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NORTH SHORE STABILITY STUDY

GEOTECHNICAL REVIEW OF THE EXISTING SHORELINE SLOPE STABILITY

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EXECUTIVE SUMMARY

Nanaimo's north shore has experienced relatively rapid development over the last 10 to 15 years. The shoreline slopes in the study area have also experienced varying degrees of instability and soil movement (mass wasting) in the recent past. Due to this mass wasting, the City of Nanaimo has authorised a regional geotechnical review of the existing shoreline slope stability as it impacts property and safety to people and structures. The study area encompasses the shoreline areas of northern Nanaimo (North Shore) between Departure Bay and Lantzville such as Icarus Point, Sealand Park and Bayshore Avenue and includes all significant soil slopes. Based on the investigations, the instabilities along the North Shore include three dominant modes of failure:

- Minor Sloughing or Slab Failures - generally minor failures involving less than 100 cubic metres of material and regression of a few metres or less per failure episode. Crest, mid-slope and toe failures are included in this category which often result from over-steepened slopes that primarily fail in tension. Contributing factors include stress relief, pore pressure dissipation, softening due to weathering, and saturation from direct precipitation or concentrated runoff.

- Regressive Piping or Blowout Failures - roughly the same magnitude as sloughing or slab failures, however, the triggering mechanism is that of pore (groundwater) pressure buildup in sandy lenses or beds due to vegetation cover, surficial soils or dumping of fill. Given the appropriate natural geologic and groundwater conditions, this type of failure appears to occur in cycles as vegetation matures, mixes the soil and restricts groundwater seepage until failure occurs. The dumping of fill and debris accelerates the restriction process and will result in failure of the debris, vegetation and some natural materials.

- Block Failures - significantly larger in size and magnitude than the above failure modes. The Sealand Park/ Driftwood Place failure, for example, is estimated to involve more than 300,000 cubic metres of material. These failures are considered to represent classical rotational - translational failures that are more deep seated than those above and can therefore be analyzed as true shear failures.

Of the above modes of mass wasting, block failures are the most critical in terms of the impact on development near the crest of the slope. The work carried out for the North Shore Study indicates that a number of relatively large scale block movements have taken place in the recent geologic past between Norasea and Lewis Roads. The Sealand Park - Driftwood Place failure appears to be the largest and most active mass wasting feature in this area with movements of up to 6 metres in the last 5 years. Evidence suggests similar size features are located near Waldbank Road, near the end of Invermere Road, between Invermere and Blueback Roads and between Blueback and Lewis Roads.

The triggering factors that have led to these large scale block movements (and continual movements) are not completely understood at this time, but include:

- over-steepened shoreline slopes by continual active shoreline erosion;
- removal of slide material at the toe of the slope by erosion;

- potential weak units or layers within the Quadra Sediments; and
- high piezometric levels associated with the Quadra Sediments.

These factors are discussed below:

- Marine Toe Erosion - Observations indicate that toe erosion along the shoreline is responsible for continual removal of toe material and ongoing slope movement between Entwhistle Drive and Icarus Point. West of Icarus Point the shoreline is susceptible to wave attack, however this area is generally considered as a zone of net deposition along the beach with less erosion of the slope toe.

- Potential Weak Units - Clay/peat associated with the Quadra Sediments have been observed within the Sealand Park area and in water well logs obtained from the Ministry of Environment. Samples of clay (interpreted failure plane/zone) obtained from atop the shoreline bluff at Sealand Park indicate this material has a liquid limit of 45 to 49 percent and a plastic limit of 24 to 31 percent. Based on Deere, 1974, the residual shear strength (effective internal angle of friction) of this material is estimated at 17 degrees. The continuity of this or other potential weak layers is not completely known at this time, but the indication is that the layers are continuous for at least several tens of metres.

- High Piezometric Levels - High piezometric levels associated with the Quadra Sediments may occur during the winter months. It is thought that the sand and coarser grained units of Quadra Sediments act as a confined aquifer which receives significant recharge south of the shoreline and "funnels" the groundwater flow to the shoreline.

Other episodic or future influences may include the following:

- Seismic Events - Seismic accelerations may lead to failure of slopes which are close to failure, but which have not yet moved, or may lead to increased movement of slopes which have already failed. For example, during the 1946 earthquake, numerous failures were observed on slopes in the Quadra Formation. Most of these observations were farther north since the epicentre of the earthquake was in the vicinity of Campbell River.

- Sea Level Rise - Over the past several years, there have been several and varied predictions regarding future rises in sea level due to global warming. Since global warming is not accepted by all, these predictions have given rise to considerable debate. However, some of the predictions are of sea level rise of over 1 to 2 metres over the next 40 to 80 years. Such rise, if it occurs, would expose many of the slope toe areas to additional erosion and would undoubtedly have a major impact in the absence of mitigative measures such as shoreline erosion protection.

The degree that development changes the stability of the slope is unclear, other than direct impacts such as concentration of runoff, slope disturbance or filling of areas on the slope. If development causes the groundwater table to rise, in general, there may be a significant decrease in the factor of safety against failure; however, very little data exists on groundwater levels near the areas of interest. Urban development can result in a significant change to runoff and groundwater environments through watering, leakage from ditches, sewers, or channelling near the crest. This coupled with a general decrease of vegetation and evapotranspiration could lead to increased infiltration and higher piezometric levels by several metres.

Further investigations should focus on confirming and quantitatively defining the triggering factors of identified failures so that existing and future building areas can be assessed in terms of Factor of Safety against slope failure. Determination of the presence and effect of weaker layers and groundwater (piezometric) levels will be of paramount importance to these investigations.

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SECTION 1.0
GENERAL

1.1 INTRODUCTION

1.1.1 Purpose

As requested, HBT AGRA Limited has carried out an overview geotechnical study of the North Shore slope, to provide a greater level of understanding of the conditions that have led to slope stability problems in this area of Nanaimo. The work included an overall geotechnical review of the existing stability of the shoreline slopes of northern Nanaimo and an evaluation of the long term implications of existing and proposed development on slope stability. The study area included three separate areas located along the northern coast of Nanaimo. These areas included:

- Schook Road to Fillinger Crescent;
- Pipers Lagoon to Stephenson Point; and
- Battersea Road to B.C. Ferries terminal in Departure Bay.

It is intended that the work carried out will be additive and complementary to previous work and will form a part of a geotechnical data base for the shoreline slopes of northern Nanaimo.

The report first discusses the purposes and objectives of the study, historic activity on the slopes and previous work carried out. The report then progresses through the methodology and site characteristics such as geology, hydrogeology and erosion processes. Slope stability and significant factors affecting stability are addressed for the various sections of the study area, identified as geotechnical regimes. Toward the end of the report, recommendations are provided for mitigative measures, remedial measures and further investigations. For convenience, the report summarizes much of the information for each geotechnical regime in table form and provides detailed regime information within the Appendices, including plans and cross-sections.

1.1.2 Objectives

The main objectives of the study were to identify and assess the main factors and geotechnical conditions leading to the formation of existing instabilities and to assess whether these factors and conditions could affect adjacent areas within the overall study area. These factors include:

- geologic conditions;
- hydrogeologic conditions;
- surface erosion - storm water runoff;
- marine erosion; and
- topography.

The study area was divided into separate geotechnical regimes which were characterized by the type of failures identified, variations in the above noted factors/conditions and by an apparently similar risk of slope failure or instability. The locations of the regimes are shown on Figure 1.1.

1.1.3 Scope of Services

The scope of services provided during the course of this investigation included:

- Review and compilation of available literature relevant to the study area. This information, which is provided in the appropriate Appendices, includes:

    - prior geotechnical consultant reports;
    - as-built drawings for storm outfalls;
    - as-built drawings for the Regional District north shoreline sewer line interceptor;
    - Geological Survey of Canada geology maps;
    - hydrographic maps, wind and tidal records;
    - Ministry of Environment water well records;
    - topographic plans; and
    - aerial photographs (air photos).

- Study of available recent and historic air photos for the purpose of identifying slope geomorphology, marine erosional/depositional processes and assessment of slope performance with time. The performance of some of the subject slopes after earthquake/seismic loading was also assessed where airphoto coverage was available.

- Mapping of geological features of the shoreline to assist in identifying and correlating the shoreline geology with past mapping by the Geological Survey of Canada.

- Geologic mapping and chain/compass surveys of several recent slope failures to assess the geometry and conditions of failure. Back analyses were carried out to further understand and confirm the critical factors.

- Assessment of marine erosion to identify sources and sinks of coastal sediments. This was based on airphoto and chart characterization, wind speed, predominant fetch, and littoral drift/current.

- Preliminary assessment of storm water catchment, resulting runoff and potential infiltration into near surface groundwater flow regime.

1.1.4 Authorization

This work was discussed in the HBT AGRA Limited proposal dated 02 July 1992 (File: P548) and was authorized by the City of Nanaimo verbally and through receipt of P.O. No.62054, near the end of July 1992.

1.2 HISTORY

Although significant development has occurred over the last ten years, the shoreline slopes of northern Nanaimo have experienced localized development adjacent to the upper slope crest throughout the past century. In the past, development typically consisted of small cottages or homes constructed in small clearings located adjacent to the slope crest. To facilitate a water view, trees located along the upper portions of the slope face would often be either topped or removed. Direct impacts of development on slope stability observed in historic air photos (last ±20 years) are restricted to unintentional concentration of storm water flows, disturbance or fill on the slope.

Development on the slope itself has been limited to the construction of stairways to permit beach access and the installation of several storm/sewer outfall lines down the slopes. These sewer lines are tied into the Regional District's North Shoreline Interceptor which was installed along the shoreline in 1978 and extends from Schook Road east to Entwhistle Drive. In the Departure Bay area, a railway alignment was constructed down the slope prior to 1950 to permit access to a docking facility located near Northfield Creek.

Localized logging of mature trees on the shoreline slopes has been carried out in the past as evidenced by existing old stumps and overgrown trails which were observed on several mid-slope terraces. The extent and time period of this logging is not known, but logging activity is evident on 1968 air photos.

Subdivisions have recently been developed near the slope crest in areas which had previously been forested. These subdivisions include Cilaire (late 1960's), Bayshore (late 1960's), areas of east of Icarus Point (early 1970's), Icarus Point (early 1980's), Driftwood Place (mid 1980's), and Greenwood Way (late 1980's). Other areas such as Waldbank Road and Forest Drive have been developed gradually. It is understood that areas such as west of Seabold Road, east of Lewis Road, and east of Bayshore Avenue are presently being developed.

1.3 PREVIOUS WORK

Geotechnical slope stability assessments have been carried out within the study area over the last decade. These assessments have originated mainly due to requests by the City of Nanaimo to provide engineering opinion on whether the proposed building areas are safe for the intended use. Available reports are tabulated by regime in the appropriate Appendix.

Prior to 1975, it is understood that subdivision approval was issued by the Ministry of Transportation and Highways with input into zoning from the Regional District of Nanaimo. It is further understood that building permits were issued by the Ministry of Municipal Affairs prior to 1970 and by the Regional District of Nanaimo between 1970 and 1975. Consultant reports and internal assessments carried out for development and building prior to 1984 were not available for this study.

SECTION 2.0
METHODOLOGY

2.1 GENERAL

The investigations carried out for the North Shore Study included reconnaissance level geologic mapping, detailed mapping of several available exposures between high tide level and the crest of the slope together with air photo analysis. This work complements and correlates with previous work carried out, including water well log information provided by the Ministry of Environment. Each phase of the investigation is discussed separately in the following subsections.

2.2 RECONNAISSANCE FIELD MAPPING

Geological mapping of soil exposures located along marine erosion cuts and recent slope failures was carried out. This work included identifying and correlating soil units with past geologic mapping completed by the Geological Survey of Canada, noting groundwater conditions, and mapping the geometry and details of recent failures.

Difficulties experienced with interpretation of the geologic field data stem primarily from the lack of significant exposures of intact glacial sediments, thick brush, or covering by failed material. Where possible, exposures of the glacial sediments found in the shoreline slopes were correlated with water well logs obtained from the Ministry of Environment. However, inconsistent or incomplete descriptions in the well logs made this work difficult.

Although the general level of confidence in the geologic interpretation is good, further refinement to improve and verify some of the interpolations of geologic contacts would improve the interpretation.

2.3 AIR PHOTO STUDY

Air photos covering the shoreline slope were used to assist in assessing features such as surficial deposits and bedrock exposures, potential groundwater flow directions, past slope instabilities, land usage and the progress of development. These photos include portions of several flightlines which were taken periodically from 1950 through 1986. A list of the available B.C. flightlines is provided in Table 2.1.

TABLE 2.1
AVAILABLE AIR PHOTOGRAPH COVERAGE

FLIGHTLINE	SCALE	YEARS	COVERAGE
BC86007	1:16,000	1986	- Schook to Entwhistle (Regimes I-V)
BC84029	1:20,000	1984	- Schook to Norasea (Regimes I - IV)
BC7754	1:20,000	1975	- Northfield Creek to Battersea (Regime III)
BCC207	1:20,000	1980	- Waldbank to Entwhistle - southern portion of Regime VII
BCC442	1:10,000	1986	
BC7075	1:15,840	1968	- all regimes
BC1667	1:31,680	1954	- all regimes
BC7409	1:15,840	1972	- Blueback to Entwhistle (Regimes II-V) - Battersea to north of Northfield (Regime VII)
BC1052	1:31,680	1950	- Regimes VI and VII

2.4 SURVEYING

Surveying, carried out as part of this study, included chain and compass traverses of existing failures, slope profiles at various locations and detailed surveying of stationing and pins installed to monitor ground movement. Details of the traverses, slope profiles measured ground movements are included in the appropriate Appendices.

2.5 SLOPE STABILITY ANALYSES

Slope stability analyses were carried out on existing failures along the shoreline slope within the study area to support the interpreted factors that have led to the failure conditions within each regime. A limited equilibrium slope stability program, G-Slope (Version 3) was utilized to perform back analyses and assess the impact of groundwater and earthquake loading for selected cross-sections.

The geological contacts between soil units, soil strength parameters, and piezometric surfaces were inferred from field assessments and some limited laboratory analyses. The field reconnaissance of many of the failures was often hindered due to the presence of overlying slumped material, vegetation and dangerous terrain. Analyses were therefore carried out at a reasonable level of detail consistent with the information and data available. Detailed results of the stability analyses carried out, if appropriate, are included in the Appendices.

Back analyses were carried out on sections which had experienced block or true shear failure, in an effort to substantiate the soil strength parameters and piezometric water levels suspected during slope movement. Although some analyses were also carried out for slabbing and regressive failures for other slope areas, the results are not truly applicable due to the nature of failure (failure in tension - slabbing, failure by piping and surface erosion).

Parametric analyses were performed to evaluate the impact of groundwater levels and earthquake loading on the stability of the slopes by assessing the reduction in the factor of safety due to increases in piezometric level and horizontal acceleration. Seismic analyses were carried out using pseudo-static methods. Although this indicates when there is a risk of movement (low factor of safety), the degree of movement which would occur can only be assessed with more sophisticated analytical methods.

Analyses carried out for the Sealand Park failure, which has moved in the last year (factor of safety assumed to be 1.0), included evaluating the existing conditions of failure such as material strengths and piezometric (groundwater) pressures. The analysis indicated that the factor of safety generally increases with distance inland of the crest or head scarp. Under the modelled failure conditions, a factor of safety against failure of 1.5 was found at roughly 40 metres south of the head scarp. Parametric analyses indicate that a difference in the interpreted piezometric surface (groundwater level) of 2 metres changes the factor of safety by 20 to 30 percent and that any earthquake loading significantly reduces the factor of safety, as shown on Figure 2.1.

SECTION 3.0
SITE CHARACTERISTICS

3.1 GENERAL

The site characteristics have a significant impact on the stability of the shoreline slopes of northern Nanaimo. The most significant characteristics include topography, climate, geology, groundwater, seismicity as well as surface and marine erosion. Details of specific site characteristics and their impact on slope stability are tabulated for each geotechnical regime in Table 3.1 - Summary of Site Characteristics. A general discussion of the site characteristics of the northern shoreline of Nanaimo follows.

3.2 TOPOGRAPHY

The shoreline slopes within the study area are in the order of 40 to 50 metres in height, measured from high tide level. Commonly the slopes are over-steepened (40 to 70 degrees below horizontal) near the crest. Mid-slope terraces or portions of the slope with significantly less relief occur in many areas at various elevations. In many areas the toe of the slope is also over-steepened due to shoreline erosion.

Surface gradients inland of the slopes are generally 6 degrees and down to the north (toward the shoreline).

3.3 CLIMATE

The climate of the area is characterized by mild temperatures and wet conditions in the fall and winter months of October to March. According to the Canadian Climate Normals (Environment Canada - Atmospheric Environment Service at the Nanaimo Departure Bay Climate Station), monthly average daily maximum temperatures range from a low of 5.7°C in January to a high of 22.6°C in July. Monthly average daily minimum temperatures range from 0.7°C in January to 13.5°C in August. Freezing conditions during the winter are discontinuous, and extreme cold weather occurs rarely. The extreme minimum temperature recorded at Nanaimo Departure Bay is -14.0°C.

Over 75 percent of the mean annual precipitation occurs in the six month period from October to March. Normally, the highest monthly precipitation occurs in December. The mean annual precipitation is 945 mm. Most of this occurs as rainfall. Snowfall accounts for about 5 percent of the total precipitation on average (50 mm water equivalent).

The area is subject of moderate short duration rainfall intensities. The greatest recorded twenty-four hour rainfall is 92 mm and the mean annual maximum daily rainfall is about 60 mm. The mean annual one hour rainfall intensity is 10 mm. The greatest likelihood of intense rainfall occurs during the months of December and January.

Wind data is available from Environment Canada's Atmospheric Environment Service (AES) weather stations at:

- Ballenas Light station; and
- Entrance Island.

This data was used to characterize the wind/wave climate in the study area. Figure 3.1 illustrates windroses for these two stations and provides an indication of predominant wind directions and wind speeds. This figure indicates a predominant southeast wind component with above average speed and hence, forms the wind component which may generate the highest waves. The southeast winds are very common in winter representing a situation where wave energy and sediment erosion/transport potential are at a maximum.

3.4 GEOLOGY

Characterization of the surficial geology of the shoreline slopes of northern Nanaimo has provided the basis of the geotechnical work. The slopes expose a significant section of sediments that range in geological age from Early Wisconsin to Holocene and are approximately 10,000 to 60,000 years old. The sediments represent at least two periods of glacial retreat and advance, and were deposited over either sedimentary rocks of the Late Cretaceous Nanaimo Group or volcanic rocks of the Triassic Karmutsen Formation.

Past geological mapping at this site was limited to a cross-section on a surficial geology map of the Nanaimo area that was completed by of J.G. Fyles of the Geological Survey of Canada in 1963. The glacial deposits outlined in the 1963 study form the basis of the stratigraphic units that were used in this study.

The four major deposit types that occur at this site include a basal till (the Dashwood Drift), overlain by an inter-till complex (the Quadra Sediments) and a more recent glacial till (the Vashon Drift). These materials are in turn overlain by marine and glaciomarine deposits (the Capilano Sediments). The Dashwood Drift material represents an early glacial incursion of the Vancouver Island lowland that preceded the deposition of Quadra Sediment. It is understood that the Quadra Sediment was deposited ahead of the ice as it advanced along Georgia Strait.

The Vashon Drift material that overlies the Quadra Sediments was deposited during the most recent glacial event. The Capilano Sediments represent post-glacial deposition.

Within these four deposit types, seven units were identified and are described in Table 3.2. The distribution of these seven units along the length of the north shore slope is variable and is presented in longitudinal cross-sections for the study area (see Figures 3.2 to 3.5).

TABLE 3.2
SUMMARY OF GLACIAL GEOLOGY

Geological Description	Unit	Description
Capilano Sediments (Marine deposits and glaciomarine)	Unit 7	Yellowish-brown varied sand and gravel layers, compact.
Vashon Drift (Glacial till and glaciofluvial deposits)	Unit 6	Brown (with rare purple tinges) silty sand with little (10-20%) gravel/cobbles, dense to very dense.
Quadra Sediments (Marine and glaciomarine deposits)	Unit 5	Light brown to yellow fine to medium grained sand, very dense, horizontally stratified and cross-bedded, with occasional gravel layers.
	Unit 4	Layers of yellow-brown to brown sand, silt, gravels and peat/organics, very dense.
	Unit 3	Grey silty sand with trace to little (0-20%) gravels, dense/hard (termed a stony clay).
	Unit 2	Light grey silty clay, trace to no gravel, hard, varies from massive to laminated, with occasional sand lenses and rare shell fragments.
Dashwood Drift (Glacial till deposit)	Unit 1	Light grey (almost bluish in places) silty clay with little (10-20%) sands, very hard.

3.4.1 Dashwood Drift

The Dashwood Drift was occasionally found at the base of the shoreline slopes (particularly along the east part of the shoreline section) and in some cases appears to be directly overlying bedrock. This basal unit consists of a grey heterogenous glacial till that is comprised of intercalated gravel, sand and silt (Unit 1). This material is heavily over-consolidated but is similar in texture to the more recent Vashon Drift.

3.4.2 Quadra Sediments

The Quadra Sediments conformably overlie the Dashwood Drift and represent a complex period of interglacial deposition. The four units within the Quadra Sediments are described in Table 3.2 and include: grey laminated to massive clays (Unit 2); a grey stony clay (Unit 3), interbedded silt, sand, gravel and clay/peat layers (Unit 4); and horizontally stratified and cross-bedded sands (Unit 5).

According to studies by Fyles (1962, 1963), the laminated and stony clays at the base of the Quadra Sediments record a period of marine submergence following the disappearance of the Dashwood glacial event. Unit 4 represent a period of marine emergence with deposition of materials in a swampy coastal lowland environment. The upper sands of the Quadra Sediments sequences originated as a fluvial deposit, with sand deposition probably occurring in a series of coalescing deltas.

In many places the stratigraphic sequence within the Quadra Sediments was not complete. For example, the grey stony clay (Unit 3) was rarely present between Unit 2 and Unit 4. The stratigraphic contact between the Dashwood Drift (Unit 1) and the lower clays of the Quadra Sediments (Unit 2) was distinct and characterized by a decrease in gravel-sized material, a decrease in overall denseness of material and the development of laminations. The contact between the laminated grey clay (Unit 2) and the inter-layered sand, silt and clay/peat (Unit 3) of the Quadra Sediments was less distinct and was based on the first appearance of sand, silt or gravel layers in the clay. The contact between Unit 4 and the cross-stratified sands (Unit 5) of the Quadra Sediments was also indistinct, with the upper contact of Unit 4 taken as the last stratigraphic appearance of silt or clay/peat within the sand.

3.4.3 Vashon Drift

The deposition of the Quadra Sediments was followed by the most recent period of glacial deposition, the Vashon Drift. This till is comprised of a brown, heterogenous till mixture of silt, sand, gravel, and cobbles. Disrupted inclusions of Quadra Sediments are found within the till. The contact between the Quadra Sediments and Vashon Drift was interpreted to be an erosional unconformity, whereby the Vashon Drift cross-cuts the pre-Vashon surface of the Quadra Sediments (Fyles 1962).

3.4.4 Capilano Sediments

In most places along the shoreline the Vashon Drift was overlain by a veneer of near-shore marine and glaciomarine sediments of the Capilano Sediments. These deposits typically included layers of sand and gravel with some silt, clay and stony clay.

3.5 HYDROGEOLOGY

Groundwater flow and pressure (pore pressure) have significant impact on the slope stability within each of the regimes studied. The groundwater investigations carried out have focused on providing a preliminary interpretation of recharge, general flow patterns and degree of confinement. In general, it is interpreted that the Quadra "Sands" (minor gravel) associated with Units 4 and 5 provide the greatest transmissivity (thickness x hydraulic conductivity) to groundwater flow and form the major aquifer along the coast of northern Nanaimo.

The position of the groundwater table and elevation of piezometric head associated with the various geologic units is unknown. A recent study by B.H. Levelton and Associates near Lewis Road showed groundwater levels associated with the upper Quadra Sediments at approximately 16 metres below ground surface. It is understood that this drill hole is located near the crest of the slope at the northern end of Lewis Road at ± Elevation 45 metres (geodetic).

Near the shoreline, thinning of the Quadra "Sands" and confinement by the overlying Vashon Drift appears to provide a "funnelling" mechanism for groundwater flowing toward the shoreline. Further inland (south of the shoreline), the Quadra Sediments become thicker, closer to ground surface and in direct contact with bedrock, based on water well information. Thinning or holes in the overlying Vashon Drift possibly lead to significant infiltration into the Quadra "Sands", while contact with bedrock may provide further recharge.

Significant recharge areas for the Quadra "Sands" include areas such as Green Lake, Brannen Lake and Rutherford Ridge. The general groundwater flow paths are interpreted, as shown in Figure 3.6, to be as follows:

- Lantzville to Icarus Point:
  In this area, flow is likely north through significantly thicker deposits of the Quadra "Sands", as compared to the following two regimes. Significant seepage observed along the shoreline within Regime I may be a result of the significant thickness and hydraulic conductivity (transmissivity) of the sand units (refer to Figure 3.7).

- Icarus Point to Norasea Road:
  This area corresponds to the Molecey Creek drainage area. Groundwater flow is likely to the northeast through confined deposits of Quadra "Sands" which may lead to "funnelling" of groundwater and higher piezometric pressures. Significant seepage was noted throughout the area between Icarus Point and Molecey Creek (Regime III). Although seepage was also observed between Molecey Creek and Norasea Road (Regime IV), the quantity of flow was less. Most seepage in both Regimes appeared to discharge from Unit 4 above the lower Quadra silt/clay (Unit 2) (refer to Figure 3.8).

- Norasea Road to Fillinger Crescent:
  Groundwater flow is to the north-northeast. Infiltration and recharge areas are interpreted to occur directly inland (south) and to the southeast of this area along Rutherford Ridge. Because the Quadra "Sands" pinch out to the east (general thinning of the glacial deposits occurs to the east as bedrock rises and outcrops along the shoreline near Entwhistle Drive), groundwater flow is believed to be limited to coarse grained lenses of sand and gravel above the basal silt/clay Dashwood and Quadra silt/clay units (Units 1 and 2). Seepage points observed appear to correspond with past failures in this area (refer to Figure 3.9). High piezometric levels associated with bedrock have also been reported to the east of this area.

- Stephenson Point:
  Recharge to this area is primarily the result of direct infiltration into areas adjacent to the shoreline. Seepage is likely concentrated immediately above the bedrock surface, however, fracture flow through bedrock may also be significant.

- Departure Bay:
  Groundwater flow toward Departure Bay likely originates directly inland from Regime VII. A groundwater divide is interpreted along Bowen Road. Recharge is therefore limited to areas directly upgradient between the shoreline and Bowen Road.

3.6 SEISMICITY

Seismic records from 1912 through to 1987 are summarized in Table 3.3. Five events have been recorded in the Nanaimo area with an intensity level (Modified Mercalli) of VI or greater, based on information provided by the Pacific Geoscience Centre. Analysis of available air photos taken after the larger 1975 and 1976 seismic events, in general, do not indicate that these events contributed to large or numerous failures in the study area. It should be noted however, that air photo coverage prior to 1968 only covered the southern three regimes.

TABLE 3.3
SUMMARY OF SIGNIFICANT SEISMIC EVENTS

DATE	INTERPRETED INTENSITY LEVEL (MODIFIED MERCALLI)	HORIZONTAL ACCELERATION (% g)
May 16, 1976	VI	2.3
November 30, 1975	VII	4.7
June 23, 1946	VII	7.7
September 17, 1926	VII	7.4
December 6, 1919	VI	4.1

Seismic design accelerations for the probable return periods in the Nanaimo region of 100, 200 and 475 year (probability of exceedence in 50 years of 40%, 22% and 10%, respectively) are presented in Table 3.4. Based on the information in Tables 3.3 and 3.4, the interpreted accelerations of seismic events which have occurred through 1912 to the present have not exceeded the predicted 100 return period.

TABLE 3.4
SEISMIC EVENT PROBABILITIES

RETURN PERIOD (YEARS)	HORIZONTAL ACCELERATION (%g)
100	9
200	14
475	22

The risk of the above earthquake events occurring is based on a probabilistic (historic records) seismic risk calculations compiled by Energy, Mines and Resources Canada, Geological Survey of Canada. A significantly larger subduction earthquake has been hypothesized for the south coastal area, but there is not presently agreement on the possibility of this earthquake occurring and at present it is not included in the seismic predictions considered in the National Building Code.

The National Building Code of Canada (NBCC) requires that foundations for occupied structures be designed such that the structure remains sufficiently intact to prevent loss of life and allow safe egress of occupants during the 1:475 year design earthquake. Further, the NBCC requires that the structure remains serviceable, with only minor damage during a 1:100 year earthquake.

The dense Quadra Sediments that form the slopes within the study area are not considered to be liquefiable. It is anticipated that under seismic (cyclic) loading, tension will develop within the slope materials near the crest. Under these conditions shallow slab failures may occur relatively suddenly. Displacement of larger blocks of material could also occur. However, it is estimated that displacement will decrease with distance inland of the crest.

3.7 SURFACE WATER HYDROLOGY

Prior to development, the surface runoff from the uplands near the shore was distributed into numerous channels; in some instances, major runoff channels such as Molecey Creek and Northfield Creek developed. All runoff channels had a size and gradient which was in the process of adjusting to the runoff from the natural forested upland area.

With the onset of development (clearing, road paving, and housing construction), the runoff characteristics of the contributing drainage area changed. The receiving streams have adjusted to more runoff and higher peak flows. Instability along the banks of these streams was observed along Molecey Creek and a runoff channel located off Driftwood Place/Greenwood Way.

It is understood that several years ago, the upstream portion of Molecey Creek was controlled by containing the creek in a conduit. It is further understood that construction of a conduit to carry the flow through the lower portion of Molecey Creek has recently been carried out.

The extreme upstream portion of Northfield Creek runs on bedrock and extends downstream to a waterfall. Thereafter, the creek runs along the valley bottom encroaching occasionally on valley walls. Northfield Creek is more stable than Molecey Creek and shows little evidence of recent degradation. The predominant erosion factor appears to be due to surface disturbances from the top of the slope such as local runoff discharge down the slope.

3.8 SHORELINE HYDROLOGY

3.8.1 Classification

Shoreline areas within the study area may be characterized broadly as either erosional or depositional. This general classification relates to the predominant shoreline processes which occur due to the prevailing wave climate. General classifications may be defined as follows:

- Erosional - Areas of shoreline which are predominantly sources of sediment for transport by waves or littoral currents.
- Depositional - Areas of shoreline which are predominantly sinks or areas of storage for sediment transported by waves or littoral currents.

Beach profiles commonly vary with time (associated with varying wave energy). Erosion along the toe of the slope generally occurs at times of high tide and high wave attack, predominantly in winter. Waves attack the toe of the slope removing silt, sand, gravel, and cobble materials. This material is either transported offshore or along shore by littoral currents, as shown on Figure 3.10 (direction of littoral currents are shown on the Regime plans in the Appendices).

Wave energy reaching the toe of the slope is limited in some areas by the beach profile. Summer beach elevations result from the build-up of beach material under the spring/summer wave environment (Figure 3.10). The beach materials are eroded under the high energy winter wave environment. This erosion also allows higher energy waves to reach the toe of the slope in winter before breaking (and losing energy). In the summer, when beach elevations are high, very low energy waves predominate, and erosion at the toe of the slope is expected to be small. Lower summer tide levels may even isolate the slope from wave attack.

On a relative scale, erosion along the coast is low but continuous from year to year. Wave energy reaching the slope is limited by the available fetch across the Strait of Georgia (approximately 50 kilometres) and by duration of the southeast winds. To produce waves capable of appreciable shoreline erosion, the wind must blow from the direction of maximum fetch for five to eight hours. The nature of the wind climate is such that peak hourly wind speeds will limit the period when peak waves are produced over this fetch.

The shore between Sealand Park/Molecey Creek and Entwhistle Drive, for example, has an erosion resistant beach consisting of clay (west end) and clay-till (east end near Bayshore). This clay layer is of unknown depth and is often covered by a shallow layer of cobbles of small boulders. High energy waves may break upon encountering this erosion resistant beach, thereby losing a significant portion of their energy before reaching the toe of the slope. However, wave attack during high tides appears to be resulting in ongoing toe erosion.

A supplementary condition which may occur during prolonged storms is storm surge. A storm surge is an increase in normal tide levels which results from wind or air pressure. This may result in increased ability of the waves to erode the toe of the slope. The storm surge events would be expected to occur in conjunction with major winter storms, but the magnitude of an event would likely be highly variable.

3.8.2 North Shoreline

The direction of longshore movement inferred from air photos and the windroses has been substantiated through observations of inadequately sized erosion control materials (limestone, riprap, and asphalt pieces) which have been displaced by wave action and moved along the shoreline by littoral currents at two locations (East of Molecey Creek and opposite Bayshore Drive).

It is evident that materials eroded from the toe of the slope between Entwhistle Drive and Invermere Road (including the Bayshore Drive, Sealand Park, and Icarus Drive areas) are transported by littoral currents travelling west and deposited in the area between Blueback Road and Schook Road, as well as areas further west toward Nanoose Bay.

3.8.3 Departure Bay

Departure Bay is protected to some extent by Newcastle and Gabriola Islands to the east and by the mainland to the north and northwest. Therefore, direct wave attack must come from the east-northeast through a 500 metre wide stretch of open water between Jesse Island and Newcastle Island. Waves approaching from the northeast to east will drift through this opening and refract as the shallower water is reached. Both of these processes tend to reduce wave energy that reaches the coastline.

The ferry traffic in Departure Bay provides additional wave energy to the shoreline. The low speeds of the ferry boats as they leave or approach the docks adds only a small amount of energy. While cumulatively these small amounts of energy may add up, the energy at the coastline produced by each boat is likely insignificant.

The shoreline of Departure Bay (from the ferry terminals to the south end of Battersea Road) has been classified as erosional with sediment being transported northward toward the public beach area. However, the rate of erosion is expected to be very low.

SECTION 4.0
SLOPE STABILITY

4.1 GENERAL

The shoreline slopes within the study area (North Shore) have experienced various degrees of instability in the past. The head scarps of failures (mass wasting features) define the southern extent of recent failures and indicate this section of shoreline is generally regressing. Many areas of the North Shore appear to be regressing as a series of coalescing failures. These failures tend to be more frequent along the western portion of the study area, west of Fillinger Crescent. However, a number of failures along the shoreline slope in the Departure Bay area were also noted. Failures and general regression of the shoreline slope are anticipated to continue without remedial measures to inhibit the natural processes which erode the shoreline materials.

Except for local sloughing near high tide level, the failures observed, in general, appear to be above the Dashwood till (Unit 1) and possibly above the lower units (Units 2 and 3) of the Quadra sediments, which together form the lower stratigraphic sequence along the north slope.

The observed failures and continued movement of significant mobilized land mass (mass wasting) observed along the North Shore can be classified into three dominant modes of failure (refer to Figure 4.1) including:

- Minor Sloughing or Slab Failures - generally minor failures involving less than 100 cubic metres of material and regression of a few metres or less per failure episode. Crest, mid-slope and toe failures are included in this category, which often result from over-steepened slopes that primarily fail in tension. Contributing factors include stress relief, softening due to weathering, pore pressure dissipation, and saturation from direct precipitation or concentrated runoff.

- Piping or Blowout Failures - approximately the same magnitude as sloughing or slab failures, however, the triggering mechanism is that of pore (groundwater) pressure build up in sandy lenses or beds due to vegetation cover, surficial soils or dumping of fill. Given the appropriate natural geologic and groundwater conditions, this type of failure is regressive and appears to occur in cycles as vegetation matures and restricts groundwater seepage until failure occurs. The dumping of fill and debris accelerates the restriction process and will result in failure of the debris, vegetation and some natural materials.

- Block Failures - significantly larger in size and magnitude than the above failure modes. The Sealand Park/Driftwood Place failure, for example, is estimated to involve more than 300,000 cubic metres of material. These failures are considered to represent classical rotational-translational failures that are deep seated and can be analyzed as true shear failures.

Of the above modes of mass wasting, block failures are the most critical in terms of impact on development near the crest of the slope. The work carried out indicates that a number of relatively large scale block movements have taken place in the recent geologic past between Norasea and Lewis Roads. The Sealand Park/Driftwood Place failure appears to be the largest and most active mass wasting feature in this area with movements of up to 6 metres in the last 5 years. Evidence suggests similar size features are located near Waldbank Road, near the end of Invermere Road, between Invermere and Blueback Roads and between Blueback and Lewis Roads.

Piping or blowout failures involve a substantially lower volume of material than block failures. However, these types of failures will likely be regressive and reoccur as vegetation or material restricts pore water dissipation from preferred seepage patterns. Observations indicate that this type of failure is dominant between Norasea Road and Fillinger Crescent, but was also observed in several areas from Icarus Point to Norasea Road.

Minor sloughing and slab failures appear to be common throughout the study area.

4.2 REGIME CLASSIFICATION

Since factors affecting slope stability vary across the study area, the North Shore has been subdivided into seven separate regimes where the characteristics of the slope and observed failures within each regime are considered to be relatively consistent. The approximate location of these regimes are identified on Figure 1.1 and include:

- Regime I — Schook Road to Lewis Road;
- Regime II — Lewis Road to Invermere Road;
- Regime III — Invermere Road to Molecey Creek;
- Regime IV — Molecey Creek to Norasea Road;
- Regime V — Norasea Road to Fillinger Road;
- Regime VI — Piper's Lagoon to Stephenson; and
- Regime VII — South of Battersea Road to B.C. Ferries wharf.

Table 3.1 presents a summary of site characteristics and the significant factors that have led to the slope failures observed, such as topography, hydrology, geology and groundwater conditions for each regime. Existing and potential failures, together with the possible performance of the slope during seismic events, are also presented. In addition, a hazard rating for each regime is included. Further discussion of the dominant factors and failure modes follows in Sections 4.3 and 4.4.

The hazard rating developed for the identified geotechnical regimes attempts to rate the hazard of slope instability into one of 4 categories based on the size of existing and potential failures, and on the impact of existing and future development along the crest of the shoreline slopes. Category 1 is viewed as the highest risk condition, or the most critical with respect to development, while Category 4 is the lowest risk. These categories were based on the potential risk of damaging movement within the conceivable life of the structures (single family residences) constructed near the shoreline slopes. It is understood that the City of Nanaimo considers the minimum life of these structures to be 100 years.

Due to the preliminary nature of this study, the rating scheme given does not provide a generalized area or distance from the crest which may be impacted. Although consideration was given to establishing reasonably safe distances from the crest, it is recommended that further work including quantitative definition of the factors presently thought to be instrumental, be carried out prior to establishing setback distances. In the interim, it is suggested that property within 80 metres of the crest, in areas considered to have a hazard rating of 1 (Category 1), be given careful consideration with respect to development. Alternatively, a detailed geotechnical assessment which includes identification of potential weak layers or high piezometric levels should be carried out in these areas to define a safe setback.

The categories for the hazard rating presented in the report include:

1. **High Risk of Deep Seated Failures:**
   Appreciable risk of deep seated block failure or movement of a substantial volume of material within the potential life of structures. The largest block movement observed along the North Shore is in Sealand Park. In 1990 and again in 1991, re-activation of portions of the mid-slope terrace in this area occurred. This movement formed fissures and new scarps that are located as much as 80 metres inland of the shoreline bluff. This recent event resulted in vertical displacement at the head scarp of more than 2.5 metres.

2. **High Risk of Smaller Regressive Failures or Erosion:**
Appreciable risk of shallow seated failures (slab or blowout) located at the crest, toe or other over-steepened sections of the slope. These failures will result in significant regression or lateral movement of the slope crest with time. Significant amounts of lateral erosion are also included in this category. The potential regression resulting from this type of failure over the next 100 years could be significant and in the order of many tens of metres. An example of this type of failure is the valley of Molecey Creek, which appears to be a regressive failure caused by a combination of concentrated runoff and piping of groundwater. Uncontrolled storm runoff could also trigger crest failures under this category.

3. **Low Risk of Deep Seated Failures:**
Potential or actual deep seated failures (similar to Category 1) which have tended to stabilize or which have not moved for an extended period of time (hundreds of years). This may involve, for example, deep seated failures which have "toed out" at or below high tide level and where there is not sufficient lateral erosion to trigger renewed movement at the present time. In Category 3 regions, the rate of lateral regression due to slab failures, blowouts or erosion is considered to be low.

4. **Limited Lateral Regression:**
Although there is a risk of small scale failures and erosion occurring in Category 4 regions, the lateral rate of erosion and regression of the slope crest is considered to be low. Deep seated failures have not been identified as a potential risk in these areas.

Plans of each regime showing the conditions and failures observed are shown on Figures A.1 through G.1 in Appendices. No regime was assessed as completely stable.

4.3 DISCUSSION OF REGIMES (WEST TO EAST)

4.3.1 Regime I - Schook Road to Lewis Road

The interpreted geology within Regime I varies from mostly stratified or cross-bedded sands west of Seabold Road to a near full stratigraphic sequence between Seabold and Lewis Roads. The significant seepage evident at the shoreline in this area is likely a result of the capacity (transmissivity) for groundwater flow through the sand. A small cave observed at approximately mid-slope may be a piping failure.

Although no significant active slope failures were observed in this area, the origin of flatter mid-slope areas and head scarps are likely related to past block movements. Because marine erosion is not a major factor, the probability of re-occurrence of deep seated block failure is considered to be low, providing piezometric (groundwater) levels or the rate of marine erosion do not increase. Observed minor sloughing and slab failures will likely continue to occur in over-steepened areas. Due to the possibility of past block movements, the hazard rating for this regime is considered to be 3.

It should be noted that only limited development, to date, has taken place in this area.

4.3.2 Regime II - Lewis Road to Invermere Road

The interpreted geology of this area includes a full stratigraphic sequence of related glacial and interglacial sediments. The lower portion of the slope is comprised of grey silt/clay (Unit 2) underlying inter-layered Quadra "Sands". Although potentially weak layers could exist, none have been positively identified. Observations indicate that ponding and seepage occur primarily near mid-slope terrace areas, but that overall seepage is less than in adjacent regimes.

Within this area, the crest of the shoreline slope appears to consist of a series of coalescing head scarps. Mid-slope terraces are interpreted as possible old block failures, although no indication of movement exists other than creep along the toe. At least two apparent deep seated block failures exist in this area. Smaller sloughing and slab failures were noted, particularity within eastern portion of this regime. A hazard rating of 1 has been assigned to this regime, however, if further investigations show that weak layers or high piezometric pressures do not exist, the hazard rating may be downgraded to 2 or 3.

The degree of marine erosion varies from east to west. Evidence of wave attack at high tide level and sloughing near the toe was observed, particularly toward Icarus Point. Marine erosion may be less of a significant factor in this area than in regimes to the east.

4.3.3 Regime III - Invermere Road to Molecey Creek

The Quadra Sediments are interpreted to comprise the lower two thirds of the shoreline slope with a significant thickness of silt/clay (Unit 2) above high tide level. Although weaker layers have not been directly observed, peat/clay layers are reported in a water well log at the east end of this regime. Historic clay mining off Brickyard and Waldbank Roads has also been reported.

This area is interpreted as the western half of the Molecey Creek groundwater flow regime, which likely receives significant recharge from inland areas, as discussed in Section 3.5. The more permeable Quadra "Sands" are confined and appear to become thinner toward the crest, possibly leading to a "funnelling" affect on groundwater flow and higher piezometric pressures. Significant seepage at mid-slope in the Quadra silt/clay was observed.

Block failures near the north end of Invermere Road and east end of Waldbank Road, and numerous crest, mid-slope, and toe (slab and blowout) failures (some of which appear to approach block size) appear to be active due to a marine erosional environment which provides continuous removal of toe material. Molecey Creek itself appears to be a regressive failure. A hazard rating of 1 has been assigned to this regime.

4.3.4 Regime IV - Molecey Creek to Norasea Road

The Quadra Sediments comprise the lower two thirds to one half of the shoreline slope. However, the sediments tend to pinch out toward the east and thin toward the shoreline (north). This is particularly true of the upper sand units. This change in geology appears to correspond to a transition in failure character from a large block mode at Sealand Park to shallower slab or blowout failures near Norasea Road.

This area is interpreted as the eastern half of the Molecey Creek groundwater flow regime. Like Regime III, the more permeable Quadra "Sands" are confined and appear to become thinner toward the crest, possibly leading to a "funnelling" affect on groundwater flow and higher piezometric pressures. This may be more pronounced due to lateral confinement along eastern side as a result of a defined change in geology. Significant seepage was observed at the interpreted failure surface and at the base of the Quadra sand unit exposed along the shoreline.

Molecey Creek and the creek north of Greenwood Way have likely formed as regressive features due to piping and surface erosion in this area. At the present time they may provide discharge points for groundwater, reducing piezometric pressures through lateral dissipation.

The Sealand Park/Driftwood Place failure(s) are considered to be the largest and most active block failure(s) within the study area, with an estimated volume of over 300,000 cubic metres moving up to 6 metres over the last 5 years. This failure has been bisected by the creek off Greenwood Way, resulting in two failed blocks. Surveying and displacement details are included in Appendix D (Regime IV).

Peat/clay was observed on top of the shoreline bluff where the failure surface is interpreted. Samples of the clay taken near the bluff have an estimated shear strength (residual effective angle of internal friction) of approximately 17°, based on Plastic and Liquid Limits of 45 to 49% and 24 to 31%, respectively (after Deere, 1974).

Continuous marine erosion along the shoreline has removed much of the failure debris and appears to be slowly eroding intact glacial soils. This constant erosion has resulted in an over-steepened toe that has continually undergone slabbing failures and may trigger further regression of the large block failures. A hazard rating of 1 has been assigned to this regime.

4.3.5 Regime V - Norasea Road to Fillinger Road

The geology is substantially different in this regime than regimes to the west. The shoreline slopes are interpreted to be comprised of Dashwood Till and the lower Quadra silt/clay unit (Unit 2) directly underlying the Vashon Drift. Occasional sand (minor gravel) lenses were observed at the Quadra-Vashon contact and may be remnants of the upper Quadra deposits.

Seepage points appear to consistently coincide with slope failures, and can likely be attributed to flow through the sand/gravel lenses at the Quadra - Vashon contact. The dominant failure mode is that of regressive piping or blowout with some minor slab failures at the toe and crest. Storm water flows likely aggravate failure conditions for both modes.

Marine erosion along the shoreline has continually removed debris and intact material and has resulted in over-steepening and slab failures near the toe. Over time, as a result of marine erosion, the regressive failures of the upper slope are expected to continue. A hazard rating of 2 has been assigned to this regime.

4.3.6 Regime VI - Piper's Lagoon to Stephenson Point

Sand overlying a silty till material make up the surficial deposits that overlie bedrock in this area. Bedrock consists of competent volcanic rock. Bedrock is exposed in many areas along the shoreline, but may be covered by surficial materials that have slumped or migrated downslope. Therefore, marine erosion is a problem only where intact surficial deposits are exposed below high tide level.

Seepage is evident in several areas near mid-slope. It is anticipated that seepage primarily occurs along the bedrock - surficial deposit contact.

The failures observed in this area were primarily classified as sloughing and slab failures that have occurred through the surficial materials above bedrock. Remedial measures in the form of a seawall have been recently carried out along the shoreline of a single lot off Piper's Crescent. Property owners should be advised that the control of runoff and surface drainage are required to reduce the potential for further failures in this area. The hazard rating for this regime is considered to be 4 providing that surface water is controlled.

4.3.7 Regime VII - Battersea Road to B.C. Ferries Wharf

The shoreline slopes in the Cilaire area are predominantly comprised of Vashon Drift (till). Small exposures of grey clay, possibly the lower Quadra unit (Unit 2), are exposed at the toe of the slope near Battersea Road. Sand may also underlie the till, with the till-sand contact as high as 50 percent of the slope height near Battersea Road. Seepage is evident along the beach in several locations, however the source horizon could not be determined.

The dominant mode of failure in this area is that of sloughing or slabbing in over-steepened areas. Significant head scarps above Battersea Road indicate that more deep seated failures are possible toward the north end of this regime and could be related to the presence of clay or high groundwater pressure near the toe of the slope. A hazard rating of 2 has been assigned to this regime. However, further investigations assessing the probability of deep seated failures near Battersea Road may change this rating.

4.4 FACTORS AFFECTING SLOPE STABILITY

Based on the findings of this study, the mechanisms, locations, and frequencies of failure appear to be controlled by several factors. The triggering factors that have lead to large scale block movements and other failures (and continual movements) are not completely understood at this time, but include:

- Geology/Stratigraphy, specifically the presence of potential weak units within the Quadra Sediments;
- Marine erosional environment with the continual active shoreline erosion removing slide debris material and causing over-steepened shoreline slopes;
- Groundwater or high piezometric levels associated with the Quadra Sediments;

- Storm water runoff and surface erosion; and

- Slope disturbance and development as it affects the above factors.

These factors are discussed in Sections 4.4.1 through 4.4.5. Other episodic or future influences may include the following:

- Seismic Events - Seismic accelerations may lead to failure of slopes which were close to failure, but which had not yet moved, or may lead to increased movement of slopes which have already failed. For example, during the 1946 earthquake, numerous failures were observed on slopes in the Quadra Formation. Most of these observations were farther north since the epicentre of the earthquake was in the vicinity of Campbell River.

- Sea Level Rise - Over the past several years, there have been several and varied predictions regarding future rises in sea level due to global warming. Since global warming is not accepted by all parties, these predictions have given rise to considerable debate. However, some of the predictions are of sea level rise of over 1 to 2 metres over the next 40 to 80 years. Such rise, if it occurs, would expose many of the slope toe areas to additional erosion and would undoubtedly have a major impact in the absence of mitigative measures such as shoreline erosion protection.

4.4.1 Potential Weak Units

Clay/peat associated with the Quadra Sediments have been observed within the Sealand Park area and in water well logs obtained from the Ministry of Environment. Samples of clay (interpreted failure plane) obtained from atop the shoreline bluff at Sealand Park indicate this material has a residual shear strength (effective internal angle of friction) of approximately 17°, based on Deere, 1974. The continuity of this or other potential weak layers is not known for certain, but appears to be at least several tens of metres.

4.4.2 Marine Toe Erosion

Observations indicate that toe erosion along the shoreline is responsible for continual removal of toe material and ongoing slope movement between Fillinger Crescent and Icarus Point. West of Icarus Point, the shoreline is susceptible to wave attack. However, this area is generally considered to be a zone of net deposition with less erosion of the slope toe.

Site observations indicate low but continuous levels of shoreline erosion have been occurring within most of the study area. Wave attack appears limited to a zone approximately one metre above the beach level. Thus, there may be some erosion of the slope toe, even in beach depositional areas.

Small increases in sea level (speculated due to global warming) could lead to an accelerated rate of regression of the slopes. Also, further movement and removal of failure material at the toe may cause additional block movements behind the existing head scarps to occur.

It should also be noted that successful shoreline protection measures in one area could potentially decrease the sand available to other areas and cause future changes to erosional patterns and thus, to slope stability in other areas.

4.4.3 <u>High Piezometric Levels</u>

High piezometric levels associated with the Quadra Sediments may occur during the winter months. It is interpreted that the sand and coarser grained units of Quadra Sediments act as a confined aquifer, which receives significant recharge south of the shoreline.

4.4.4 <u>Surface Erosion</u>

At present, the risk of surface erosion is limited to existing channels or low areas. Changes to the runoff regime resulting from urbanization of the drainage basins has altered the natural runoff channels. However, the nature of the glacial soils which resist erosion to some extent, and whose coarser fractions can armour the creek bed/banks when the finer fractions are eroded, has lessened the potential impacts of these changes. Abundant vegetation and fast growth may also assist in this regard.

4.4.5 <u>Development</u>

Although it is difficult to confirm due to the lack of historical records and limited air photo coverage, the impact of development over the past 50 years may or may not be accelerating the rate of shoreline slope regression throughout much of the study area. Aspects of development which may contribute to changes in the rate of regression include:

- change of the regional hydrogeology characteristics such as infiltration and piezometric levels;

- past disturbance of the slope including construction of trails to facilitate logging operations or construction of trails by home owners;

- significant removal or degradation of vegetation along the shoreline slope;

- discharge of concentrated storm water flows at the top of the slope through drain lines (eg: eaves, patios, etc.), overflow of municipal drainage systems, and excessive lawn watering;

- dumping fill or debris over the slope crest; and

- excessive lawn and garden watering.

Changes to the hydrogeologic (groundwater) flow regime which may result from development could include either an increase or reduction in piezometric levels. Storm and sanitary drainage systems are generally effective in removing surface water and reducing infiltration. However, if these systems rupture or leak, significant local infiltration may occur.

Past slope disturbance may have resulted in oversteepened areas of the shoreline slope or may have disturbed and weakened near surface soils. Degradation of vegetation may increase the potential for near surface failures, and fill or debris placed on or adjacent to the slope may increase the driving forces that cause failure. Further, failure through the debris may result as degradation or saturation weakens this material.

SECTION 5.0
RECOMMENDATIONS

5.1 GENERAL

Guidelines for improving or maintaining the stability of the shoreline slopes in the vicinity of existing and future development fall into two general categories that include mitigative and remedial measures that might be considered by property owners or by the City of Nanaimo. Further investigations are recommended to provide a sufficiently detailed understanding of existing and potential failures and for design of significant remedial measures in developed areas.

It appears that typical geotechnical assessments for development have provided a safe building setback for structures. Although these assessments have generally maintained that slope failures will continue, the loss of property value due to failures has not typically been addressed.

Property owners should be encouraged to practise mitigative measures, such as those discussed below, that will tend to minimize the impact of some of the factors affecting slope stability. If significant failures or conditions leading to failure such as tension cracks, soil displacement, toe erosion, excessive seepage or piping are identified on individual properties, the owners should be encouraged to seek engineering advice and implement remedial measures.

5.2 MITIGATIVE MEASURES

5.2.1 Runoff Erosion Control

On slopes, erosion control may be achieved by ensuring that runoff is not concentrated, and that a healthy natural vegetation buffer is maintained from a point behind the slope crest down to the toe of slope at the beach. Often, landscaping in the urban environment, or road construction, leads to concentration of upland runoff. This concentration can lead to crest failures, rill development and gullying. Preservation of natural vegetation buffers adjacent to cleared/landscaped areas can maintain a runoff attenuation capability which will assist in maintaining the stability of the soil/vegetation cover. In addition, storm water detention may be used to reduce peak flows.

For individual lots, drainage from hard surface areas, roofs, and foundations should be controlled in non-perforated pipes and discharged away from the slope. Roof drainage should not be discharged into footing drains. Discharge over the crest should not take place unless conveyed beyond the toe of the slope. In addition, facilities such as pools and ponds should not be constructed adjacent to the crest of the slope unless special measures are taken in case concentrated leakage occurs.

If stream bank erosion control is necessary, Figure 5.1 provides schematic illustration of commonly used control methods; it should be noted that these do not represent a final design suitable for installation.

5.2.2 Slope Disturbance

With the exception of slope toe stability measures discussed below, it is recommended that disturbance of the shoreline slope be avoided. Unsupported cuts in the slope will likely destabilize the slope and cause further local failures.

It is judged that end-dumping fill, roots or slash over the crest of the slope will not promote or improve the stability of the slope and could destabilize local areas as this material degrades or blocks natural seepage. It is recommended, therefore, that no material be placed on the crest or the slope itself. It is further recommended that any existing significant piles of fill or debris be removed from the slope.

5.2.3 Vegetation Removal

Selected removal of isolated trees or topping of trees on the slope has no significant impact to slope stability, provided that the slope is not stripped or clear cut. Topping of trees to the point that the tree is killed, particularly if practised on several adjacent trees, may tend to degrade near surface slope stability, allow further erosion and reduce the amount of water removed by evapotranspiration. Removal of tree roots/stumps should not be permitted. Vegetation on the slope should be encouraged and managed so that a permanent, dense evergreen cover is maintained.

5.3 POTENTIAL REMEDIAL MEASURES

Potential remedial measures or construction that will improve the stability of the shoreline slopes will depend on the dominant mode of failure. In general, the measures for each mode of failure will include:

- Sloughing and Slab Failures - provision of support, reduction of slope angles of over-steepened portions of the slope (or removal), shoreline erosion protection or storm water diversion or detention may be required. If tension cracking becomes visible, the cracks should be filled to prevent infiltration. Additional support using shotcrete and anchors could be provided if economically feasible.

- Piping or Blowout Failures: - enhance the natural seepage and provide support by installation of french drains/horizontal drains and appropriate supporting berm.

- Block Failures: - reduce piezometric pressures or other driving forces. Shoreline erosion protection may be required to stabilize toe material. Support of the head scarp may be paramount depending on proximity of dwellings or value of property.

In general, decreasing the overall slope angle is an effective method of protection for structures. For new developments, determination of a setback (inland of the setback line the property is considered safe for its intended use) for new construction provides a decrease in the overall angle between structure and toe. For existing development, however, decrease in the overall slope angle is not generally feasible.

The level of shoreline erosion due to wave attack will likely be significant over the long term. Without providing erosion protection along the toe of the slope, long term stabilization of the shoreline will not occur. Toe protection, if properly engineered, will promote stability of the slope, but there are several undesirable affects which may occur from inadequately engineered structures. These may include:

- Increased erosion at the ends of structures. For riprap or a wall ending at the property boundary, there may be increased erosion at the toe of the adjacent property.

- Increased erosion in the down littoral drift direction as a result of a decrease in available sediment. In the past, this has led to some spectacular failures in the Quadra Formation at other locations in Georgia Strait. The conditions may differ, but the failures serve to warn about the consequences of inadequate planning for beach protection structures.

- Increased toe erosion may undercut the erosion measures if proper provisions are not made.

Mitigative erosion protection measures such as shoreline revetment using riprap, gabions or concrete blocks or retaining walls of similar materials may be employed to control erosion along shoreline subject to engineering investigations and design. Examples of suitable erosion control measures which may be considered are presented on Figures 5.2 and 5.3.

Recent work in Florida has shown that beach enhancement may also be carried out by installing properly filtered drains in the wave run-up zone. These drains create a strong vertical downward gradient that promotes beach stability. It is not known, however, whether these works will be successful over the long term.

Groynes are not recommended for erosion control at this time. By interrupting the littoral transport of sediment by constructing long narrow erosion resistant structures out from the coastline, instabilities in the beach/coastline in the down drift direction may occur. Detailed modelling of littoral transport would be required to ensure the groynes would perform both satisfactorily and safely.

In areas where riprap has been placed along the shoreline adjacent the slope, such as the western limits of Sealand Park, it appears that the riprap may be providing some protection against erosion of the slope toe. However, there appears to be no filter relationship between the natural slope soils and the riprap which has resulted in the natural material being washed through the larger, coarser riprap. Further, the riprap is becoming buried with slope material as it reaches its angle of repose.

If rates of erosion are significant (greater than 0.1 metres per year), it is recommended that consideration be given to improving existing erosion protection along the toe of the slope by ultimately developing an enlarged riprap cross-section with filter materials between the natural material and the riprap. Alternatively, a seawall may be developed along the toe of the slope. Design and construction engineering for shoreline erosion protection measures should be required. Properly engineered measures will be beneficial in increasing the stability of the shoreline slope, however, down drift potential erosion requires careful consideration.

If no direct measures are taken to protect the slope toe from erosion, a program should be established to monitor the erosion over time. Surveys (detailed air photo or traverse) to establish position of the slope toe should be carried out every 5 to 10 years initially with subsequent monitoring based on the initial results. Surveys should be carried out in Regimes II through V and Regime VII as summarized in Table 5.1.

5.4 FURTHER INVESTIGATION

Further investigations are recommended for many of the areas studied to provide a reasonably detailed understanding of the geologic and groundwater conditions. The study area is large in extent with limited available hydrogeological/geological information. Information obtained from additional investigative work would provide useful stratigraphic and groundwater data which would be used to validate the interpretations made in this study and define safe areas for structures.

Further investigations should start by defining the conditions associated with the Sealand Park-Driftwood Place failures. Once interpretations have been validated, other areas where block failures are suspected should be investigated and compared to the data obtained for Sealand Park and Driftwood Place. The objective of these investigations is to provide a reasonably detailed understanding of the geologic and groundwater conditions as they impact shoreline slope stability. In Regimes considered to have a hazard rating of 1, specific objectives include the identification and sampling of weak zones or layers, if they exist, and quantification of piezometric levels, if weak layers are present. This objective is intended to focus directly on the lithology of the shoreline slopes and the mechanism of block movement.

The recommendations have been presented in a general manner to allow for flexibility of further exploration. It is anticipated that exploration methodologies may require change, adjustment or "fine tuning" to reflect new data as it becomes available. From a regional point of view, drilling investigations involving continuous sampling are thought to be the most appropriate. However, other investigation methodologies that fulfil the above objectives may also suffice, particularly for individual properties. Possible methods may include:

- Surface trenching to expose intact material and detailed geologic mapping. This method may be more appropriate for individual properties or for areas where significant geologic exposures already exist. For example, the valley formed by Molecey Creek may provide an opportunity to expose significant sections of geology in this area. This method, however, is not appropriate for areas in which large thicknesses of slough or mobilized material exist.

- Rotary drill holes carried out in conjunction with geophysical micro-logging techniques. The micro-logging must be suitable for identification of thin clay laminations (resolution greater than ± 1 cm). This technique may not be 100 percent effective and would require confirmation and correlation with continuously sampled drill holes.

Drilling investigations involving continuous sampling and installation of geotechnical instrumentation are recommended as likely the most appropriate means of providing the regional information outlined in the North Shore study. Five shallow (<30m) and twelve deep (50 - 70m) drill holes are recommended for the study area over the next few years, as shown on the Regime Plans included in the Appendices of the report. These drill holes represent recommended approximate locations for further investigations. If drilling is utilized, each of these holes should be instrumented with piezometers or slope indicator casing as appropriate to provide the required information. If other methodologies are used, this instrumentation may not be appropriate.

Significant success in coring sediments has recently been obtained using PQ triple tube wire line equipment. In some recent cases, this method has provided, generally, 100% recovery of a 9cm core and creates a nearly 12cm diameter hole for instrumentation. Successful drilling and coring of sediments is to some extent dependent on the particular materials involved. This method would require a test drill hole to verify that success that has been achieved elsewhere could be matched in the Quadra Sediments within the study area. Another possible method that could be considered is the use of vibratory coring equipment.

The advantage of coring over other drilling methods is that a continuous sample is generally produced. This is considered important in this area since the shear surfaces for deep seated movement may only be a few centimetres thick. Discontinuous sampling, such as that produced by Shelby tubes, may miss these thin zones. A rotary drill hole with logging of the returned material, while suitable for determining the lithology of thick units, generally is not suitable for picking up thin weak beds or laminations, such as has been observed within the Quadra Formation during surface mapping. In softer sediments, the electric cone has been used to identify thin zones, but, in general, the sediments found in the North Shore area are too dense for use of the cone.

It is emphasized that the maximum benefit of the regional investigation program recommended in this report would only be gained by correlating all of the information obtained from the holes with site specific information which is summarized in the report.

For budgeting purposes, it is assumed that coring with PQ triple tube equipment would provide the best recovery (of sample). With this method, it is estimated drilling and the installation of instrumentation will cost between $3,000 to $5,000 for each shallow drill hole and between $8,000 to $10,000 for each deep drill hole. The work carried out for each site should include (budget estimates shown):

Drilling and instrumentation (including supervision):		
- shallow holes (<30m)	$3,000 - $ 5,000.00	ea.
- deep holes (50 - 70m)	$8,000 - $10,000.00	ea.
Laboratory Testing (per hole):		
- index testing	$1,500.00	ea.
- strength testing (if required)	$3,000.00	ea.

It is anticipated that index testing will be carried out on numerous fine grained horizons in an effort to find the weakest layers, laminations or bedding planes. Samples for strength testing would be selected based on the index tests and should be limited to 2 or 3 samples.

Detailed mapping & correlation with drilling	$3,000.00	per site
Monitoring of Instrumentation and Compilation of Data	$5,000.00	per site

Stability Analyses $1,000.00 per site

Stability analyses should be carried out using actual data; parametric analyses should be carried out to determine the sensitivity of slope stability to changes in piezometric elevations and general sea levels. It is understood that a Federal Government report for the east coast of Canada considered sea level rise as an integral part of the assessment.

Design of Remedial Measures (if required) variable

The further work recommended would provide understanding and quantitative information on the factors which are thought to be instrumental in the observed failures along the North Shore. It is considered that this work is more critical for the area encompassing Sealand Park to Icarus Point. As a minimum first step, 7 relatively deep drill holes (to below sea level) should be carried out in this area. Initially, 4 drill holes (2 cross-sections) should be completed in Sealand Park with instrumentation to form cross-sections through the existing failure. After completion of that work, the next three holes should be carried out near the northern end of Brickyard Road, Invermere Road and Blueback Road. Further investigations should be modified to reflect the results of this work.

5.5 TERMS OF REFERENCE

It is recommended that the City of Nanaimo adopt terms of reference for future geotechnical engineering assessments that include, as a minimum, identification of possible failure mechanisms, determination of the risk of possible failure modes and provision of evidence for engineering opinion. The terms of reference should further include the following:

- A statement that the property/site is safe for the intended use from a geotechnical point of view and that a period of safety should be provided. It is recommended that if certain factors affecting stability can not be accurately quantified and the geotechnical engineer can not state that the site is safe for at least 100 years then periodic review or monitoring should be required.

- The methodology of the investigations should be summarized in the report.

- The scope of the discussion and investigations should include detailed consideration of the types of failure modes which could affect the property. Details of the field investigations and the resulting data should be summarized in the report.

- The conclusions of the report should be backed up by the field data and other data which may be available. Any limitations of the conclusions and recommendations (for example, lack of conclusive data) should be discussed.

TABLES

AGRA
Earth & Environmental Group

In critical areas, it may be appropriate to tie the geotechnical report to the property deed by means of covenant to insure that future purchasers of the property are informed about the geotechnical conditions of the property. This is being done on an increasing scale in British Columbia where the property is subject to some risk or where some item of maintenance/inspection is required on the part of the owner.

SECTION 6.0
CLOSURE

The opportunity to be of service on this project is appreciated. If you have any comments or questions, kindly contact us at your earliest convenience.

Yours truly,

HBT AGRA Limited

Per:

D. Hogg, P.Eng.

Per:

B.A. Musgrave, P.Eng.

Reviewed by:

D.S. Cavers, M.Eng., P.Eng.
Principal Engineer

TABLE 3.1

SUMMARY OF SITE CHARACTERISTICS
NORTH SHORE STABILITY ASSESSMENT

REGIME	TOPOGRAPHY	HYDROLOGY	GEOLOGY	GROUNDWATER	SURFACE EROSION	MARINE EROSION	STABILITY	HAZARD RATING
I	- average slope height of 35 to 40 metres with an overall slope angle of 30 to 45°. - change in relief located near mid-slope; the upper portion of the slope is steep averaging 30 to 70°, while mid-slope is 10 to 30°, east and west of Seabold Road. - slope is significantly steeper off the end of Seabold Road where a point in the shoreline exists. - surface gradients are approximately 10% toward the shoreline (north) inland of the crest.	- numerous small surface water flows observed at slope toe. Some seepage/flow appears to originate on the slope near the mid-slope change in topography. - sewer and storm outfall lines in place on slope located off Seabold Road. - catchment is directly up-slope; with storm water controlled by measures along Dickenson Road, Waldbank Road and throughout existing subdivisions.	West of Seabold Road: - comprised of yellowish to light brown sands (unit 6) and possibly overlain with of Vashon drift (units 6 and 7). East of Seabold Road: - the materials vary between primarily sand (unit 6) and a full stratigraphic sequence comprised of units 7, 6, 5, 4 and 2. Unit 6 diminishes in thickness from west to east.	- the Quadra sands unit 6 and unit 4, likely transmit much of the groundwater in this area. Water levels reported in well's are 15 to 20m below the crest of the slope. This aquifer appears to thicken with less vertical and lateral confinement to the west. - recharge is likely significant in areas to the south or where the Quadra sands are closer to surface. - seasonal water table or saturation possibly occurs within the upper deposits (unit 7) under significant rain.	- several surface channels up to 1 to 2 feet deep exposing intact sediments on channel bottom. - slope potentially susceptible to erosional gullying if concentrated run-off occurs. - provided that the slope is not disturbed and up-slope surface water flows are directed away from the slope, the risk of erosion due to surface runoff down the foreshore slope is estimated to be low.	- occasional small soil exposures located along slope toe are associated with surface water flows; wave action may also be significant during high tide levels indicating some erosion potential exists. - regime can be generally characterized as a depositional sink with a low erosion risk overall.	- small scale soil sloughing or slab failures were observed along the slope toe and the over-steepened crest area. - origin of flatter mid-slope areas is not known but may be related to past movements. Stabilization may have occurred through a decrease in marine erosion. - seismic performance not known, however, pseudostatic analysis suggests ± 10 to 20% reduction of factor of safety under 1:100 year event. - stability analyses indicate sensitivity to piezometric levels (refer to Appendix A). - small cave observed roughly 200m west of Seabold Road may be a small piping failure.	- hazard rating of 3 provided that the slope is not disturbed and that upland storm water is directed away from the slope. - shallow sloughing or slab failures may continue to occur.
II	- average slope height of 40 to 60 metres with an overall slope angle of between 24° and 40°. - slope is characterized by a mid-slope terrace. This terrace averages 20 to 60 metres in width and dips 0 to 10° seaward. - upper portion of slope is generally over-steepened at 40 to 70°, while mid-slope is 10 to 20° and steepens toward the shoreline. - occasional over-steepened 1 to 2 metre high clay exposure at toe. - The area from Blueback Road to Invermere Road is a topographic ridge with general surface gradients approximately 10% toward the shoreline, inland of the crest.	- city services in place on slope located off Blueback Road, Invermere Road and between Blueback and Invermere. - catchment primarily includes areas directly south with runoff varying from the northwest to the northeast over the topographic nose. - ponding and channelling of surface water on mid-slope terrace near the upper slope toe. Several small channels conduct surface water downslope to beach.	Upper Slope: - comprised of marine sands (unit 7) overlying Vashon Drift (unit 6). Lower Slope: - consists of Quadra sand (unit 5) overlying inter-layered sand, silt (unit 4) overlying laminated clay (unit 2). - grey clay (unit 2) which was overlain by inter-layered silts and sands (unit 4) was encountered along the slope toe primarily between Lewis Road and Invermere Road. - substantial deposits of glacio-fluvial sand and gravel exist in this area inland of the shoreline. Topography appears to be a result of these thicker deposits. - water well information agrees with mapping.	- a perched water table is anticipated within the upper units 7 and 6 during heavy rain. - much of the groundwater flow is interpreted to be within the Quadra units which appear to have some degree of vertical and lateral confinement. - Recharge area appears to be significant inland, however direct recharge to the Quadra units may be limited. - small pump house (reported artesian well) is located on mid-slope terrace between Lewis and Blueback Roads.	- several surface erosion channels up to 1 foot deep and 1 to 2 feet wide cross the mid-slope terrace and lower slope to beach exposing intact material. - surface erosion of over-steepened clay exposures along shoreline. - provided that the slope is not disturbed and up-slope surface water flows are directed away from the slope the risk of erosion due to surface runoff down slope is considered to be low.	- occasional small soil exposures along slope toe. - regime characterized by a depositional sink with a low erosion risk. - wave action during high tides may result in small scale erosion, particularly near Icarus Point.	- at least two potential block failures have been identified in this regime, however, the possible block off Blueback Road may be either a depositional or erosional feature. - the existing mid-slope terraces are interpreted as past block failures which potentially could re-activate. - possible failure blocks visible in logged area. - uncontrolled surface erosion and runoff has resulted in crest or debris flow failures along the crest leaving over-steepened soils on upper slope. - in general the crest line appears to consist of a series of coalescing head scarps. - actual performance under seismic loading is not known, however, pseudostatic analysis suggests ± 10 to 20% reduction of factor of safety under 1:100 year event.	- a hazard rating of 1 if the existing mid-slope terrace originated from past block failures. - if further investigation(s) show that weak layers or high piezometric pressures do not exist the hazard rating may be down graded to 2. - relatively shallow surface failures are expected to continue within the upper slope. - slips at toe may be more frequent depending on marine erosion.

TABLE 3.1

SUMMARY OF SITE CHARACTERISTICS
NORTH SHORE STABILITY ASSESSMENT

REGIME	TOPOGRAPHY	HYDROLOGY	GEOLOGY	GROUNDWATER	SURFACE EROSION	MARINE EROSION	STABILITY	HAZARD RATING
III	- average slope height of 40 metres with an overall slope angle of between 24° and 46°. - the upper half of the slope generally has a dips of 40 to 60° with head scarps located near the crest of up to 80°, while the lower portion of the slope is somewhat flatter with dip of 20 to 40°. - gradients inland (south) of the crest are 10% toward the shoreline. - surficial deposits (unit 7) south of Icarus Point and along Waldbank form a topographic ridge.	- Small surface water flows were observed along much of the beach, particularly on the western side of this regime. - several seepage points were observed originating from near the mid-slope region discharging over the Quadra clay (unit 2). - surface gradients are generally to the northeast toward the slope. - south of Waldbank Road, drainage patterns are directed toward north-northeast, toward the Molecey Creek drainage system which is identified as the boundary between Regimes III and IV.	Upper Slope: - comprised glaciofluvial sand and gravel (unit 7) overlying Vashon till (unit 6) which in turn overlies the Quadra sediments (units 2, 4, and 5) with the Quadra sediments making up two thirds of the slope. Lower Slope: - the lower grey clay (unit 2) of the Quadra is the most frequent unit outcropping along the slope toe with some minor exposures of Dashwood till (unit 1). - the presence of potentially weaker clays is not known, however past mining of clay near the eastern end of the regime has been reported.	- a perched water table is anticipated within the surficial deposits during heavy rain. - much of the groundwater flow is interpreted to be concentrated within the Quadra sediments, predominantly the sand units. These units appear to be confined vertically. - this area is interpreted to form the eastern half of the Molecey Creek regime. Significant recharge may be available from areas to the south. - water well records indicate that the Quadra sands become thinner towards the crest, possibly leading to a "funnelling" effect and build up of pressure near the slope.	- several surface erosion channels of 1 to 4 feet deep cross the mid-slope terrace and lower slope to beach exposing intact sediments. - surface water and erosion has likely caused a number of crest failures. The failures tend to coincide with development areas. - provided that the slope is not disturbed and up-slope surface water flows are directed away from the slope the risk of erosion due to surface runoff down slope is considered to be low. - Molecey Creek itself appears to be a regressive failure likely caused by a combination of concentrated runoff and groundwater piping.	- the regime is characterized by a marine erosional environment where significant wave attack occurs at the base of the slope during storm events. The eroded material is transported westward by littoral currents. - the present rate of marine erosion is estimated to be low but relatively continuous.	- numerous head scarps and crest failures are located along the over-steepened upper slope throughout this regime. - at least two possible block failures were identified. - mid-slope terrace at eastern end of regime may be the result of clay mining and large block failure (equal magnitude to Sealand). Presence of weaker clay layer is not proven. - failure(s) (1988) located off Waldbank Road (east end of regime) were triggered by uncontrolled runoff. The upper portion of this site has subsequently been resurfaced with shot-rock; heavy seepage noted coming from the base of the Quadra sands in this area. - possible block or blowout failures present at west end of regime along Icarus Drive. - Molecey Creek is interpreted as a regressive piping failure aggravated by runoff. - failures sensitive to seismic loading and increases in piezometric levels.	- Hazard rating of I. The potential for block failures is significant as well as the potential for significant shallow failures to occur within the over-steepened upper slope. - possible blowout failures have been identified at several locations. - further investigations will assist in confirming this hazard rating and the potential for further failures.
IV	- average slope height of 40 metres with an overall slope angle ranging from 18° at Sealand Park to 40° near Norasea Road. The upper slope and head scarp slopes 40 to 70°. - slope is characterized by a bisected, relatively flat-lying translational block failure (Sealand Park and Driftwood Place). The upper surface of block (terrace) is located near mid-slope and extends roughly 100m north to a foreshore bluff approximately 20m high. - the surface gradient inland of the crest is roughly 10% to the northeast for 400m before flattening immediately below Rutherford Ridge. - surface gradients at the eastern end of the regime are more northerly.	- Molecey Creek is a major run-off channel and forms the western edge of the regime. This creek extends 400 metres inland and drains a topographic depression. - a run-off channel 1 to 4 metres deep is located in the middle of the regime and bisects the Sealand/Driftwood failure. - earlier storm/sewer services have been severed within the failing Sealand and Driftwood areas, new service lines lie on the surface. - possible runoff path 60m north of Norasea Road in a narrow clearing was observed in the 1988 air photos.	- the upper head scarp located above the failure blocks consists of Vashon drift (unit 6). - clay and organic materials, less than a metre in thickness were observed at the top of the sand (unit 4/5). This is interpreted as the failure zone. - A 150 to 200 metre long exposure along the shoreline reveals a 3 to 6 metre thick deposit of gray clay (unit 2) overlain by 2 to 6 metres of brown sand (unit 4 or 5) which in turn is overlain by the Vashon Drift (unit 6). - Vashon Drift ?? is also observed over much of the failure block. - the upper Quadra sediments (units 4 and 5) appear to pinch out roughly 300m west of Norasea. This area is coincident with the transition zone between block failure to the west and blowout failures to the east.	- this regime is the eastern half of the Molecey Creek groundwater regime. - the groundwater flow is likely substantial within this regime and is interpreted to be confined to the sand units exposed along the shore line. - the degree of vertical and horizontal confinement likely controls pore pressure; Molecey Creek may provide release mechanism to the west while lateral confinement to the east may be governed by the change in geology. Thinning of the Quadra Sands near the shoreline may provide a "funnelling" effect. - Molecey Creek and the small creek located near the eastern end of Parkway are likely discharge areas for groundwater and may have been formed by piping. - perched water table and saturation is evident along the contact between units 2 and 4.	- surface erosion was occurring along both creeks within this regime based on observed intact material in the creek bed. - minor surface erosion was observed within the large failure located to the east of Driftwood Place.	- the regime is characterized by a marine erosional environment where wave attack on the slope toe during storm events is significant. - the eroded material is then transported to westward by littoral currents. -debris or colluvium from the noted failures was removed by marine erosion within 1 year. - the overall present rate of marine erosion is estimated to be low, however, continual erosion is considered to be a primary factor in the overall regression of the shoreline in this regime.	- this regime includes the largest, most active block failure in the study area. The block appears to be rotational near the head scarp and translational near the shoreline. It appears to be bisected into two blocks by a creek off Greenwood Way: i) Sealand Park failure (area of 350x100 metres) which is believed to extend from the base of the upper head scarp northward to the foreshore and from an extension of Forest Drive eastward to a surface water drainage channel. This block is has moved toward the shoreline, up to 6m over the last 5 years. ii) Driftwood Place failure is believed to extend from the base of the upper slope to some 150m northward and creek off Greenwood to 150 to 200m eastward. This block is falling to the northwest, into the creek. Movements of up to 15cm have been recorded over the last year. - two additional failure regions are located at 150 to 300m east of Driftwood Place. These failures may have been triggered by an over-steepened head scarps, heavy surface water flows or groundwater blowouts. They are included in a transition zone between block failures to the east and blowout failures to the west. - impact of seismic loading and piezometric levels may be significant based on analyses.	Hazard rating of I. Large block failure was occurring within Sealand Park and Driftwood Place areas. - although the probability of block failures diminishes to the eastern end of this regime due to changing geologic conditions, large crest or smaller block failures are located in this transition area.

TABLE 3.1

SUMMARY OF SITE CHARACTERISTICS
NORTH SHORE STABILITY ASSESSMENT

REGIME	TOPOGRAPHY	HYDROLOGY	GEOLOGY	GROUNDWATER	SURFACE EROSION	MARINE EROSION	STABILITY	HAZARD RATING
V	- slope height varying from 40 metres at west edge (Norasea) to 10-20 metres at the eastern end of the regime. - the overall slope angle is 30 to 50 degrees: the upper 6-10 metres at the slope crest (in existing failures) and 1-3 metre high exposures along the slope toe are sub-vertical. - Bayshore area forms the western flank of a drainage basin that extends through Fillinger Creek and southeast along Hammond Bay Rd. - surface gradients are approximately 10° toward the shoreline (northeast).	Norasea-Bayshore area: - runoff through the area is mostly due to direct catchment up-slope of the crest. - surface flows to the north-northeast toward the shoreline in western half of regime. Fillinger Crescent: - The catchment area toward Fillinger is significantly larger and involves areas to the southeast. - a small creek located near Enthistle/Fillinger likely takes most of the runoff from this area. - other surface water runoff appears to be confined to steep gullies located perpendicular to the slope.	- Vashon drift materials (unit 6) directly overlie Quadra clay, however, remnants or coarse grained lenses of Quadra sediments are suspected to remain. - Quadra grey clay (unit 2) overlies Dashwood till (unit 1). - Dashwood till is 10 to 16 metres thick and located along the slope toe. - Based on water well information the Quadra sands (unit 4 and unit 5) are present and roughly 40m in thickness, 500m southwest of the shoreline but appear to pinch out toward the shoreline.	- the Quadra sand aquifer(s) appear to pinch out near the shoreline adjacent to Bayshore Drive. - groundwater seepage occurs primarily from sandy layers (underlying Vashon till) within "cusp-like" failures located near the base of existing head scarps. - a perched water table is anticipated within the surficial deposits (unit 7), during heavy rain. - the Bayshore area is interpreted to lie east of a potential groundwater divide and significant change in geology, which occurs near Norasea Road. This is consistent with the localized piping observed and explains the differences in failure character across Regime IV and V. - In the Norasea-Bayshore area, recharge from Rutherford Ridge is probably significant. Bedrock may further recharge the glacial sediments. High piezometric pressures associated with bedrock have been reported. - significantly more recharge potential exists toward the eastern end of the regime and may lead to regressive piping failures within the creek off Fillinger Crescent.	- surface erosion was noted along existing gullies from runoff and seepage occurring from within surficial granular materials. - surface erosion likely results in regression of the creek off Fillinger Crescent. - failures have been reported within the creek slopes off Fillinger Crescent.	- the regime is characterized by a marine erosional environment where wave attack at the slope toe during storm events occurs. The eroded material is then transported to west by littoral currents. - the present rate of marine erosion is anticipated to be low but continuous.	- blowout or piping failures off Bayshore Drive are characterized by "cusp-like" shapes. These failures are 10 to 30 metres wide and are 6 to 15 metres below the crest. The region below the failures narrows into a gully which slopes 10 to 30° seaward for a distance of 20 to 60 metres. Near the foreshore, the slope steepens for 3 to 5 metres. This steepening may reflect marine erosion of the toe. - these failures predate development in this area based on air photo interpretations. Regression of the natural slopes in this area is not significant since development occurred. - the failures are interpreted as regressive piping or blowout failures that are known to occur in cycles. Debris dumped into these features probably accelerates the failure return period. - sloughing and slab failures were observed in over-steepened areas near the crest and toe. - a significant failure near Norasea (1950) may have resulted from the 1946 earthquake. - Psuedostatic analyses indicates roughly a 15% decrease in the factor of safety for 1:100 year earthquake.	- Hazard rating of 2 provided that storm water discharge is not permitted to flow over the slope face and that the slope is not disturbed. - regressive piping or blowout failures along the existing head scarps and potential new cusp-like failures are expected to continue. - some potential exists for piping failures to occur toward the eastern end of this regime, where development is currently underway. - sloughing and slab failures are expected to continue.
VI	Piper's Lagoon: - shoreline slopes are relatively small, up to 6m in height with variable slopes. South of Piper's Lagoon: - shoreline slopes are up to 35m in height with overall slope angles between 10° and 40°. - surface gradient inland of slope varies from 10 to 30% toward the shoreline.	- runoff is indistinct.	- Sand and silt till materials overlie bedrock, which consists of Karmutsen Volcanics. - bedrock exposed along shoreline through a significant portion of regime. Piper's Lagoon: - bedrock exposed at toe underlying silt/till, some sand (no good exposures). Hammond Bay Road: - sand overlying silt till; bedrock was not observed.	- seepage along bedrock contact is likely with additional groundwater flow through bedrock.	- surface erosion possible if concentrated surface flows occur over till.	- presence of bedrock mitigates erosional potential. - toe erosion evident where materials have sloughed onto beach.	- several failures predate development (1968), however, vegetation on failure surfaces varies indicating further sloughing. Piper's Lagoon: - surface slip aggravated by toe erosion. - seawall construction up to 3m (1:5 batter) as remedial measure. Hammond Bay Road: - slab or blowout failure through surficial soils occurred through winter of 1991-1992.	- Hazard rating of 4 providing surface water is controlled.

TABLE 3.1

SUMMARY OF SITE CHARACTERISTICS
NORTH SHORE STABILITY ASSESSMENT

REGIME	TOPOGRAPHY	HYDROLOGY	GEOLOGY	GROUNDWATER	SURFACE EROSION	MARINE EROSION	STABILITY	HAZARD RATING
VII	- slope height between 20 and 30m with relatively uniform slopes of approximately 25 to 50 degrees; steeper scarp areas. - surface gradients inland of the shoreline are approximately 10% to northeast.	- runoff prior to (1950 A/P) development is indistinct except for Northfield Creek. - it is understood that existing runoff is controlled by storm sewer and ditch discharging into Northfield Creek or Departure Bay.	- slope is comprised mostly of Vashon drift (unit 6). - small exposures of grey clay (unit 2) at toe of slope in the northern portion near Battersea Road. - some sand exposures were reported during earlier investigations.	- recharge is limited to infiltration in areas directly up gradient extending to the surface water divide near Northfield and Bowen Roads. - groundwater/piezometric levels are not known.	- surface erosion occurring near crest due to concentrated surface storm flows. - surface erosion along Northfield Creek is evident.	- the regime is characterized by a marine erosional environment where wave attack at the slope toe during storm events occurs. The eroded material is then transported to the northwest by littoral currents in Departure Bay. - the present rate of marine erosion is anticipated to be low.	- dominant mode of failure appears to be slabbing in over-steepened areas. - significant full height scarps at northern end of regime, predate 1950, but with mature trees. This area may be more affected by groundwater if permeable material exists at the lower contact of the Vashon Drift. - very little impact form 1946 earthquake based on air photo analysis, while pseudostatic analyses suggest a reduction of 20% in factor of safety for similar 1:100 year event. - stability of slope appears to be sensitive to groundwater elevations.	- Hazard rating of 2 providing surface water is controlled. - the probability of re-occurrence of deep seated failures observed near Battersea Road is not known. The results of further investigations may change this rating.

TABLE 5.1

SUMMARY OF GEOTECHNICAL HAZARDS - ENGINEERING RECOMMENDATIONS NORTH SHORE STABILITY ASSESSMENT

REGIME	STABILITY	MITIGATIVE MEASURES	POTENTIAL REMEDIAL MEASURES	FURTHER INVESTIGATIONS
I	- origin of flatter mid-slope areas is not known but may be related to past movements. - small scale soil sloughing or slab failures along the slope toe and the over-steepened crest area.	- define flood paths over crest. - maintain dense evergreen cover on the slopes. - provide vegetated buffer zones. - prevent dumping or disturbance to slopes.	- none required at this time.	- drilling to define lithologic detail and piezometers to establish piezometric levels and position of groundwater table. One deep drill hole recommended initially near Seabold Road. - detailed mapping and correlation with drilling results. - lab testing of suspected weaker units.
II	- the existing mid-slope terraces are interpreted as past block failures which potentially could be re-activated. - uncontrolled surface erosion and runoff has resulted in crest or debris flow failures along the crest leaving over-steepened soils on upper slope. - in general, the crest line appears to consist of a series of coalescing head scarps.	- define flood paths over crest. - maintain dense evergreen cover on the slopes. - provide vegetated buffer zones. - prevent dumping or disturbance to slopes.	- groundwater control, if required. - shoreline erosion protection over eastern area of regime, if required over long term.	- drilling to define lithologic detail and piezometers to establish piezometric levels and position of groundwater tables. - detailed mapping and correlation with drilling results. - lab testing of suspected weaker units. - define rate of marine erosion (survey). - two shallow holes or test pits off end of Blueback to investigate potential block movement (Lot 1-4, Plan 39552). Holes should be located to form north to south section. Possible piezometer (south hole) and inclinometer (north hole) depending on results. - one 60 metre drill hole with multiple standpipe piezometer near intersection of Icarus and Blueback Roads. - one 100 metre hole near the intersection of Dover and Blueback Roads with multiple standpipe piezometers.

TABLE 5.1

SUMMARY OF GEOTECHNICAL HAZARDS - ENGINEERING RECOMMENDATIONS
NORTH SHORE STABILITY ASSESSMENT

REGIME	STABILITY	MITIGATIVE MEASURES	POTENTIAL REMEDIAL MEASURES	FURTHER INVESTIGATIONS
III	- numerous head scarps and crest failures are located along the over-steepened upper slope throughout this regime. - failure(s) (1968) located along the slope crest, off Waldbank Road (east end of regime) were triggered by uncontrolled runoff. Mid-slope terrace may be the result of clay mining and large block failure (equal magnitude to Sealand). Presence of weaker clay layer has not been shown. - several possible block failures present at west end of regime. - several possible blowout failures. - Molecey Creek is interpreted as a regressive piping failure aggravated by runoff.	- define flood paths over crest. - maintain dense evergreen cover on the slopes. - provide vegetated buffer zones. - prevent dumping or disturbance to slopes.	- storm water flow diversion or detention. - shoreline erosion protection subject to further study. - construction of french drains or horizontal drains together with stabilizing berms may be appropriate for blowout failures.	- drilling to define lithologic detail and piezometers to establish piezometric levels and position of groundwater table. - one deep drill hole near the intersection of Icarus Road and Invermere Road. Multiple standpipe piezometers are recommended. - one deep hole near the intersection of Waldbank Road and Brickyard Road. Multiple standpipe piezometers recommended. Results should be compared with investigations near Sealand Park. - one shallow hole off the end of Invermere Road on the mid-slope terrace. Lithology should be compared to deep hole to south. - define rate of marine erosion (survey).

TABLE 5.1

SUMMARY OF GEOTECHNICAL HAZARDS - ENGINEERING RECOMMENDATIONS NORTH SHORE STABILITY ASSESSMENT

REGIME	STABILITY	MITIGATIVE MEASURES	POTENTIAL REMEDIAL MEASURES	FURTHER INVESTIGATIONS
IV	- this regime includes a single block failure that has been bisected by a creek: i) Sealand Park failure (area of 350x100 metres) which is believed to extend from the base of the upper head scarp northward to the foreshore and from an extension of Forest Drive eastward to a surface water drainage channel. This block is failing towards the shoreline. ii) Driftwood Place failure is believed to extend from the base of the upper slope to some 150m northward and creek off Greenwood to 150 to 200m eastward. This block is failing to the northwest, into the creek. - two additional failure regions are located at 150 to 300 east of Driftwood Place. These failures are located in a transition zone between block failures to the west and blowout failures to the east.	- define flood paths over crest. - maintain dense evergreen cover on the slopes. - provide vegetated buffer zones. - prevent dumping or disturbance to slopes. - inspect for tension cracks behind existing head scarp, if they occur.	- storm water flow diversion or detention. - shoreline protection subject to further study. - dewater or reduce piezometric pressures and groundwater levels by horizontal drains or dewatering wells, if required.	- drilling to define lithologic detail and piezometers to establish piezometric levels and position of groundwater table. - one deep hole south of the head waters of Molecey Creek to define information for Regimes III and IV. Multiple piezometers required. - 2 hole section through Sealand Park; 1 inclinometer/piezometer located within the sliding mass and 1 multiple piezometer roughly 40 metres south of crest. - 2 hole section through Driftwood Place; 1 inclinometer/piezometer located within the sliding mass and 1 multiple piezometer roughly 40 metres south of crest. - 1 deep hole and multiple piezometer installation located roughly 50 to 100 metres west of Norasea Road, roughly 50 metres from the crest. - define rate of marine erosion (survey).

TABLE 5.1

SUMMARY OF GEOTECHNICAL HAZARDS - ENGINEERING RECOMMENDATIONS
NORTH SHORE STABILITY ASSESSMENT

REGIME	STABILITY	MITIGATIVE MEASURES	POTENTIAL REMEDIAL MEASURES	FURTHER INVESTIGATIONS
V	- crest failures off Bayshore Drive are characterized by cusp-like shapes. These failures are 10 to 30 metres wide and are 5 to 15 metres below the crest. - these failures predate development in this area and regression of the natural slopes in this area has not been significant since development occurred. - the failures are interpreted as regressive piping or blowout failures that are known to occur in cycles. Debris dumped into these features may accelerate the occurrence of failures.	- control storm flow over the crest, preventing dumping of fill/debris onto slope and maintaining seepage channels. - define flood paths over crest. - maintain dense evergreen cover on the slopes. - provide vegetated buffer zones. - prevent dumping or disturbance to slopes.	- horizontal or french drain systems installed in existing failures to provide release of pore pressure. - french drains with associated berm could improve stability of crest and building areas. - shoreline protection, subject to further study.	- 1 to 2 shallow drill holes south of existing failures on Bayshore Drive with multiple piezometers to assess piezometric levels. - define rate of marine erosion (survey).
VI	- several failures predate development (1968), however, vegetation on failure surfaces varies indicating further sloughing. <u>Piper's Lagoon:</u> - surface slip aggravated by toe erosion. - seawall construction up to 3m (1:5 batter) as remedial measure. <u>Hammond Bay Road:</u> - slab or blowout failure through surficial soils occurred during winter of 1991-1992.	- define flood paths over crest. - maintain dense evergreen cover on the slopes. - provide vegetated buffer zones. - prevent dumping or disturbance to slopes.	- none at this time.	- nothing at this time. - site specific investigations are recommended prior to design and construction of remedial measures or structures.

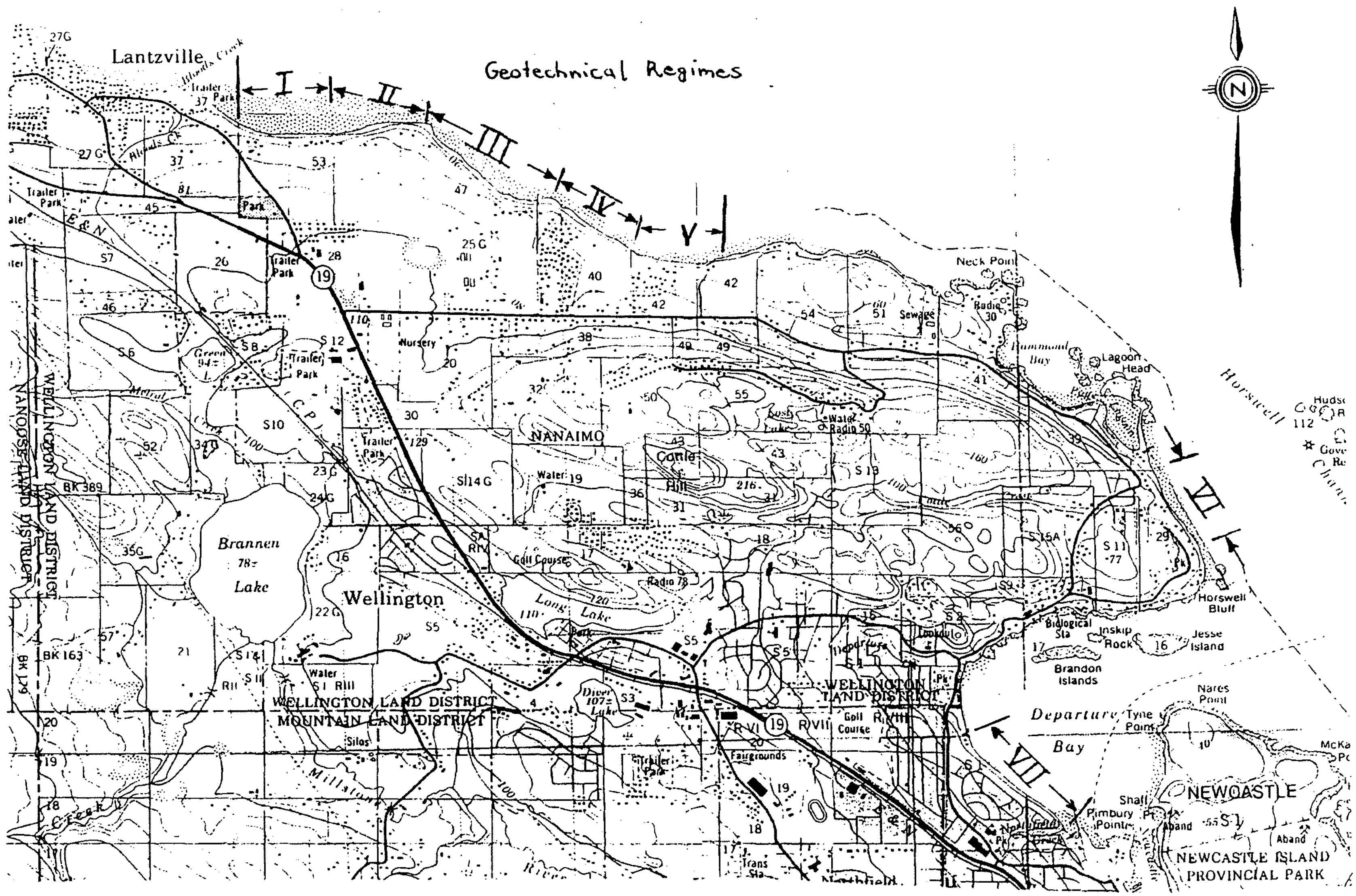
TABLE 5.1

SUMMARY OF GEOTECHNICAL HAZARDS - ENGINEERING RECOMMENDATIONS
NORTH SHORE STABILITY ASSESSMENT

REGIME	STABILITY	MITIGATIVE MEASURES	POTENTIAL REMEDIAL MEASURES	FURTHER INVESTIGATIONS
VII	- dominant mode of failure appears to be slabbing in over-steepened areas. - significant full height scarps at northern end of regime, predate 1950, but with mature trees. - very little impact form 1946 earthquake based on air photo analysis. Psuedostatic analyses suggest a reduction of 20% in factor of safety for similar 1:100 year event.	- define flood paths over crest. - maintain dense evergreen cover on the slopes. - prevent dumping or disturbance to slopes.	- control of storm runoff. - erosion control in Northfield Creek, if stability along the creek slopes becomes a problem.	- 1 deep drill hole within the Cilaire development with multiple piezometers. - samples should be obtained for laboratory testing. - survey of the slope toe between Northfield Creek and Battersea Road to define marine erosion.

FIGURES

AGRA
Earth & Environmental Group



HBT AGRA Limited

Engineering & Environmental Services

REGIME LOCATION PLAN
NORTH SHORE STUDY
NANAIMO, B.C.

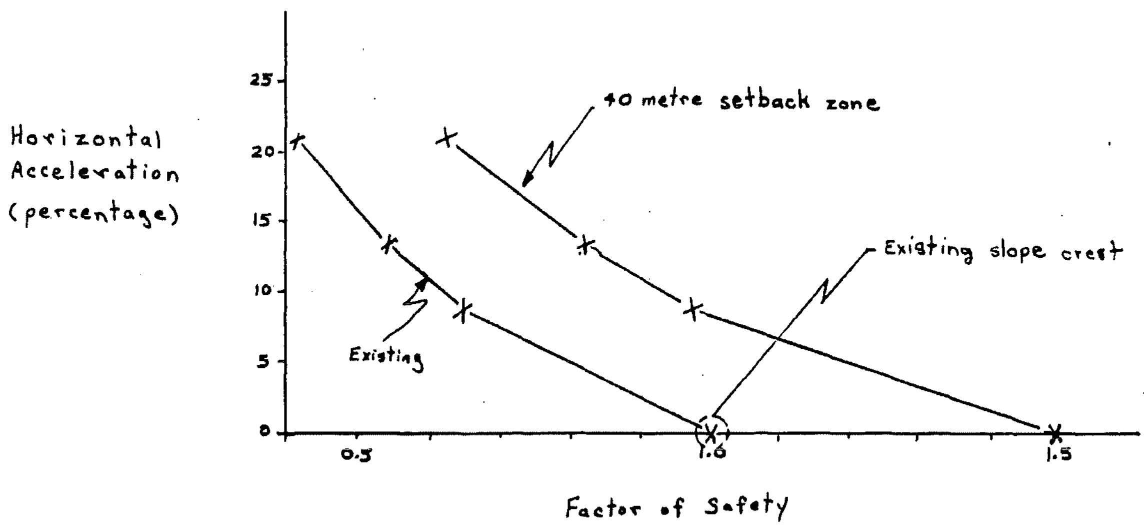
Scale 1 : 50,000

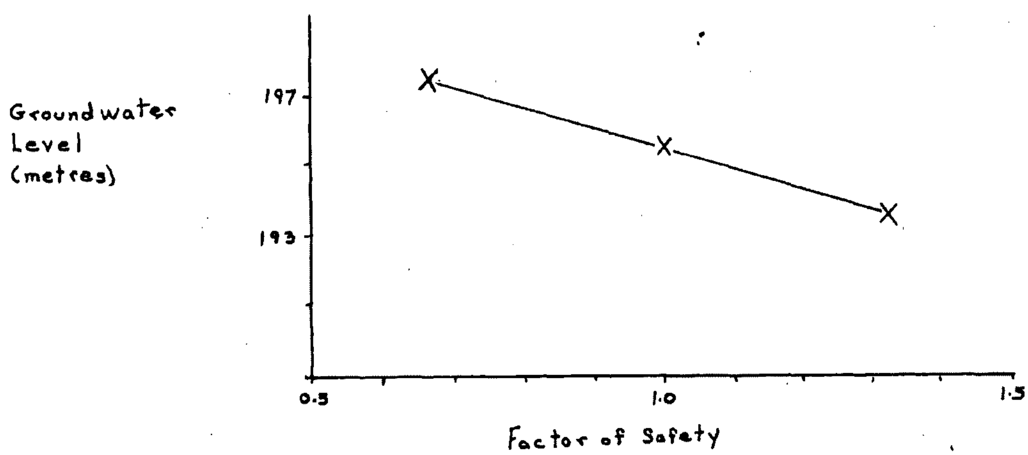
Date October 1992

Drawn By S.V.

FIGURE 1.1

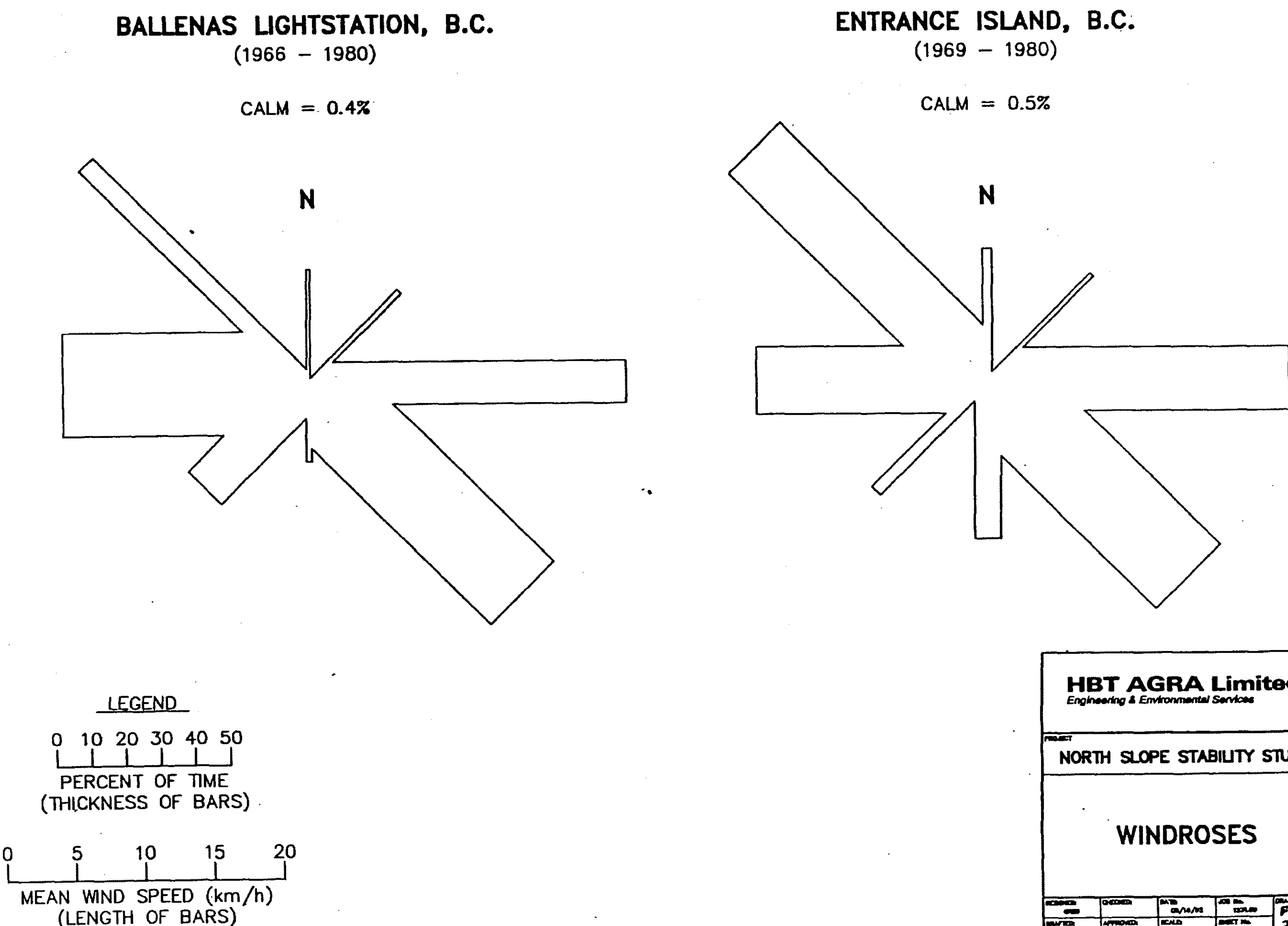
REGIME IV





HBT AGRA Limited Engineering & Environmental Services	Parametric Analysis Regime IV - Sealand Park North Slope - Nanaimo		
	Scale 1:50,000	Date Nov/92	Drawn By DH	Figure 2.1

HBLT 11-87/05

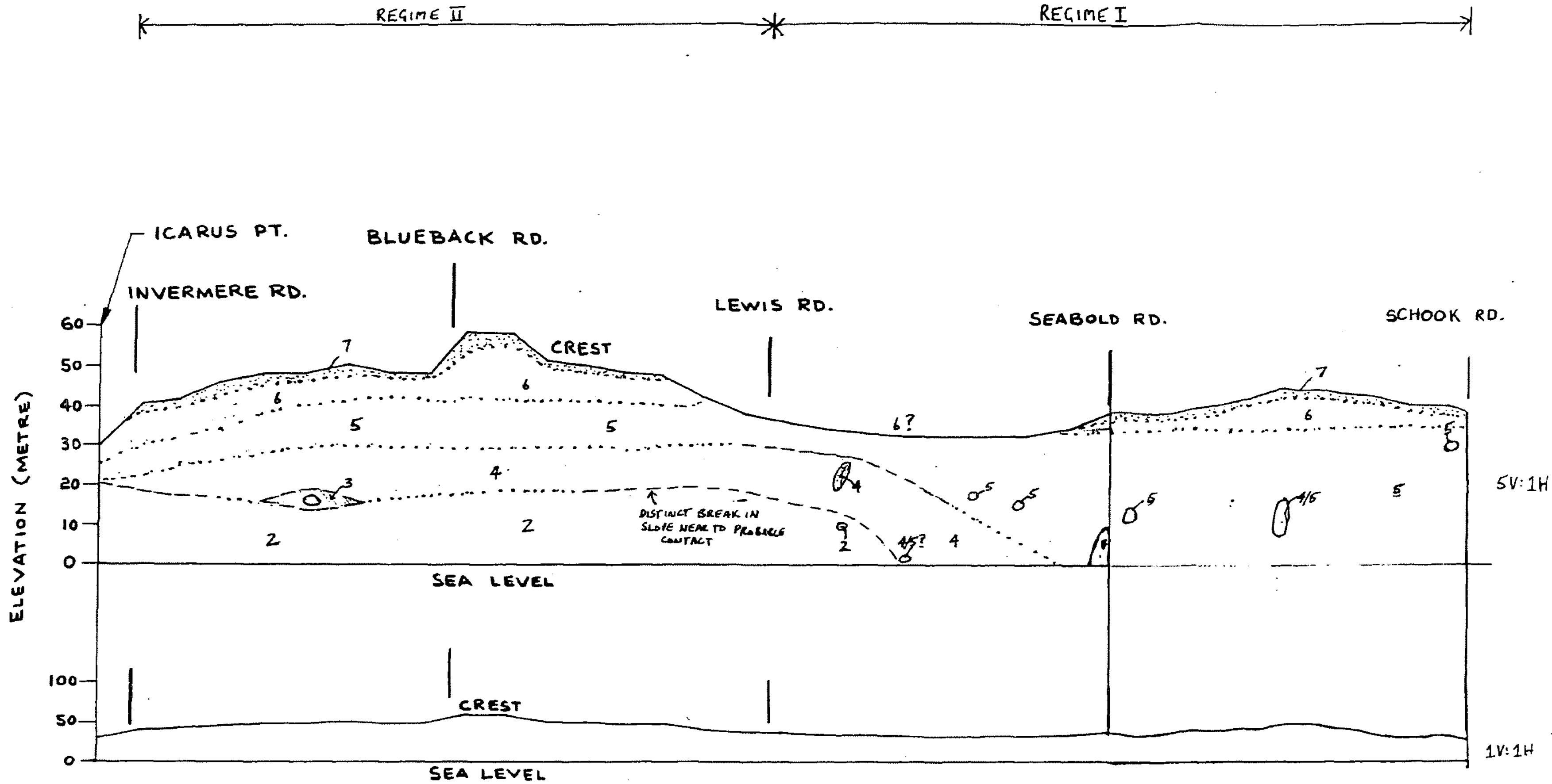


HBT AGRA Limited
Engineering & Environmental Services

NORTH SLOPE STABILITY STUDY

WINDROSES

FIG. 3.1



LEGEND

VASHON DRIFT (Glacial till and glaciofluvial deposits)

- Unit 7 - Brown sands and gravel, loose to compact
- Unit 6 - Brown (with rare purple tinges) silty sand with little (10-20%) gravels, dense to very dense

QUADRA SEDIMENTS (Marine and glaciomarine deposits)

- Unit 5 - Light brown to yellow fine- to medium grained sand, loose to compact, stratified and cross-bedded
- Unit 4 - Layers of yellow-brown to brown sand, silt, gravels and peat/organics, loose to dense
- Unit 3* - Grey silty sand with trace to little (0-20%) gravels, dense
- Unit 2 - Light grey silty clay trace to no gravel, dense, varies from massive to laminated, with occasional sand lenses and rare shell fragments

DASHWOOD DRIFT (Glacial till deposits)

- Unit 1 - Light grey (almost bluish in places) silty clay with little (10-20%) sands, dense to very dense.

* This unit is interpreted by Fyles to represent a stony clay deposited during a minor glacial advance.

- definite geological contact
- probable geological contact
- possible geological contact
- soil exposure

ORIENTATION : 180°

HBT AGRA Limited
3070 Barons Road, Nanaimo, British Columbia
Canada, V9T 4B5

LONGITUDINAL SECTION OF SHORELINE FROM SCHOOK ROAD TO INVERMERE ROAD

Scale	H - 1:5000 V - AS SHOWN
Date	AUG. 26, 1992
Drawn By	K. RILEY
Approved By	RLS

Figure 3.2

LEGEND

VASHON DRIFT (Glacial till and glaciofluvial deposits)

- Unit 7 - Brown sands and gravel, loose to compact
- Unit 6 - Brown (with rare purple tinges) silty sand with little (10-20%) gravels, dense to very dense

QUADRA SEDMENTS (Marine and glaciomarine deposits)

- Unit 5 - Light brown to yellow fine- to medium grained sand, loose to compact, stratified and cross-bedded
- Unit 4 - Layers of yellow-brown to brown sand, silt, gravels and peat/organics, loose to dense
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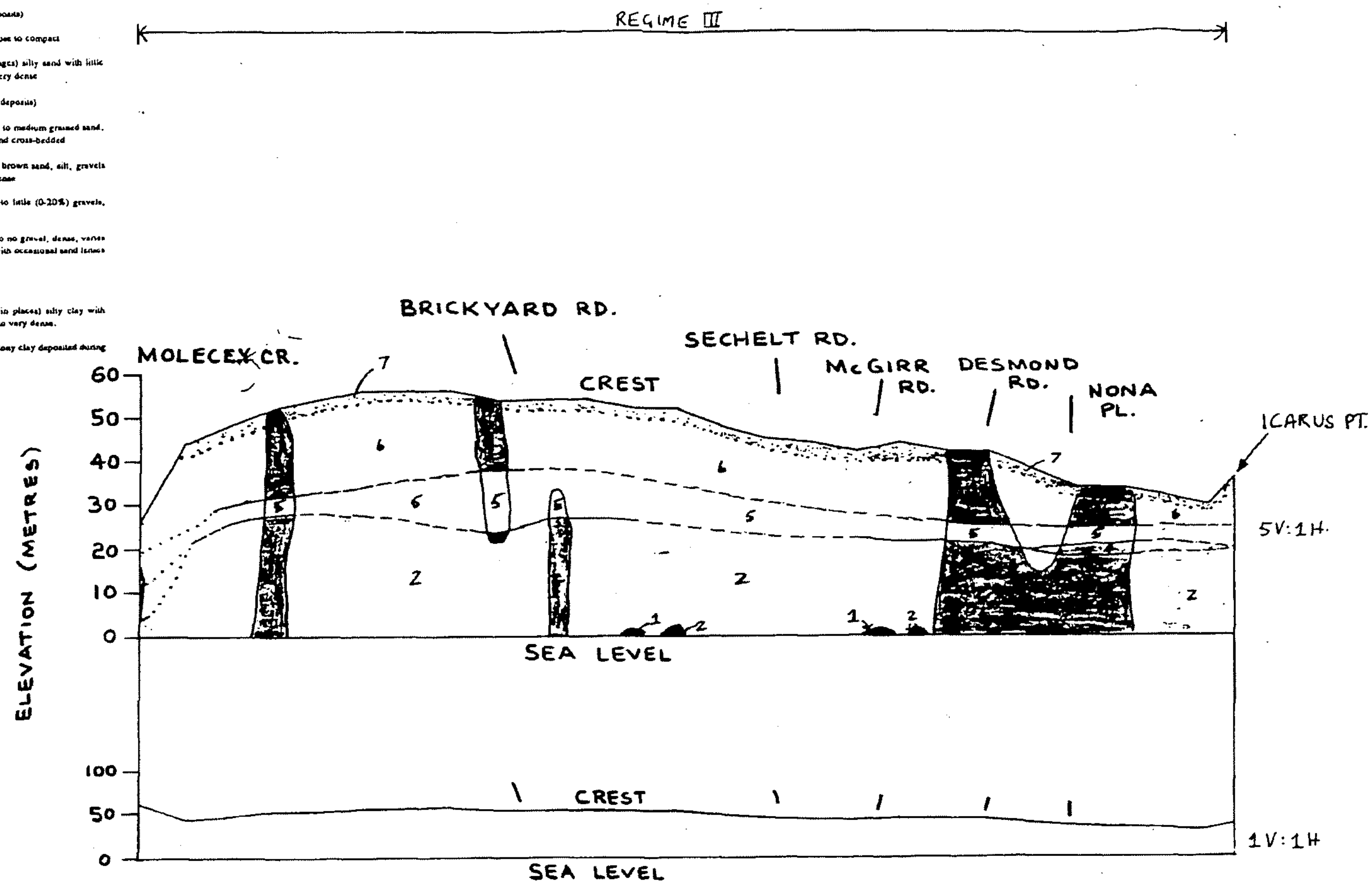
- Unit 1 - Light grey (almost bluish in places) silty clay with little (10-20%) sands, dense to very dense.

* This unit is interpreted by Fyles to represent a stony clay deposited during a minor glacial advance.

- definite geological contact
- probable geological contact
- possible geological contact
- soil exposure



ORIENTATION : 210°

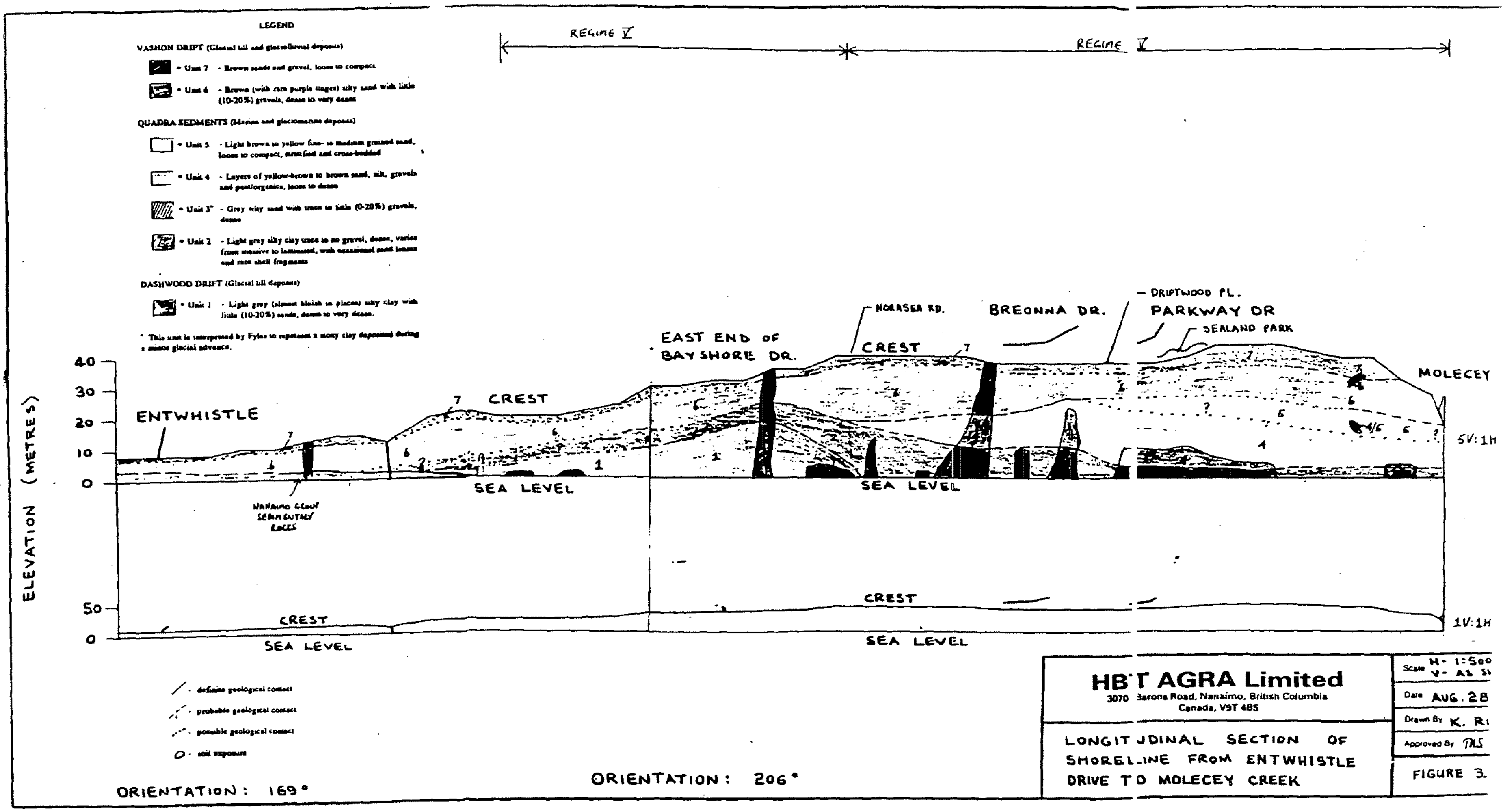
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

LONGITUDINAL SECTION OF SHORELINE FROM MOLECEY CREEK TO ICARUS POINT

Scale H- 1:5000 V- AS SHOWN
Date AUG. 26, 1982
Drawn By K. RILEY
Approved By RLS

Figure 3.3

HBLT 13 87/05


LEGEND
VASHON DRIFT (Glacial till and glaciofluvial deposits)
• Unit 7 - Brown sands and gravel, loose to compact
• Unit 6 - Brown (with rare purple tinges) silty sand with little (10-20%) gravels, dense to very dense
QUADRA SEDIMENTS (Marine and glaciomarine deposits)
• Unit 5 - Light brown to yellow fine- to medium grained sand, loose to compact, stratified and cross-bedded
• Unit 4 - Layers of yellow-brown to brown sand, silt, gravels and peat/organics, loose to dense
• Unit 3* - Grey silty sand with trace to little (0-20%) gravels, dense
• Unit 2 - Light grey silty clay trace to no gravel, dense, varies from massive to laminated, with occasional sand lenses and rare shell fragments
DASHWOOD DRIFT (Glacial till deposits)
• Unit 1 - Light grey (almost bluish in places) silty clay with little (10-20%) sands, dense to very dense.
* This unit is interpreted by Fyles to represent a stony clay deposited during a minor glacial advance.
REGIME V
REGIME V
ELEVATION (METRES)
40
30
20
10
0
50
0
ENTWHISTLE
CREST
EAST END OF BAYSHORE DR.
NORASEA RD.
CREST
BREONNA DR.
DRIPTWOOD PL.
PARKWAY DR
SEALAND PARK
MOLECEY
SEA LEVEL
SEA LEVEL
NANAIMO GROUP SEDIMENTARY ROCKS
5V:1H
CREST
SEA LEVEL
CREST
SEA LEVEL
1V:1H
definite geological contact
probable geological contact
possible geological contact
soil exposure
ORIENTATION: 169°
ORIENTATION: 206°
HBT AGRA Limited
3070 Barons Road, Nanaimo, British Columbia
Canada, V9T 4B5
LONGITUDINAL SECTION OF SHORELINE FROM ENTWHISTLE DRIVE TO MOLECEY CREEK
Scale H - 1:500
V - As S
Date AUG. 28
Drawn By K. R
Approved By TNS
FIGURE 3.

LEGEND

VASHON DRIFT (Glacial till and glaciofluvial deposits)

- Unit 7 - Brown sands and gravel, loose to compact
- Unit 6 - Brown (with rare purple tinges) silty sand with little (10-20%) gravels, dense to very dense

QUADRA SEDMENTS (Marine and glaciomarine deposits)

- Unit 5 - Light brown to yellow fine- to medium grained sand, loose to compact, stratified and cross-bedded
- Unit 4 - Layers of yellow-brown to brown sand, silt, gravels and peat/organics, loose to dense
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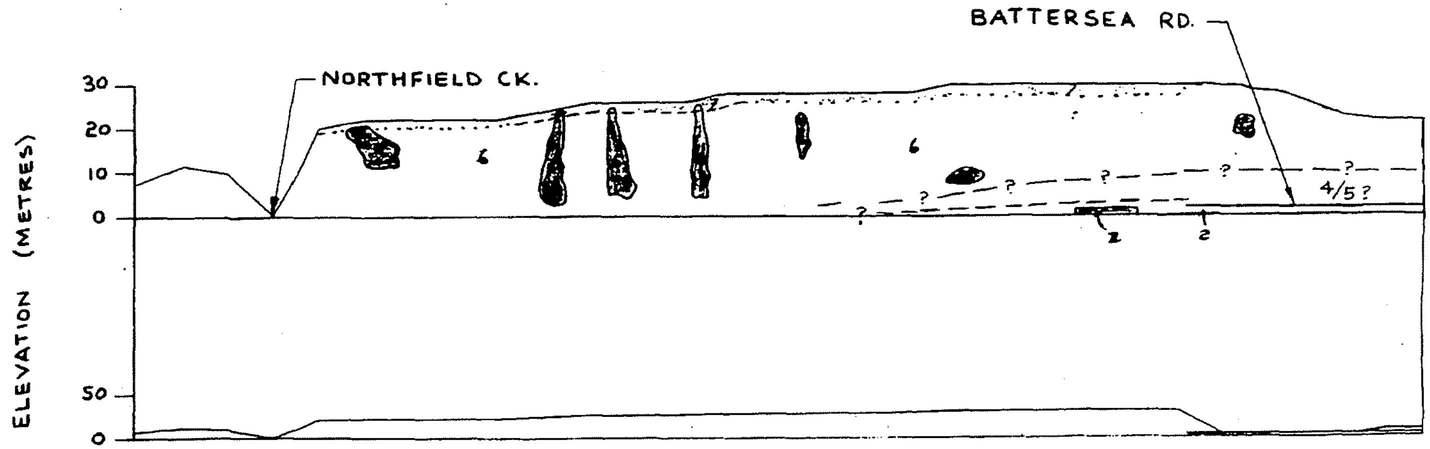
- Unit 2 - Light grey silty clay trace to no gravel, dense, varies from massive to laminated, with occasional sand lenses and rare shell fragments

DASHWOOD DRIFT (Glacial till deposits)

- Unit 1 - Light grey (almost bluish in places) silty clay with little (10-20%) sands, dense to very dense.

* This unit is interpreted by Fyles to represent a stony clay deposited during a minor glacial advance.

- definite geological contact
- probable geological contact
- possible geological contact
- soil exposure



ORIENTATION: 223°

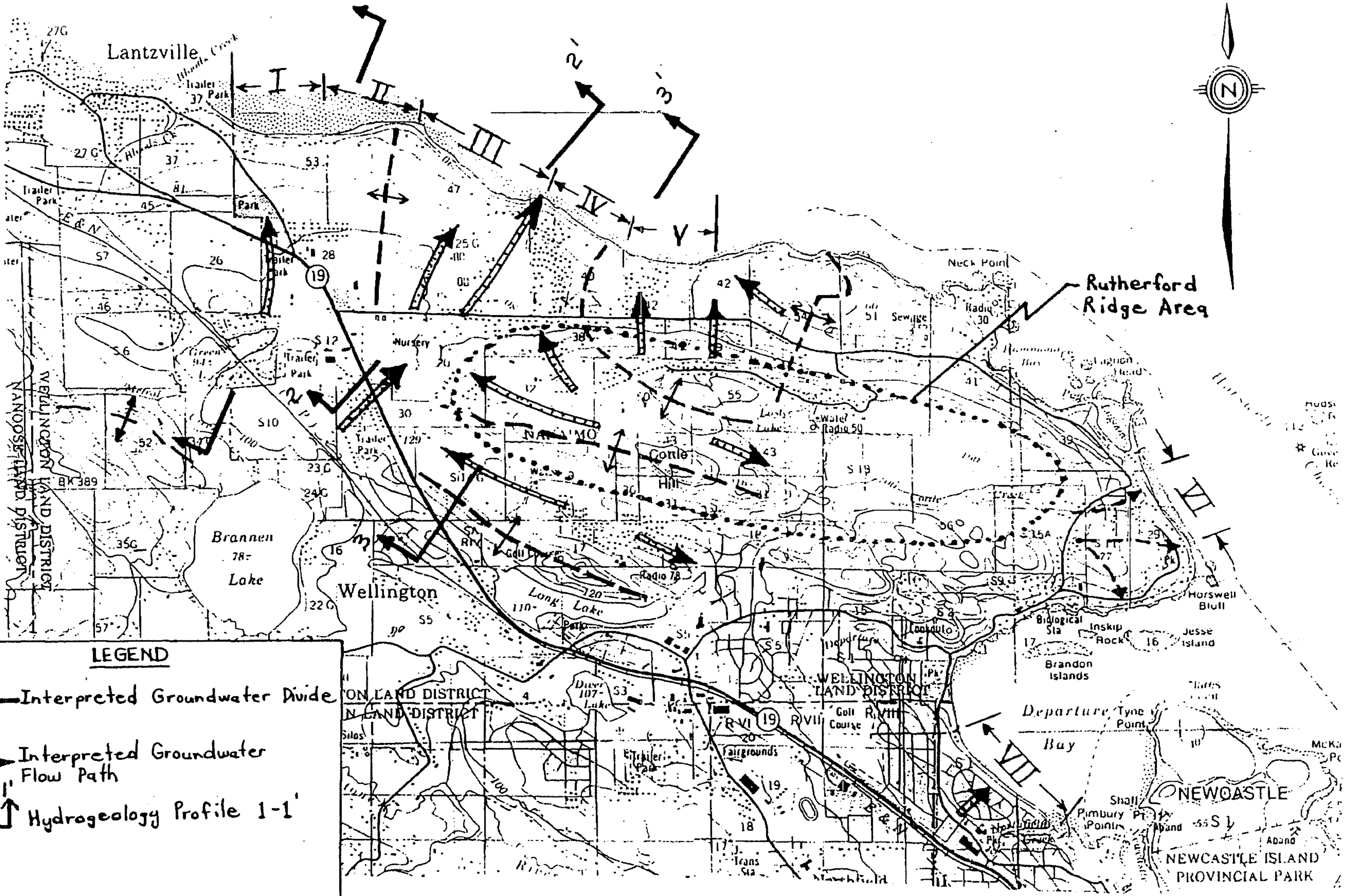
Hardy BBT Limited
CONSULTING ENGINEERING & PROFESSIONAL SERVICES

LONGITUDINAL SECTION OF SHORELINE FROM NORTHFIELD CREEK TO BATTERSEA ROAD

Scale	H- 1:5000 V- AS SHOWN
Date	AUG. 28, 1992
Drawn By	K. RILEY
Approved B.	

Figure 3.5

HBT 13 2/C5



HBT AGRA Limited
Engineering & Environmental Services

GROUND WATER DIVIDES, REGIMES AND FLOW PATHS

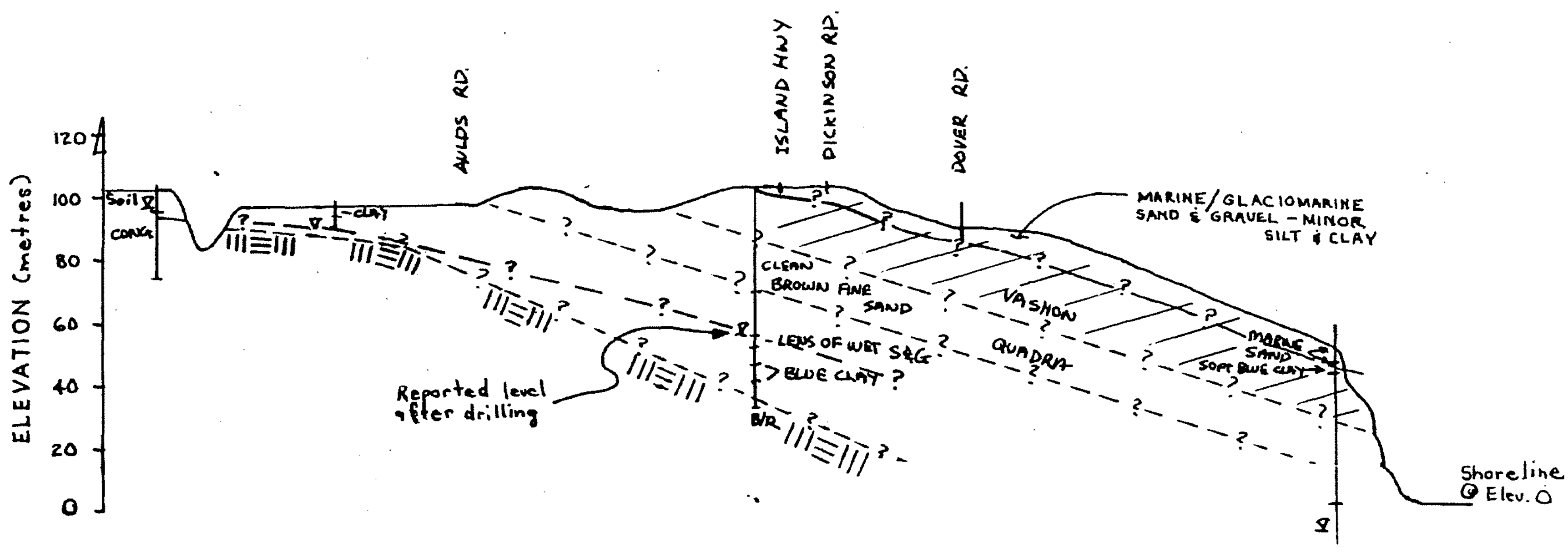
North Slope - Nanaimo

Scale 1:50,000

Date November 1992

Drawn By S.V.

FIGURE 3 5



NOTE:

The interpreted stratigraphy is based on available water well logs (MOE) as well as mapping of the foreshore geology and test pits associated with the sewer line interceptor.

SCALE

Horizontal 1:12,000
Vertical 1: 2,000

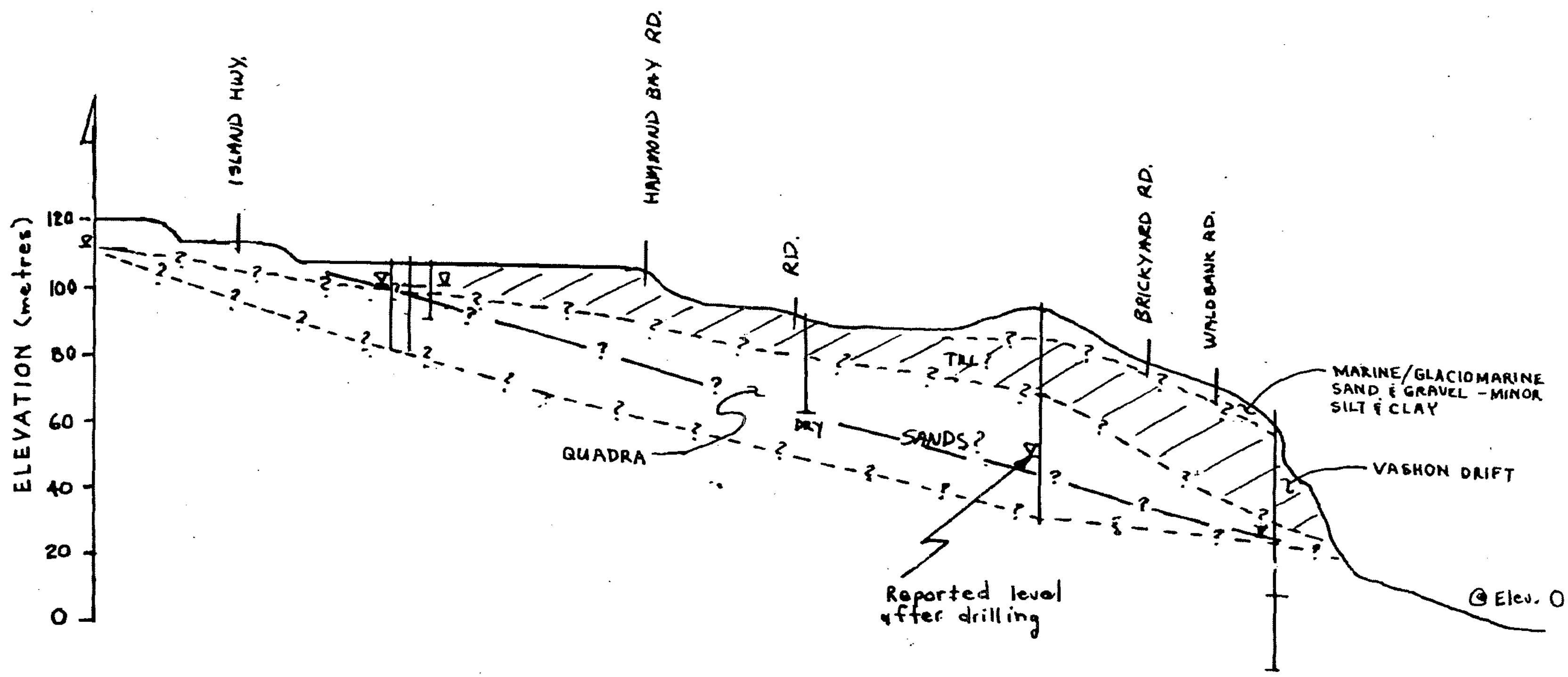
HBT AGRA Limited
3070 Barons Road, Nanaimo, British Columbia
Canada, V9T 4B5

PROFILE 1 - 1'

NORTH SLOPE - NANAIMO

Date NOV/92
Drawn By S.V.

Figure 3.7



NOTE:

The interpreted stratigraphy is based on available water well logs (MOE) as well as mapping of the foreshore geology and test pits associated with the sewer line interceptor.

SCALE

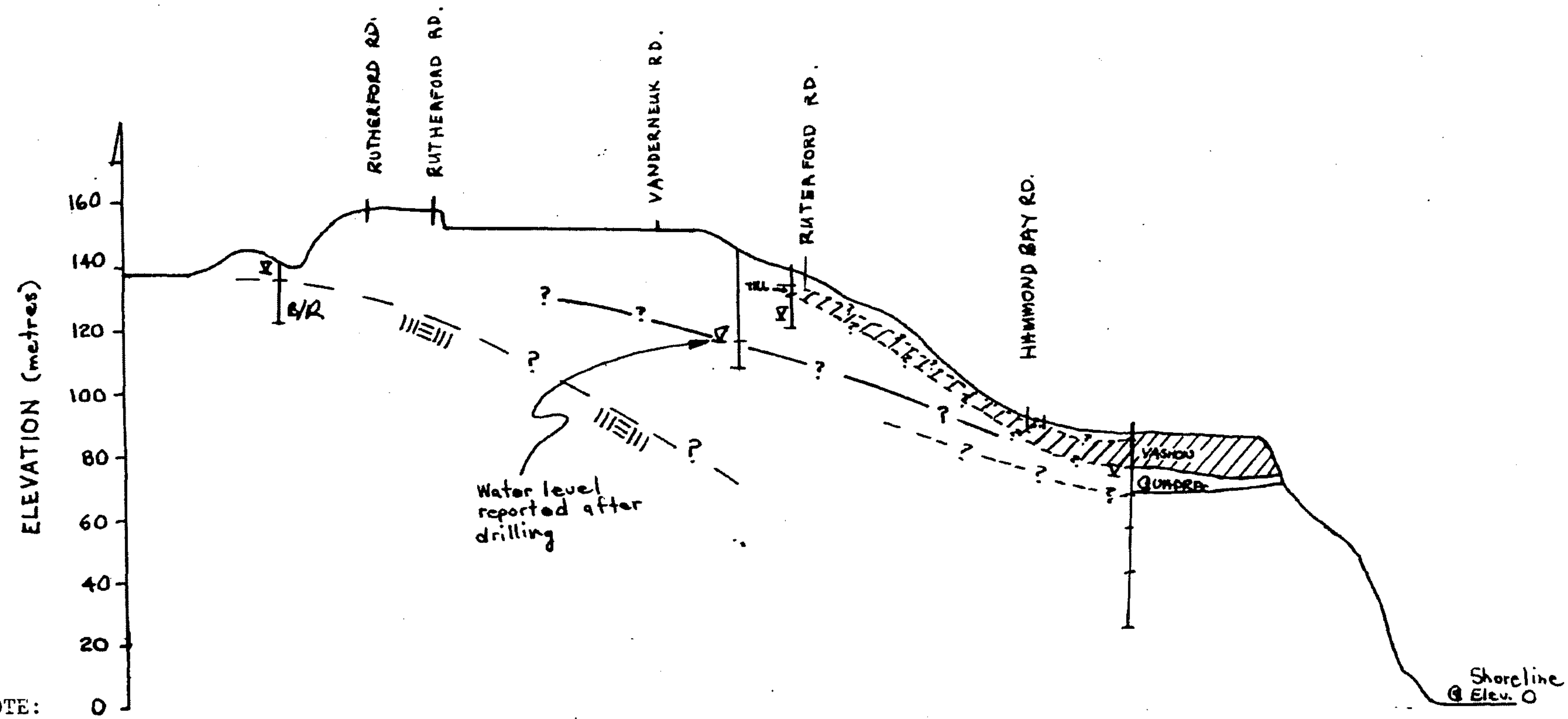
Horizontal 1:12,000
Vertical 1: 2,000

HBT AGRA Limited
3070 Barons Road, Nanaimo, British Columbia
Canada, V9T 4B5

PROFILE 2 - 2'
NORTH SLOPE - NANAIMO

Date NOV/92
Drawn By S.V.

Figure 3.8



NOTE:

The interpreted stratigraphy is based on available water well logs (MOE) as well as mapping of the foreshore geology and test pits associated with the sewer line interceptor.

SCALE

Horizontal 1:12,000
Vertical 1: 2,000

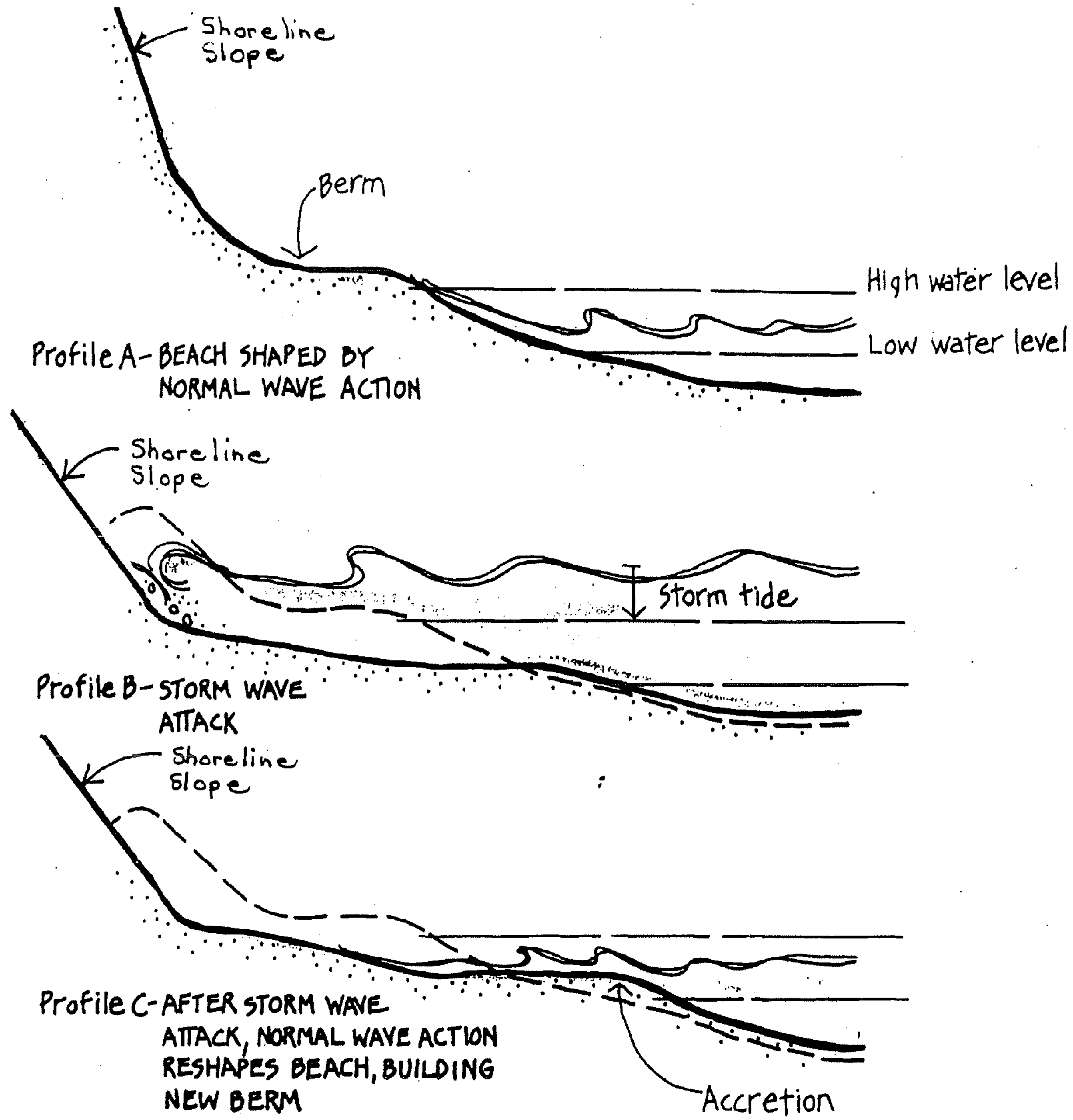
HBT AGRA Limited
3070 Barons Road, Nanaimo, British Columbia
Canada, V9T 4B5

PROFILE 3 - 3'

NORTH SLOPE - NANAIMO

Date NOV/92
Drawn By S.V.

Figure 3.9



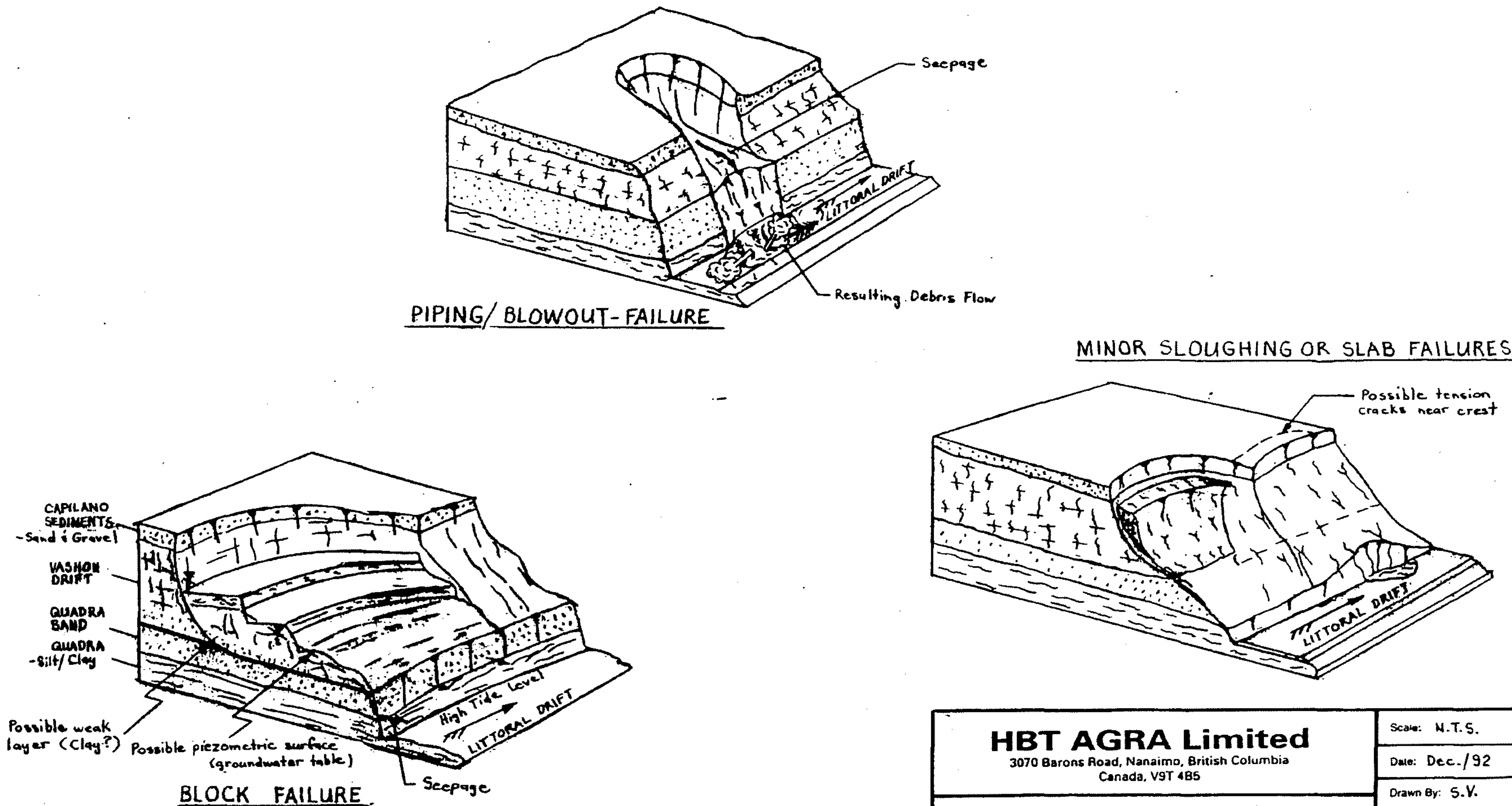
REV	DATE	REVISION DESCRIPTION	ENG	APPR

HBT AGRA Limited
Engineering & Environmental Services

PROJECT
NORTH SLOPE STABILITY STUDY

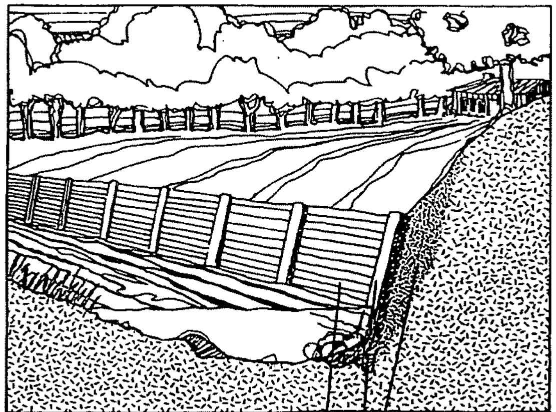
SHORELINE PROFILES

Figure 3.10

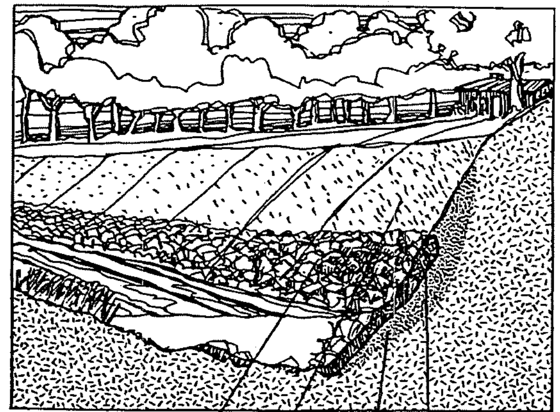


HBT AGRA Limited 3070 Barons Road, Nanaimo, British Columbia Canada, V9T 4B5	Scale: N.T.S. Date: Dec./92 Drawn By: S.V. Approved By:
NORTH SHORE STUDY CITY OF NANAIMO THREE DOMINANT MODES OF FAILURE	FIGURE 4.1

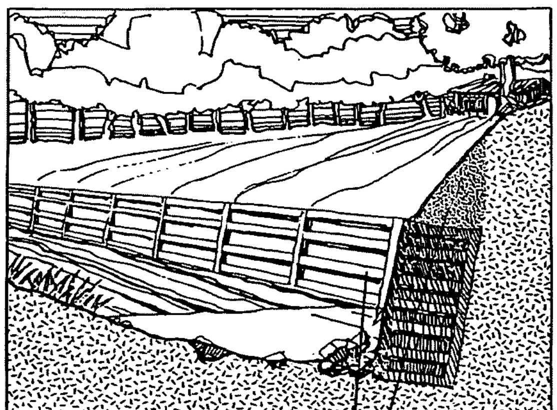
HBLT 13-87/05



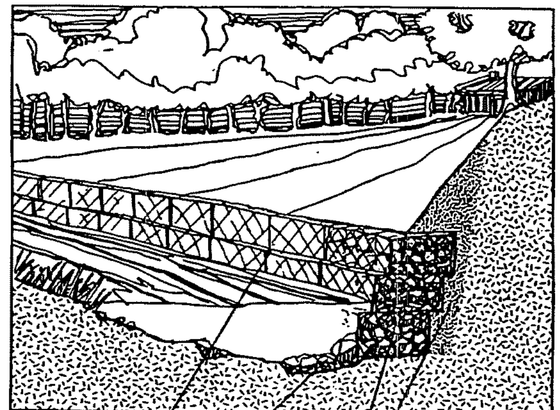
TIMBER RETAINING WALL



RIPRAP ARMOURING



STEEL BIN WALL



GABIONS

Notes:

1. The erosion control options shown will provide protection against lateral erosion. If down cutting is significant, extension of these measures may be required throughout the channel.

2. Only schematic streambank erosion control options are shown. These do not represent a final design suitable for installation. Detailed engineering should be carried out prior to construction.

REV.	DATE	REVISION DESCRIPTION	CHK.	APPR.

HBT AGRA Limited
Engineering & Environmental Services

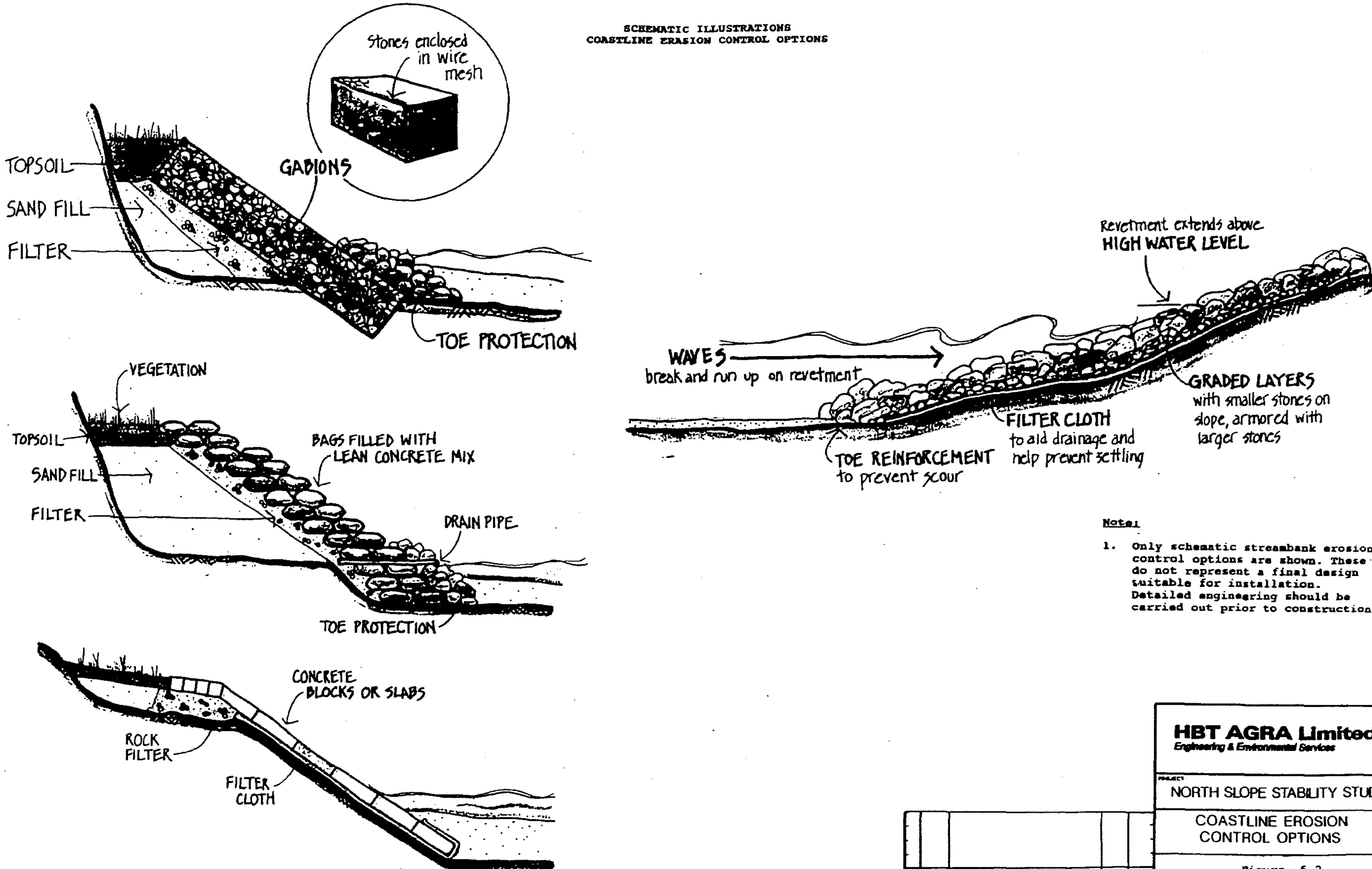
PROJECT
NORTH SLOPE STABILITY STUDY

STREAMBANK EROSION CONTROL OPTIONS

Figure 5.1

1231

SCHEMATIC ILLUSTRATIONS
COASTLINE ERASION CONTROL OPTIONS



Note:

1. Only schematic streambank erosion control options are shown. These do not represent a final design suitable for installation. Detailed engineering should be carried out prior to construction.

HBT AGRA Limited
Engineering & Environmental Services

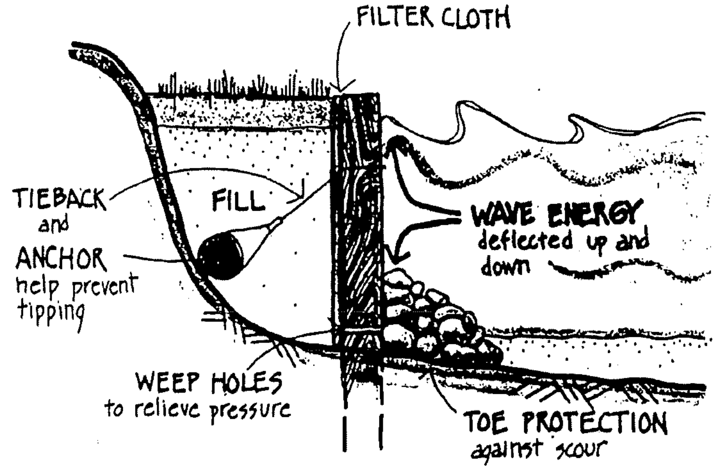
PROJECT
NORTH SLOPE STABILITY STUDY

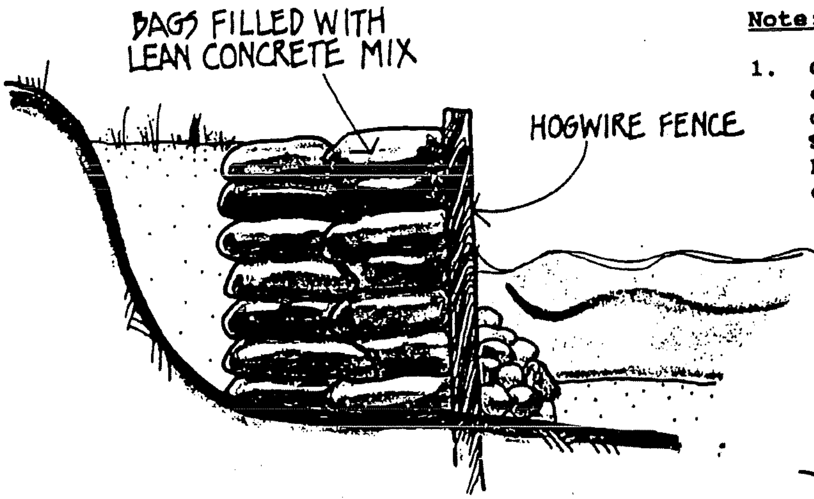
COASTLINE EROSION
CONTROL OPTIONS

Figure 5.2

REV	DATE	REVISION DESCRIPTION	ENG	APPR

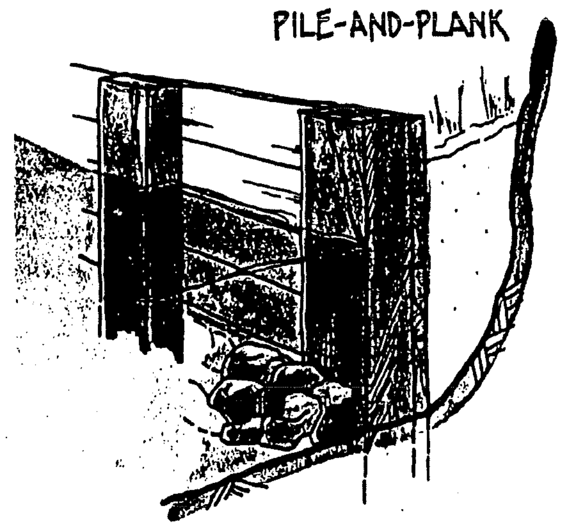
1231

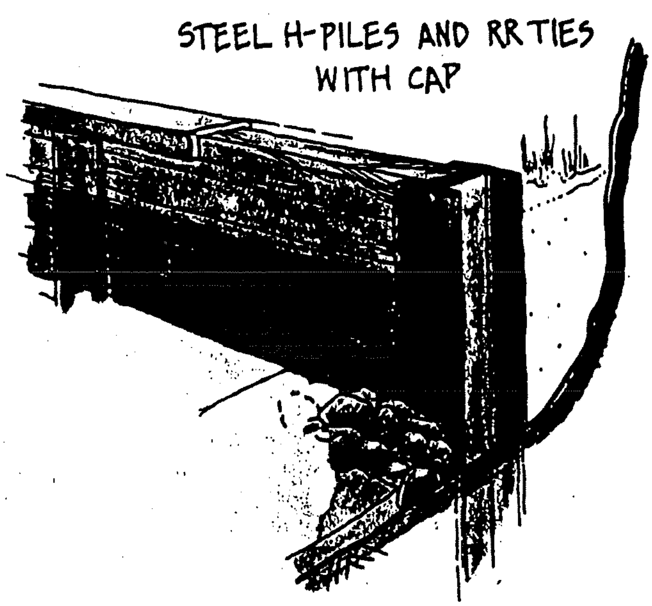




Note:

1. Only schematic streambank erosion control options are shown. These do not represent a final design suitable for installation. Detailed engineering should be carried out prior to construction.





REV.	DATE	REVISION DESCRIPTION	ENG	APPR

HBT AGRA Limited
Engineering & Environmental Services

PROJECT
NORTH SLOPE STABILITY STUDY

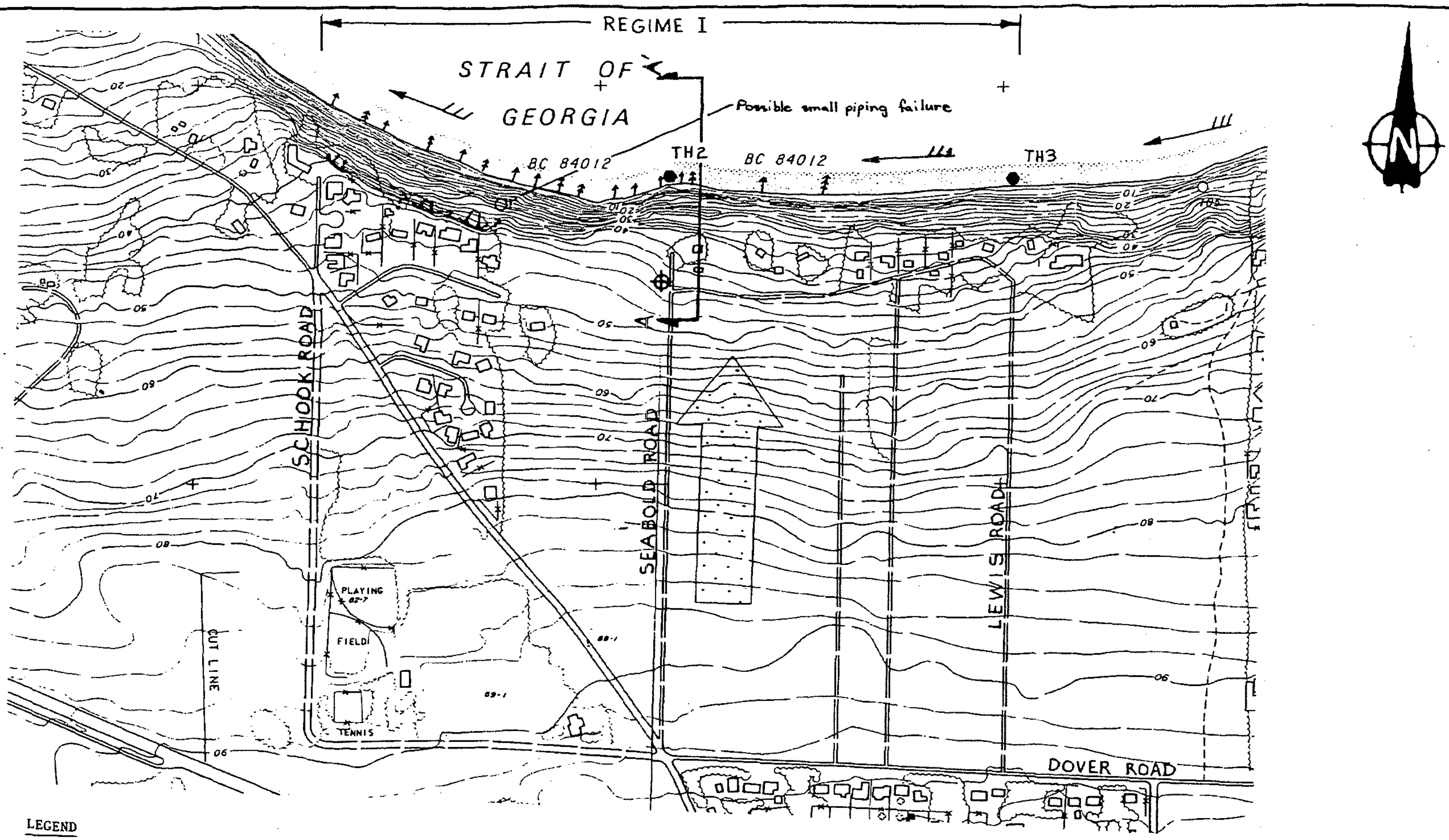
BULKHEAD & SEAWALLS
FOR EROSION CONTROL

Figure 5.3

APPENDIX A

REGIME I
SCHOOK ROAD TO LEWIS ROAD

AGRA
Earth & Environmental Group



LEGEND

- Approximate location of failure scarps
- TH1 Test Pit #1 (by others)
- A Cross Section A - A'
- Approx. location of drilled waterwell (MOE records)
- Littoral Drift
- Surface gradient & probable groundwater flow direction.

APPROXIMATE LOCATION OF SEEPAGE AREAS ALONG THE BASE OF SLOPE WITH ESTIMATE OF FLOW RATE.

- ≃ 4 to 8 l/min.
- ~ 8 to 16 l/min.
- ~>16 l/min.

Approx. location of proposed drill hole.

HBT AGRA Limited
Engineering & Environmental Services

REGIME I LOCATION PLAN
North Slope - NANAIMO

Scale 1:5000
Date October 1992
Drawn By S.V.
Approved By

FIGURE A.1

REGIME 1

CROSS SECTION A - A'

F = 1.448

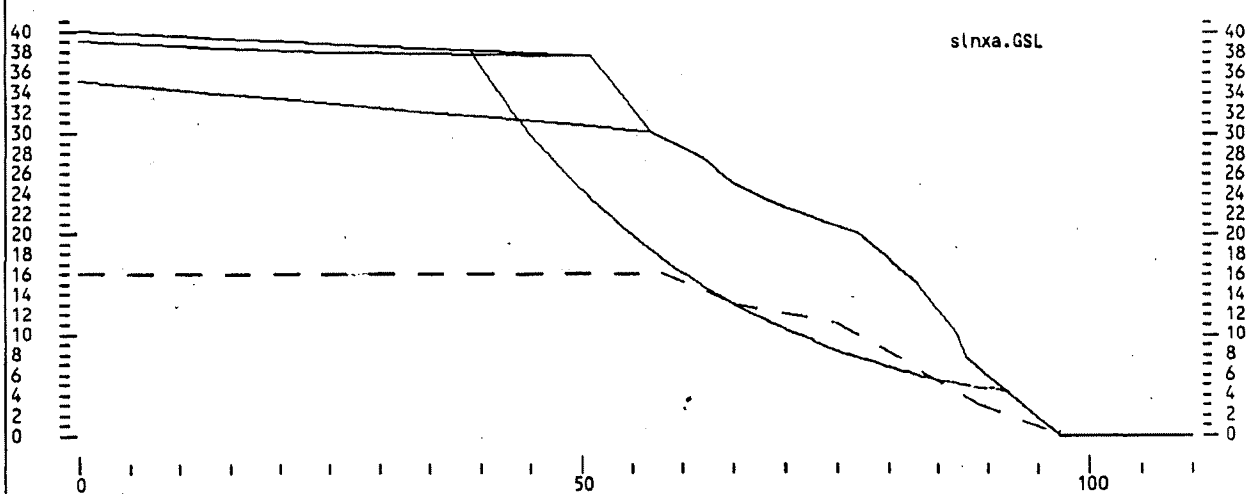
Material	Unit Wt kN/m3	C kPa	Phi deg	Piezo Surf.	Ru
marine sands	20	0	36	0	0
till	22	0	40	0	0
quadra sands	22	0	40	1	0

Hardy BBT Limited

2

NSlope-site a

10.dec.92



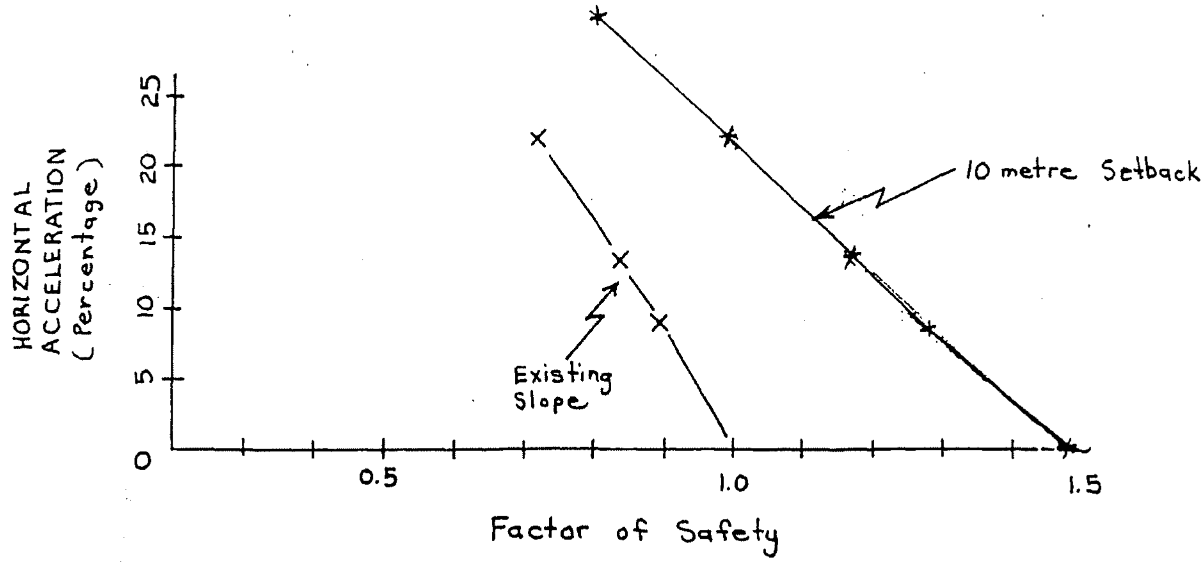
FIELD INVESTIGATIONS

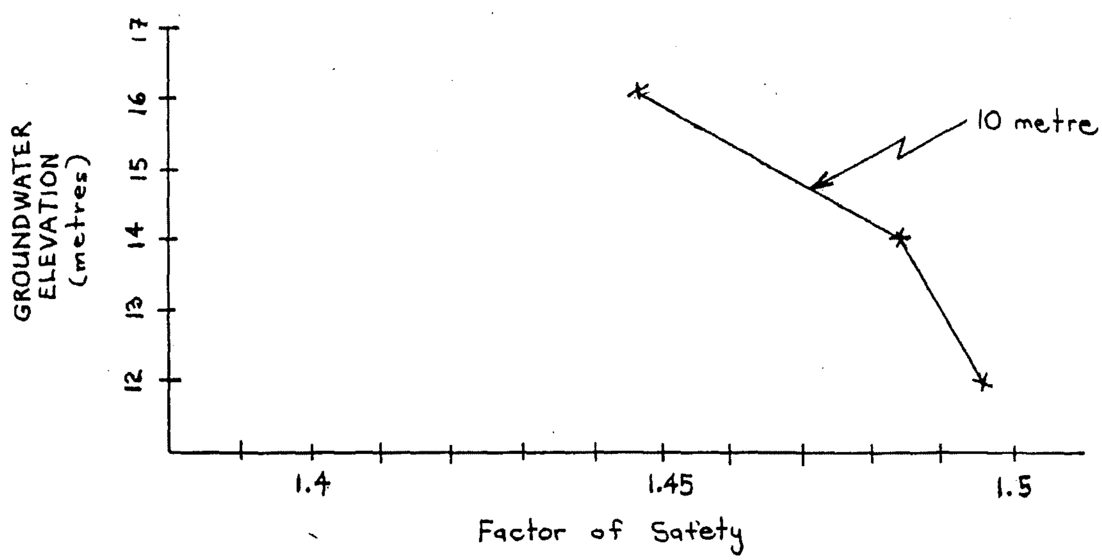
REGIME I - Schook Road to Lewis Road

Although no continuous or significant soil exposures along the foreshore slope were noted below Schook and Seabold Roads, the geology of the slope is interpreted to be dominated by brown and yellow sands (unit 5). These sand are possibly covered with Vashon Drift materials (units 1 and 2). Between Seabold Road and Lewis Road the first occurence of the grey clay (unit 2) was encountered along the slope base. This clay is overlain (commencing in the eastern portion of this regime) by interlayered silts and sands (unit 4).

Seepage at the time of the mapping was quite considerable along the base of the slope for most of the section, with seepage flow of approximately 4-16 litres/minute found every 20-40 metres. Some minor seepage was also observed on the slope flowing over the grey clay unit.

REGIME I





HBT AGRA Limited 3070 Barons Road, Nanaimo, British Columbia Canada, V9T 4B5	Parametric Analyses Regime I North Slope - Nanaimo		
	Scale	Date Nov/92	Drawn By S.V.

HBLT 11-87/05

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

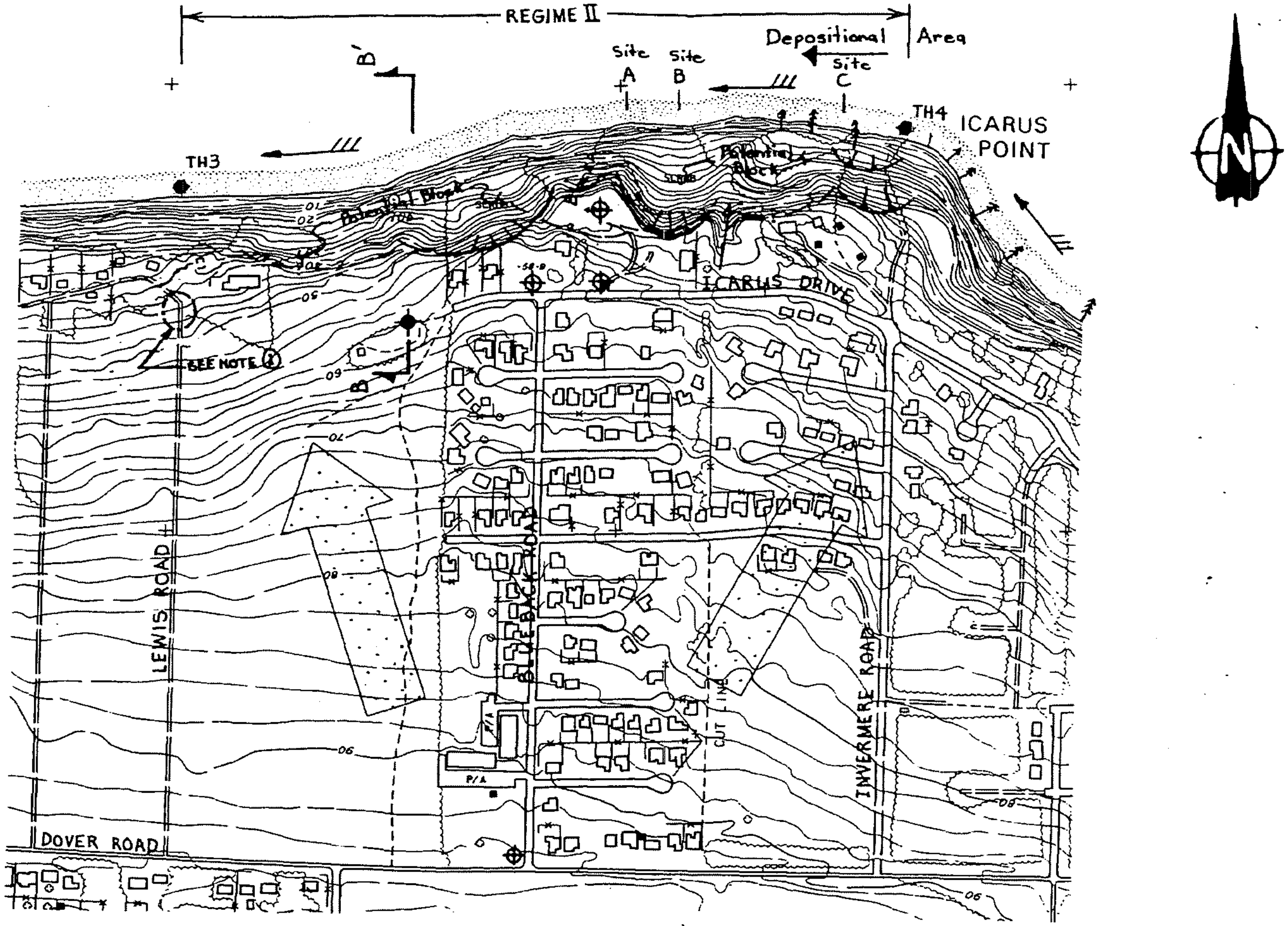
REGIME I

Area	Purpose	Type of Information	Source of Information	Year	Sources File No.	Provided Comments Relevant to Study	Geology	Legal
Lewis Road	granting building permit	Setback 90 m from toe (set for ± 19° from toe)	BH Levelton	1984	84-N-32C	- active erosion at toe - tidal - groundwater common in lower half - logged in past - remaining mature trees have curved or leaning trunks - creep - slope of 36° with local zones of 45 to 50°	- fine to medium SAND - dense glacial till - stiff to hard laminated silts and clays	Pt 4 lying west of PCL 'A' DL 53
Lewis Road	Re-assess granting building permit	Setback of 30 m from crest	Hardy BBT Limited	1989-90	NX00417	- irregular 35 - 40° (average 37°) - slope height of approximately 28 m - foot trails along slope (cuts) - active marine erosion - exposure (2 m high) along toe for 60 m to east - seepage at toe - logging at toe - protective measures		Lot 4, Plan 1792, DL53
Seabold Road	Geotechnical Evaluation	Setback of 13 to 20 m from crest	BH Levelton	12/03/92	692-057.001	- vegetation on slope is second growth coniferous and deciduous with occasional 1 m diameter old growth. Tree growth essentially straight. - slope angle averages 36 to 38°. - slope essentially smooth. - minor sloughing at central portion of property. - slope grossly stable, no evidence of large scale slope movements. - setback of 13 to 20 m from crest, established by a projected 30° angle from the slope toe.	Slope soils in upper 5 m include: - compact, brown, gravelly sand; overlying - dense, uniformly graded sand with some silt. No evidence of groundwater seepage observed.	Lot 2, Plan 1792, DL53
Seabold Road	Response to City of Nanaimo letter		BH Levelton	08/10/92	692-057.003	- the part of the slope and setback areas that have been cleared should be planted with grasses to minimize erosion during the oncoming winter. Planting may be achieved by hydroseeding.	Subsurface materials include: - surface veneer of compact sand and gravel (marine deposit); overlying - very dense, over-consolidated, predominately granular soils for a majority of the slope. (this sequence is interpreted to be an over-consolidated interglacial soil called the Quadra sediments).	Lot 2, Plan 1792, DL53

APPENDIX B

REGIME II
LEWIS ROAD TO ICARUS POINT

AGRA
Earth & Environmental Group



NOTES

① Approximate location of recent borehole

LEGEND

- Approx. location of failure scraps
- TH1 Test Pit #1 (by others)
- B Cross Section B-B'
- Approx. location of drilled waterwell (MOE records)
- Littoral Drift
- Surface gradient & probable groundwater flow direction.

APPROXIMATE LOCATION OF SEEPAGE AREAS ALONG THE BASE OF SLOPE WITH ESTIMATE OF FLOW RATE.

- 4 to 8 l/min.
- 8 to 16 l/min.
- >16 l/min.

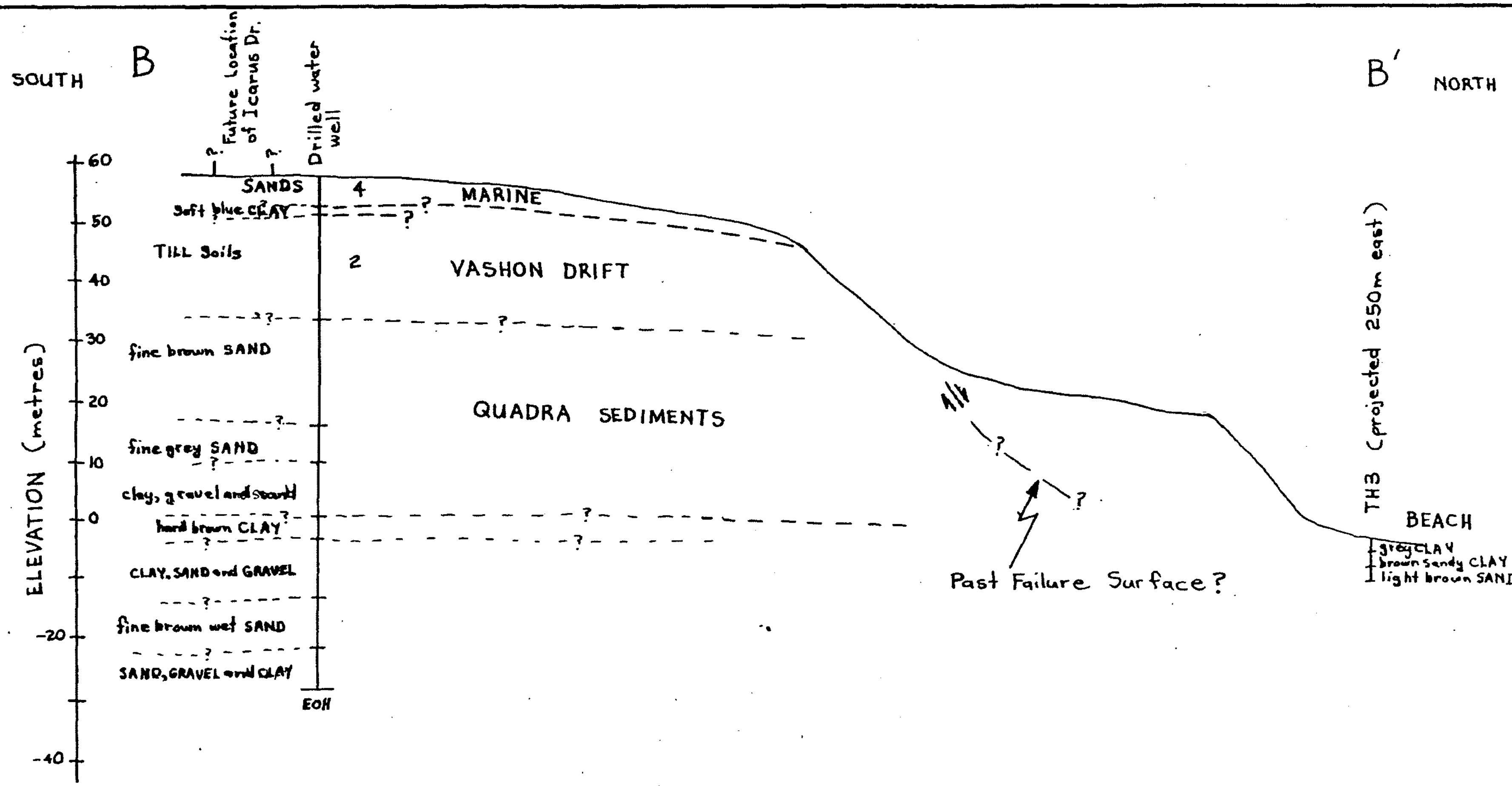
Approx. location of proposed drill hole.

HBT AGRA Limited
Engineering & Environmental Services

REGIME II LOCATION PLAN
North Slope - NANAIMO

Scale 1:5000
Date October 1992
Drawn By S.V.
Approved By

FIGURE B.1



NOTE:

The interpreted stratigraphy is based on the waterwell log as well as mapping of the foreshore geology and test pits associated with the sewer line interceptor.

HBT AGRA Limited
Engineering & Environmental Services

CROSS SECTION B - B'
REGIME II

Scale 1:1000
Date October 1992
Drawn By S.V.

FIELD INVESTIGATIONS

REGIME II - Lewis Road to Icarus Point (Invermere Road)

No continuous exposures were encountered in this section of the study area. The stratigraphy was interpreted to consist of Vashon Drift materials (units 6 and 7) underlain by sands (unit 5) which in turn are underlain by interlayered silts and sands (unit 4). The grey clay (unit 2) is located along the slope toe.

It was noted that the slope profile is dominated by a mid-slope terrace or level area located approximately 20 metres up from the base of the slope. In some places seepage was encountered on the surface of this level area. The break in slope coincides with the top of the grey clay (unit 2) which suggests a large block failure similar to Sealand Park (Regime IV) may have occurred in the recent geologic past. Less seepage was observed on the beach in this regime, with the exception of around Icarus Point.

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

REGIME II

Area	Purpose	Type of Information	Source of Information	Year	Sources File No.	Provided Comments Relevant to Study	Geology	Legal
Icarus		Setback - 33 m from crest for FS=1.6 m - peak strength of 43° + residual of 27°	HBT AGRA Limited	1992	NX01091	- slope back analyses carried out for Sealand Park and results used for this property. - mid-slope terrace, past failure or, flat, terrace - seepage at upper/TILL contact - one small scarp near crest - lower portion of slope logged somewhat in past - pump house of western property on terrace - no signs of creep nor recent failure	- Surface Sand overlying - SAND overlying - gravelly SAND, some fines (TILL) overlying - inter-layered dense SAND, clay - dense sand, grey, some gravel, till-like	Parcel "A" of Lot 6
Icarus		setback mostly 18 m	Hardy BBT Limited	1988	NX00093	- active marine erosion - recent slope failure - on-going creep - 3 ft high scarp near top of bank - slope 36 m high - shot rock later placed over lower two thirds of slope creating approximate 20° slope	- well graded, rusty brown gravelly SAND overlying - dense silt to clayey silt, some cobbles and boulders	Lot A, Plan 10318, DL53
Icarus	Slope Stability Evaluation	Setback varies from: - 32 m at eastern edge; - narrowing to 19 m within central portion; and - widening to 45 m at western edge.	BH Levelton	25/06/92	692-138.001	- slope generally 40 m high. - slope vegetated sporadically with old trees and light second growth. Recently cut stumps were noted to be of 200 to 300 year old trees. - east and central portions of slope include an intermediate bench while western portion is essentially smooth. - upper portion of slope is 35 to 45° from horizontal. The intermediate bench is about 30 m wide and slope below bench is typically 25°. - no evidence of large scale movements. - bench - slide activity occurred at least 200 to 300 years ago. - setback established by projection of 2:1 (horizontal:vertical) (26.5°) from toe of upper slope for eastern edge of property or from toe of the overall slope at western edge. Setback varies from 32 m at eastern edge narrowing to 19 m within central portion and widening to 45 m at western edge. - proposed services line off Lewis Road is down slope face. - there is a high risk due to slope failure under design seismic loading or extreme groundwater regime increases; - if constructed, a recommended minimal burial depth of 1.5 metres, backfill with coarse fill, and provide seepage cut-off collars.	- water seepage was observed generally throughout the slope's width, corresponding to the southern edge of the intermediate bench. - exposed soils include sand and gravel within upper 10 ft of slope. - uniform sand exposed at mid-slope. - Vashon Till may not be present within section.	Lot 5, Plan 1792, DL53

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

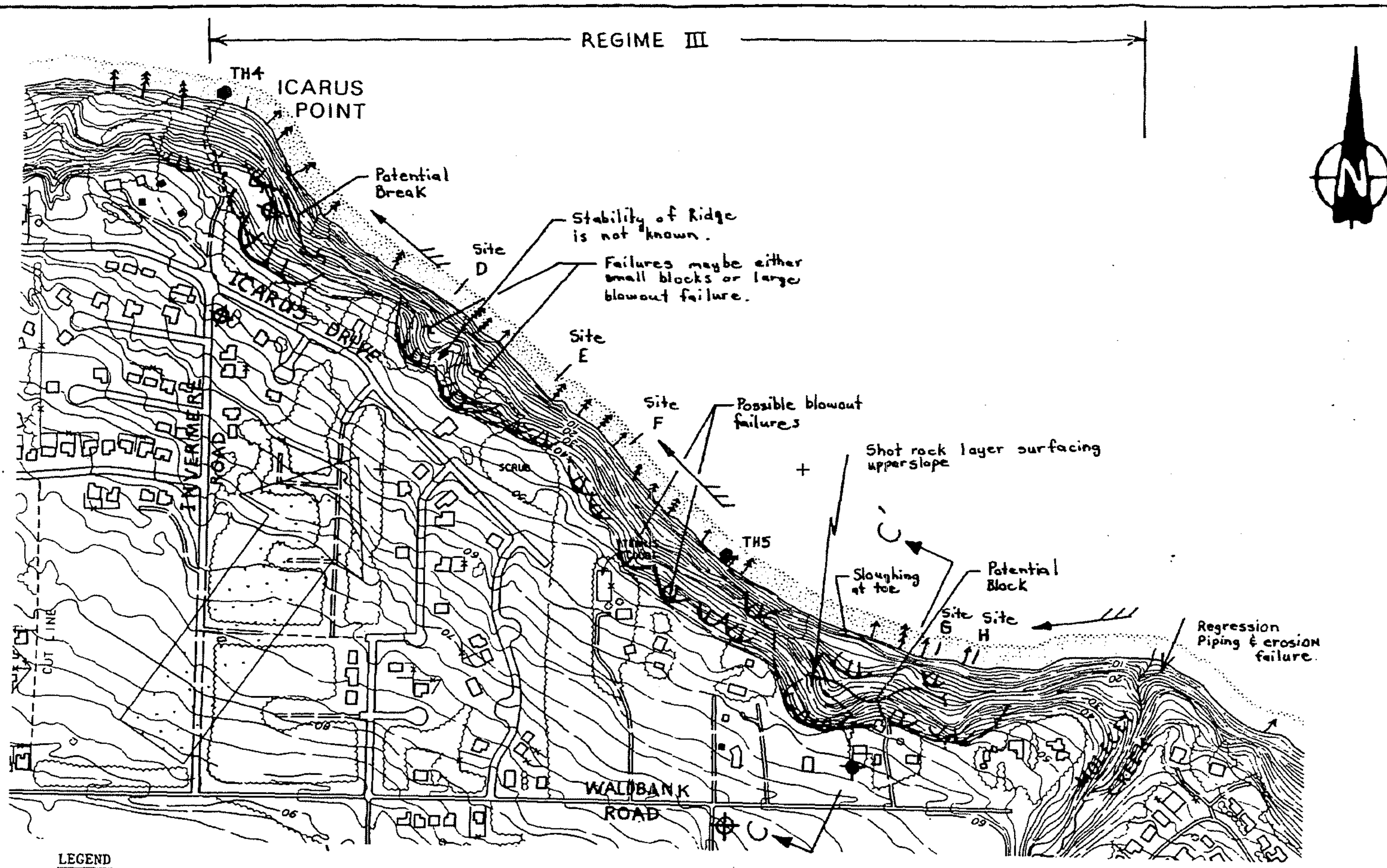
REGIME II

Area	Purpose	Type of Information	Source of Information	Year	Sources File No.	Provided Comments Relevant to Study	Geology	Legal
Icarus	Response to City of Nanaimo letter		BH Levelton	06/10/92	692-138.003	- service lines to be installed down slope face by boring. - a borehole of 28.3 metres deep was advanced by wet rotary method on September 16, 1992. - slope height of 35 metres with average slope of 37°. - SPT results of 99 and greater commencing at 3 metres depth. - detailed stability analyses using G-Slope carried out using soil parameters of C=0 and angle of shearing resistance of 45° for soils from 2.4 metre depth and greater. - for a 1.8:1 (horizontal:vertical) slope using a maximum horizontal ground acceleration of 0.15 g, a factor of safety of 1.13 used obtained..	Subsurface materials encountered at borehole include: - layered, compact sands and gravels to 2.4 metres; overlying - very dense, uniformly graded fine to medium sand, with occasional layers of sand and gravel to 20.4 metres; overlying - very hard silt/clay to 23.4 metres; overlying - very dense uniformly graded sand to 27.7 metres; overlying - very dense, cobbled sand and gravel to 28.3 metres. Standpipe installed in borehole at completion. Water level depth of 15.9 metres measured on October 5, 1992.	Lot 5, Plan 1792, DL53

APPENDIX C

REGIME III
ICARUS POINT TO MOLECEY CREEK

AGRA
Earth & Environmental Group



LEGEND

- Approximate location of failure scarps
- TH1 Test Pit #1 (by others)
- C Cross Section C-C'
- Approximate location of drilled waterwell (MOE records)
- Littoral Drift
- Surface gradient & probable groundwater flow direction.

APPROXIMATE LOCATION OF SEEPAGE AREAS ALONG THE BASE OF SLOPE WITH ESTIMATE OF FLOW RATE.

- 4 to 8 l/min.
- 8 to 16 l/min.
- >16 l/min.

Approx. location of proposed drill hole.

HBT AGRA Limited
Engineering & Environmental Services

REGIME III LOCATION PLAN
North Slope - NANAIMO

Scale	1 : 5000
Date	October 1992
Drawn By	S.V.
Approved By	

FIGURE C.1

FIELD INVESTIGATIONS

REGIME III - Icarus Point (Invermere Road) to Molecy Creek

Four relatively continuous sediment exposures were noted extending from the base to crest of the slope with overall changes in elevation of 30-40 metres. The base of the slope along the beach is dominated by exposures of grey clay (unit 2) with some minor exposures of the Dashwood till (unit 1). Units 3, 4, and 5 were encountered directly above the clay, with the brown-yellow sand being the most dominant unit. Vashon till material (Unit 6) was found in all four of the principal exposures overlying the Quadra sediments.

Near Molecy Creek, the Vashon till was encountered along the base of the shoreline slope. This suggests that either the Quadra sediments in this part of the slope were eroded and removed prior to deposition of the Vashon till or that slumping sections of till are masking older intact sediments. In upstream areas of Molcey Creek, exposures of Quadra sands and Vashon till were found on the side slopes of the creek. In some places lenses of disturbed sand were found within the till. In one location at the base of Molcey Creek dense grey till was found that is interpreted to be Dashwood till (unit 1).

Seepage was observed along much of the beach, particular on the western side of this section, with some seepage also encounted flowing over the grey clay unit. Seepage flows varied from 4-40 l/min and were spaced approximatly every 30-50 metres.

Reminants of old activity in the area include steam boiler, wire, bricks, cables, etc. There is an old fuel tank on a stand part way up the slope.

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

REGIME III

Area	Purpose	Type of Information	Source of Information	Year	Sources File No:	Provided Comments Relevant to Study	Geology	Legal
Icarus	stability of slope	setback defined at 25° from toe (15 m from crest at central portion of property)	Levelton	12/31/86	586-248	- approximately 35 m (115 ft) high slope - 28 to 35° overall angle - trees up to 1.5 m (5 ft) diameter on slope have curved trunks - creep - several large slump blocks at toe - marine erosion - vertical scarp at toe - large recent scarp at top of crest: circular shape with seepage at upper till contact - several gullies developed	- granular soils overlying - till (gravelly, silty SAND) overlying - inter-layered sands, silts and clays	Rem Lot 5, and Part of Parcel A of Lot 7, Block 3, Plan 1110, DL47
Icarus	foundation design and construction		BH Levelton	08/31/88	588-221	- four test pits excavated up to 3.5m - minimum setback was previously established by Levelton - fill on portions of lot including west property line	- compact brown sand and gravel (fill) overlying - compact native sand, as well as sand and gravel No seepage	Lot 2
Icarus	Building setback		BH Levelton	10/04/89	589-228	- five proposed lots adjacent slope - slope angle varies from 24 to 30°: locally much steeper - trees recently cut down over entire slope (trees had consisted of alders of up to 2 ft diameter - significant curvature on trunks on flatter, lower portion of slope - near vertical scarp (3 m high) at top of slope - significant seepage from central and lower portions of slope; several small streams issuing from the slope toe - set back defined by a 22° slope angle measured from the base of the upper steep portion of slope varies from 23 to 30 m north of Icarus Drive	- head scarp consists of dense grey gravelly silty sand till overlying sands - intermittent bluff in hard silty to clayey soils along slope toe	Lot 6, Plan 1110 DL47
Icarus	relaxation of setback		BH Levelton	01/18/91	691-009	- relaxation of setback for 1.5 m required northern footings founded at least 0.8 m below ground surface	- compact, native soils	proposed Lot 11 of existing Lot 6, Plan 1110, DL 47
Icarus	rock pit		BH Levelton	01/16/91 01/27/91	589-278	- installation of a rock pit to provide drainage for the rear portion of footing tile system was considered safe. Rock pit was some 4 m^3 in volume with drain rock	- installed in fine to medium grained sand, some gravel, trace silt. No seepage	Proposed Lot 8 of existing Lot 6, Plan 1110
Icarus	relaxation of setback		BH Levelton	02/28/91	589-278	- variance of footing construction 2.5 m from setback would be acceptable if footings constructed 1.2 m below ground surface		
Icarus	Access Stability	Setback of 23 m from street (25 - 18 m from crest)	Hardy BBT Limited	1991	NX00882	- survey plan showing toe and crest: slope 38 m high - deep seated failures in vicinity - middle slope wet and spongy - slide debris at mid-slope - upper half logged in past? while lower half heavily vegetated. Most trees bent toward shore - near surface creep - no evidence of marine erosion, however, recent failures in marine clay to east and west of lot. -2 failures at crest near property edges	- silty sand (0.6 m) overlying - compact fine to medium SAND (colluvium)(1.2 m) overlying - silty sand and gravel with boulders (TILL)(7 m) Failures at toe 30 m to east consisted of: - very dense TILL (1.5m) overlying - very dense fine to medium SAND (Quadra sand)(7.5m) overlying - Quadra marine bluish grey, very stiff/hard clay	Lot 20, Plan 35673, DL 47

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

REGIME III

Area	Purpose	Type of Information	Source of Information	Year	Sources File No:	Provided Comments Relevant to Study	Geology	Legal
Walbank		setback 200 to 215 ft from street, 90 ft from crest	Hardy BBT Limited	1991	NX00876	- dips at 25 to 80° - past failures - 20 ft high scarp near crest - minor seepage at till and colluvium contact - trees bent or tilted - downslope creep - recent failures in Quadra Marine clay at slope toe in Lots 2, 8, 9 and 10. Scrap in Lot 10 extended to top of bank	Scarp at crest - brown silty sand and gravel overlying - silty sand and gravel with cobble, very dense, grey brown (TILL) overlying - very dense, light grey firm to medium SAND (Quadra) - Talus very stiff to hard, blueish grey to grey, fissured, thinly laminated silty CLAY along toe for 400 ft (Quadra Marine CLAY)	Lot 6, Plan 12718, Block 4, DL 47
Waldbank	Determine slope stability and assess causes of instability		Hardy BBT Limited	04/17/87	NX00301A	- existing house setback 30 - 35 m from steep slope - slope height of 30 to 35 m - active erosion on upper slope on March 9, 1989 - upper portion of slope essentially vertical for 5 to 6 m with overhanging sections - slope then rapidly flattens to essentially level area some 4 m above shoreline - in plan the slope has a concave shape in central part of lot with ridges (located down hill from upper portion of lot) flanking the edges of the erosional feature - failed slope material located at slope toe was being eroded by marine action - drainage lines daylighting onto the slope - causes for erosion in Quadra Sands include: i) groundwater seepage ii) differential drainage of surface runoff through till soils iii) undercutting from marine erosion - slope is over-steepened	Information was obtained from geological maps	Lot 4, Plan 12718, DL47
Waldbank	Proposed Gazebo		Levelton	12/06/91	691- 236	- slope below gazebo is covered with shot rock which extends to lot to west - after Hardy report the slope was cut back some 10 m to flatten slope. After the removal of trees on slope shot rock of at least 5 m in locations was placed over slope - property to west was being filled with shot rock similar to subject lot	- marine sand and gravel (overlying) - dense silty sand and gravel, occasional cobble and boulder (TILL) overlying - dense, uniformly graded cross bedded SAND (Quadra) overlying - hard laminated silty clay/clayey SILT (Quadra Marine)	Lot 4, Plan 12718 DL47

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

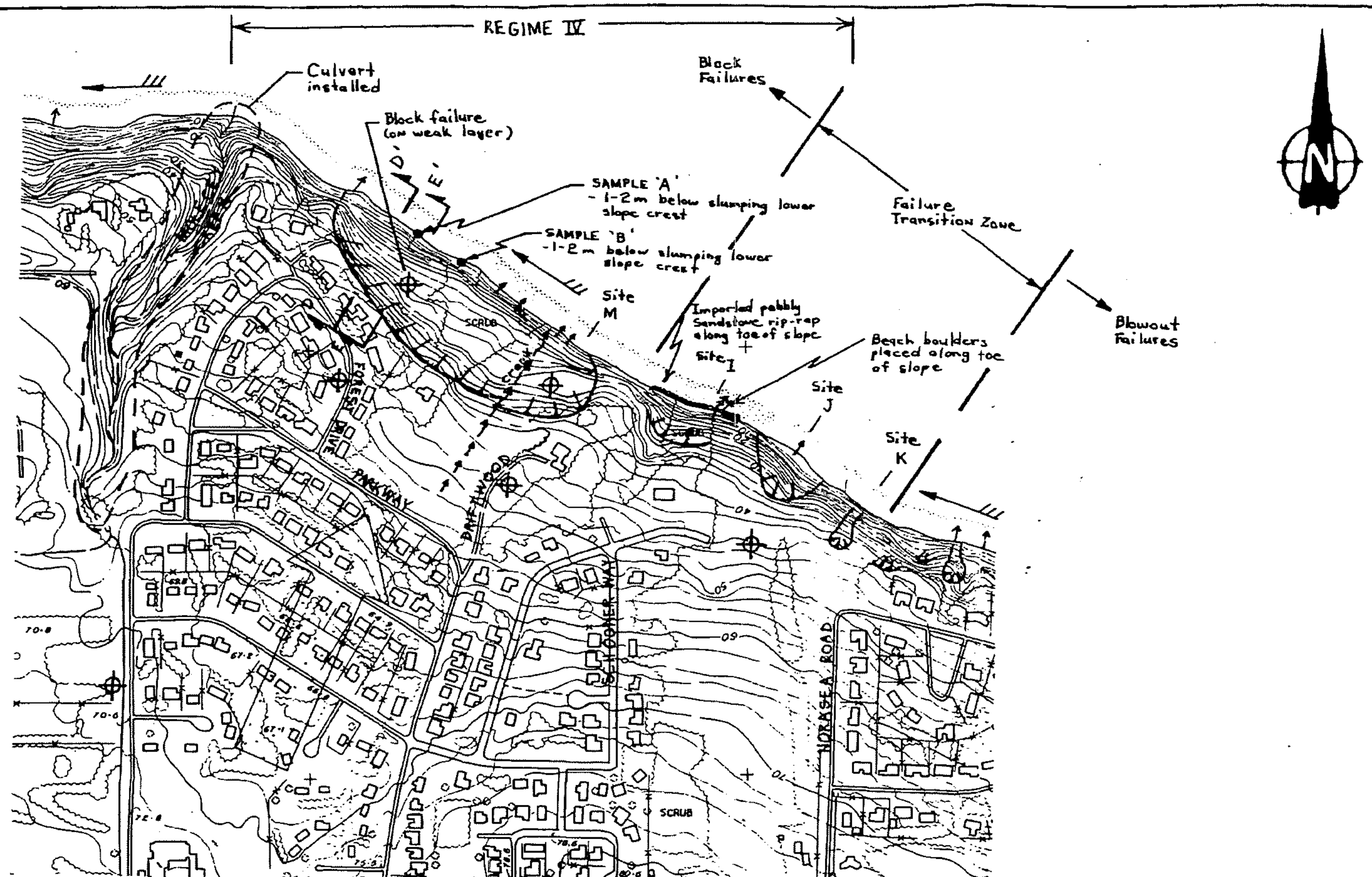
REGIME III

Area	Purpose	Type of Information	Source of Information	Year	Sources File No.	Provided Comments Relevant to Study	Geology	Legal
Waldbank	Slope Evaluation	Setback varies between 15 and 28 m (26.5° from slope toe)	BH Levelton	22/09/92	692-238.001	- slope vegetation described as light cover of second growth trees and moderately heavy underbrush. - slope geometry is complex: - slope angle from 25 to 30°, in general; - portions of slope include relatively recent sliding with near vertical head scarps, with heights to about 5 metres; and - recent sloughing within middle portion of slope. Water seepage coincident with this sloughing. Recent flows were observed within other portions midway down slope. - intermediate benches with slight slopes are present midway along the slope. - other portions of slope have inclinations near 45°. - setback established by projection of 2:1 (horizontal:vertical) (26.5°) from the toe of the slope, measured above the intermediate benching. - setback varies between 15 and 28 metres.	- uniform, fine sand within upper 20 metres of slope. - very dense, grey, silty clay with some gravel exposed above foreshore. - no evidence of active marine erosion. - conclude sand extends approximately to the level of intermediate benching and marine clay comprises lower portion of slope.	Lot 1, DL47, Plan 32362
Waldbank	Slope Evaluation		BH Levelton	30/10/92	692-238.002	- development is to include installation of underground storm sewers. Disturbance of the slope is not expected through the installation of subsurface piping. - setbacks, determined by ground survey methods, are in consonance with previous recommendations.		Lot 1, DL47, Plan 32362

APPENDIX D

REGIME IV
MOLECEY CREEK TO EAST END OF BAYSHORE DRIVE

AGRA
Earth & Environmental Group



LEGEND

- Approx. location of failure scarps
- TW1 Test Pit #1 (by others)
- D Cross Section D-D'
- Approx. location of drilled waterwell (MOE records)
- Littoral Drift
- Surface gradient & probable groundwater flow direction.

APPROXIMATE LOCATION OF SEEPAGE AREAS ALONG THE BASE OF SLOPE WITH ESTIMATE OF FLOW RATE.

- 4 to 8 l/min.
- 8 to 16 l/min.
- >16 l/min.

Approx. location of proposed drill hole.

HBT AGRA Limited
Engineering & Environmental Services

REGIME IV LOCATION PLAN
North Slope - NANAIMO

Scale	1:5000
Date	October 1992
Drawn By	S.V.
Approved B.	

FIGURE D.1

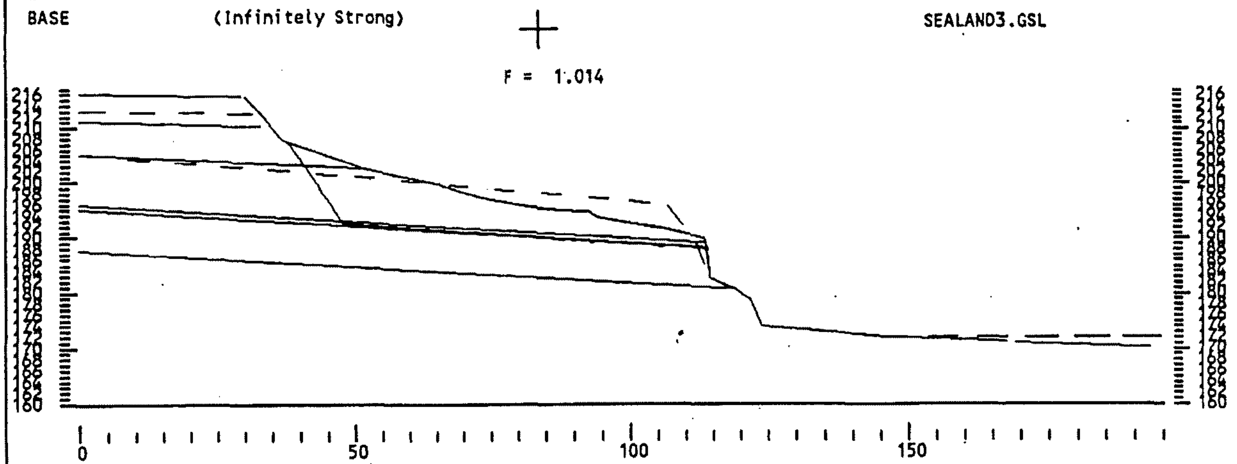
SECTION IV

CROSS SECTION E - E'

Material	Unit Wt kN/m3	C kPa	Phi deg	Piezo Surf.	Ru
MARINE SANDS	20	0	36	2	0
UPPER VASHON	22	0	40	2	0
LOWER VASHON	22	0	40	1	0
CLAY SHEAR ZONE	22	0	17	1	0
UPPER QUADRA	22	0	40	1	0
LOWER QUADRA	22	30	40	1	0
BASE	(Infinitely Strong)				

Hardy BBT Limited
NX01193
NORTH SHORE - SEALAND
OCTOBER 1992

SEALAND3.GSL



SECTION IV

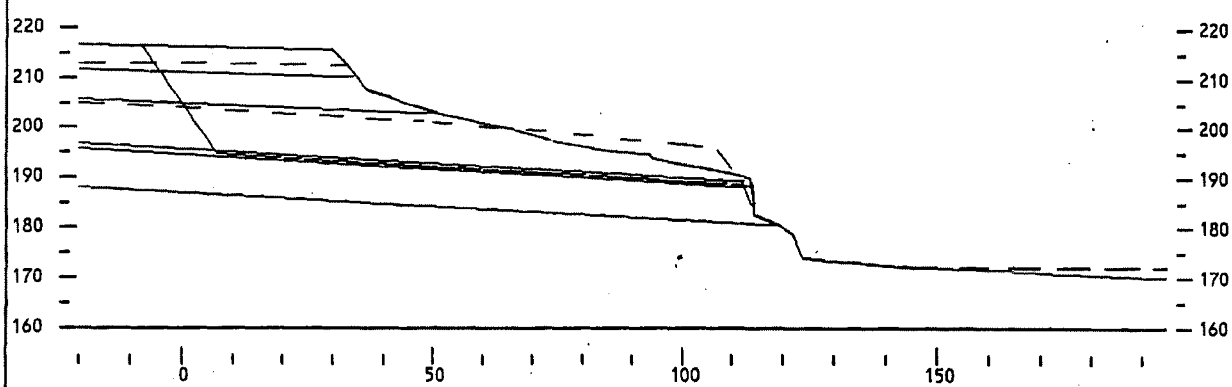
CROSS SECTION E - E'

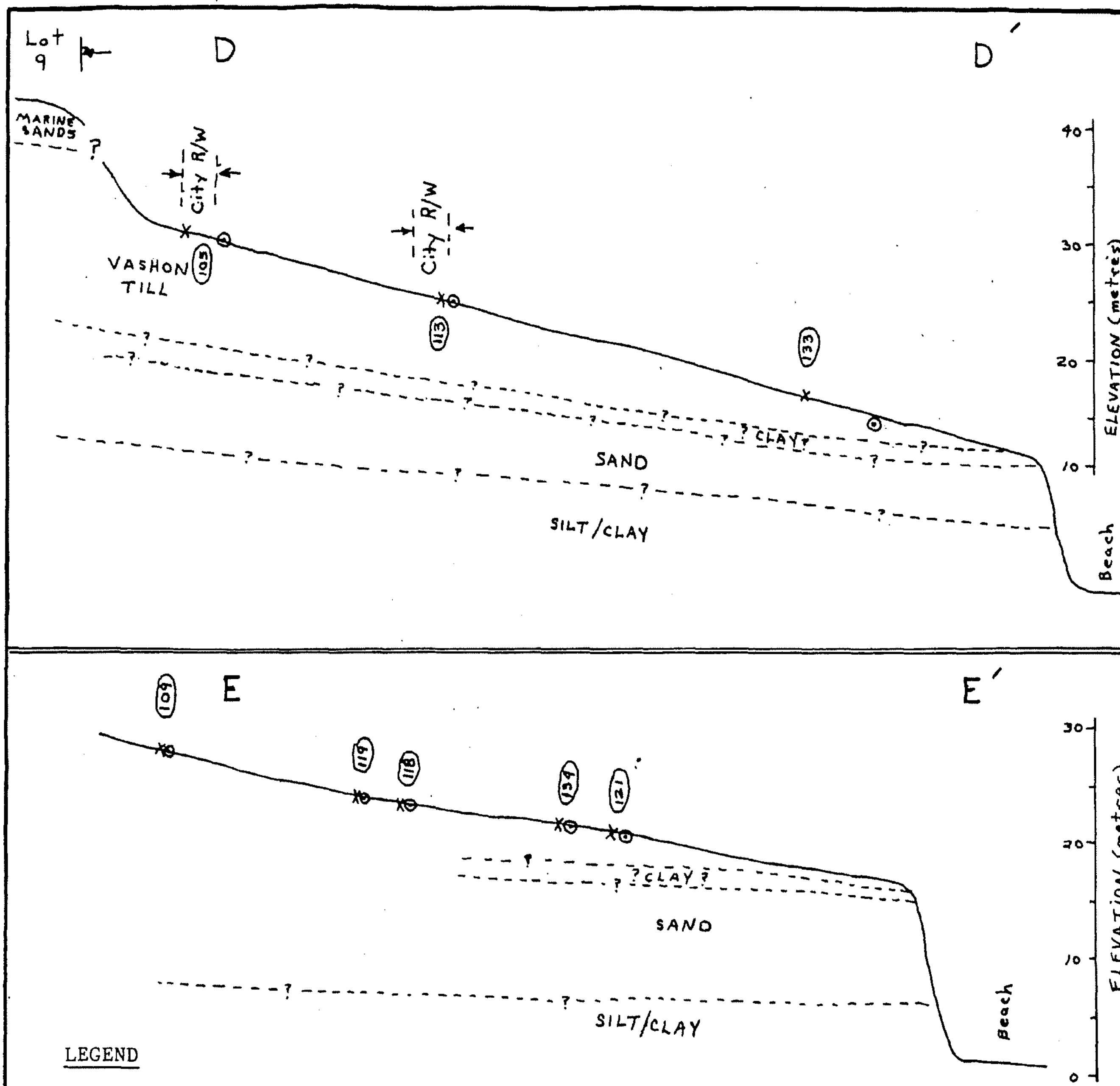
Material	Unit Wt kN/m3	C kPa	Phi deg	Piezo Surf.	Ru
MARINE SANDS	20	0	36	2	0
UPPER VASHON	22	0	40	2	0
LOWER VASHON	22	0	40	1	0
CLAY SHEAR ZONE	22	0	17	1	0
UPPER QUADRA	22	0	40	1	0
LOWER QUADRA	22	30	40	1	0
BASE	(Infinitely Strong)				

F = 1.536

Hardy BBT Limited
NX01193
NORTH SHORE - SEALAND
OCTOBER 1992

SEALAND4.GSL





LEGEND

× Survey station location on Nov. 2/87

⊙ Survey station location on Oct. 21/92

(133) Survey station #133

NOTE

1) For location of cross sections, see Figure D1.

HBT AGRA Limited *Engineering & Environmental Services*	CROSS SECTIONS X - X' AND Y - Y' SEALAND PARK		
	Scale 1:500	Date Oct./92	Drawn By S.V.

HBLT 11-87/05

FIELD INVESTIGATIONS

REGIME IV - Molecy Creek to East End of Bayshore Drive

Relatively good exposures were encountered in this section of the slope, particularly along the beach, where a continuous exposure of approximately 150-200 metres long provides a view of the sediments directly underlying the Sealand Park/Driftwood Place slides. This exposure was comprised of a 3-5 m thick layer of grey clay (Unit 2) that was overlain by 2-6 m of brown sand (Unit 4 or 5). In many places the brown sand was capped by more resistant clay and organic layers. In the upper parts of the slope, Vashon till material was encountered.

Less seepage along the base of the slope was encountered in this regime as compared to Regimes I and III.

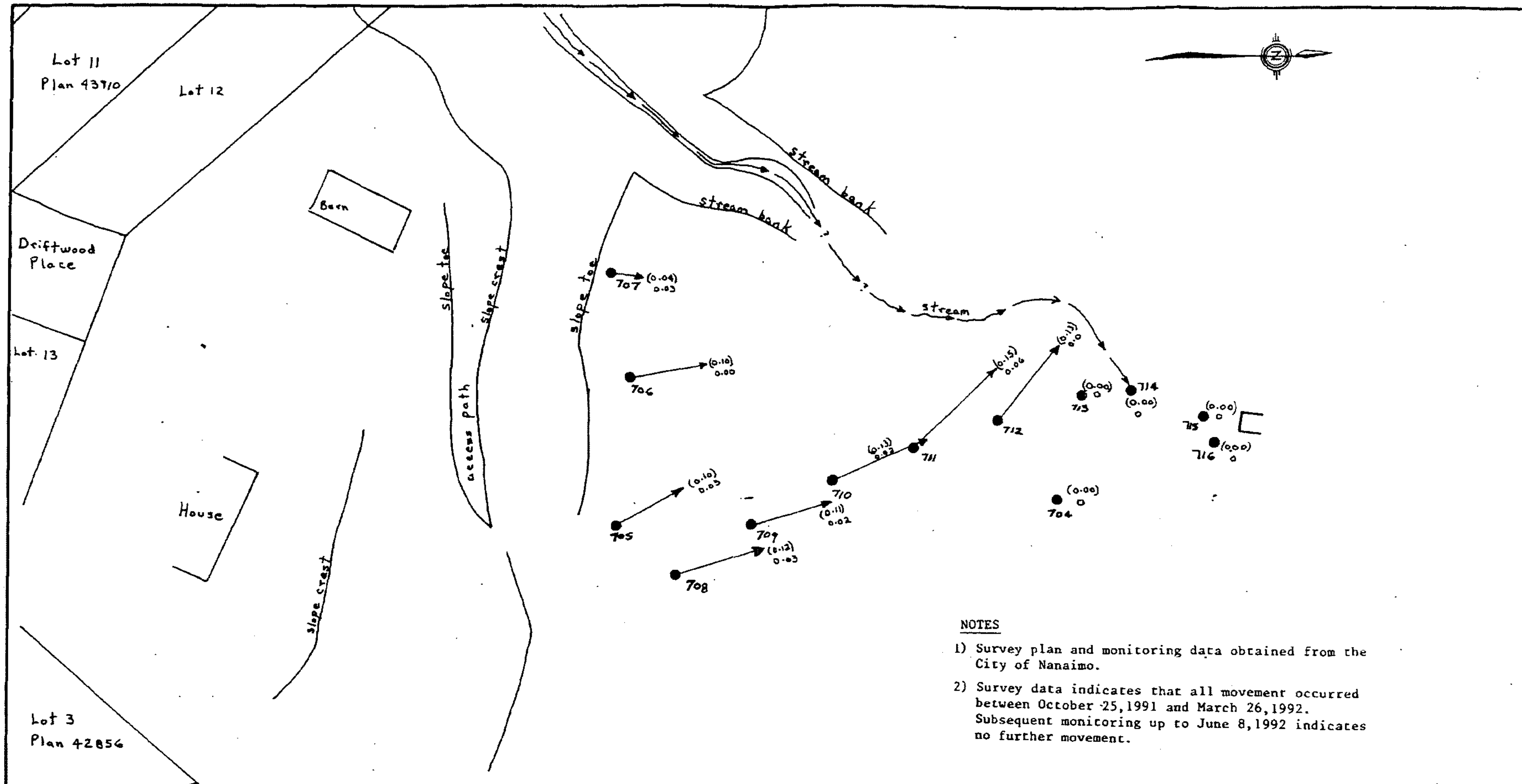
SURVEYING INFORMATION

REGIME IV - Molecy Creek to East End of Bayshore Drive

The Sealand Park failure block is noted to have moved in January of 1986 and again in January of 1992. Additional movements may have occurred between these periods or following the 1992 movement. In November 1987, survey control to monitor potential ground movement in the Sealand Park area was installed by Wright, Hillyard, Parry and Fuller. At that time, survey hubs were established to within $\pm$0.01m horizontal and 0.005m vertical. Manholes constructed along the foreshore as part of the Regional District interceptor line were positioned less accurately in 1976-77. Resurveying of these hubs and manholes which were identified in the field was carried out in October 1992. In addition to this monitoring, Wright, Parry, Taylor and Fuller have carried out surveying of additional hubs which were installed in the spring of 1992.

Analysis of the survey data indicates that although the manholes appear to have been stationary (within the accuracy of the surveys) surface material in Sealand Park has moved up to 6 metres towards the shoreline between November 2, 1987 and October 21, 1992. The directional movement vectors and monitored movement of monitored survey hubs are presented as Figure 3.14.

The Driftwood Place failure block is noted to have moved during Dec/90-Jan/91, September 1991, and late January 1992. Additional movements may have occurred between these periods. Survey monitoring hubs were installed within this failure block by Wright, Parry, Taylor and Fuller in the fall of 1991. Surveying data of these hubs indicates that the Driftwood Place failure block has moved translationally up to 0.15 metres between October 25, 1991 and March 26, 1992. The direction of movement is northwesterly, towards the above noted creek. The directional movement vectors and survey monitored movement are presented as Figure 3.15 and show a translational movement.



NOTES

1) Survey plan and monitoring data obtained from the City of Nanaimo.

2) Survey data indicates that all movement occurred between October 25,1991 and March 26,1992. Subsequent monitoring up to June 8,1992 indicates no further movement.

LEGEND (0.20) 0.03

Vector Plot indicating direction of movement, distance moved (0.20m) and drop in elevation (0.03 metres) between October 25, 1991 and March 26, 1992.

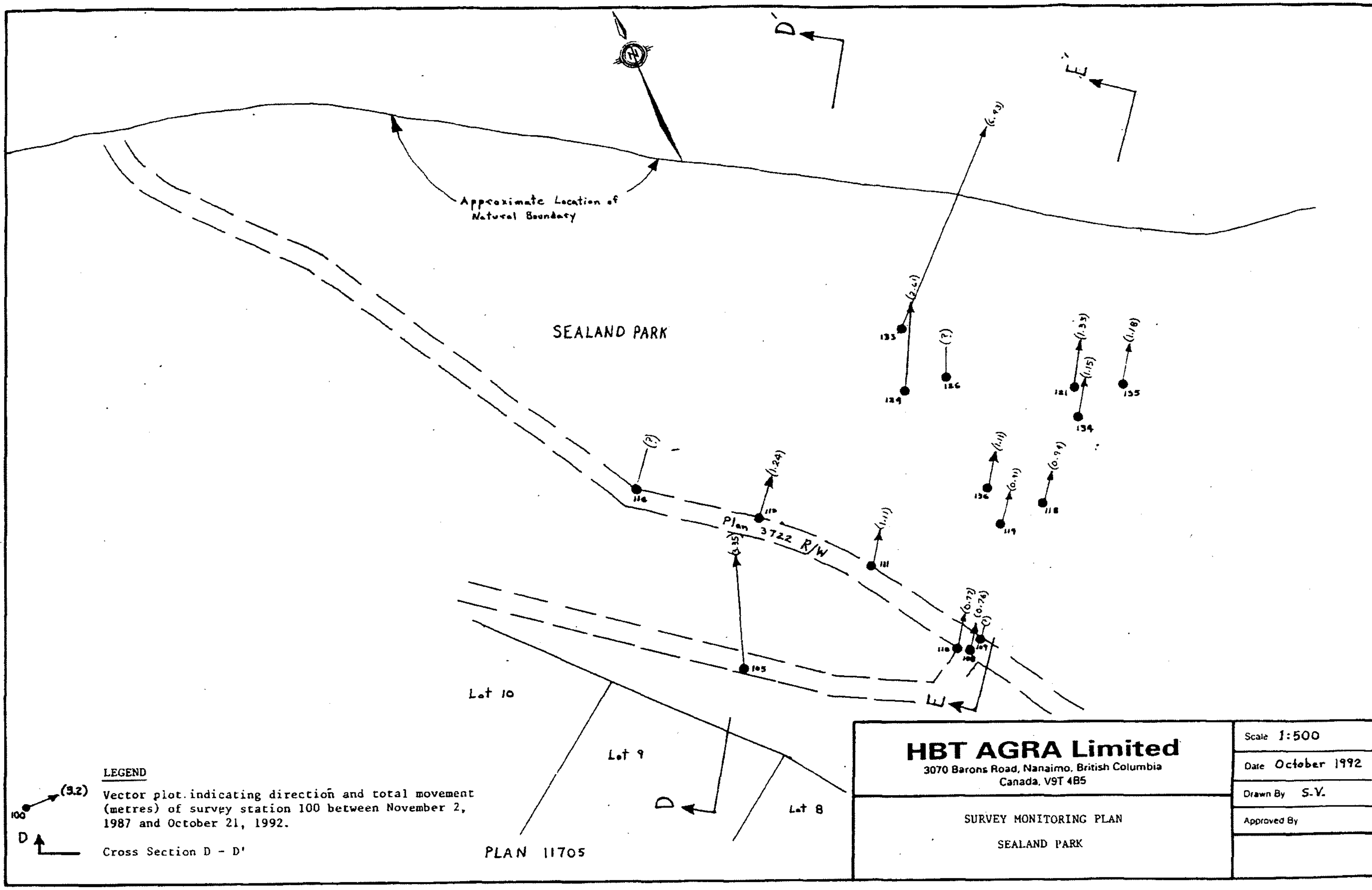
HBT AGRA Limited
Engineering & Environmental Services

SURVEY MONITORING PLAN

DRIFTWOOD PLACE

Scale	1: 500
Date	October 1992
Drawn By	S.V.
Approved By	

HBLT 12 87-05



LEGEND

(3.2) 100 — Vector plot indicating direction and total movement (metres) of survey station 100 between November 2, 1987 and October 21, 1992.

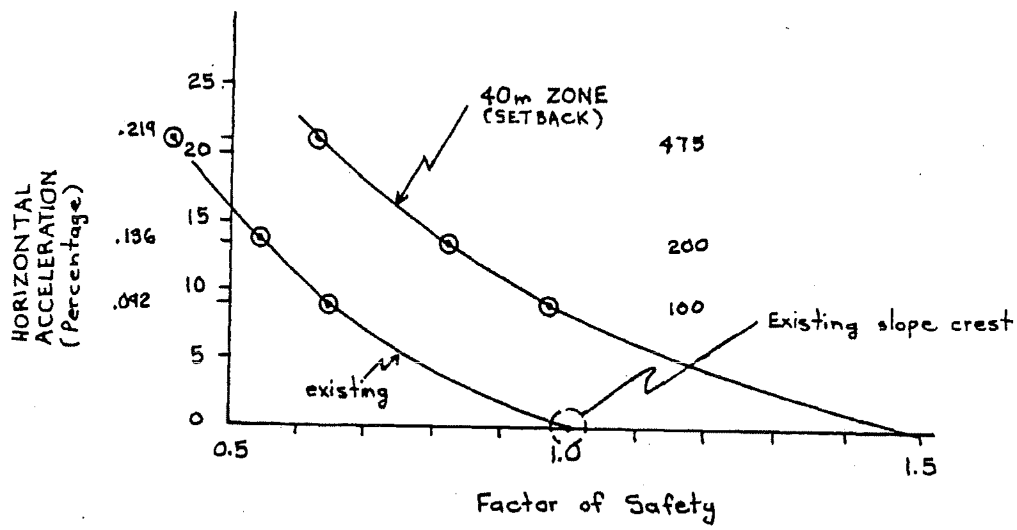
D — Cross Section D - D'

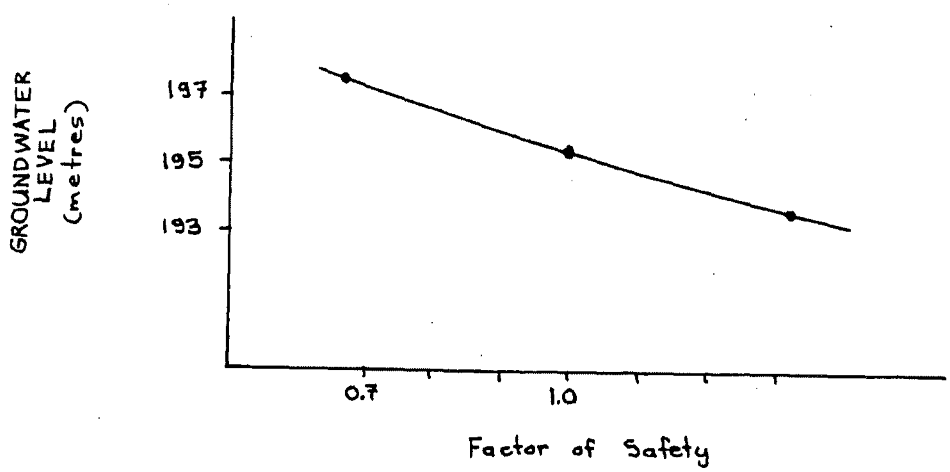
HBT AGRA Limited
3070 Barons Road, Nanaimo, British Columbia
Canada, V9T 4B5

SURVEY MONITORING PLAN
SEALAND PARK

Scale	1:500
Date	October 1992
Drawn By	S.V.
Approved By	

SEALAND
Regime IV





HBT AGRA Limited *Engineering & Environmental Services*	Parametric Analysis Regime IV - Sealand Park North Slope - Nanaimo

Scale	Date	Drawn By
	Nov/92	S.V.

HBLT 11 87/05

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

REGIME IV

Area	Purpose	Type of Information	Source of Information	Year	Sources File No:	Provided Comments Relevant to Study	Geology	Legal
Sealand Park			HBT AGRA Limited	1992	NX01091	- recent large failure, dropped approximately 1 metre - upper scarp exposed - lower vertical scarp along toe from marine erosion - 73 metres in height - flat failed mid-slope area	- surface sand overlying - SAND, some fines (TILL) overlying - SAND overlying - clay seam overlying - dense sand overlying - clay	Part of Sealand Park
Sealand Park		Slope Protection	Island Geotechnical	1986	86921-1	- survey hubs installed November 2, 1987 - although undercutting at toe (for east side) failure above has not extended into this region. - failure brought on by high W.T. in colluvium/Till contact Main Failing Midslope Area - active marine erosion: several slope failures recently due to the undercutting.	East of mid-slope failing area - dense (till) silt, sand and gravel with cobbles overlying - very dense finely layered silt and fine sand (near toe)	PARK
Sealand Park			Island Geotechnical	1987	86021-3	Follow Up - records for graded filter to be placed on shoreline adjacent slope to help prevent undercutting and on-going erosion		PARK
Sealand Park		Setback 135 m from street	Hardy BBT	1988-89 06/06/88 08/08/88 04/19/89 05/17/89 12/05/89	NX00114 (later NX00176)	- crest 35-40 m above toe - wide terrace exists near mid-slope - seepage noted on terrace and lower slope - active marine erosion along toe - small creek at east edge: creek has consistent gradient (even across mid-slope) - terrace continuation from Sealand Park) is part of ancient landslide: extends 150 m east of site - vegetated with young to mature trees	- dense glacial (Till) silty sand and gravel encountered at 3 ft depth	Previous: Lots 12&13, Plan 11705 Now: Lots 1-15, Plan 48602
Sealand Park	Block slide		Levelton	02/19/92	692-031.001	- recent slope movement first noted on January 31, 1992 during period of heavy rainfall - failure extended between manholes 131 to 134 - services lines broken - head scarp coincides with northern boundary of adjacent properties - vertical movement approximately 1.5 m along head scarp - differential movement and lateral spreading further down along slope - cracks on ground surface up to 300 mm wide - movement appears similar to that of Driftwood Place - it is considered probable that the sand and clay inter-till materials are factors in the sliding - manhole 131 is considered stable - promontory points such as east of manhole 131 and area between this slide, the easterly slide at Driftwood Place, appear to remain stable based on observations	- Surficial sand and gravel overlying - glacial till soils overlying - sand grading to marine clays (Quadra) - This Quadra clay is underlain by second glacial till (Dashwood)	PARK

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

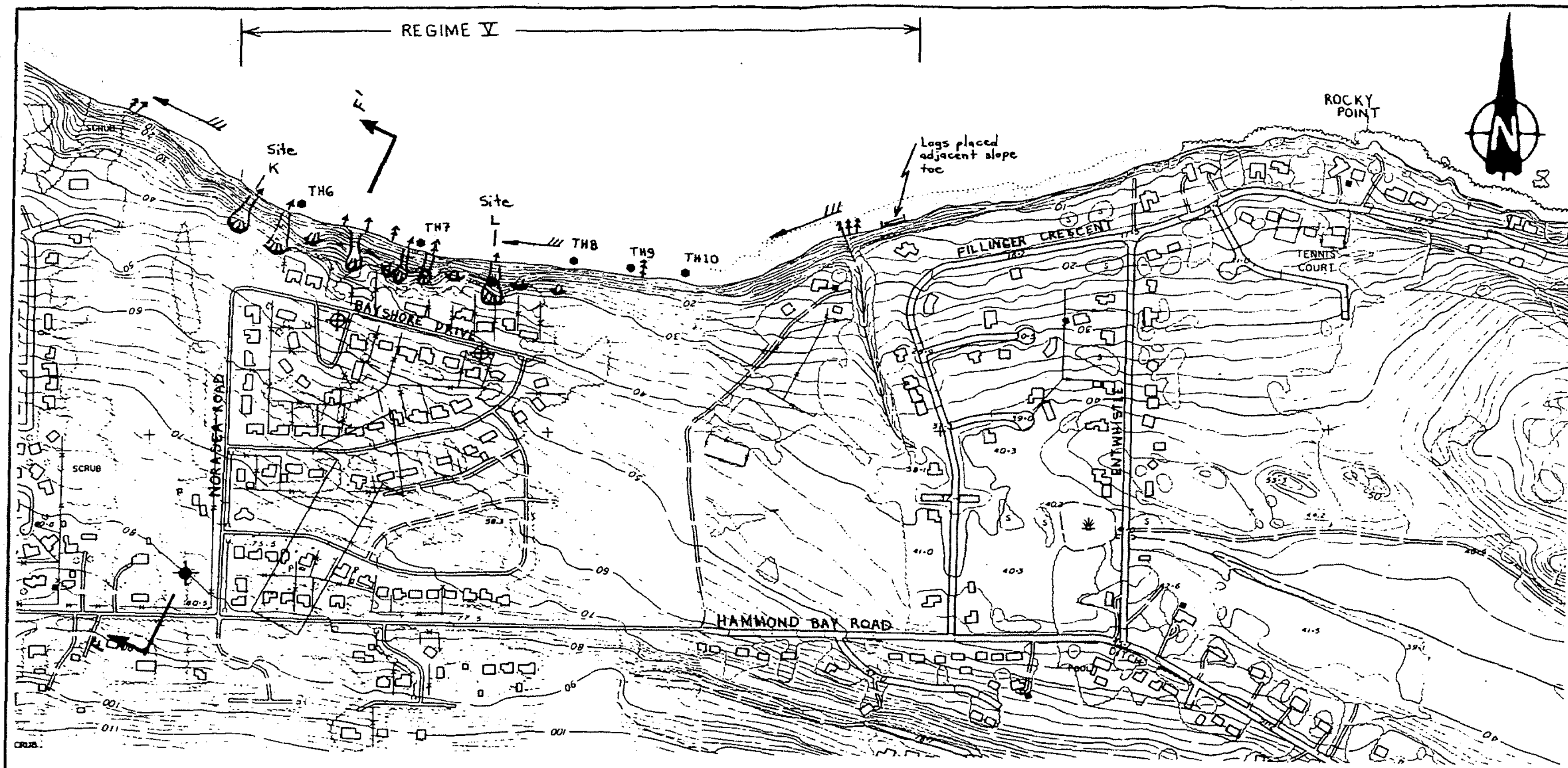
REGIME IV

Area	Purpose	Type of Information	Source of Information	Year	Sources File No:	Provided Comments Relevant to Study	Geology	Legal
Sealand	Site Inspection	Relaxation of set back	Levelton	12/05/89	589-338	- with the construction of basements in homes, the setback may be relaxed by 7.5 m provided footings are at least 2.5 m deep.		Lots 7&10, Plan 48602
Sealand	Site Inspection	Relaxation of set back	Levelton	03/16/90	590-104	- footings for Lot 7 maybe 6 m closer to crest provided set at a depth of 3 m.		
Sealand	Site Inspection	Relaxation of set back	Levelton	04/09/90	590-140.2		- undisturbed, competent, till-like soils were exposed at basement level (3 m depth)	Lot 7, Plan 48602
Sealand Park		survey monitoring data	Wright, Parry, Taylor & Fuller			- survey monitoring results for 20 hubs from March 4/92 through June 8/92. - no movement detected through this period		PARK
Parkway Drive/ Driftwood Place	Slump block movement		Hardy BBT Limited	04/09/91	NX00824	- steep foreshore cut slope (5 to 20 metres height) - mid-slope terrace (60-70 m wide terrace) - steep slope at upper crest to mid-slope (15 m) - block slump winter of 1990/91 - surface water flow over crest of failed block and also from a gravelly layer within slump block - mid-slope bounded by arc shaped escarpment to east and south and by drainage channel to west - recent movement along southern boundary of mid-slope (vertical displacement of ± 1.5 m) - large translational component: no rotation - probable contributing factors include: high porewater pressures; reduced residual strength; accumulated slide debris; and glacial unloading of Quadra clays	- foreshore includes dense uniform sand overlying - hard laminated silty clay with a 4" gravelly layer at base of sand - head scarp includes dense non-layered silty SAND with some gravei and cobbles - tension cracks in mid-slope terrace reveal naturally deposited sand and gravel - exposure above drainage channel to the west is dense uniform sand	Rem A, Plan 43909
Parkway Drive/ Driftwood Place	review of sewer line reconstruction		Levelton	10/02/91	691-198	- proposed common trench (storm and sewer) would be up to 1.5 m deep - construction of pipeline was not recommended - grading fill and retaining wall within access road would surcharge block - pipeline would be located within known sliding block		Rem A Plan 43909
Parkway Drive/ Driftwood Place	set back		Levelton	09/22/80	80-V-108C	- slope averages 33 m height - overall slope angle of 44° - slope over-steepened by toe erosion from wave action - generally immature tree cover - setback at least 25 m from crest (30° angle measured from toe)	- horizontally bedded marine sands and clays	Lots 21 & 22, DL 40 Viewpoints Estates
Parkway Drive/ DriftwoodPlace		survey monitoring data	Wright,Parry, Taylor & Fuller			- survey monitoring results for 15 hubs from Oct. 25/91, March 26, April 2, May 5 and June 8, 1992 - No movements detected from March 26/92 to June 8/92, however, 10 hubs had moved between Oct. 25/91 and March 26/92		Rem A, Plan 43909

APPENDIX E

REGIME V
EAST END OF BAYSHORE DRIVE TO ENTWHISTLE DRIVE

AGRA
Earth & Environmental Group



LEGEND

- Approx. location of failure scarps
- TH1 Test Pit #1 (by others)
- F Cross Section
- Approx. location of drilled waterwell (MOE records)
- Littoral Drift
- Surface gradient & probable groundwater flow direction.

APPROXIMATE LOCATION OF SEEPAGE AREAS ALONG THE BASE OF SLOPE WITH ESTIMATE OF FLOW RATE.

- 4 to 8 l/min.
- 8 to 16 l/min.
- >16 l/min.

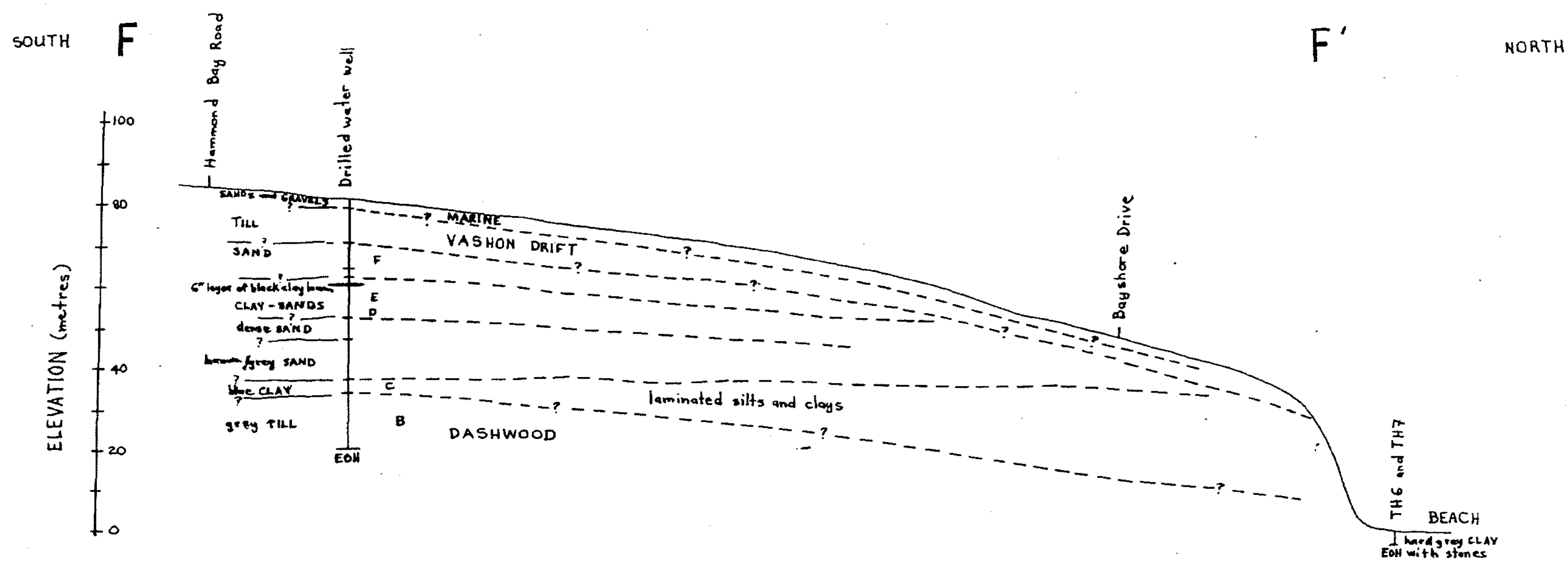
Approx. location of proposed drill hole.

HBT AGRA Limited
Engineering & Environmental Services

REGIME V LOCATION PLAN
North Slope - NANAIMO

Scale	1:5000
Date	October 1992
Drawn By	S.V.
Approved B.	

FIGURE E.1



NOTE

The interpreted stratigraphy is based on the water well log, as well as the foreshore geology and test pits associated with the sewer line interceptor.

HBT AGRA Limited *Engineering & Environmental Services*	Scale Hor 1:2000 Vert 1:1000
	Date October 1992
Cross Section F-F' REGIME V	Drawn By S.V.
	Approved By

HBLT 13 E7-05

FIELD INVESTIGATIONS

REGIME V - East End of Bayshore Drive to Entwhistle Road

The geology of this section of the Northshore slope differs from that of Regimes I - IV in that the Dashwood till (Unit 1) is found along most of the base of the slope. In places this till appears up to 10-15 m thick and is overlain by grey clay of Unit 2. The grey clay is directly overlain by Dashwood drift material instead of Quadra sands, which are absent.

In this section seepage areas are confined to steep gullies that are located approximately perpendcular to the slope face. Flow rates for these seepage zones are approximatly 4-8 l/min.

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

REGIME V

Area	Purpose	Type of Information	Source of Information	Year	Sources File No.	Provided Comments Relevant to Study	Geology	Legal
Bayshore	Assessment of recent failure	Slope Stabilization	Levelton	01/91	691-001	- failure on western neighbouring property in December, 1990 during heavy rainfall. Uncontrolled storm water off Bayshore entered property. - recent failure area is site of past failures evidenced by steep-sided semi-circular shape - during visit heavy seep at sand and till contact and other seeps in Quadra sands - gully formed in Quadra sands during groundwater flows - tension cracks in lawn about 2 m from foundation - recommended coarse granular blanket in recent failed area (at mid-slope area).	- gravelly sands (5 m) overlying - dense grey silty till (10 m) overlying - Quadra interbedded silts and sands (Seepage at approximately 3 m depth)	Lot 7, Plan 16772, DL 42
Bayshore	Assess impact from a second slope failure		Levelton	05/90	691-001	- recent slide on February 1991 affecting east side of property - shape of semicircle leading to deep gully below - concludes that failure result of prior heavy storms in November to early January. Heavy groundwater runoffs here, too.	- gravelly sands (5m) overlying - dense grey silty till (10 m) overlying - Quadra interbedded silts and sands (Seepage at approximately 3 m depth)	Lot 7, Plan 16772, DL 42
Bayshore	evaluate geotechnical condition and comment on feasibility of residential construction		Hardy BBT Limited	04/16/89	NX00296	- slope is approximately 30 m high - average slope is approximately 40° - trees (mature) on lower portion of slope only - fill up to 1.5 m high on slope - bank erosion will continue to occur (presently occurring)		Lot 7, Plan 16772, DL 42
Bayshore	Investigation of fill soils supporting existing footings		Island Geotechnical Services Ltd.	10/15/87	87193-1	- variable thickness of fill placed on upper terrace adjacent crest	<u>upper terrace</u> - fill soils overlying - (topsoil) silty sand overlying - orange brown, silty, fine to medium SAND	Lot 4, Plan 44070, DL 42
Bayshore	Slope Stability Evaluation		BH Levelton	11/05/92	692-097.002	- slope varies between 15 to 19 metres in height. - average slope angle of 40 to 42°. - slope vegetated with sporadic old trees and light growth of second growth. - creek channel, which cuts through slope, drains marshy upland area. Creek bank faces vegetated with mixture of sporadic ancient and second growth trees. - low erosional scours at foreshore for western half of property. - localized soil exposures on slope were sporadically present. - recent slump along the western flank of the creek (located south of slope crest). - no evidence of large or moderate slope movement. - no groundwater seepage from slope face, however, light flow within creek. - setback established by projecting 30° angle from horizontal to be 10 to 11 metres - minimum of 5 metres. - bedrock exposed at eastern portion of slope toe.		Rem DL42

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

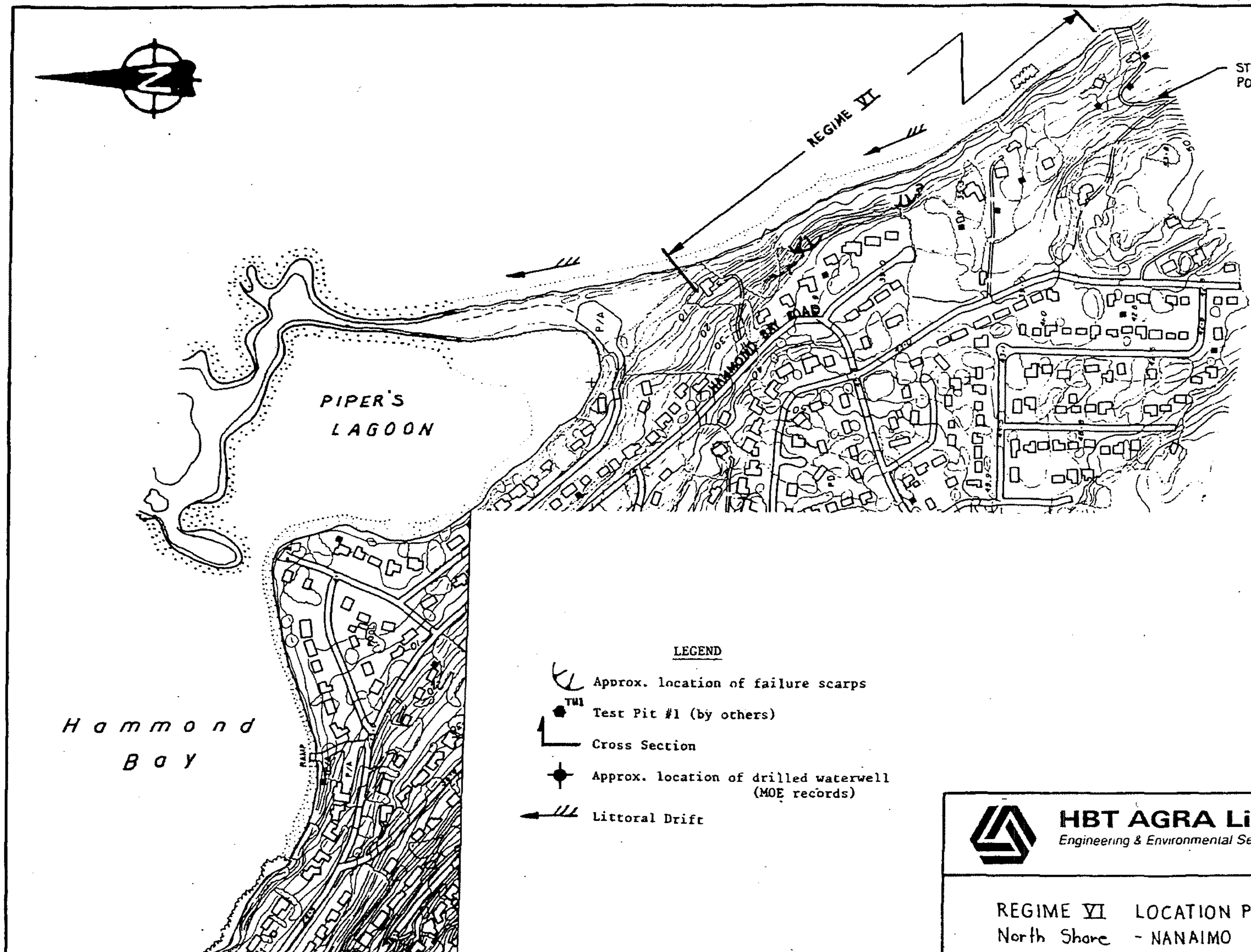
REGIME V

Area	Purpose	Type of Information	Source of Information	Year	Sources File No:	Provided Comments Relevant to Study	Geology	Legal
Bayshore	Geotechnical Evaluation in response to City of Nanaimo review		BH Levelton	22/09/92	692-097.002	- existing slope, including creek, is currently forested with mixed coniferous/deciduous growth. - in general, it is desirable to leave vegetation cover on steep slopes to minimize erosion; however, it is permissible to selectively remove larger trees. Root systems should be left in place. - where portions of the slope are cleared, vegetation should be re-established or alternative slope erosion control measures taken.		Rem DL42

APPENDIX F

REGIME VI
PIPER'S LAGOON TO STEPHENSON POINT

AGRA
Earth & Environmental Group



LEGEND

- Approx. location of failure scarps
- TH1 Test Pit #1 (by others)
- Cross Section
- Approx. location of drilled waterwell (MOE records)
- Littoral Drift

HBT AGRA Limited Engineering & Environmental Services	Scale 1:5000
	Date October 1992
	Drawn By S.V.
REGIME VI LOCATION PLAN North Shore - NANAIMO	Approved By
	FIGURE F.1

HBLT 13-87/05

FIELD INVESTIGATIONS

REGIME VI - Piper's Lagoon to Stephenson Point

The slope geology in this regime differs form the other regimes in that bedrock is located along the base of the slope. Overburden which consists of sand and gravel overlying a silt till. This material appears to lie in direct contact with bedrock.

Seepage appears predominately along the bedrock-overburden contact.

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

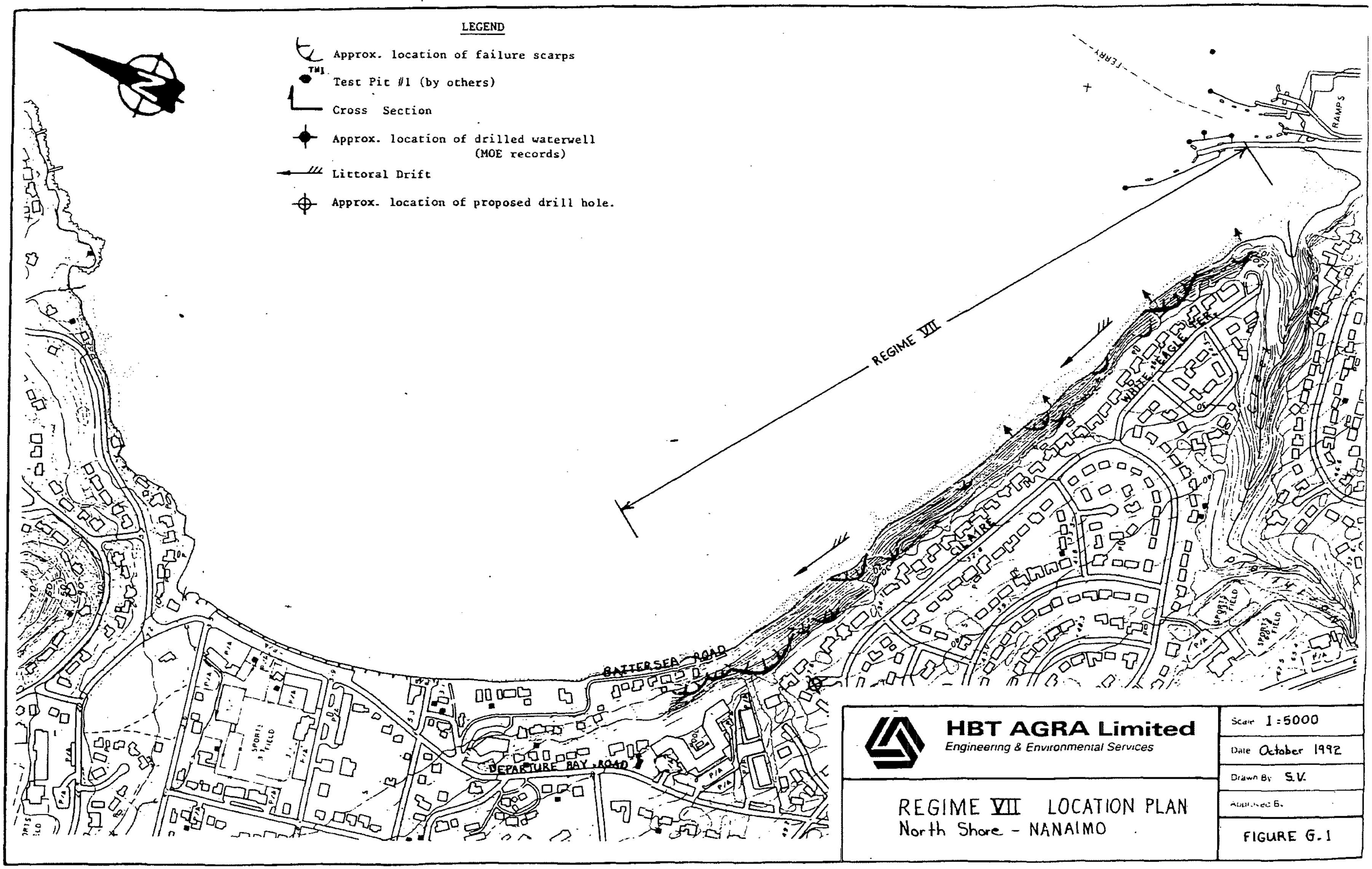
REGIME VI

Area	Purpose	Type of Information	Source of Information	Year	Sources File No.	Provided Comments Relevant to Study	Geology	Legal
Hammond Bay Road	Assessment of Recent Failure	Slope Stability	HBT AGRA Limited	28/05/92	NX01111	- eastern two thirds of property consists of shore cliff. - city right-of-way (sanitary sewer) located on site parallel to crest. - slope failure occurred near end of January of early February 1992 after period of heavy rainfall. This failure destroyed a cabin, which was located near beach level, and staircase accessing beach. - recent failure near crest of slope; the sub-vertical scarp was 15 to 18 ft (4.6 - 5.5 m) high. Failure zone was 60 ft (18.3 m) across at crest and extended onto beach. Scarp was 80 ft (24.4 m) from residence of Lot 1. Scarp was directly behind residence on Lot 3. - cliff is approximately 80 ft (24.4 m) high with slope angle of 1H:0.75V in undisturbed areas. Undisturbed areas were heavily vegetated with thick underbrush and trees up to 2 ft (0.6 m) in diameter); some trees were leaning or bent. - large logs and driftwood scattered along slope toe; active wave erosion along slope toe. - man-made drainage channel has been cut across the middle of shore cliff slope from Chinook Road to near base to failure scarp. - seepage of unknown source was noted on the north side of failure scarp and flowed through an erosional channel. An additional erosional channel noted on south side of failure zone.	scarp near crest revealed: - 10 ft (3.0 m) of very dense sand with gravel overlying 5 to 8 ft (1.5 - 2.4 m) of hard silt till. - failure debris covered the lower portions of the slope.	Lot 1, Plan 23739, DL29

APPENDIX G

REGIME VII
BATTERSEA ROAD TO NORTHFIELD CREEK

AGRA
Earth & Environmental Group


LEGEND
Approx. location of failure scarps
Test Pit #1 (by others)
Cross Section
Approx. location of drilled waterwell (MOE records)
Littoral Drift
Approx. location of proposed drill hole.
REGIME VII
WHITE EAGLE TER.
CLARE
BATTERSEA ROAD
DEPARTURE BAY ROAD
SPORTS FIELD
RAMPS
FERRY
HBT AGRA Limited
Engineering & Environmental Services
REGIME VII LOCATION PLAN
North Shore - NANAIMO
Scale 1:5000
Date October 1992
Drawn By S.V.
FIGURE G.1

FIELD INVESTIGATIONS

REGIME VII - Battersea Road to Northfield Creek

The geology is this regime is dominated by the Vashon till (unit 6) with a thin covering of marine deposits (unit 7). A small exposure of laminated silty clay (unit 2) was noted along the northern portion of this regime.

SUMMARY TABLE

AVAILABLE REFERENCE INFORMATION

REGIME VII

Area	Purpose	Type of Information	Source of Information	Year	Sources File No:	Provided Comments Relevant to Study	Geology	Legal
Departure Bay Road	provide geotechnical input for feasibility of residential construction		HBT AGRA Limited	06/18/92	NX01136	- test pits done in 1983: fill through out site - slope unstable - at other sites slope is 27-30° - erosion of Departure Bay Creek; run-off increased in last 5 years; Creek bed has been widened and deepened due to erosion from increased flow and could result in undermining - groundwater seeping out of slope: springs? no present slope instability		PCL A DD-44093-N Section 15
Departure Bay Road	slope stability analyses		HBT AGRA Limited	1992 ongoing	NX01167	- road embankment slipping toward creek - tension cracks up road shoulder - heavy storm water flows over bank had destabilized the slope to east of site several years ago: This region had failed and is presently surfaced with riprap.	- Road Fill overlying - sands overlying - dense Till sand, some fines overlying - bedrock	Portion of Lot 1, Plan 24407, Section 15
Battersea	foundation investigation of wet soft surface soils		Island Geotechnical	03/31/87	87076	- much seepage through near surface soils resulting in soft surface conditions. Artesian pressure within sand and gravel? - ground surface slopes gently (5°) toward east	- black sandy SILT, organics (2 ft) overlying - silty SAND, loose, saturated (4 ft) overlying - compacted, brown sand and gravel, clean, saturated (13 ft) overlying	Lot 9, Plan 425-A, Section 1
Cilaire			CTI	11 - 12/88	GB1123	- Water Table at 2 ft - overall slope of 34° - 30 ft setback - steeper upper section of the slope - no records for toe protection now, however, if "extraordinary wave action" could cause erosion and then riprap blanket should be placed	- topsoil and loose organic rust brown SILT (2 ft) overlying - dense grey sand SILT Till, sandier with depth (5 ft)	Lot 27, Plan 18900