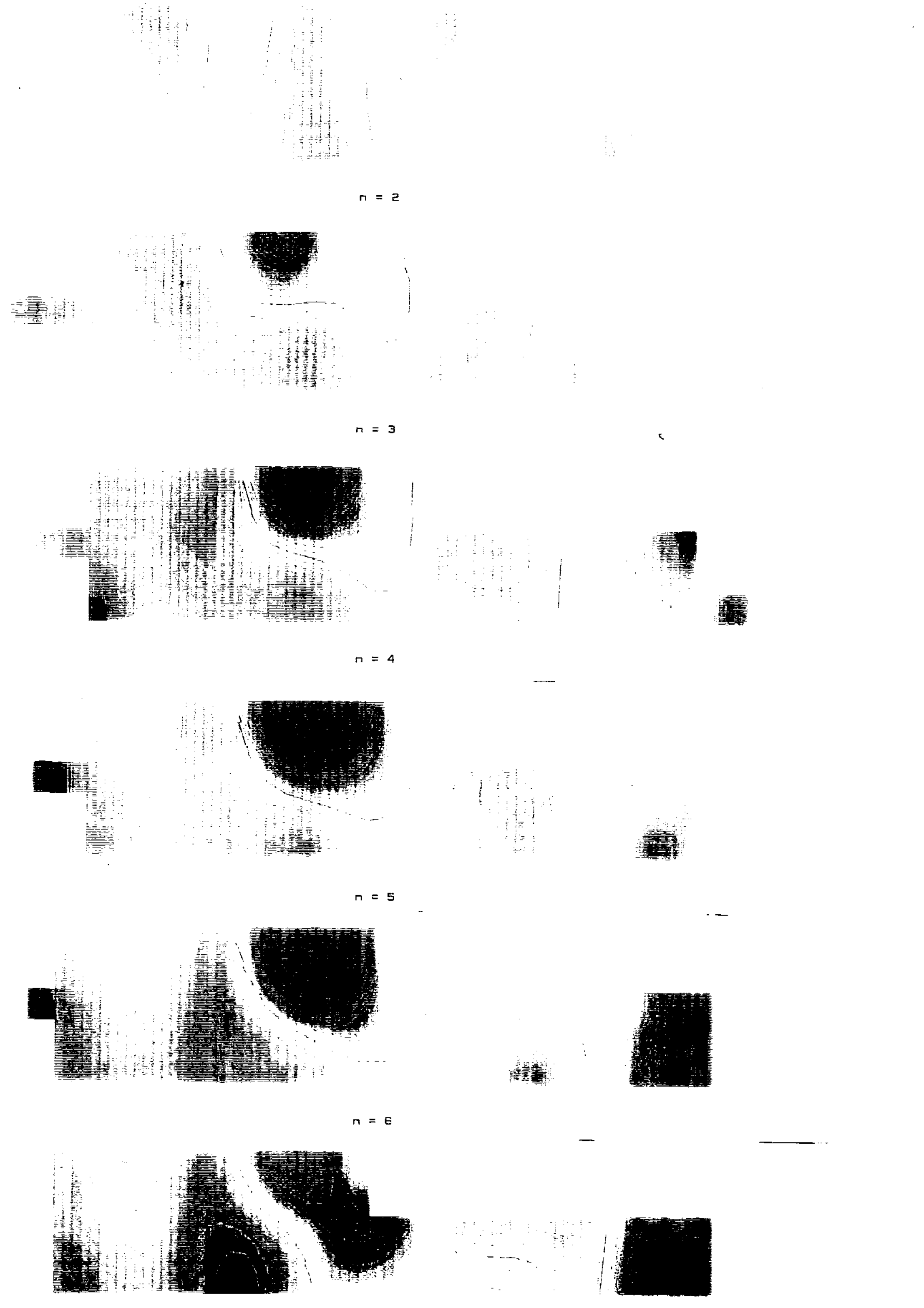
DATE OF ISSUE: AUG 10, 1992

APPROVED: ER Aug/92

PROJECT No.: PB5847 01

DWG. No.: APP.III–1

REV.



SCALE

KLOHN LEONOFF LTD.

PROJECT: WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW

TITLE: DIPOLE–DIPOLE RESISTIVITY SURVEY RESISTIVITY MAPS (SEPARATIONS n=2 TO n=7)

CLIENT: REGIONAL DISTRICT OF OKANAGAN–SIMILKAMEEN

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
AUG 10, 1992	PB5847 01	APP.III–2	

APPROVED: ER AUG/92

APPENDIX IV

WATER BALANCE

General Water Balance	1	2	3	4	5	6	7	8	9	10	TOTAL
To / From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation	X	X	X	X	X	X	X	X	X	X	0
2 Irrigation	X	X	X	X	X	X	X	X	X	X	0
3 Domestic	X	X	X	X	X	X	X	X	X	X	0
4 Catchment	5,360,000	0	0	X	X	X	X	X	X	X	5,360,000
5 Roads and Roofs	0	X	X	X	X	X	X	X	X	X	0
6 Gravel	1,340,000	0	0	1,393,600	0	X	0	X	X	X	2,733,600
7 Silt	670,000	0	0	X	0	0	X	X	X	X	670,000
8 Sub-silt	X	X	X	X	X	35,537	40,200	X	X	X	75,737
9 Evapotranspiration	X	X	X	3,966,400	0	2,022,864	495,800	X	X	X	6,485,064
10 Lake	X	X	X	X	X	675,199	134,000	75,737	X	X	884,936
Flows are in cubic metres per year											
TOTAL FROM UNIT	7,370,000	0	0	5,360,000	0	2,733,600	670,000	75,737	0	0	16,209,337

West Bench

0 houses
545 acres
0 gallons per day (1991 consumption average)

Flow through silt to sub-silt (in rainfall equivalent)
0.0201 m/yr/m²

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General Water Balance Notes

FROM	TO	NOTES
Precipitation	Catchment	Average rain (0.355 m.) over catchment (16,000,000 m^2)
Precipitation	Roads and Roofs	None
Precipitation	Gravel	Average rain (0.355 m.) over gravel (4,000,000 m^2)
Precipitation	Silt	Average rain (0.355 m.) over silt (2,000,000 m^2)
Irrigation	Catchment	None
Irrigation	Gravel	None
Irrigation	Silt	None
Domestic	Catchment	None
Domestic	Gravel	None
Domestic	Silt	None
Catchment	Gravel	26% of catchment water goes to gravel
Catchment	Evapotranspiration	74% of catchment water goes to evapotranspiration
Roads and Roofs	Gravel	None
Roads and Roofs	Silt	None
Roads and Roofs	Evapotranspiration	None
Gravel	Silt	No water flows from the gravel to the silt
Gravel	Sub-silt	1.2% of water in the gravel flows to the sub-silt
Gravel	Evapotranspiration	74% of water in the gravel is evapotranspired
Gravel	Lake	24.70% of the water in the gravel flows out the gullies into the lake
Silt	Gravel	No water flows from the silt to the gravel
Silt	Sub-silt	6% of precipitation moves through the silt to the sub-silt
Silt	Evapotranspiration	74% of precipitation is evapotranspired
Silt	Lake	20% of precipitation runs off into the lake
Sub-silt	Lake	All if the sub-silt water flows out to the lake

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General Water Balance	1	2	3	4	5	6	7	8	9	10	TOTAL
To From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation	X	X	X	X	X	X	X	X	X	X	0
2 Irrigation	X	X	X	X	X	X	X	X	X	X	0
3 Domestic	X	X	X	X	X	X	X	X	X	X	0
4 Catchment	5,360,000	61,000	17,500	X	X	X	X	X	X	X	5,438,500
5 Roads and Roofs	16,750	X	X	X	X	X	X	X	X	X	16,750
6 Gravel	1,340,000	108,600	24,679	1,414,010	2,345	X	0	X	X	X	2,889,634
7 Silt	670,000	473,400	114,715	X	9,380	0	X	X	X	X	1,267,495
8 Sub-silt	X	X	X	X	X	37,565	86,086	X	X	X	123,651
9 Evapotranspiration	X	X	X	4,024,490	5,025	2,138,329	1,003,615	X	X	X	7,171,459
10 Lake	X	X	X	X	X	713,740	177,795	123,651	X	X	1,015,186
Flows are in cubic metres per year											
TOTAL FROM UNIT	7,386,750	643,000	156,894	5,438,500	16,750	2,889,634	1,267,495	123,651	0	0	17,922,675

West Bench
358 houses
545 acres
208 gallons per day (1991 consumption rate)

Flow through silt to sub-silt (in rainfall equivalent)
0.0430 m/yr/m²

Average lot size in West Bench (25% of area for roads)
1.14 acres per lot

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General Water Balance		1	2	3	4	5	6	7	8	9	10	TOTAL
To	From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation		X	X	X	X	X	X	X	X	X	X	0
2 Irrigation		X	X	X	X	X	X	X	X	X	X	0
3 Domestic		X	X	X	X	X	X	X	X	X	X	0
4 Catchment		5,360,000	61,000	17,500	X	X	X	X	X	X	X	5,438,500
5 Roads and Roofs		16,750	X	X	X	X	X	X	X	X	X	16,750
6 Gravel		1,340,000	108,600	44,493	1,414,010	2,345	X	0	X	X	X	2,909,448
7 Silt		670,000	473,400	193,973	X	9,380	0	X	X	X	X	1,346,753
8 Sub-silt		X	X	X	X	X	37,823	117,789	X	X	X	155,612
9 Evapotranspiration		X	X	X	4,024,490	5,025	2,152,992	1,027,392	X	X	X	7,209,898
10 Lake		X	X	X	X	X	718,634	201,572	155,612	X	X	1,075,817
Flows are in cubic metres per year												
TOTAL FROM UNIT		7,386,750	643,000	255,966	5,438,500	16,750	2,909,448	1,346,753	155,612	0	0	18,152,778

West Bench
358 houses
545 acres
375 gallons per day (1991 consumption average)

Flow through silt to sub-silt (in rainfall equivalent)
0.0589 m/yr/m²

Average lot size in West Bench (25% of area for roads)
1.14 acres per lot

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General Water Balance		1	2	3	4	5	6	7	8	9	10	TOTAL
To	From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation		X	X	X	X	X	X	X	X	X	X	0
2 Irrigation		X	X	X	X	X	X	X	X	X	X	0
3 Domestic		X	X	X	X	X	X	X	X	X	X	0
4 Catchment		5,360,000	61,000	17,500	X	X	X	X	X	X	X	5,438,500
5 Roads and Roofs		16,750	X	X	X	X	X	X	X	X	X	16,750
6 Gravel		1,340,000	108,600	48,222	1,414,010	2,345	X	0	X	X	X	2,913,177
7 Silt		670,000	473,400	208,886	X	9,380	0	X	X	X	X	1,361,666
8 Sub-silt		X	X	X	X	X	37,871	123,755	X	X	X	161,626
9 Evapotranspiration		X	X	X	4,024,490	5,025	2,155,751	1,031,866	X	X	X	7,217,132
10 Lake		X	X	X	X	X	719,555	206,046	161,626	X	X	1,087,226
Flows are in cubic metres per year												
TOTAL FROM UNIT		7,386,750	643,000	274,608	5,438,500	16,750	2,913,177	1,361,666	161,626	0	0	18,196,077

West Bench

388 houses

545 acres

375 gallons per day (1991 consumption average)

Flow through silt to sub-silt (in rainfall equivalent)

0.0619 m/yr/m²

Average lot size in West Bench (25% of area for roads)

1.05 acres per lot

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General Water Balance		1	2	3	4	5	6	7	8	9	10	TOTAL
To	From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation		X	X	X	X	X	X	X	X	X	X	0
2 Irrigation		X	X	X	X	X	X	X	X	X	X	0
3 Domestic		X	X	X	X	X	X	X	X	X	X	0
4 Catchment		5,360,000	61,000	17,500	X	X	X	X	X	X	X	5,438,500
5 Roads and Roofs		16,750	X	X	X	X	X	X	X	X	X	16,750
6 Gravel		1,340,000	108,600	50,956	1,414,010	2,345	X	0	X	X	X	2,915,911
7 Silt		670,000	473,400	219,823	X	9,380	0	X	X	X	X	1,372,603
8 Sub-silt		X	X	X	X	X	37,907	128,129	X	X	X	166,036
9 Evapotranspiration		X	X	X	4,024,490	5,025	2,157,774	1,035,147	X	X	X	7,222,436
10 Lake		X	X	X	X	X	720,230	209,327	166,036	X	X	1,095,593
Flows are in cubic metres per year												
TOTAL FROM UNIT		7,386,750	643,000	288,279	5,438,500	16,750	2,915,911	1,372,603	166,036	0	0	18,227,829

West Bench

410 houses

545 acres

375 gallons per day (1991 consumption average)

Flow through silt to sub-silt (in rainfall equivalent)

0.0641 m/yr/m²

Average lot size in West Bench (25% of area for roads)

1.00 acres per lot

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General Water Balance		1	2	3	4	5	6	7	8	9	10	TOTAL
To	From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation		X	X	X	X	X	X	X	X	X	X	0
2 Irrigation		X	X	X	X	X	X	X	X	X	X	0
3 Domestic		X	X	X	X	X	X	X	X	X	X	0
4 Catchment		5,360,000	61,000	17,500	X	X	X	X	X	X	X	5,438,500
5 Roads and Roofs		16,750	X	X	X	X	X	X	X	X	X	16,750
6 Gravel		1,340,000	108,600	67,734	1,414,010	2,345	X	0	X	X	X	2,932,689
7 Silt		670,000	473,400	286,936	X	9,380	0	X	X	X	X	1,439,716
8 Sub-silt		X	X	X	X	X	38,125	154,974	X	X	X	193,099
9 Evapotranspiration		X	X	X	4,024,490	5,025	2,170,190	1,055,281	X	X	X	7,254,986
10 Lake		X	X	X	X	X	724,374	229,461	193,099	X	X	1,146,934
Flows are in cubic metres per year												
TOTAL FROM UNIT		7,386,750	643,000	372,170	5,438,500	16,750	2,932,689	1,439,716	193,099	0	0	18,422,674

West Bench

545 houses

545 acres

375 gallons per day (1991 consumption average)

Flow through silt to sub-silt (in rainfall equivalent)

0.0775 m/yr/m²

Average lot size in West Bench (25% of area for roads)

0.75 acres per lot

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General Water Balance		1	2	3	4	5	6	7	8	9	10	TOTAL
To	From »	Precip.	Irr.	Domestic	Catchment	Roads ...	Gravel	Silt	Sub-silt	Evap.	Lake	INTO UNIT
1 Precipitation		X	X	X	X	X	X	X	X	X	X	0
2 Irrigation		X	X	X	X	X	X	X	X	X	X	0
3 Domestic		X	X	X	X	X	X	X	X	X	X	0
4 Catchment		5,360,000	61,000	17,500	X	X	X	X	X	X	X	5,438,500
5 Roads and Roofs		16,750	X	X	X	X	X	X	X	X	X	16,750
6 Gravel		1,340,000	108,600	102,533	1,414,010	2,345	X	0	X	X	X	2,967,488
7 Silt		670,000	473,400	426,132	X	9,380	0	X	X	X	X	1,578,912
8 Sub-silt		X	X	X	X	X	38,577	210,653	X	X	X	249,230
9 Evapotranspiration		X	X	X	4,024,490	5,025	2,195,941	1,097,040	X	X	X	7,322,496
10 Lake		X	X	X	X	X	732,970	271,220	249,230	X	X	1,253,419
Flows are in cubic metres per year												
TOTAL FROM UNIT		7,386,750	643,000	546,165	5,438,500	16,750	2,967,488	1,578,912	249,230	0	0	18,826,796

West Bench
825 houses
545 acres
375 gallons per day (1991 consumption average)

Flow through silt to sub-silt (in rainfall equivalent)
0.1053 m/yr/m²

Average lot size in West Bench (25% of area for roads)
0.50 acres per lot

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General Water Balance Notes

FROM	TO	NOTES
Precipitation	Catchment	Average rain (0.355 m.) over catchment (16,000,000 m^2)
Precipitation	Roads and Roofs	Average rain (0.355 m.) over roads and roofs (50,000 m^2)
Precipitation	Gravel	Average rain (0.355 m.) over gravel (4,000,000 m^2)
Precipitation	Silt	Average rain (0.355 m.) over silt (2,000,000 m^2)
Irrigation	Catchment	Irrigation water form Hsula Highlands and Pine Hills Golf Course (17,000 m3 + 44,000 m3)
Irrigation	Gravel	20 % of irrigation water from West Bench (0.2 * 543,000 m3)
Irrigation	Silt	Irrigation water from Sage Mesa and 80% from West Bench (39,000 + 0.8 * 543,000 m3)
Domestic	Catchment	Domestic water from Hsula Highlands (17,500 m3)
Domestic	Gravel	20 % of domestic water from West Bench
Domestic	Silt	Domestic water from Sage Mesa and 80% from West Bench (16,000 m3 + 0.8*West Bench)
Catchment	Gravel	26% of catchment water goes to gravel
Catchment	Evapotranspiration	74% of catchment water goes to evapotranspiration
Roads and Roofs	Gravel	20% of roads and roofs are in gravel areas and 70% of water goes into the ground
Roads and Roofs	Silt	80% of roads and roofs are in gravel areas and 70% of water goes into the ground
Roads and Roofs	Evapotranspiration	30% of water from roads and roofs is evapotranspired
Gravel	Silt	no water flows from the gravel to the silt
Gravel	Sub-silt	1.2% of water in the gravel flows to the sub-silt
Gravel	Evapotranspiration	74% of water in the gravel is evapotranspired
Gravel	Lake	24.70% ofwater in the gravel flows out the gullies into the lake
Silt	Gravel	no water flows from the silt to the gravel
Silt	Sub-silt	6% of precipitation and 60% of domentic water moves through the silt to the sub-silt
Silt	Evapotranspiration	All irrigation, 74% of precipitation and 30% of domestic water is evapotranspired
Silt	Lake	All road and roof drainage, 20% of precipitation and 30% of domestic water runs off into the lake
Sub-silt	Lake	All if the sub-silt water flows out to the lake

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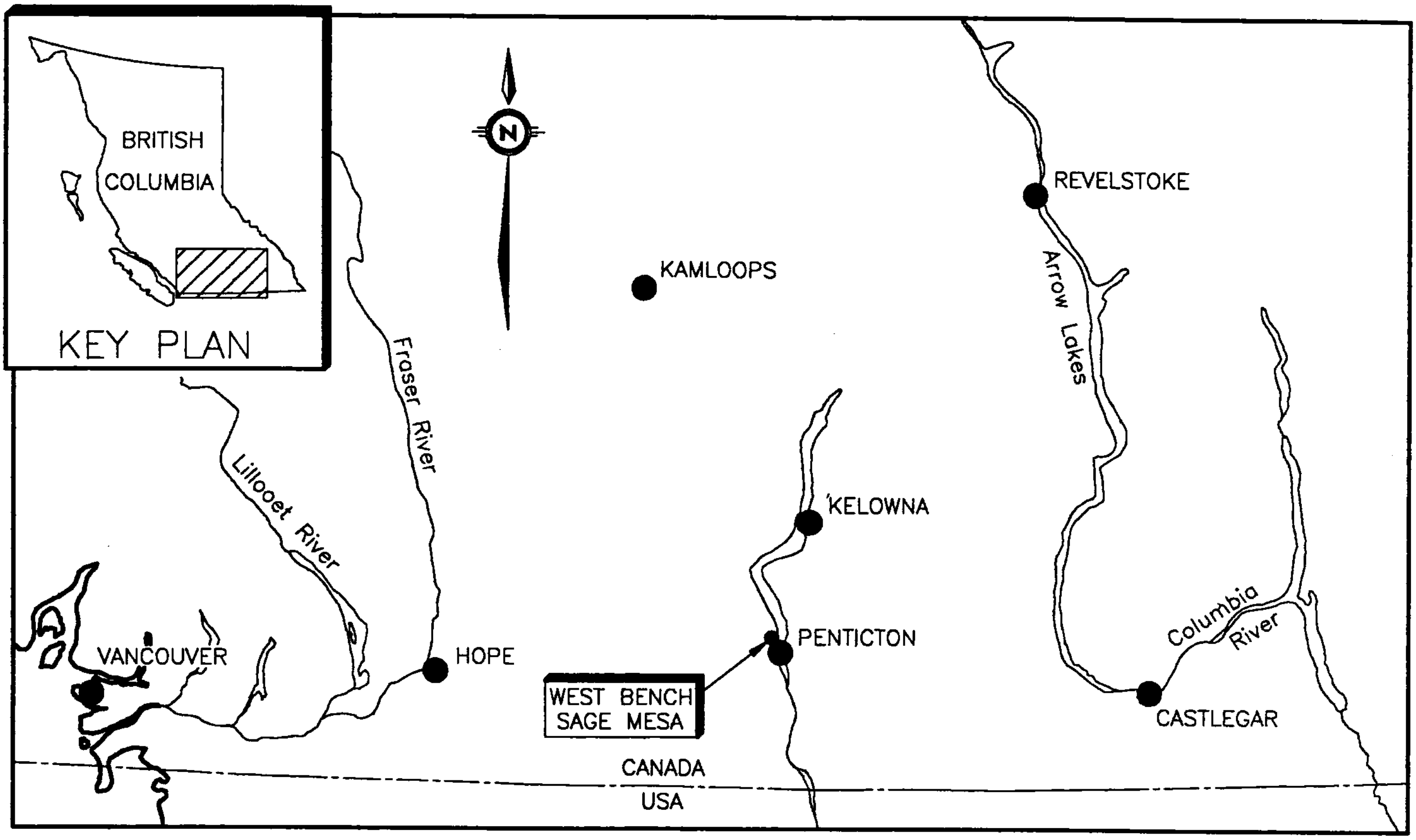
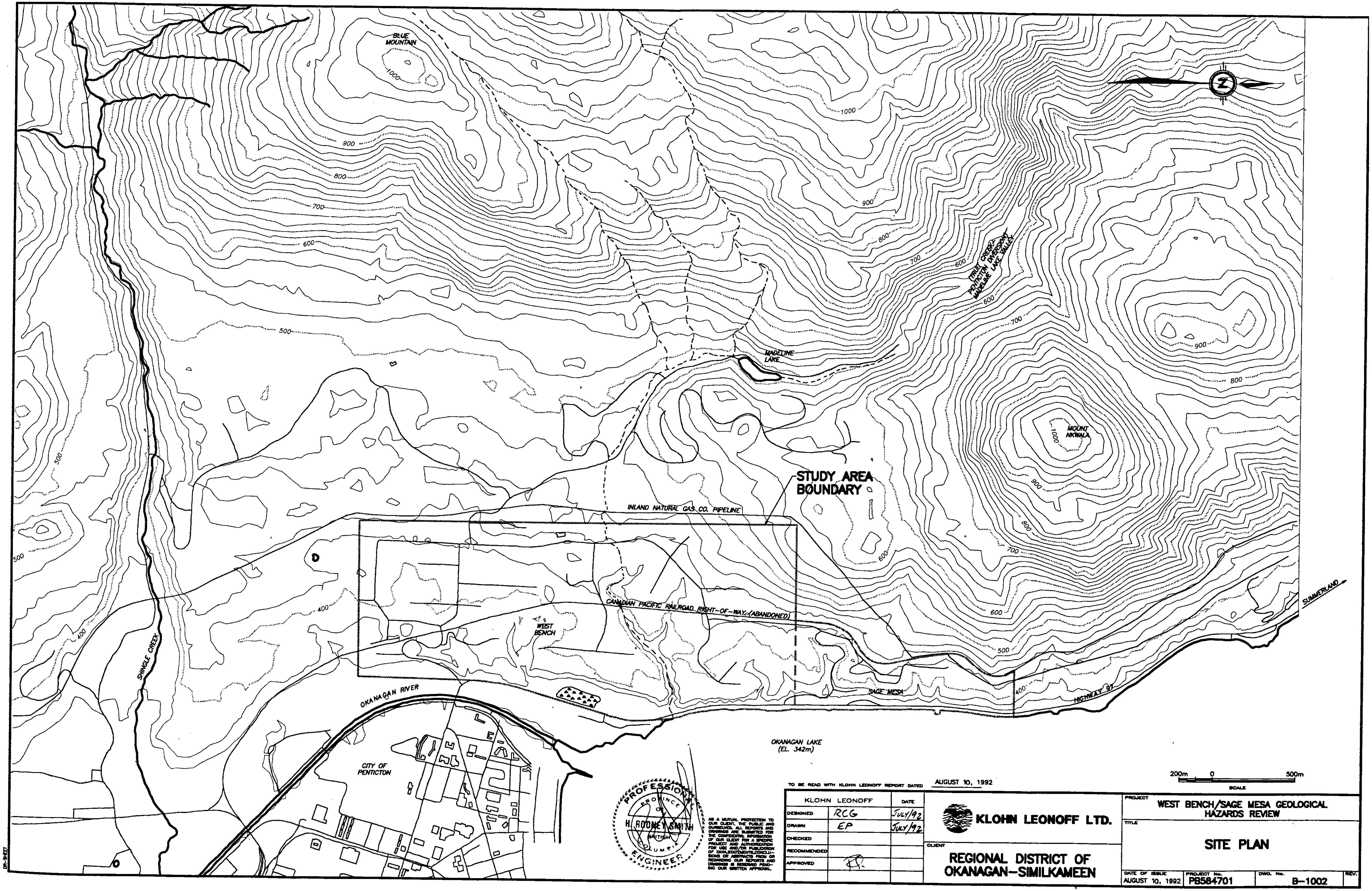
DRAWINGS



SCALE N.T.S.

KLOHN LEONOFF LTD.	PROJECT: WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW			
	TITLE: LOCATION PLAN			
CLIENT: REGIONAL DISTRICT OF OKANAGAN-SIMILKAMEEN	DATE OF ISSUE: AUG 10, 1992 APPROVED	PROJECT No.: PB584701	DWG. No.: A-1001	REV.



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TO BE READ WITH KLOHN LEONOFF REPORT DATED AUGUST 10, 1992

KLOHN LEONOFF		DATE
DESIGNED	RCG	JULY/92
DRAWN	EP	JULY/92
CHECKED		
RECOMMENDED		
APPROVED		

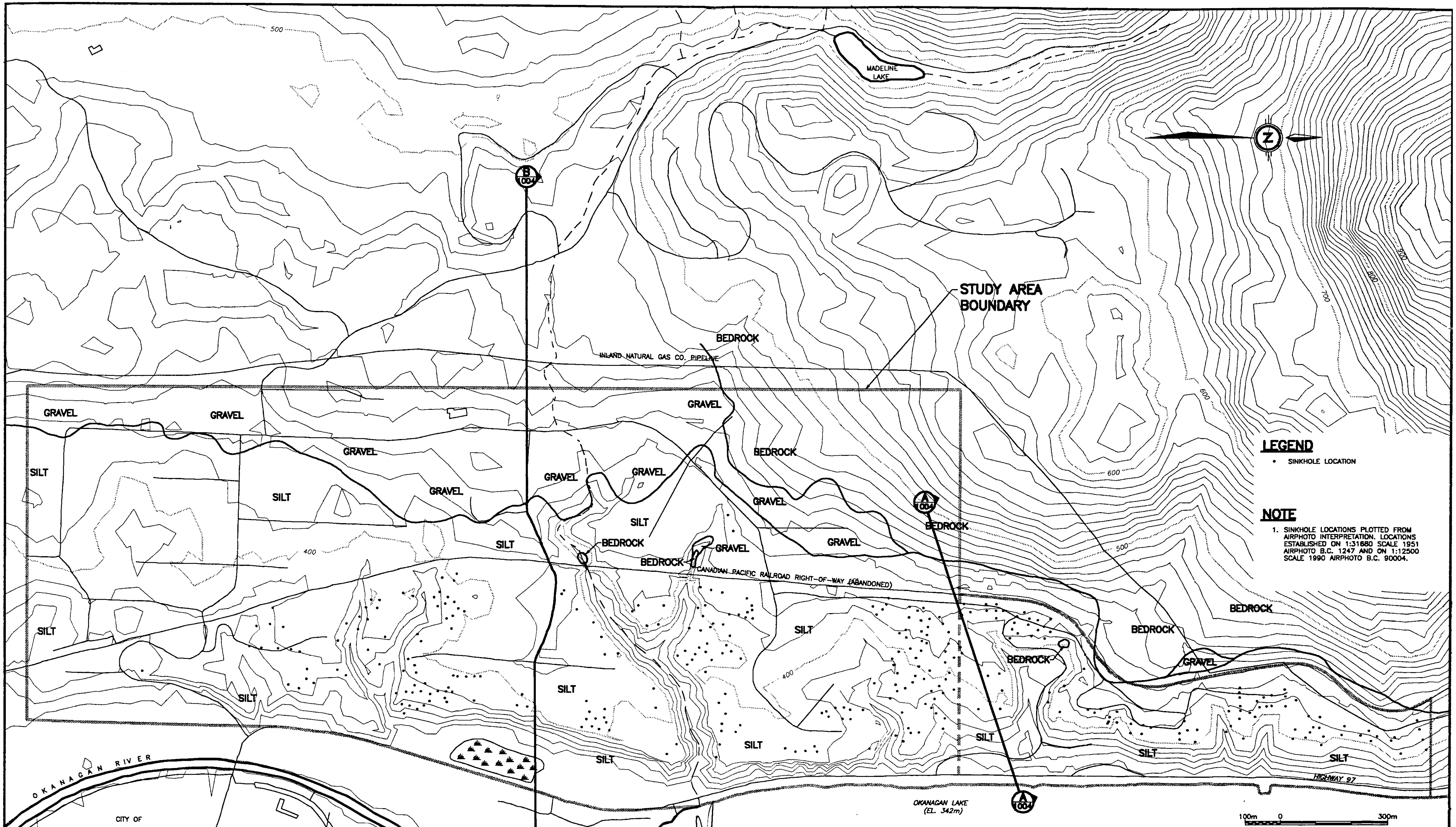
KLOHN LEONOFF LTD.

CLIENT: REGIONAL DISTRICT OF OKANAGAN-SIMILKAMEEN

PROJECT: WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW

TITLE: SITE PLAN

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
AUGUST 10, 1992	PB584701	B-1002	



TO BE READ WITH KLOHN LEONOFF REPORT DATED AUGUST 10, 1992

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KLOHN LEONOFF		DATE
DESIGNED	RCG	JULY/92
DRAWN	EP	JULY/92
CHECKED		
RECOMMENDED		
APPROVED	[signature]	

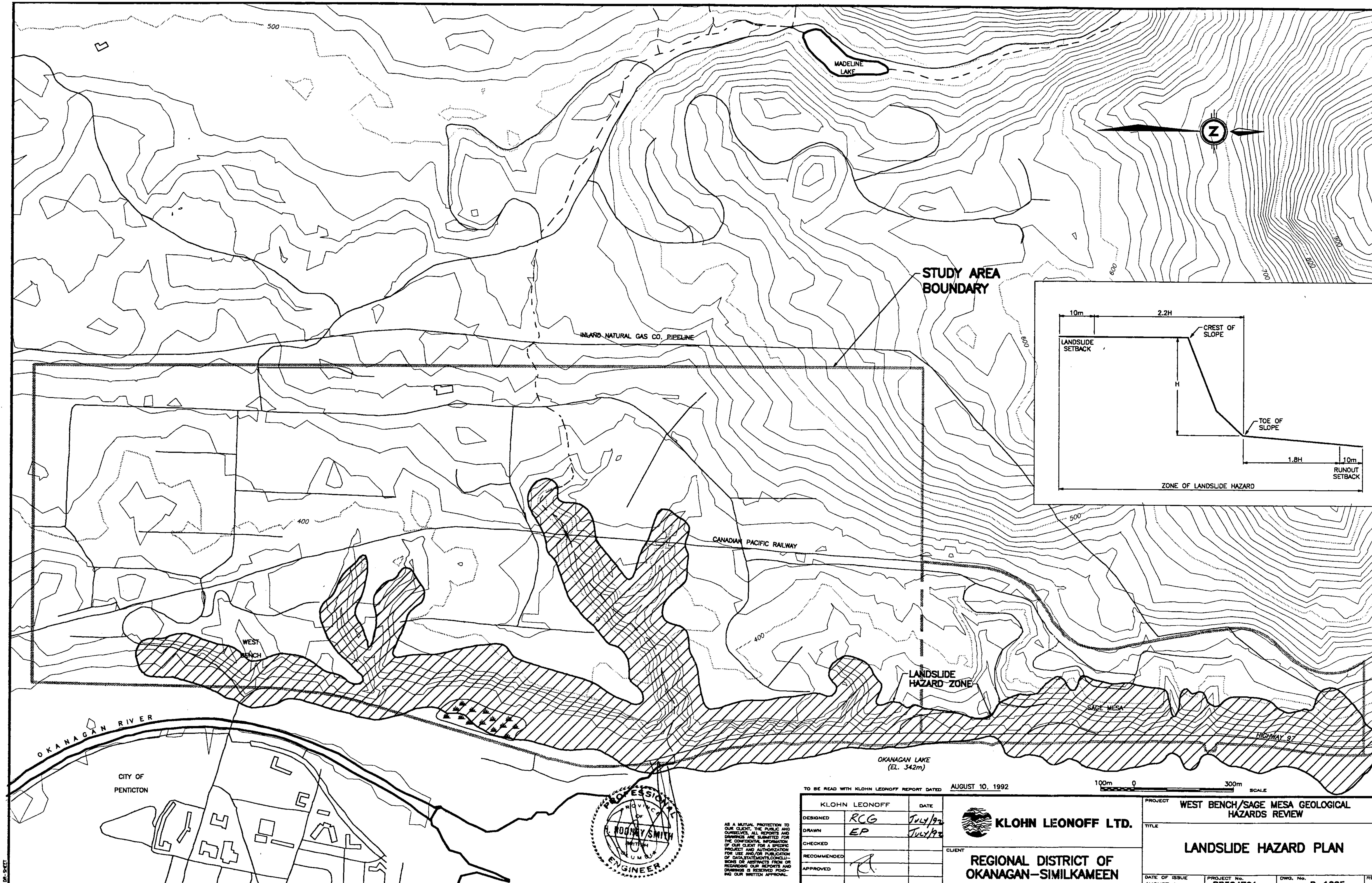
KLOHN LEONOFF LTD.

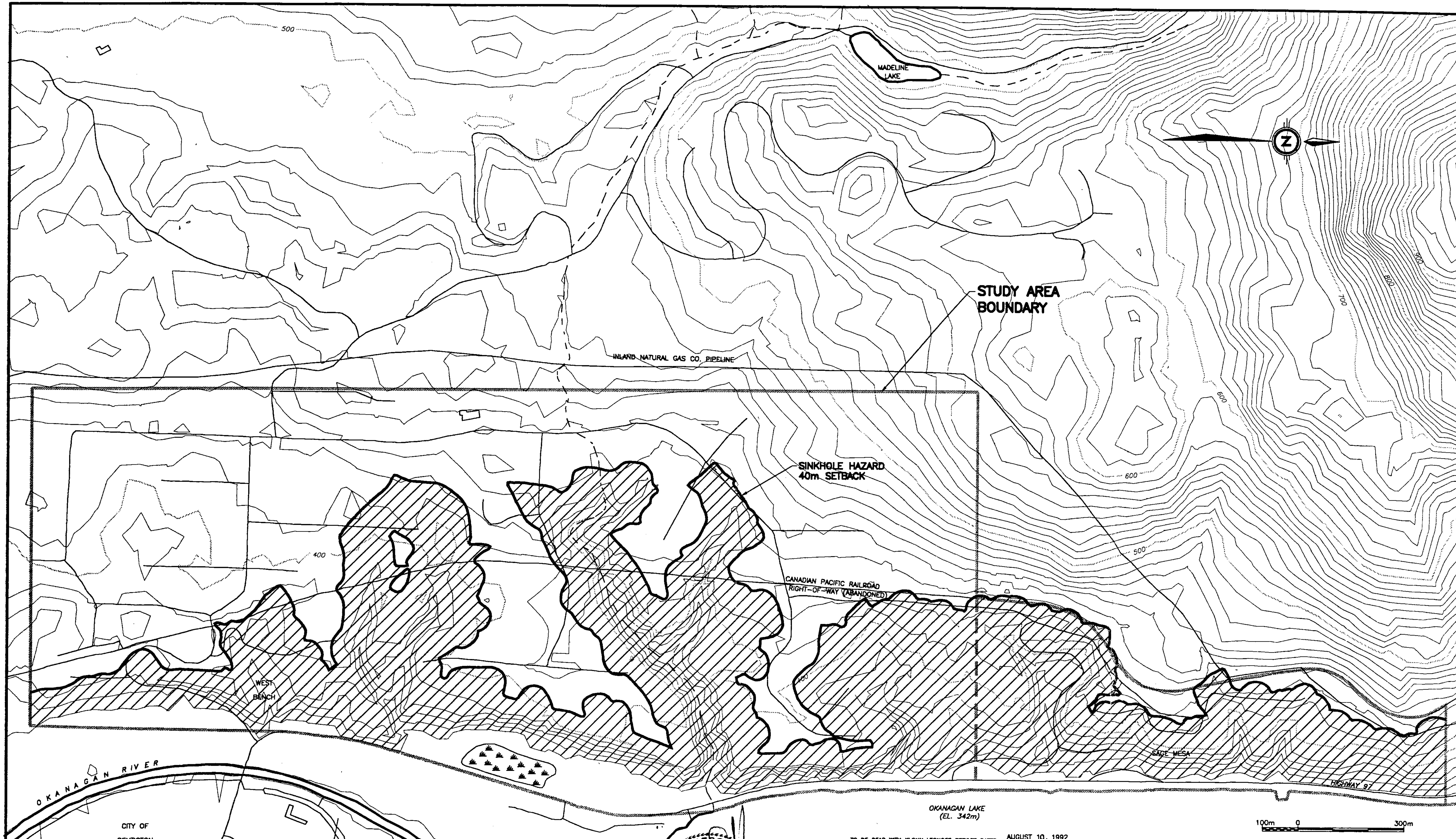
CLIENT: REGIONAL DISTRICT OF OKANAGAN-SIMILKAMEEN

PROJECT: WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW

TITLE: GEOLOGY PLAN

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
AUGUST 10, 1992	PB584701	B-1003	


500
MADELINE LAKE
STUDY AREA BOUNDARY
INLAND NATURAL GAS CO. PIPELINE
10m
2.2H
CREST OF SLOPE
LANDSLIDE SETBACK
H
TOE OF SLOPE
1.8H
10m
RUNOUT SETBACK
ZONE OF LANDSLIDE HAZARD
600
700
800
900
400
500
CANADIAN PACIFIC RAILWAY
WEST BENCH
LANDSLIDE HAZARD ZONE
SAGE MESA
HIGHWAY 97
OKANAGAN RIVER
CITY OF PENTICTON
OKANAGAN LAKE (EL. 342m)
100m 0 300m SCALE
TO BE READ WITH KLOHN LEONOFF REPORT DATED AUGUST 10, 1992
PROFESSIONAL ENGINEER
PROVINCE OF BRITISH COLUMBIA
R. RODNEY SMITH
AS A MUTUAL PROTECTION TO OUR CLIENT, THE PUBLIC AND OURSELVES, ALL REPORTS AND DRAWINGS ARE SUBMITTED FOR THE CONFIDENTIAL INFORMATION OF OUR CLIENT FOR A SPECIFIC PROJECT AND AUTHORIZATION FOR USE AND/OR PUBLICATION OF DATA, STATEMENTS, CONCLUSIONS OR ABSTRACTS FROM OR REGARDING OUR REPORTS AND DRAWINGS IS RESERVED PENDING OUR WRITTEN APPROVAL.
KLOHN LEONOFF
DATE
DESIGNED RCG JULY/92
DRAWN EP JULY/92
CHECKED
RECOMMENDED
APPROVED
KLOHN LEONOFF LTD.
CLIENT
REGIONAL DISTRICT OF OKANAGAN-SIMILKAMEEN
PROJECT
WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW
TITLE
LANDSLIDE HAZARD PLAN
DATE OF ISSUE AUGUST 10, 1992
PROJECT No. PB584701
DWG. No. D-1005
REV.



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KLOHN LEONOFF		DATE
DESIGNED	RCG	JULY/92
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RECOMMENDED		
APPROVED	[signature]	

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CLIENT
REGIONAL DISTRICT OF OKANAGAN-SIMILKAMEEN

PROJECT
WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW

TITLE
SINKHOLE HAZARD PLAN

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
AUGUST 10, 1992	PB584701	D-1006	

LEGEND

5 DENOTES ZONE NO.

ZONE NO.	DESCRIPTION	NEW COMMUNITY	DENSITY OF 0.5 ACRE TO 1.0 ACRE	DENSITY OF >1.0 ACRE
1	LANDSLIDE HAZARD	e	e	e
2	SINKHOLE HAZARD	e	e	e
3	SILT BLUFF	e	c	c
4	GRAVEL OR BEDROCK IN STUDY AREA	c	c	d
5	GRAVEL OR BEDROCK OUTSIDE STUDY AREA	c	c	d

a – PERMIT APPROVED WITHOUT CONDITIONS

b – PERMIT APPROVED ONLY WITH A CONVENANT REGISTERED ON THE PROPERTY TITLE CLEARLY DEFINING THE HAZARDS PRESENT

c – PERMIT APPROVED ONLY WITH INSTALLATION OF SEPTIC SEWERS AND STORM SEWERS

d – PERMIT APPROVED ONLY WITH IRRIGATION OR DOMESTIC WATER DRAWN FROM GROUNDWATER

e – PERMIT NOT APPROVED

TO BE READ WITH KLOHN LEONOFF REPORT DATED AUGUST 10, 1992

KLOHN LEONOFF		DATE
DESIGNED	RCG	JULY/92
DRAWN	EP	JULY/92
CHECKED		
RECOMMENDED		
APPROVED		

KLOHN LEONOFF LTD.

CLIENT: REGIONAL DISTRICT OF OKANAGAN–SIMILKAMEEN

PROJECT: WEST BENCH/SAGE MESA GEOLOGICAL HAZARDS REVIEW

TITLE: STUDY AREA ZONE PLAN

DATE OF ISSUE	PROJECT No.	DWG. No.	REV.
AUGUST 10, 1992	PB584701	D–1007	