DISTRICT OF NORTH VANCOUVER

BERKLEY LANDSLIDE RISK MANAGEMENT

PHASE 1 RISK ASSESSMENT

FINAL

PROJECT NO: 0404-002-02
DATE: January 13, 2006

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January 13, 2006
Project No. 0404-002-02

Mr. Jozsef L. Dioszeghy, P.Eng.
District North Vancouver
355 West Queens Road
North Vancouver, BC
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Dear Jozsef:

Re: Berkley Landslide Risk Management, Phase 1 Risk Assessment

Please find attached seven copies and one digital copy of our above-referenced final report dated January 13, 2006. A copy has also been forwarded to Dr. N.R. Morgenstern, P.Eng., who was retained by BGC Engineering Inc. as an independent advisor for the study and as a reviewer of this final report.

Should you have any questions or comments, please do not hesitate to contact me at the number listed above.

Yours sincerely,
BGC Engineering Inc.
per:

Michael Porter, M.Eng., P.Eng.
Senior Geological Engineer

cc. Dr. Norbert Morgenstern

MJP/mjp

EXECUTIVE SUMMARY

Houses have been constructed at the top and bottom of a steep slope located east of the Seymour River, North Vancouver, herein referred to as the Berkley-Riverside Escarpment. During construction and ongoing occupation of the houses, fill was indiscriminately placed at the top of the escarpment, locally oversteepening the top-of-slope and increasing the potential for landslides. At some locations, other factors such as the concentration of surface runoff and deterioration of retaining walls also increase landslide potential.

Since 1972, heavy rainfall triggered at least six extremely rapid landslides that appear to have originated from the crest of the escarpment. On average, this corresponds to one landslide occurring every 5.5 years.

Two of the landslides caused structural damage to houses located at the bottom of the escarpment, as well as damages to patios and loss of backyards at the escarpment crest. The most recent landslide (which occurred on January 19, 2005) resulted in one serious injury and one fatality.

Where homes are constructed on or below sloping ground, landslide risks cannot be eliminated, only managed in an informed and proactive manner. Following the January 2005 landslide, the District of North Vancouver commissioned a study to evaluate the risks from future landslides originating from the Berkley-Riverside Escarpment during periods of heavy rainfall, and options to reduce landslide risk. BGC Engineering Inc. was retained to carry out this risk assessment using a phased approach. The results of the first phase - risk estimation - are documented in this report. The focus has been to highlight the factors contributing to the risks and to understand how the relative risks are distributed using a repeatable and transparent process.

The escarpment crest was subdivided into 75 increments representing hypothetical landslide source areas. The likelihood and consequence of landslide occurrence from each source area was systematically assessed in order to obtain estimates of the risk of loss of life for occupants at the base and crest of the escarpment. Two types of risk were estimated: individual and societal. Individual risk represents the incremental risk of fatality faced by an individual exposed to a landslide hazard. Societal risk accounts for the potential for one or more fatalities that arises when multiple people are exposed to a particular landslide.

The total sum of landslide risk estimates for the entire escarpment was purposely calibrated to match the historical record of landslide occurrences leading to serious injury or fatality.

Risk management requires that estimated risks are compared against risk acceptance criteria established by the affected community. Quantitative tolerable risk or risk acceptance

criteria for landslides have not been defined for British Columbia or the District of North Vancouver. In the absence of local criteria, individual and societal risk estimates for the landslide source areas were compared against criteria developed for other jurisdictions, namely, Hong Kong and Australia. These societies have a relatively low tolerance for risk, and have considerable experience managing landslide risk.

Approximately 52 properties were identified where individual risk estimates exceed tolerable criteria defined for existing developments in Australia and Hong Kong. Occupants of these properties are exposed to an incremental risk of fatality exceeding 10^{-4} per annum, or a 1 in 10,000 chance of fatality per year. 10^{-4} is, coincidentally, equivalent to the Canadian mortality rate arising from motor vehicle accidents. Of the 52 properties, one is located at the crest of the escarpment – the remainder are located at the bottom of the slope.

Based on comparisons with Hong Kong criteria for societal risk, 22 of the 75 hypothetical landslide source areas along the crest of the escarpment pose unacceptable risk levels and 37 other source areas require further efforts to reduce risks to as low as reasonably practicable.

The results provide a defensible justification for risk control, which has already been initiated by the District of North Vancouver. Land acquisitions have occurred and construction works are underway. Other mitigation measures will be evaluated during the next phase of study and implemented, as appropriate. Risk exposure will be re-evaluated to demonstrate the effectiveness of control measures in reducing landslide risk exposure.

The impacts of recent property acquisitions, as well as monitoring and storm sewer drainage improvement efforts currently underway, are not included in the results reported above. These will reduce the total risk exposure along the escarpment. At this time, rainfall and groundwater monitoring are being carried out on a continuous basis, providing an opportunity to evacuate affected residents if conditions that triggered landslides in the past recur. Re-direction of roof drainage into the storm sewer system represents best practices and is expected to improve the stability of the escarpment. The potential benefits of these and other possible risk reduction options will be quantified and documented in the next phase of study.

Also in the next phase of study, additional investigations and analyses will be carried out to reduce uncertainties associated with some of the input parameters and to refine risk estimates. Other options that will be evaluated to reduce landslide risk include: regular slope inspections; removal of marginally stable retaining walls and fills; recompaction of loose soils; installation of soil nails to reinforce the slope; and, surface and sub-surface drainage improvements.

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LIMITATIONS OF REPORT

BGC Engineering Inc. (BGC) prepared this report for the account of the District of North Vancouver. It presents the results of a preliminary quantitative risk assessment for shallow, extremely rapid landslides initiating at or near the crest of a steep escarpment west of Berkley Road and East of Riverside Drive in North Vancouver. Other natural processes, such as flooding, soil erosion, debris flows, and deep-seated landslides are not included in this study. The risk assessment is limited to landslides triggered by intense rainfall. Landslides triggered by earthquakes, slope excavation, or other processes are not included in this study.

The material in this report reflects the judgement of BGC staff in light of the information available to BGC at the time of report preparation. Any use which a Third Party makes of this report, or any reliance on decisions to be based on it are the responsibility of such Third Parties. BGC accepts no responsibility for damages, if any, suffered by any Third Party as a result of decisions made or actions based on this report. In particular, BGC accepts no responsibility for changes in real estate values that may occur as a consequence of this report.

As a mutual protection to our client, the public, and ourselves, this report and drawings are submitted for the confidential information of the District of North Vancouver. It is understood that the District of North Vancouver will make this report and drawings available to the community for the sole purpose of conveying current information about landslide risk management as limited in paragraph one, above. Authorization for any other use and/or publication of data, statements, conclusions or abstracts from or regarding this report and drawings is reserved pending our written approval.

Anyone in the community receiving a copy of this report and drawings is urged to recognize that these documents represent an interim step in the risk management process as defined by Canadian Standards Association Guidelines. Unmitigated landslide risks have been quantified, which has enabled clear comparisons with other jurisdictions where similar landslide risk exposure has lead to the adoption of public policies regarding acceptable limits for landslide risk exposure. Using the thresholds for individual and societal risk from these jurisdictions, this report and drawings conclude some of the Berkley Road and Riverside Drive areas are exposed to unacceptable landslide risk. It remains for the community to decide if these risk tolerance thresholds are acceptable. This notwithstanding, the District has already authorized BGC Engineering Inc. to proceed with investigations that will evaluate the efficacy of mitigation measures already implemented and those considered feasible, as well as re-evaluation of mitigated landslide risk exposure in the affected area. This is the important final step in the risk management process.

1.0 INTRODUCTION

Houses have been constructed at the top and bottom of a steep slope located east of the Seymour River, North Vancouver, herein referred to as the Berkley-Riverside Escarpment. The escarpment comprises interbedded glaciofluvial sands and gravels and tills, and is capped by a thin layer of stratified sands and silts of glaciomarine origin. During construction and ongoing occupation of the houses, fill was indiscriminately placed at the top of the escarpment, locally oversteepening the top-of-slope and increasing the potential for landslides.

Since 1972, heavy rainfall has triggered at least six extremely rapid landslides (flow slides) that appear to have originated from the crest of the escarpment. On average, this corresponds to one landslide occurring every 5.5 years. Landslides may have occurred prior to 1972 but have not been documented, thus 1972 was selected as the start date for the statistics used in this study.

Two of the landslides (one occurring in December of 1979 and one occurring in January 2005) caused structural damage to houses located at the bottom of the escarpment, as well as damages to patios and losses of backyards at the crest of the escarpment. The January 2005 landslide resulted in one serious injury and one fatality.

Following the January 2005 landslide, the District of North Vancouver (DNV) committed to commissioning a study for the purpose of evaluating the risks from future landslides originating from the Berkley-Riverside Escarpment and options to reduce landslide risk. BGC Engineering Inc. (BGC) submitted a proposal to DNV outlining a framework and cost estimate for the study (BGC, 2005a), and a contract for the work was awarded on October 26, 2005.

The scope of work addresses shallow, extremely rapid landslides (referred to as flow slides) potentially initiating from the backyards of approximately 75 properties located at the crest of the escarpment between the corner of Bendale Road and Berton Place (the southern limit) and the corner of Berkley Avenue and Whitman Avenue (the northern limit). The northern limit is the same as that used in a 1980 Klohn Leonoff study (Klohn, 1980), while the southern limit includes an additional 11 properties that were not assessed by Klohn.

This report documents the results of a preliminary unmitigated landslide risk assessment, based on the first phase of investigations carried out as part of this study. This risk assessment will be updated upon completion of an additional phase of study at which time the efficacy of mitigation measures already implemented and those considered feasible will be included in a revised quantitative risk assessment.

2.0 LANDSLIDE RISK MANAGEMENT

Traditionally, geotechnical engineers manage the risks from landslides by the use of a factor of safety against slope failure. The factor of safety provides an estimate of the stability of a slope. The minimum factor of safety adopted for design addresses:

- uncertainty in the geological model and input parameters, such as soil strength and groundwater conditions;
- uncertainty introduced by the mathematical assumptions used in the calculations; and,
- the consequences should a failure occur.

Larger minimum factors of safety are used where the uncertainties or the consequences of failure are high. Due to the high consequences of a slope failure in a residential development, a factor of safety of 1.5 is often used.

Increasingly, population growth in urban centres has resulted in the development of properties on or beneath slopes where the factor of safety may fall below 1.5 under certain conditions, such as during periods of heavy rainfall or after years of human occupation and consequent modification to the slope configuration. In many of these cases, it is not practical to calculate the current factor of safety against failure for every slope affecting a development, nor is it practical to remediate all slopes so that the factor of safety always exceeds 1.5. Furthermore, it is often impractical and cost-prohibitive to permanently sterilize all property where the potential for landslides exists.

As a result, new techniques involving quantitative risk assessment are emerging as the standard of practice for the explicit management of landslide risks in urban settings. For example, DNV recently adopted a similar approach for management of debris flow risks; and, a recent international conference on landslide risk management[1] held in Vancouver provided examples of quantitative risk management practices from around the world.

Quantitative risk assessment (or QRA) involves:

- developing an inventory of landslide hazards;
- estimating the likelihood, consequence and risk of landslide occurrence; and,
- evaluating whether the affected community finds the estimated risks acceptable.

QRA allows the risks from landslides to be compared with risks from other natural hazards and hazards the community is exposed to in everyday life, such as daily commuting.

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[1] See, Proceedings of the International Conference on Landslide Risk Management, held in Vancouver from May 31 through June 3, 2005.

Risk management involves two additional steps:

- identification of feasible options to reduce risk and an evaluation of the cost and benefit of each option; and,
- implementation of the preferred risk control options, usually involving ongoing monitoring and re-evaluation.

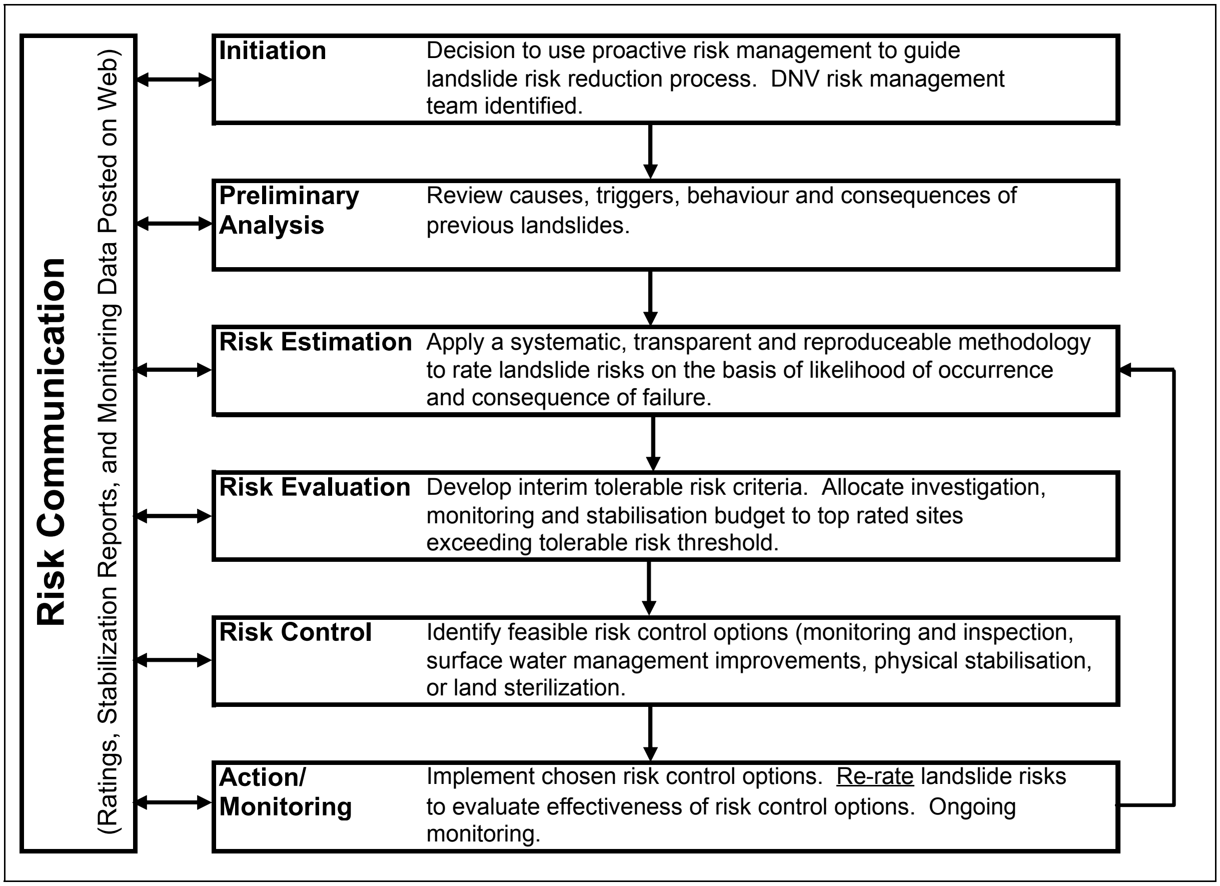
Landslide risk management for the Berkley-Riverside Escarpment is well suited to the use of QRA because:

- many hazards may be present;
- they may have the potential to impact residents both at the top (source area) and base (runout area) of the escarpment. Issues of landslide runout potential are not easily addressed by a factor of safety approach;
- it is both difficult and expensive to remediate all slopes with a factor of safety less than 1.5 or to permanently sterilize all property where the potential for landslides exists; and,
- information necessary to calibrate quantitative risk estimates is readily available.

The DNV and other municipalities are beginning to adopt QRA to manage risks from debris flows and debris floods, thus the methodology is fully compatible with those used by the District to address other landslide hazards. Furthermore, pressures for development of slopes and fans potentially subject to landslides throughout British Columbia are expected to increase over the next few decades, particularly in the Lower Mainland. The concepts and processes developed here may have regional application.

A framework for the landslide risk management program is outlined in Figure 1. This is compatible with Canadian and international guidelines for risk management (CAN/CSA Q850-97). Other jurisdictions, such as Hong Kong and Australia, use a similar framework.

Figure 1. Landslide Risk Management Program for the Berkley-Riverside Escarpment



The remainder of this report documents the landslide risk assessment for the Berkley-Riverside Escarpment. Recommendations for risk control and action/monitoring components of the risk management process will be prepared in light of the risk assessment results and will be documented under separate cover.

3.0 PREVIOUS LANDSLIDES

Since 1972 four storm events have triggered at least six landslides near the crest of the Berkley-Riverside escarpment (Drawing 1). These include the December 1972, December 1979, January 1999, and January 2005 storms. The four-week antecedent rainfall leading up to each landslide, and the amount of rainfall generated by each storm are shown in Table 1.

Table 1. Precipitation Leading to Previous Landslides

Landslide Date	4-Week Antecedent Rainfall	Storm Rainfall Leading to Landslide
December 25, 1972	327 mm	135 mm
December 17, 1979	325 mm	135 mm
January 14, 1999	229 mm	79 mm
January 19, 2005	105 mm	175 mm

Table 2 provides a summary of site observations for each landslide and the consequences of each failure. Data presented in Table 1 were gathered from inspections reported by Klohn Leonoff (Klohn, 1980), and recent BGC airphoto interpretation and field inspection. Additional detail regarding soil and drainage conditions in the immediate vicinity of the headscarp of the January 19, 2005 landslide are reported in BGC (2005b).

Table 2. Summary Data for Previous Landslides

Date of Occurrence	Address Near Initiation Zone	Site Observations	Consequences
December 25, 1972	1425 Lennox	• Originated in fill • 35 to 46° slopes • Fill replaced, settled and cracked during December 1979 storm • Runoff from 3 properties directed towards slope • Pool not cracked but drains down the slope • Approx width at crest = 15 m • Approx runout angle = 23 – 25°	• Damaged sundeck at 1425 Lennox • No houses were present below the slope – no damages or injuries down slope
December 17, 1979	2379 Carman	• Originated in fill • 42° slopes • Seepage evident 20 ft below crest • Fewer conifers than adjacent slopes • Pool drained down the slope • Approx width at crest = 20 m • Approx runout angle = 22 – 24°	• Pool and back yard were lost • 1 house destroyed, another damaged down slope, no injuries
December 17, 1979	2360 Carman	• Originated in fill • 37 to 45° slopes • Young deciduous trees and brambles at crest of slope • Roof and foundation drains extended over bank • Seepage 15 feet below scarp along surface of dense silts • Approx width at crest = 18 m • Approx runout angle = 24 – 26°	• Backyard lost, no other damages • No damages or injuries down slope
December 17, 1979	2205 Berkley	• Originated in fill • 36 to 40° slopes • Driveway runoff directed to storm sewer • Approx width at crest = 25 m • Approx runout angle = 23 – 25°	• Backyard lost, no other damages • No damages or injuries down slope
January 14, 1999	2391 Berkley	• Originated in fill • 40 to 45° slopes • Seepage evident at base of fill • Approx width at crest = 20 m • Approx runout angle = 30° (stopped by right bank of Canyon Creek)	• Portion of back yard lost • No houses were present below the slope – no damages or injuries down slope • Walking trail temporarily closed
January 19, 2005	2175 Berkley	• Appears to have originated in thick fill and colluvium • Adjacent slopes >35° • Runoff from 3 properties and portion of Berkley Road directed towards slope • Fishpond present, not cracked • Approx slide width = 25 m • Approx runout angle = 21 – 23°	• Retaining wall and back yard lost, failed to within 1.1 m of house • 1 house with two occupants destroyed (1 serious injury; 1 fatality) • 1 house seriously damaged (3 of 5 occupants sustained minor injuries)

4.0 FIELD INSPECTIONS

Field inspections were carried out for each property located at the top of the escarpment within the study area. Visual observations made by two teams of two geotechnical engineers and geoscientists focused on gathering:

- slope angles;
- evidence of slope deformation at and immediately below the crest of the escarpment;
- the nature of the tree cover on the escarpment slope;
- presence and condition of retaining walls, pools and ponds;
- distance from each house to the crest of the escarpment;
- sources of surface drainage directed towards the crest of the escarpment; and,
- representative site photographs.

In keeping with best practices, data were recorded on standard field forms to maintain consistency and repeatability. Observations were compared with those made by Klohn (1980) and changed conditions were noted. Additionally, shallow hand auger holes were drilled at the escarpment crest and about 10 m below the crest for preliminary assessment of the thickness of loose fill and colluvial soils. Borehole logs document visual soils classification for each auger hole.

Field inspection forms, photographs, and summary tables are provided in Appendix I. Key site features and approximate auger hole locations are shown on Drawing 1.

It is important to note that the field inspections and subsequent risk calculations were referenced to civic addresses as a matter of convenience and to maximize report clarity. In reality, the locations of landslide initiation zones will not respect property boundaries. This was illustrated by the 1979 landslides that originated near the boundary of 2379 and 2391 Carman Place, and at the boundary of 2205 and 2217 Berkley Avenue.

5.0 LANDSLIDE LIKELIHOOD ESTIMATION

Six rapid flow slides are known to have occurred along the Berkley-Riverside Escarpment since 1972, a period of 33 years. This corresponds to an average failure frequency of 0.18, or about 1 slide every 5.5 years.

Previous flow slides have had a width at the crest of the escarpment ranging from about 15 to 25 m. This is similar to the width of each backyard, which conveniently allows us to subdivide the escarpment into 75 potential landslide source areas, each corresponding to a property along the crest of the escarpment. The average likelihood of a single flow slide initiating from each of the 75 source areas is approximately:

- $P_{slide(avg)} = 0.18 / 75 = 0.0024$ (or, 2.4×10^{-3}).

Because landslides occur infrequently, there is insufficient data to determine if landslide frequency along the escarpment is increasing, decreasing, or steady-state. Frequency might increase if climate patterns change and/or the deterioration of surface water management works result in wetter soil conditions; or, if human activity such as the placement of fill, lawn cuttings, etc. at the crest of the escarpment, or deterioration of retaining structures cause a gradual reduction in the stability of the slopes. Frequency might decrease if there is only a limited number of potential slide locations and, if each time there is a landslide, the remaining number of potential slides decreases. Steady-state conditions might apply if the factors identified above tend to offset each other. For the purpose of this risk assessment, it has been assumed that steady-state conditions will apply for the next several years and that the landslide frequency estimated from historical events is an appropriate approximation.

The likelihoods of landslide initiation from each backyard along the escarpment are not expected to be equal. Three main factors would tend to make a given slope more prone to landslides than others:

- steep slope angles;
- layers of weak or collapsible soils such as loose silty fill and colluvium; and,
- surface and subsurface drainage conditions that promote high groundwater levels, especially during heavy rainfall events.

Slopes prone to landslides often show evidence of past deformation. This might include:

- an abundance of trees leaning down slope;
- tension cracks or small landslide scarps;
- leaning, bulging or cracking retaining walls or other structures placed near the crest of the slope; or,
- settlement of soil along the crest of the slope.

An algorithm was developed to adjust the estimated landslide likelihood up or down from the average for the whole escarpment by as much as a factor of 10 using the field observations gathered for each property. Using this algorithm, sites with steep slopes (including those with retaining structures), abundant fill, and adverse drainage conditions, and that show evidence of past deformation, are assigned a landslide likelihood estimate as high as 2.4×10^{-2} (or 0.024). Sites that appear well-drained, with shallow slopes, limited fill and no evidence of past deformation are assigned a landslide likelihood estimate as low as 2.4×10^{-4} (or 0.00024).

The algorithm takes the form of:

- $P_{slide(site)}$ = [slope score] x [loose soil score] x [water score] x [deformation score] x [$P_{slide(avg)}$]

where slope, loose soil, water, and deformation scores were assigned as shown in Table 3.

Table 3. Landslide Likelihood Algorithm

Slope Score	Loose Soil Score	Water Score	Deformation Score	Max / Min Scores
< 35^{o} = 0. 8 35 – 40^{o} deg. = 1.0 > 40^{o} deg. = 1.25	< 2 m deep at and below crest = 0.5 > 2 m deep at or below crest = 1.0 > 2 m deep at and below crest = 2	Connected to Storm Sewer = 0.5, else: Runoff from backyard = 0.5 Plus half roof = 0.75 Plus full roof = 1.0 Plus driveway = 1.5 Plus street = 2	None Observed = 0.5 Deformation at or below crest = 1.0 Deformation at and below crest = 2	Adjustment range = 0.1 to 10 $P_{slide(avg)}$ = 0.0024

Because there are many attributes that influence the likelihood of landslide occurrence, and because only a few landslides are known to have occurred along the escarpment, there are insufficient data to assign attribute scores based on the results of rigorous statistical analyses. The attributes selected for inclusion in the analysis are ones that could be assessed through field inspection and completion of shallow hand auger drill holes. The attribute scores shown in Table 3 are based on engineering judgement. They have been calibrated to ensure that the calculated annual probability of a flow slide somewhere along the escarpment is in line with historical averages. Currently, the model predicts a landslide frequency of 1 every 5 years somewhere along the escarpment, compared to the observed frequency of 1 every 5.5 years. Thus the model is slightly conservative. As new data are added, these initial estimates might be updated using Bayesian techniques, or by modifying the attribute scores.

Twelve of the 75 landslide source areas were assessed as having failure likelihoods greater than two times the average for the escarpment. These top rated sites for landslide initiation potential, referenced to the nearest civic address, include:

- 1231 Lennox (P_{slide} = 0.006);
- 1491 Lennox (P_{slide} = 0.007);
- 1535 Lennox (P_{slide} = 0.010);
- 1593 Lennox (P_{slide} = 0.019);
- 2402 Swinburne (P_{slide} = 0.006);
- 2175 Berkley (P_{slide} = 0.008);
- 2191 Berkley (P_{slide} = 0.014);
- 2205 Berkley (P_{slide} = 0.005);
- 2217 Berkley (P_{slide} = 0.006);
- 2377 Berkley (P_{slide} = 0.006);
- 2391 Berkley (P_{slide} = 0.006); and,
- 2409 Berkley (P_{slide} = 0.010).

Thirty-eight sites were assessed as having failure likelihoods similar to the average for the escarpment, while another 25 sites were assessed as having failure likelihoods less than half the average for the escarpment.

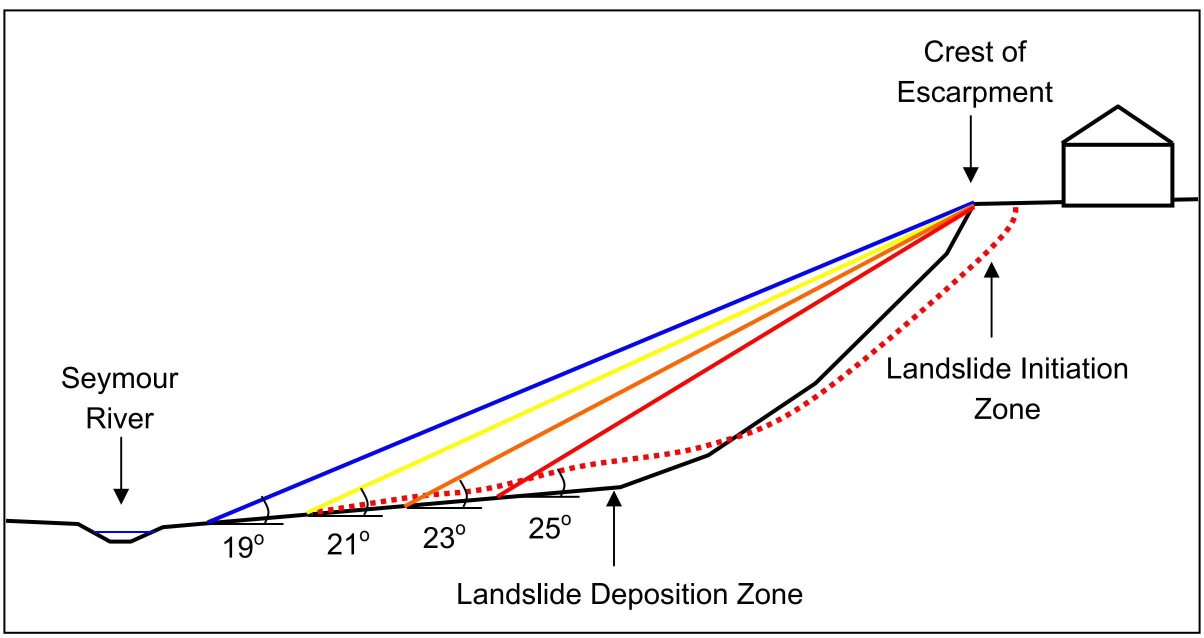
Landslide likelihood estimates are tabulated in Appendix II, and are illustrated in Drawing 2.

6.0 LANDSLIDE RUNOUT ANALYSIS

Historically, landslides along the Berkley-Riverside Escarpment appear to have initiated near the crest of the slope and have run out beyond the base of the slope. Landslide source volumes appear to have been relatively small (less than 1,000 m^3). As the landslides travelled down the escarpment, however, they entrained loose fill and colluvial soils, thereby increasing their width and volume. The maximum width of the destructive impact zone at the base of the escarpment appears to have been less than 50 m.

Detailed surveying of the January 19, 2005 landslide deposit, travel path, and headscarp were carried out shortly after the event, facilitating an evaluation of runout behaviour (BGC 2005b, 2005c, and 2005d). The nature of the landslide deposit and the damage caused by the slide was spatially variable. Observed changes could be related to the angle above the horizontal as measured from the deposit to the slide headscarp, referred to here as the runout angle. Steep runout angles intersect the ground surface close to the base of the escarpment, while shallow runout angles intersect the ground surface further from the base of the slope (Figure 2).

Figure 2. Schematic Illustration of Landslide Runout Angles



At runout angles steeper than 25°, the January 19, 2005 landslide deposit comprised abundant large woody debris and mineral soil, and was typically greater than 2 m deep. Significant structural damage occurred to houses located within the slide path at angles steeper than 25° to the crest of the escarpment. At runout angles between 23° and 25°, the thickness of debris and amount of mineral soil decreased dramatically, as did the structural damage caused by the landslide. At runout angles between 21° and 23°, landslide impacts were limited to flooding and deposition of a thin layer of organic soil.

Other landslide runout angles along the escarpment, as measured in the field and recorded by Klohn (1980) range from about 22^{o} to 30^{o}.

The January 19, 2005 landslide had an observed width of 25 m at the headscarp, although the initial failure width may have been slightly less. As it descended the slope the width of the slide path increased at an angle of about 10^{o}, on average, on either side of the landslide. Other slides along the escarpment have had observed widths at the headscarp of between 15 and 25 m.

Details gathered from the January 19, 2005 landslide were used to calibrate a three-dimensional landslide runout model under development at the University of British Columbia (McDougall and Hungr, 2004). The model showed that landslide runout angles are relatively insensitive to the initial landslide source volume, at least for volumes ranging from about 200 to 1,000 m^3. This corresponds well with observations made for the other landslides along the escarpment: an obvious correlation between landslide volume and runout angle has not been observed. This may be due to the fact that all slides had similar source and ultimate volumes and all achieved flow-like behaviour. The exception is the January 1999 landslide which only travelled a short distance before entering a small creek at the base of the escarpment.

Based on the foregoing, a digital topographic map with 1 m contours, provided by DNV, was used to illustrate potential landslide runout for hypothetical landslides located along the crest of the escarpment. Landslide initiation zones and travel directions from each property were located by visual inspection of the topographic information. Each hypothetical slide had an assumed initial width of 20 m, with path width increasing down the slope at a 10^{o} angle on either side of the landslide until reaching a maximum width of 50 m. Points located at between 19^{o} and 25^{o} from each potential landslide source area were marked on the topographic map. The locations of these points as generated from adjacent hypothetical landslide source areas usually overlapped slightly. Four lines were then drawn across the base of the escarpment to capture the down slope limits of these data points. The results represent conservative estimates of the locations of 19^{o} to 25^{o} runout angles from all landslide source locations along the crest of the escarpment. These lines were overlain on a digital orthophoto, as shown in Drawing 2.

The accuracy of the position of the runout lines is dependent on the accuracy of the topographic data. The topography used, which was extracted from airphotos, indicates the crest of the escarpment is located further west than it actually is at some locations where the crest was hidden in the airphotos by dense tree cover. In these instances, the runout lines have likely been conservatively positioned several metres to the west of their true location along the base of the escarpment.

There are some scenarios where debris from flow slides originating from near the crest of the escarpment could stop at shallower or steeper angles than have been observed historically. The most important factors are considered to be lateral confinement of the slide debris and the presence of obstructions or barriers not captured in the topographic data.

Landslides with flow-like characteristics tend to travel further where they are laterally confined. Slides originating from properties along Layton Drive, between Carman Place and Swinburne Avenue, could enter a broad gully that might provide lateral confinement and promote longer runout distances. To date, none of the landslides has been channelized. At the next phase of study, detailed three-dimensional modelling might be carried out to refine the estimated runout potential for these hypothetical slides subject to lateral confinement.

Obstructions at the base of the escarpment may lead to shorter-than-expected runout distances. These might include houses or dense stands of large trees that reduce landslide flow velocity when impacted. These effects have conservatively been ignored at this phase of study.

Lastly, it is important to reiterate that slides that do not develop flow-like behaviour are unlikely to travel to the shallow runout angles used in this phase of risk assessment. At this time it has been conservatively assumed that all hypothetical landslides originating from near the crest of the escarpment will behave as flow slides.

7.0 CONSEQUENCE ESTIMATION

Landslide consequences include, but are not limited to:

- injury or fatality;
- damage to property or infrastructure;
- loss of property value; and
- litigation.

This risk assessment addresses the potential for loss of life to house occupants as a result of landslides initiating from the top of the escarpment. This singular consequence focus was decided upon through consultation with DNV and in an effort to make the safety of the community the underpinning of the study.

For a landslide to cause fatalities to house occupants, several things must coincide in time and space:

- elements (people, private property) must be present that could be impacted by a landslide. Each element has a value (E). For loss of life, 'E' represents the number of lives potentially at risk;
- the physical effects of the landslide must reach the elements at risk, referred to as the spatial probability of impact, given the hazard occurs ($P_{S:H}$). For each element at risk, this is expressed as a number between 0 (certain not to reach the element) and 1 (certain to reach the element);
- the elements at risk must be present in the zone of impact at the time that the landslide occurs, referred to as the temporal probability of impact ($P_{T:S}$). This is expressed as a number between 0 and 1;
- the load or deformation imposed on the elements at risk must be sufficient to cause damage or loss of life, referred to as the vulnerability. Vulnerability is also expressed as a number between 0 and 1. This can be thought of as the estimated proportion of loss or damage to a specific element.

For each hypothetical landslide, consequence (measured in terms of the statistical number of expected fatalities) is estimated as follows:

$N = P_{S:H} \times P_{T:S} \times V \times E$.

Expanded descriptions of these terms are provided in BC MOF (2004). The procedures and assumptions used to estimate the potential for loss of life, both at the base and crest of the escarpment, are provided in the sections that follow. Consequence estimates for landslides originating from each hypothetical source area are tabulated in Appendix III.

7.1 Consequences at Base of Escarpment

Spatial Probability of Impact

The angle between houses located at the base of the escarpment and the initiation zone of potential landslides was used to obtain systematic estimates of spatial probability of impact. In the January 19, 2005 landslide, one house was located at a runout angle of >25°, two were located at between 23° and 25°, none was located between 21 and 23°, and one was located between 19° and 21°. The house located at >25° was completely destroyed. One of the two houses located between 23° and 25° was partially damaged. Organic soil, water, and small woody debris travelled as far as 21°, but because no houses were present in this zone no damage occurred. The house located at between 19° and 21° from the landslide initiation zone was not impacted.

An assessment of damage to houses at the base of the escarpment from the 1972 and 1979 landslides, in addition to the January 2005 landslide, indicates a total of two of five houses situated at an angle >25° from the crest of the escarpment were completely destroyed. This corresponds to a ratio of 2:5 (or 0.40). Two of seven houses situated between 23° and 25° from the escarpment crest were partially damaged. Assuming each was 50% damaged, this corresponds to a ratio of 1:7 (or 0.14).

Based on these observations, and on engineering judgement, values have been assigned to the spatial probability of impact leading to structural damage as shown in Table 4. Houses located in potential impact zones beneath each hypothetical landslide source area were identified by visual inspection using Drawing 3.

Table 4. Spatial Probability of Impact for Houses at Base of Escarpment

Angle from House to Landslide Initiation Zone	Spatial Probability of Impact Leading to Damage $P_{S:H}$
> 25°	0.40
23° to 25°	0.14
21° to 23°	0.014
19° to 21°	0.0014
< 19°	Not evaluated

Temporal Probability of Impact

In assessing the potential for loss of life, it was assumed that house occupants are present 12 hrs per day, on average, during the rainy season when landslides are most likely to occur. This represents a temporal probability of impact of 12hrs/24hrs = 0.50. Note that this assumes an effective monitoring program and evacuation protocols are not in place. The estimated effect of such a program on the temporal probability of impact will be documented in an evaluation of potential risk control options to follow under separate cover.

An assessment of the temporal probability of impact for individuals most at risk was also made. It was assumed that the individuals most at risk spend 16 hrs per day, on average, in their homes, corresponding to a temporal probability of impact of 0.67. These estimates could be validated through resident interviews and, if modifications are required, they could be incorporated in the second phase of risk assessment.

Vulnerability

The January 19, 2005 landslide was the only event to cause structural damage to houses at the base of the escarpment at a time when they were occupied. Two people were present in the house that was completely destroyed. One of them was killed, while the other sustained very serious injuries and was in the hospital under intensive care for several months. It is reported that the injured person would have likely also perished had it not been for the quick intervention of his neighbours (North Shore News, 2005a).

Five people were present in the second house that was impacted. Three of them were sleeping in the area that sustained structural damage. They received minor cuts and bruises as a result (North Shore News, 2005b). The two people occupying the undamaged portion of the house were uninjured.

Based strictly on these observations, the vulnerability of occupants of houses struck by landslides of the type that occurred on January 19, 2005, is approximately 1 in 7, or a value of 0.14. A more conservative approach, however, is to acknowledge that the slide nearly resulted in two fatalities amongst the seven people occupying homes that sustained damage. This leads to a vulnerability of 0.29, and is the value that was adopted for this risk assessment.

Element Value

Lives have not been assigned a monetary value. Only the estimated number of lives lost (N) in a given hypothetical landslide has been reported. It has been assumed that four people occupy each home, on average. This assumption has been applied uniformly across the base of the escarpment. Variations in house occupancy have not been considered at this phase of study, but could be incorporated in the next phase of risk assessment, if desired.

Results

The top rated landslide initiation sites in terms of the statistical number of estimated fatalities (N) at the base of the escarpment, should a landslide occur, include:

- 1863 Layton (N = 1.0);
- Hayseed/Layton Gully (N = 1.0);
- 2448 Hayseed (N = 1.0);
- 2454 Hayseed (N = 1.3); and,

- 2462 Hayseed (N = 1.0).

At least one fatality is expected if a landslide were to initiate from any of these source areas.

7.2 Consequences at Crest of Escarpment

With the exception of the house at 2175 Berkley, houses at the crest of the escarpment are believed to be founded on native soils. Consequently, the potential for slope failure leading to house foundation collapse and subsequent loss of life to house occupants has not been evaluated as part of this study. This is not to say that the potential for structural damage to houses at the top of the escarpment is negligible, only that the potential for loss of life is very low. Consequence estimation has focused on the potential for landslides to impact persons occupying the backyards (including pools and decks) leading to loss of life. In general, consequences at the crest of the escarpment are expected to be much lower than they are at the base of the slope.

Spatial Probability of Impact

Backyard length, or distance from houses to the crest of the escarpment, varies from house to house. Two assumptions have been made to estimate the spatial probability of impact to people occupying backyards when a slide occurs:

- backyards are occupied for equal amounts of time, regardless of yard size; and,
- on average, a 3 m wide strip of ground extending the full width of each backyard will fail rapidly in the event of a landslide.

Distance from the crest of the escarpment to each house was measured during the field inspections, and reported to the nearest 3 m increment. The spatial probability of impact for people occupying backyards at the time of a landslide is estimated as the ratio of the amount of ground lost to the distance from the escarpment crest to the house, as shown in Table 5.

Table 5. Spatial Probability of Impact to Occupants of Backyards at Escarpment Crest

Distance from House to Crest of Escarpment	Spatial Probability of Impact $P_{S:H}$
< 3m	0.99
3 – 6 m	0.67
6 – 9 m	0.40
9 – 12m	0.29
> 12 m	0.20

Temporal Probability of Impact

In assessing the potential for loss of life, it was estimated that each house occupant spends 15 minutes per day, on average, in their backyard on rainy days during the winter when landslides are most likely to occur. This represents a temporal probability of impact of 0.25hrs/24hrs = 0.01.

An assessment of the temporal probability of impact for individuals most at risk was also made. It was assumed that the individuals most at risk spend 0.5 hrs per day, on average, in their backyards, corresponding to a temporal probability of impact of 0.02. These estimates could be validated through resident interviews and, if modifications are required, they could be incorporated in the second phase of risk assessment.

Vulnerability

Historical data from the study area are not available to calibrate vulnerability estimates for people caught in a landslide while in their back yards at the top of the escarpment. For the purpose of this phase of study, a value of 0.5 has been assumed. This implies there is an estimated 50% chance of escaping from the slide headscarp area as the landslide starts to move.

Element Value

As for the base of the escarpment, lives have not been assigned a monetary value. Only the estimated number of lives lost (N) in a given hypothetical landslide has been reported. It has been assumed that four people occupy each home, on average.

Results

The top rated sites in terms of the estimated number of fatalities (N) at the crest of the escarpment, should a landslide occur, include:

- 1275 Lennox (N = 0.02);
- 1583 Lennox (N = 0.02);
- 1593 Lennox (N = 0.02);
- 2402 Swinburne (N = 0.02);
- 2414 Swinburne (N = 0.02);
- 2379 Carman Place (N = 0.02);
- 2468 Hayseed (N = 0.02);
- 2474 Hayseed (N = 0.02); and
- 2175 Berkley (N = 0.02).

A value of 0.02 implies there is about a 1 in 50 chance of a fatality to occupants at the crest of the escarpment, should a landslide initiate from one of these hypothetical source areas.

8.0 RISK ESTIMATES

8.1 Individual Versus Societal Risk

Individual and societal risks are two ways of evaluating the potential for loss of life. Individual risk to life is the increment of risk imposed on a particular individual by the existence of the landslide hazard. This increment of risk is in addition to the background risk to life, which the person would live with on a daily basis if the hazard did not exist. Individual risk is usually expressed as the annual probability of the individual being killed as a result of the hazard (Leroi et al. 2005). Often these probabilities are reported for the individual deemed to be most at risk. In the case of the Berkley landslide risk assessment, the individuals deemed to be most at risk are the ones in each household who spend the most time in their homes (at the base of the escarpment) or in their backyards (at the crest of the escarpment).

Individual risk estimates do not provide an indication of the total number of expected fatalities should a hazard occur. The total number of expected fatalities is illustrated by societal risk estimates, which are based on a consideration of the whole population exposed to each potential hazard. In the case of the Berkley landslide risk assessment, the population exposed includes the occupants of the house at the crest of the escarpment nearest to each hypothetical landslide source, as well as the occupants of all houses at the base of the escarpment located within the hypothetical slide path.

Evaluation of risk acceptability is carried out differently for individual and societal risk estimates as described in Section 9.

8.2 Estimates of Individual Risk for Individuals Most at Risk

The individual risk was estimated for individuals most at risk at each property located at the base and crest of the escarpment. At the crest of the escarpment, it was assumed that the individual most at risk spends 0.5 hrs per day, on average, in their backyard on rainy days during the winter months when slides are most likely to occur. At the base of the escarpment, it was assumed that the individual most at risk spends 16 hours per day in their home on rainy days during the winter months.

Estimates of individual risk tabulated in Appendix IV. Properties where estimated individual risks exceed 10^{-5} (0.00001, or 1 chance in 100,000) per year are highlighted on Drawing 3.

8.3 Estimates of Societal Risk

The societal risk of loss of life was estimated for each hypothetical landslide source along the crest of the escarpment. Risk is presented in terms of the frequency of events (F) resulting in an expected number of fatalities (N). The resulting F-N pairs are amenable to plotting on F-N graphs, which can be used to evaluate if the risks are acceptable (Section 9).

For each hypothetical landslide, the expected number of fatalities (N) was calculated by summing the estimated number of lives lost at the base and crest of the escarpment, should the slide occur. Where this sum was greater than 1, the estimated landslide frequency was used to represent the expected event frequency (F).

F-N graphs are typically used to illustrate events leading to 1 or more fatalities. In most cases, the statistical number of fatalities expected from hypothetical landslides along the Berkley-Riverside Escarpment is less than 1. In these instances, the frequency of events leading to a loss of life was adjusted by multiplying the estimated landslide frequency by the estimated number of lives lost. The expected number of fatalities was then set to 1.0. By doing so, the frequency (F) was reduced and the number of fatalities (N) was increased in equal proportions.

Societal risk estimates for each hypothetical landslide source are illustrated on Drawing 3 and tabulated in Appendix IV.

The total expected number of lives lost per year and the average time interval between events leading to loss of life were determined for occupants at the crest of the escarpment, the base of the escarpment, and all occupants. The results suggest a return period of events leading to loss of a statistical life at the crest of the escarpment is about 1 every 460 years, while the results for the base of the escarpment suggest loss of a statistical life will occur every 15.5 years, on average. When societal risk estimates for the base and crest of the escarpment are combined, a fatality is predicted to occur once every 15 years, on average.

Based on historical data, one life has been lost in 33 years, although two lives were nearly lost, which would yield a return period of about 1 fatality every 16.5 years. This was the general target established for calibrating the risk model. The calculated results therefore appear slightly conservative, but match the historical record used to calibrate model with sufficient accuracy to validate the methodology and results. Consequently, they can provide a useful and defensible guide for evaluating and prioritising future mitigation efforts.

9.0 RISK EVALUATION

Tolerable risks are risks within a range that society can live with so as to secure certain net benefits. It is a range of risk regarded as non-negligible and needing to be kept under review and reduced further if practicable (Leroi et al. 2005). Where houses are built on or near slopes, such as along the Berkley-Riverside Escarpment, the residual risks from landslides cannot be eliminated. Instead, they can be compared with criteria that have been established with the purpose of evaluating if the risks are tolerable. Where they are not, risk control measures can be designed and implemented to reduce risk to tolerable levels.

The evaluation criteria for individual and societal risk are different, but some common general principles can be applied (Leroi et al. 2005):

- the incremental risk from a hazard to an individual should not be significant compared to other risks to which a person is exposed in everyday life;
- the incremental risk from a hazard should be reduced wherever reasonably practicable, ie. the As Low As Reasonably Practicable (ALARP) principle should apply;
- if the possible number of lives lost from a landslide incident is high, the likelihood that the incident might actually occur should be low. This accounts for society's particular intolerance to many simultaneous casualties, and is embodied in societal tolerable risk criteria;
- higher risks are likely to be tolerated for existing slopes than for planned projects; and,
- tolerable risks may vary from country to country, and within countries, depending on historic exposure to landslide hazard, and the system of ownership and control of slopes and natural landslide hazards.

9.1 Individual Risk

Quantitative tolerable risk or risk acceptance criteria for landslides have not been defined for British Columbia or DNV. The Australian Geomechanics Society guidelines for landslide risk management suggest a tolerable limit of 10^{-4} per annum for individuals most at risk on existing slopes or developments and a limit of 10^{-5} per annum for new developments. The Hong Kong Special Administrative Regional Government has adopted, on an interim basis, the same tolerable limits for landslides from natural slopes (Leroi et al. 2005). Some discussion is required to put these numbers into perspective.

First, what does 10^{-4} mean? An annual probability of 10^{-4} (or 0.0001) implies that individuals most at risk have a 1 in 10,000 chance of fatality for each year they are exposed to the hazard. This increment of risk is generally less than other risks individuals are exposed to in everyday life. For example, the probability of death per annum for a 20 year old Australian male is about 10^{-3} and increases with age. This corresponds to a 1 in 1,000 chance per year of fatality which is about 10 times greater than the tolerable limit adopted by other jurisdictions (Leroi et al. 2005). In 1997 the Canadian population as a whole faced a mortality rate of 7×10^{-3} (a 1 in 143 chance per year), which is about 70 times greater than the tolerable limit (Statistics Canada, 2005). A Canadian's annual risk of death from motor vehicle accidents in the same year was 10^{-4}, which coincidentally is identical to the tolerable limit.

In the absence of risk tolerance criteria defined for British Columbia or DNV, BGC has identified properties at the crest and base of the Berkley-Riverside Escarpment where the estimated risk of loss of life from landslides exceeds the Australian and Hong Kong limits of 10^{-4} per annum for individuals most at risk. This is provided herein as a starting point for community discussion. Only one property exceeds the criteria at the crest of the escarpment (1593 Lennox); the remainder are situated at the base of the escarpment. These properties are shaded red in Drawing 3, and are listed below in Table 6. Calculations are provided in Appendix IV. It is left to DNV and the affected community to determine if 10^{-4} is an appropriate tolerable risk threshold for individuals most at risk on existing slopes or developments such as the Berkley-Riverside Escarpment.

Table 6. Properties with Individual Risk Estimates Exceeding 10^{-4} per annum

Lennox: • 1593 Treetop: • 2336 • 2318 Chapman: • 2440 • 2430 • 2290 • 2274 • 2256 • 2230 • 2222 • 2206 • 2192 • 2180 • 2158 • 2148	Rivergrove: • 2067 • 2086 • 2078 • 2064 • 2050 • 2038 • 2026 • 1978 • 1950 • 1946 • 1940 • 1928 • 1916 Riverbank: • 2352	Riverside (north): • 1892 • 1884 • 1880 • 1838 • 1818 • 1810 • 1802 • 1788 • 1780 • 1758 • 1748 • 1730 • 1718 Swinburne: • 2311 • 2315 • 2320 • 2326	Riverside (south): • 1554 • 1530 • 1502 • 1488 • 1408 • 1320

9.2 Societal Risk

Societal risk is often presented on F-N graphs showing the frequency of events leading to loss of life (F) and the expected number of lives lost (N). An example plot showing the risk estimates for landslide source areas along the Berkley-Riverside escarpment is provided in Figure 3.

The risk evaluation criteria shown in Figure 3 were developed by the Geotechnical Engineering Office of Hong Kong (Fell, et al., 2005) and are gaining acceptance in Australia, the United Kingdom, and North America. Figure 3 is subdivided into 4 zones:

- Unacceptable – where risks are generally considered unacceptable by society and require mitigation;
- ALARP – where the incremental risks from a hazard should, wherever reasonably practicable, be reduced;
- Broadly Acceptable – where incremental risks from a hazard are within the range that society can generally tolerate; and,
- Intense Scrutiny Region – where a low potential for large loss of life exists that requires careful consideration.

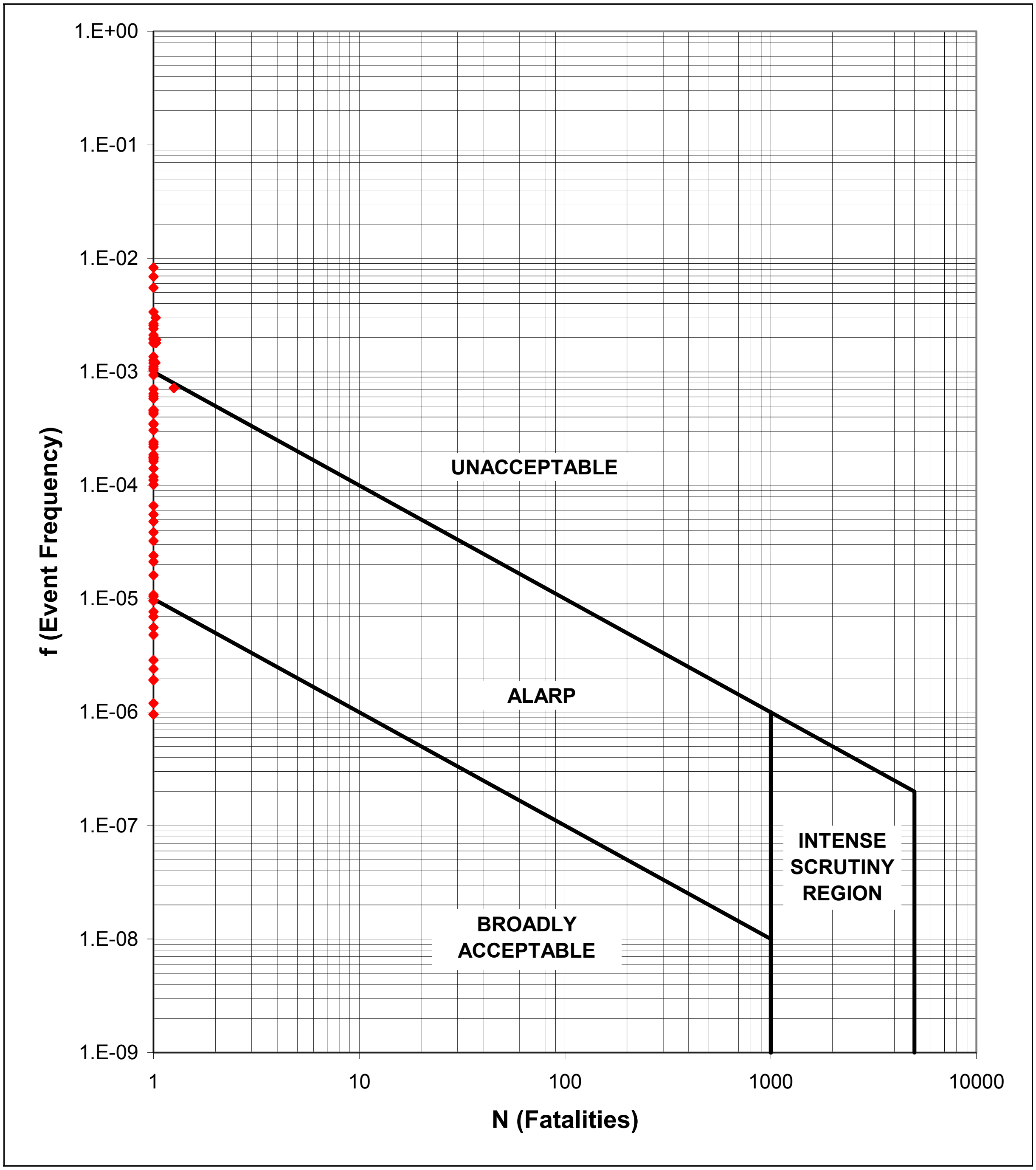
As shown in Figure 3, as well as on Drawing 3 and in Appendix IV, societal risk estimates for 16 hypothetical landslide source areas fall in the Broadly Acceptable zone, 37 source areas fall in the ALARP zone, and 22 source areas fall in the Unacceptable zone.

The civic addresses nearest to the hypothetical landslide source areas with societal risk estimates plotting in the Unacceptable zone on Figure 3 include:

- 1491 Lennox
- 1535 Lennox
- 1557 Lennox
- 1583 Lennox
- 1593 Lennox
- 2402 Swinburne
- 2319 Carman Place
- 2379 Carman Place
- 2360 Carman Place (2 source areas)
- 2372 Carman Place
- 1863 Layton
- Hayseed/Layton Gully (located on District property)
- 2448 Hayseed
- 2462 Hayseed
- 2125 Berkley

- 2141 Berkley
- 2157 Berkley
- 2175 Berkley
- 2191 Berkley
- 2205 Berkley
- 2217 Berkley

Figure 3. Societal Risk Estimates for Hypothetical Flow Slides Originating near the Escarpment Crest



10.0 DISCUSSION

Based on Hong Kong and Australian criteria, preliminary risk estimation and evaluation has identified 22 potential landslide source areas presenting unacceptable levels of societal risk and an additional 37 source areas where efforts should be undertaken to reduce risks to as low as reasonably practicable. It has also identified 52 properties where the estimated risk to individuals most at risk exceeds 10^{-4} per annum.

The preliminary risk estimates do not account for the positive effects of improving storm water management, which are underway. Nor do they account for the monitoring and early warning system that has been implemented by DNV.

The monitoring system involves full-time monitoring of storm and antecedent rainfall, rainfall forecasts, and groundwater levels in the vicinity of the January 2005 landslide. These enable a prediction of when conditions will be reached that have triggered landslides along the escarpment in the past. This information could be used by DNV to evacuate affected residents during periods of heavy rainfall before conditions that have triggered past slides are exceeded, reducing the residents' temporal probability of impact and risk of fatality. An evaluation of the costs and benefits of long-term operation of the warning system is required, and will be carried out in the next phase of investigation and risk assessment.

Additionally, the preliminary risk estimates do not account for recent property acquisitions at the top and bottom of the escarpment in the vicinity of the January 19, 2005 landslide. The following eight properties have been acquired by DNV:

- 2157 Berkley
- 2175 Berkley
- 2191 Berkley
- 2205 Berkley

- 2274 Chapman Way
- 2290 Chapman Way
- 2440 Chapman Way
- 2318 Treetop Lane

In the short-term, abandonment of the eight homes will move three landslide source areas (2175, 2191, and 2205 Berkley) currently rated as Unacceptable into the Broadly Acceptable category. The resulting risk reduction will be documented in the second phase of study.

The measures outlined above have reduced landslide risks along the escarpment, although the level of risk reduction remains to be quantified. None the less, additional efforts will be required to reduce the risks from hypothetical landslide source areas that continue to present unacceptable or ALARP risk levels according to the acceptability criteria adopted by the community. Other options for managing risk, to be assessed in the next phase of study, are briefly outlined below.

Options to Reduce Uncertainty

Areas to focus on include:

- preliminary runout analyses and associated estimates of spatial probability of house impact (which are believed to be conservative at some locations as a result of the topographic dataset used);
- resident surveys to verify temporal probability of impact estimates and estimates of the average number of residents per home;
- cone penetration testing and installation of additional piezometers to verify soil and groundwater conditions at several of the high-ranking sites, and to measure benefits of storm sewer connections currently underway;
- improving our understanding of groundwater response to antecedent rainfall and intense precipitation; and,
- improved criteria to distinguish between sites prone to debris slides versus sites where slope movements may transform into flow slides, since the former are expected to have shorter runout distances.

Inspection and Stabilization Options

Other options to be evaluated include: regular slope inspections to identify worsening conditions before they result in a landslide; removal of marginally stable retaining walls and fills; recompaction of loose soils to reduce the potential for and mobility of future landslides; installation of soil nails to reinforce slopes; and, surface and sub-surface drainage improvements. In each case, concepts will be developed and conceptual costs estimated. Ways that each option might reduce landslide risk will be identified and defensible techniques to systematically quantify associated risk reduction will be applied. This will facilitate risk cost-benefit analysis and selection of optimal risk reduction techniques.

11.0 CLOSURE

This report presents the results of a Phase 1 landslide risk assessment for the Berkley-Riverside Escarpment. The results have been calibrated to match the historical record of landslide incidents and will provide a defensible framework for the prioritization, design and evaluation of risk control measures, and for ongoing monitoring of risk levels. These activities have already been initiated.

Please do not hesitate to contact us if you have any questions or comments, or if we may be of further assistance.

Sincerely,

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APPENDIX I – FIELD INSPECTIONS

DNV - Berkley Landslide Risk Assessment
Summary of Field Inspection Observations

Address	Loose Materials at Fence	Loose Materials Down Slope	Slope Angle	Slope Deformation	% Conifers	Tree Condition	Retaining Wall	Wall Type	Wall Deformation	Backyard Deformation	Dist. To Crest	Runoff From	Pool?	Pool Condition	Seepage	Conn. Storm Sewer
2477 Berton	1-2m	1-2m	30-35 deg.	Erosion	50-75%	Leaning	No	NA	NA	None	>12m	Backyard	No	NA	No	Unknown
2475 Berton	<1m	1-2m	35-40 deg.	Erosion	25-50%	Leaning	No	NA	NA	None	>12m	Backyard	No	NA	No	Unknown
2469 Berton	1-2m	1-2m	25-30 deg.	None	50-75%	Straight	No	NA	NA	None	>12m	Backyard	No	NA	No	Unknown
2465 Berton	<1m	<1m	25-30 deg.	None	>75%	Leaning	No	NA	NA	None	>12m	Backyard	Yes	Undeformed	No	Unknown
2461 Berton	<1m	1-2m	30-35 deg.	Erosion	>75%	Leaning	No	NA	NA	None	>12m	Backyard	No	NA	No	Unknown
2441 Mowat	<1m	1-2m	30-35 deg.	None	>75%	Straight	No	NA	NA	None	>12m	Backyard	No	NA	No	Unknown
2437 Mowat	1-2m	1-2m	30-35 deg.	Erosion	>75%	Leaning	Yes	Timbers	None	None	>12m	Backyard	No	NA	No	Unknown
2433 Mowat	1-2m	1-2m	35-40 deg.	Erosion	50-75%	Straight	No	NA	NA	None	>12m	Backyard	Yes	Undeformed	No	Unknown
2429 Mowat	1-2m	1-2m	30-35 deg.	Erosion	>75%	Leaning	No	NA	NA	None	>12m	Half Roof	Yes	Undeformed	No	Unknown
2425 Mowat	<1m	1-2m	35-40 deg.	Slides	25-50%	Leaning	Yes	Timbers	None	None	>12m	Street	No	NA	No	Unknown
1231 Lennox	2-3m	1-2m	30-35 deg.	Slides	>75%	Straight	Yes	Other	Bulging	None	3-6m	Frontyard	No	NA	No	No
1275 Lennox	1-2m	<1m	>40 deg.	Slides	<25%	Straight	No	NA	NA	None	<3m	Full Roof	Yes	Undeformed	No	Unknown
1279 Lennox	1-2m	<1m	>40 deg.	Slides	>75%	Straight	Yes	Timbers	Bulging	None	3-6m	Full Roof	No	NA	No	Yes
1305 Lennox	2-3m	2-3m	35-40 deg.	Erosion	50-75%	Straight	Yes	Other	Bulging	None	9-12m	Full Roof	Yes	Undeformed	No	No
1345 Lennox	1-2m	2-3m	35-40 deg.	Slides	25-50%	Pistol Butt	Yes	Timbers	None	None	9-12m	Full Roof	No	NA	No	No
1383 Lennox	1-2m	2-3m	35-40 deg.	Erosion	50-75%	Straight	Yes	Blocks	None	Settled	3-6m	Full Roof	Yes	Undeformed	No	Unknown
1425 Lennox	1-2m	1-2m	>40 deg.	Slides	50-75%	Straight	Yes	Timbers	None	Settled	6-9m	Frontyard	Yes	Undeformed	No	Yes
1477 Lennox	2-3m	1-2m	30-35 deg.	Erosion	25-50%	Straight	Yes	Timbers	None	None	6-9m	Backyard	No	NA	No	No
1479 Lennox	2-3m	1-2m	35-40 deg.	Erosion	25-50%	Straight	Yes	Timbers	None	Settled	6-9m	Backyard	No	NA	No	Yes
1491 Lennox	2-3m	1-2m	35-40 deg.	Erosion	25-50%	Leaning	Yes	Concrete	Cracked	None	3-6m	Frontyard	No	NA	No	Unknown
1535 Lennox	2-3m	1-2m	35-40 deg.	None	25-50%	Leaning	Yes	Timbers	Bulging	Settled	3-6m	Street	No	NA	No	No
1557 Lennox	>3m	1-2m	35-40 deg.	Erosion	<25%	Straight	Yes	Timbers	Cracked	Settled	3-6m	Frontyard	Yes	Undeformed	No	No
1583 Lennox	2-3m	1-2m	35-40 deg.	None	<25%	Straight	Yes	Other	Cracked	None	<3m	Full Roof	No	NA	No	No
1593 Lennox	>3m	2-3m	35-40 deg.	Erosion	>75%	Leaning	Yes	Timbers	Bulging	Settled	<3m	Street	No	NA	Yes	No
2402 Swinburne	2-3m	1-2m	>40 deg.	Erosion	>75%	Pistol Butt	Yes	Timbers	Bulging	Cracked	<3m	Full Roof	No	NA	No	No
2410 Swinburne	1-2m	<1m	30-35 deg.	Erosion	>75%	Leaning	No	NA	NA	None	6-9m	Backyard	No	NA	No	No
2414 Swinburne	1-2m	1-2m	35-40 deg.	Cracks	50-75%	Leaning	Yes	Other	None	None	<3m	Half Roof	No	NA	No	No
1677 Layton	1-2m	<1m	35-40 deg.	Slides	>75%	Leaning	No	NA	NA	None	>12m	Full Roof	No	NA	No	Yes
1691 Layton	1-2m	2-3m	35-40 deg.	Cracks	50-75%	Leaning	No	NA	NA	Cracked	>12m	Full Roof	No	NA	No	Yes
1709 Layton	2-3m	2-3m	35-40 deg.	None	50-75%	Leaning	No	NA	NA	None	>12m	Full Roof	Yes	Undeformed	No	Yes
1731 Layton	2-3m	2-3m	35-40 deg.	None	50-75%	Straight	No	NA	NA	Settled	>12m	Full Roof	Yes	Undeformed	No	Yes
1753 Layton	1-2m	1-2m	30-35 deg.	None	50-75%	Leaning	Yes	Other	Settled	Settled	>12m	Full Roof	Yes	Undeformed	No	Yes
1775 Layton	>3m	2-3m	35-40 deg.	None	>75%	Straight	Yes	Timbers	None	None	6-9m	Frontyard	Yes	Undeformed	No	Unknown
1797 Layton	1-2m	1-2m	>40 deg.	None	50-75%	Straight	No	NA	NA	None	6-9m	Full Roof	No	NA	No	Unknown
1815 Layton	1-2m	2-3m	30-35 deg.	None	>75%	Straight	Yes	Concrete	None	Settled	6-9m	Backyard	No	NA	No	Unknown
2391 Carman	>3m	1-2m	35-40 deg.	Erosion	50-75%	Straight	Yes	Other	Bulging	Settled	6-9m	Frontyard	Yes	Undeformed	No	No
2379 Carman	2-3m	1-2m	>40 deg.	Slides	50-75%	Straight	No	NA	NA	None	<3m	Frontyard	Yes	Undeformed	No	No
2360 Carman S.	1-2m	1-2m	35-40 deg.	Slides	50-75%	Straight	No	NA	NA	Settled	3-6m	Frontyard	No	NA	No	No
2360 Carman N.	1-2m	1-2m	35-40 deg.	Slides	50-75%	Straight	No	NA	NA	Settled	3-6m	Frontyard	No	NA	No	No
2372 Carman	1-2m	1-2m	30-35 deg.	None	>75%	Leaning	No	NA	NA	Settled	9-12m	Full Roof	No	NA	No	Unknown
2386 Carman	1-2m	1-2m	30-35 deg.	None	50-75%	Straight	No	NA	NA	None	>12m	Half Roof	No	NA	No	Yes
1839 Layton	1-2m	1-2m	30-35 deg.	None	>75%	Straight	No	NA	NA	None	>12m	Full Roof	No	NA	No	Yes
1847 Layton	1-2m	1-2m	30-35 deg.	None	>75%	Straight	No	NA	NA	Settled	>12m	Street	No	NA	No	Yes
1855 Layton	<1m	1-2m	35-40 deg.	None	>75%	Straight	No	NA	NA	None	>12m	Street	No	NA	No	Yes
1863 Layton	1-2m	1-2m	35-40 deg.	None	>75%	Pistol Butt	No	NA	NA	Settled	>12m	Full Roof	Yes	Undeformed	No	Yes
Hayseed/Layton Gully	2-3m	2-3m	30-35 deg.	Erosion	>75%	Leaning	No	NA	NA	None	>12m	Backyard	No	NA	No	No
2448 Hayseed	1-2m	2-3m	35-40 deg.	Erosion	>75%	Pistol Butt	Yes	Timbers	None	None	6-9m	Half Roof	Yes	Undeformed	No	No
2454 Hayseed	2-3m	1-2m	30-35 deg.	Erosion	>75%	Straight	Yes	Timbers	None	None	9-12m	Half Roof	No	NA	No	No
2462 Hayseed	1-2m	1-2m	>40 deg.	Erosion	25-50%	Leaning	Yes	Other	Bulging	Settled	9-12m	Full Roof	No	NA	No	No
2468 Hayseed	1-2m	1-2m	35-40 deg.	None	50-75%	Straight	No	NA	NA	None	<3m	Full Roof	Yes	Undeformed	No	No
2474 Hayseed	1-2m	<1m	30-35 deg.	Erosion	>75%	Straight	Yes	Concrete	None	None	<3m	Full Roof	No	NA	Yes	Yes
2480 Hayseed	1-2m	<1m	30-35 deg.	Erosion	>75%	Leaning	Yes	Timbers	Bulging	Settled	3-6m	Full Roof	No	NA	No	No
2486 Hayseed	1-2m	1-2m	35-40 deg.	Erosion	>75%	Straight	Yes	Timbers	Settled	Settled	6-9m	Half Roof	No	NA	No	No
2125 Berkley	1-2m	1-2m	30-35 deg.	None	25-50%	Straight	Yes	Other	None	Settled	>12m	Street	No	NA	No	No

DNV - Berkley Landslide Risk Assessment
Summary of Field Inspection Observations

Address	Loose Materials at Fence	Loose Materials Down Slope	Slope Angle	Slope Deformation	% Conifers	Tree Condition	Retaining Wall	Wall Type	Wall Deformation	Backyard Deformation	Dist. To Crest	Runoff From	Pool?	Pool Condition	Seepage	Conn. Storm Sewer
2141 Berkley	2-3m	2-3m	30-35 deg.	None	>75%	Straight	Yes	Timbers	None	None	3-6m	Half Roof	No	NA	No	No
2157 Berkley	2-3m	1-2m	30-35 deg.	Slides	>75%	Straight	Yes	Blocks	None	None	>12m	Full Roof	No	NA	No	No
2175 Berkley	2-3m	<1m	30-35 deg.	Slides	<25%	Straight	No	NA	NA	Slides	<3m	Street	Yes	Undeformed	No	No
2191 Berkley	2-3m	2-3m	35-40 deg.	Slides	25-50%	Leaning	Yes	Concrete	Settled	Cracked	3-6m	Frontyard	No	NA	No	No
2205 Berkley	2-3m	2-3m	35-40 deg.	Slides	25-50%	Pistol Butt	No	NA	NA	None	9-12m	Full Roof	No	NA	No	No
2217 Berkley	>3m	2-3m	>40 deg.	Slides	<25%	Leaning	No	NA	NA	None	9-12m	Full Roof	No	NA	Yes	No
2223 Berkley	2-3m	1-2m	30-35 deg.	Erosion	50-75%	Straight	No	NA	NA	Settled	9-12m	Full Roof	No	NA	Yes	No
2249 Berkley	2-3m	2-3m	35-40 deg.	None	25-50%	Straight	No	NA	NA	Settled	>12m	Full Roof	No	NA	Yes	No
2251 Berkley	2-3m	1-2m	30-35 deg.	Erosion	>75%	Straight	No	NA	NA	None	>12m	Street	No	NA	Yes	No
2265 Berkley	1-2m	1-2m	35-40 deg.	None	50-75%	Pistol Butt	Yes	Concrete	Cracked	Cracked	6-9m	Full Roof	No	NA	Yes	No
2279 Berkley	1-2m	1-2m	30-35 deg.	Erosion	25-50%	Leaning	Yes	Timbers	None	None	9-12m	Full Roof	No	NA	Yes	No
2293 Berkley	2-3m	1-2m	35-40 deg.	Slides	25-50%	Leaning	Yes	Timbers	None	None	>12m	Full Roof	Yes	Undeformed	No	No
2307 Berkley	2-3m	1-2m	35-40 deg.	None	<25%	Straight	Yes	Timbers	None	None	9-12m	Full Roof	Yes	Cracked	No	No
2321 Berkley	1-2m	1-2m	35-40 deg.	Erosion	50-75%	Straight	Yes	Timbers	Settled	Settled	3-6m	Full Roof	No	NA	Yes	No
2335 Berkley	2-3m	1-2m	35-40 deg.	None	>75%	Straight	No	NA	NA	None	>12m	Full Roof	No	NA	No	No
2349 Berkley	1-2m	1-2m	35-40 deg.	Erosion	>75%	Pistol Butt	Yes	Other	Bulging	Settled	>12m	Full Roof	No	NA	No	No
2363 Berkley	1-2m	1-2m	35-40 deg.	Slides	25-50%	Pistol Butt	No	NA	NA	None	9-12m	Frontyard	No	NA	Yes	No
2377 Berkley	1-2m	2-3m	>40 deg.	Slides	50-75%	Straight	Yes	Concrete	Cracked	Settled	6-9m	Full Roof	No	NA	Yes	No
2391 Berkley	1-2m	<1m	>40 deg.	Slides	<25%	Straight	Yes	Other	Bulging	Cracked	>12m	Street	No	NA	Yes	No
2409 Berkley	1-2m	>3m	35-40 deg.	Cracks	25-50%	Leaning	No	NA	NA	Settled	>12m	Street	No	NA	No	No
2425 Berkley	1-2m	<1m	<25 deg.	Slides	<25%	Straight	No	NA	NA	Settled	>12m	Full Roof	No	NA	No	No

APPENDIX II – LANDSLIDE LIKELIHOOD ESTIMATES

DNV - Berkley Landslide Risk Assessment
Landslide Likelihood Estimates

Average Slide Likelihood = 0.0024

Address	Slope Score	Soil Score	Water Score	Deformation Score	Adjustment Factor	P_{slide}	Klohn Ranking
2477 Berton	0.8	0.5	0.5	1	0.200	4.8E-04	NR
2475 Berton	1	0.5	0.5	1	0.250	6.0E-04	NR
2469 Berton	0.8	0.5	0.5	0.5	0.100	2.4E-04	NR
2465 Berton	0.8	0.5	0.5	1	0.200	4.8E-04	NR
2461 Berton	0.8	0.5	0.5	1	0.200	4.8E-04	NR
2441 Mowat	0.8	0.5	0.5	0.5	0.100	2.4E-04	NR
2437 Mowat	0.8	0.5	0.5	1	0.200	4.8E-04	NR
2433 Mowat	1	0.5	0.5	0.5	0.125	3.0E-04	NR
2429 Mowat	0.8	0.5	0.75	1	0.300	7.2E-04	NR
2425 Mowat	1	0.5	2	1	1.000	2.4E-03	NR
1231 Lennox	0.8	1	1.5	2	2.400	5.8E-03	VL
1275 Lennox	1.25	0.5	1	1	0.625	1.5E-03	L
1279 Lennox	1.25	0.5	0.5	2	0.625	1.5E-03	L
1305 Lennox	1	2	1	1	2.000	4.8E-03	MH
1345 Lennox	1	1	1	1	1.000	2.4E-03	MH
1383 Lennox	1	1	1	1	1.000	2.4E-03	VL
1425 Lennox	1.25	0.5	0.5	2	0.625	1.5E-03	MH
1477 Lennox	0.8	1	0.5	0.5	0.200	4.8E-04	VL
1479 Lennox	1	1	0.5	1	0.500	1.2E-03	VL
1491 Lennox	1	1	1.5	2	3.000	7.2E-03	L
1535 Lennox	1	1	2	2	4.000	9.6E-03	L
1557 Lennox	1	1	1.5	1	1.500	3.6E-03	L
1583 Lennox	1	1	1	1	1.000	2.4E-03	VL
1593 Lennox	1	2	2	2	8.000	1.9E-02	L
2402 Swinburne	1.25	1	1	2	2.500	6.0E-03	L
2410 Swinburne	0.8	0.5	0.5	1	0.200	4.8E-04	VL
2414 Swinburne	1	0.5	0.75	1	0.375	9.0E-04	L
1677 Layton	1	0.5	0.5	1	0.250	6.0E-04	L
1691 Layton	1	1	0.5	2	1.000	2.4E-03	MH
1709 Layton	1	2	0.5	1	1.000	2.4E-03	MH
1731 Layton	1	2	0.5	1	1.000	2.4E-03	VL
1753 Layton	0.8	0.5	0.5	2	0.400	9.6E-04	MH
1775 Layton	1	2	1.5	0.5	1.500	3.6E-03	VL
1797 Layton	1.25	0.5	1	0.5	0.313	7.5E-04	L
1815 Layton	0.8	1	0.5	1	0.400	9.6E-04	L
2391 Carman	1	1	1.5	1	1.500	3.6E-03	MH
2379 Carman	1.25	1	1.5	1	1.875	4.5E-03	MH
2360 Carman S.	1	0.5	1.5	2	1.500	3.6E-03	MH
2360 Carman N.	1	0.5	1.5	2	1.500	3.6E-03	MH
2372 Carman	0.8	0.5	1	2	0.800	1.9E-03	VL
2386 Carman	0.8	0.5	0.5	0.5	0.100	2.4E-04	VL
1839 Layton	0.8	0.5	0.5	0.5	0.100	2.4E-04	VL

BGC Summary Stats

25	<1/2 Average
38	1/2 to 2 x Average
12	>2 x Average
75	

Klohn Ranking (Risk of Major Instability)

NR	Not Rated
VL	Very Low
L	Low
MH	Moderate to High

DNV - Berkley Landslide Risk Assessment
Landslide Likelihood Estimates

Average Slide Likelihood = 0.0024

Address	Slope Score	Soil Score	Water Score	Deformation Score	Adjustment Factor	P_{slide}	Klohn Ranking
1847 Layton	0.8	0.5	0.5	1	0.200	4.8E-04	VL
1855 Layton	1	0.5	0.5	0.5	0.125	3.0E-04	VL
1863 Layton	1	0.5	0.5	2	0.500	1.2E-03	L
Hayseed/Layton Gully	0.8	2	0.5	1	0.800	1.9E-03	L
2448 Hayseed	1	1	0.75	1	0.750	1.8E-03	VL
2454 Hayseed	0.8	1	0.75	0.5	0.300	7.2E-04	VL
2462 Hayseed	1.25	0.5	1	2	1.250	3.0E-03	L
2468 Hayseed	1	0.5	1	0.5	0.250	6.0E-04	VL
2474 Hayseed	0.8	0.5	0.5	0.5	0.100	2.4E-04	VL
2480 Hayseed	0.8	0.5	1	2	0.800	1.9E-03	L
2486 Hayseed	1	0.5	0.75	1	0.375	9.0E-04	VL
2125 Berkley	0.8	0.5	2	1	0.800	1.9E-03	VL
2141 Berkley	0.8	2	0.75	0.5	0.600	1.4E-03	L
2157 Berkley	0.8	1	1	1	0.800	1.9E-03	L
2175 Berkley	0.8	1	2	2	3.200	7.7E-03	L
2191 Berkley	1	2	1.5	2	6.000	1.4E-02	L
2205 Berkley	1	2	1	1	2.000	4.8E-03	MH
2217 Berkley	1.25	2	1	1	2.500	6.0E-03	MH
2223 Berkley	0.8	1	1	1	0.800	1.9E-03	MH
2249 Berkley	1	2	1	1	2.000	4.8E-03	L
2251 Berkley	0.8	1	2	0.5	0.800	1.9E-03	L
2265 Berkley	1	0.5	1	2	1.000	2.4E-03	VL
2279 Berkley	0.8	0.5	1	1	0.400	9.6E-04	L
2293 Berkley	1	1	1	1	1.000	2.4E-03	VL
2307 Berkley	1	1	1	0.5	0.500	1.2E-03	L
2321 Berkley	1	0.5	1	1	0.500	1.2E-03	VL
2335 Berkley	1	1	1	0.5	0.500	1.2E-03	VL
2349 Berkley	1	0.5	1	2	1.000	2.4E-03	VL
2363 Berkley	1	0.5	1.5	1	0.750	1.8E-03	VL
2377 Berkley	1.25	1	1	2	2.500	6.0E-03	L
2391 Berkley	1.25	0.5	2	2	2.500	6.0E-03	L
2409 Berkley	1	1	2	2	4.000	9.6E-03	VL
2425 Berkley	0.8	0.5	1	2	0.800	1.9E-03	VL
						0.206 (slides/year)	4.9 (years/slide)

APPENDIX III – CONSEQUENCE ESTIMATES

DNV - Berkley Landslide Risk Assessment
Consequence Estimates at Base of Escarpment

Address	# Houses >25°	# Houses >23°	# Houses >21°	# Houses 19-21°	House Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)
2477 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2475 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2469 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2465 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2461 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2441 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2437 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2433 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2429 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2425 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
1231 Lennox	0	0	2	0	0.03	0.50	0.29	4	1.6E-02
1275 Lennox	0	0	2	1	0.03	0.50	0.29	4	1.7E-02
1279 Lennox	0	0	1	0	0.01	0.50	0.29	4	8.1E-03
1305 Lennox	0	1	1	0	0.15	0.50	0.29	4	8.9E-02
1345 Lennox	0	1	1	1	0.16	0.50	0.29	4	9.0E-02
1383 Lennox	0	2	0	2	0.28	0.50	0.29	4	1.6E-01
1425 Lennox	1	2	0	2	0.68	0.50	0.29	4	4.0E-01
1477 Lennox	2	3	0	1	1.22	0.50	0.29	4	7.1E-01
1479 Lennox	1	3	0	1	0.82	0.50	0.29	4	4.8E-01
1491 Lennox	0	3	2	0	0.45	0.50	0.29	4	2.6E-01
1535 Lennox	1	1	3	0	0.58	0.50	0.29	4	3.4E-01
1557 Lennox	1	1	3	0	0.58	0.50	0.29	4	3.4E-01
1583 Lennox	1	2	2	0	0.71	0.50	0.29	4	4.1E-01
1593 Lennox	1	2	2	0	0.71	0.50	0.29	4	4.1E-01
2402 Swinburne	1	1	2	3	0.57	0.50	0.29	4	3.3E-01
2410 Swinburne	1	1	2	3	0.57	0.50	0.29	4	3.3E-01
2414 Swinburne	0	1	1	4	0.16	0.50	0.29	4	9.3E-02
1677 Layton	0	2	2	3	0.31	0.50	0.29	4	1.8E-01
1691 Layton	0	2	2	2	0.31	0.50	0.29	4	1.8E-01
1709 Layton	0	2	3	2	0.32	0.50	0.29	4	1.9E-01
1731 Layton	0	2	3	1	0.32	0.50	0.29	4	1.9E-01
1753 Layton	0	2	2	1	0.31	0.50	0.29	4	1.8E-01
1775 Layton	0	2	3	1	0.32	0.50	0.29	4	1.9E-01
1797 Layton	0	2	2	1	0.31	0.50	0.29	4	1.8E-01
1815 Layton	1	0	1	3	0.42	0.50	0.29	4	2.4E-01
2391 Carman	1	1	1	2	0.56	0.50	0.29	4	3.2E-01
2379 Carman	2	1	0	3	0.94	0.50	0.29	4	5.5E-01
2360 Carman S.	3	0	3	3	1.25	0.50	0.29	4	7.2E-01
2360 Carman N.	2	2	3	1	1.12	0.50	0.29	4	6.5E-01
2372 Carman	2	1	3	3	0.99	0.50	0.29	4	5.7E-01
2386 Carman	2	0	3	2	0.84	0.50	0.29	4	4.9E-01

DNV - Berkley Landslide Risk Assessment
Consequence Estimates at Base of Escarpment

Address	# Houses >25°	# Houses >23°	# Houses >21°	# Houses 19-21°	House Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)
1839 Layton	3	0	3	2	1.24	0.50	0.29	4	7.2E-01
1847 Layton	3	0	3	2	1.24	0.50	0.29	4	7.2E-01
1855 Layton	3	0	3	3	1.25	0.50	0.29	4	7.2E-01
1863 Layton	4	1	1	2	1.76	0.50	0.29	4	1.0E+00
Hayseed/Layton Gully	4	1	2	2	1.77	0.50	0.29	4	1.0E+00
2448 Hayseed	4	1	1	2	1.76	0.50	0.29	4	1.0E+00
2454 Hayseed	5	1	1	2	2.16	0.50	0.29	4	1.3E+00
2462 Hayseed	4	1	1	1	1.76	0.50	0.29	4	1.0E+00
2468 Hayseed	2	0	3	0	0.84	0.50	0.29	4	4.9E-01
2474 Hayseed	3	0	3	1	1.24	0.50	0.29	4	7.2E-01
2480 Hayseed	2	0	1	1	0.82	0.50	0.29	4	4.7E-01
2486 Hayseed	3	0	1	2	1.22	0.50	0.29	4	7.1E-01
2125 Berkley	4	0	0	2	1.60	0.50	0.29	4	9.3E-01
2141 Berkley	4	0	0	3	1.60	0.50	0.29	4	9.3E-01
2157 Berkley	4	0	0	2	1.60	0.50	0.29	4	9.3E-01
2175 Berkley	3	0	0	1	1.20	0.50	0.29	4	7.0E-01
2191 Berkley	2	0	0	2	0.80	0.50	0.29	4	4.7E-01
2205 Berkley	1	2	0	3	0.68	0.50	0.29	4	4.0E-01
2217 Berkley	0	2	1	1	0.30	0.50	0.29	4	1.7E-01
2223 Berkley	0	1	1	2	0.16	0.50	0.29	4	9.1E-02
2249 Berkley	0	0	1	2	0.02	0.50	0.29	4	9.7E-03
2251 Berkley	0	0	0	2	0.00	0.50	0.29	4	1.6E-03
2265 Berkley	0	0	0	1	0.00	0.50	0.29	4	8.1E-04
2279 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2293 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2307 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2321 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2335 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2349 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2363 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2377 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2391 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2409 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00
2425 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00

DNV - Berkley Landslide Risk Assessment
Consequence Estimates at Crest of Escarpment

Address	Yard Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)
2477 Berton	0.2	0.01	0.5	4	4.0E-03
2475 Berton	0.2	0.01	0.5	4	4.0E-03
2469 Berton	0.2	0.01	0.5	4	4.0E-03
2465 Berton	0.2	0.01	0.5	4	4.0E-03
2461 Berton	0.2	0.01	0.5	4	4.0E-03
2441 Mowat	0.2	0.01	0.5	4	4.0E-03
2437 Mowat	0.2	0.01	0.5	4	4.0E-03
2433 Mowat	0.2	0.01	0.5	4	4.0E-03
2429 Mowat	0.2	0.01	0.5	4	4.0E-03
2425 Mowat	0.2	0.01	0.5	4	4.0E-03
1231 Lennox	0.67	0.01	0.5	4	1.3E-02
1275 Lennox	0.99	0.01	0.5	4	2.0E-02
1279 Lennox	0.67	0.01	0.5	4	1.3E-02
1305 Lennox	0.29	0.01	0.5	4	5.8E-03
1345 Lennox	0.29	0.01	0.5	4	5.8E-03
1383 Lennox	0.67	0.01	0.5	4	1.3E-02
1425 Lennox	0.4	0.01	0.5	4	8.0E-03
1477 Lennox	0.4	0.01	0.5	4	8.0E-03
1479 Lennox	0.4	0.01	0.5	4	8.0E-03
1491 Lennox	0.67	0.01	0.5	4	1.3E-02
1535 Lennox	0.67	0.01	0.5	4	1.3E-02
1557 Lennox	0.67	0.01	0.5	4	1.3E-02
1583 Lennox	0.99	0.01	0.5	4	2.0E-02
1593 Lennox	0.99	0.01	0.5	4	2.0E-02
2402 Swinburne	0.99	0.01	0.5	4	2.0E-02
2410 Swinburne	0.4	0.01	0.5	4	8.0E-03
2414 Swinburne	0.99	0.01	0.5	4	2.0E-02
1677 Layton	0.2	0.01	0.5	4	4.0E-03
1691 Layton	0.2	0.01	0.5	4	4.0E-03
1709 Layton	0.2	0.01	0.5	4	4.0E-03
1731 Layton	0.2	0.01	0.5	4	4.0E-03
1753 Layton	0.2	0.01	0.5	4	4.0E-03
1775 Layton	0.4	0.01	0.5	4	8.0E-03
1797 Layton	0.4	0.01	0.5	4	8.0E-03
1815 Layton	0.4	0.01	0.5	4	8.0E-03
2391 Carman	0.4	0.01	0.5	4	8.0E-03
2379 Carman	0.99	0.01	0.5	4	2.0E-02
2360 Carman S.	0.67	0.01	0.5	4	1.3E-02
2360 Carman N.	0.67	0.01	0.5	4	1.3E-02
2372 Carman	0.29	0.01	0.5	4	5.8E-03
2386 Carman	0.2	0.01	0.5	4	4.0E-03

DNV - Berkley Landslide Risk Assessment
Consequence Estimates at Crest of Escarpment

Address	Yard Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)
1839 Layton	0.2	0.01	0.5	4	4.0E-03
1847 Layton	0.2	0.01	0.5	4	4.0E-03
1855 Layton	0.2	0.01	0.5	4	4.0E-03
1863 Layton	0.2	0.01	0.5	4	4.0E-03
Hayseed/Layton Gully	0.2	0.01	0.5	4	4.0E-03
2448 Hayseed	0.4	0.01	0.5	4	8.0E-03
2454 Hayseed	0.29	0.01	0.5	4	5.8E-03
2462 Hayseed	0.29	0.01	0.5	4	5.8E-03
2468 Hayseed	0.99	0.01	0.5	4	2.0E-02
2474 Hayseed	0.99	0.01	0.5	4	2.0E-02
2480 Hayseed	0.67	0.01	0.5	4	1.3E-02
2486 Hayseed	0.4	0.01	0.5	4	8.0E-03
2125 Berkley	0.2	0.01	0.5	4	4.0E-03
2141 Berkley	0.67	0.01	0.5	4	1.3E-02
2157 Berkley	0.2	0.01	0.5	4	4.0E-03
2175 Berkley	0.99	0.01	0.5	4	2.0E-02
2191 Berkley	0.67	0.01	0.5	4	1.3E-02
2205 Berkley	0.29	0.01	0.5	4	5.8E-03
2217 Berkley	0.29	0.01	0.5	4	5.8E-03
2223 Berkley	0.29	0.01	0.5	4	5.8E-03
2249 Berkley	0.2	0.01	0.5	4	4.0E-03
2251 Berkley	0.2	0.01	0.5	4	4.0E-03
2265 Berkley	0.4	0.01	0.5	4	8.0E-03
2279 Berkley	0.29	0.01	0.5	4	5.8E-03
2293 Berkley	0.2	0.01	0.5	4	4.0E-03
2307 Berkley	0.29	0.01	0.5	4	5.8E-03
2321 Berkley	0.67	0.01	0.5	4	1.3E-02
2335 Berkley	0.2	0.01	0.5	4	4.0E-03
2349 Berkley	0.2	0.01	0.5	4	4.0E-03
2363 Berkley	0.29	0.01	0.5	4	5.8E-03
2377 Berkley	0.4	0.01	0.5	4	8.0E-03
2391 Berkley	0.2	0.01	0.5	4	4.0E-03
2409 Berkley	0.2	0.01	0.5	4	4.0E-03
2425 Berkley	0.2	0.01	0.5	4	4.0E-03

APPENDIX IV – RISK ESTIMATES

DNV - Berkley Landslide Risk Assessment
Risk Estimates at Base of Escarpment

Address	# Houses >25°	# Houses >23°	# Houses >21°	# Houses 19-21°	House Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)	F (P_{slide})	Societal Risk (per year)
2477 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	4.8E-04	0.0E+00
2475 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	6.0E-04	0.0E+00
2469 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	2.4E-04	0.0E+00
2465 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	4.8E-04	0.0E+00
2461 Berton	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	4.8E-04	0.0E+00
2441 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	2.4E-04	0.0E+00
2437 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	4.8E-04	0.0E+00
2433 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	3.0E-04	0.0E+00
2429 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	7.2E-04	0.0E+00
2425 Mowat	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	2.4E-03	0.0E+00
1231 Lennox	0	0	2	0	0.03	0.50	0.29	4	1.6E-02	5.8E-03	9.4E-05
1275 Lennox	0	0	2	1	0.03	0.50	0.29	4	1.7E-02	1.5E-03	2.6E-05
1279 Lennox	0	0	1	0	0.01	0.50	0.29	4	8.1E-03	1.5E-03	1.2E-05
1305 Lennox	0	1	1	0	0.15	0.50	0.29	4	8.9E-02	4.8E-03	4.3E-04
1345 Lennox	0	1	1	1	0.16	0.50	0.29	4	9.0E-02	2.4E-03	2.2E-04
1383 Lennox	0	2	0	2	0.28	0.50	0.29	4	1.6E-01	2.4E-03	3.9E-04
1425 Lennox	1	2	0	2	0.68	0.50	0.29	4	4.0E-01	1.5E-03	5.9E-04
1477 Lennox	2	3	0	1	1.22	0.50	0.29	4	7.1E-01	4.8E-04	3.4E-04
1479 Lennox	1	3	0	1	0.82	0.50	0.29	4	4.8E-01	1.2E-03	5.7E-04
1491 Lennox	0	3	2	0	0.45	0.50	0.29	4	2.6E-01	7.2E-03	1.9E-03
1535 Lennox	1	1	3	0	0.58	0.50	0.29	4	3.4E-01	9.6E-03	3.2E-03
1557 Lennox	1	1	3	0	0.58	0.50	0.29	4	3.4E-01	3.6E-03	1.2E-03
1583 Lennox	1	2	2	0	0.71	0.50	0.29	4	4.1E-01	2.4E-03	9.9E-04
1593 Lennox	1	2	2	0	0.71	0.50	0.29	4	4.1E-01	1.9E-02	7.9E-03
2402 Swinburne	1	1	2	3	0.57	0.50	0.29	4	3.3E-01	6.0E-03	2.0E-03
2410 Swinburne	1	1	2	3	0.57	0.50	0.29	4	3.3E-01	4.8E-04	1.6E-04
2414 Swinburne	0	1	1	4	0.16	0.50	0.29	4	9.3E-02	9.0E-04	8.3E-05
1677 Layton	0	2	2	3	0.31	0.50	0.29	4	1.8E-01	6.0E-04	1.1E-04
1691 Layton	0	2	2	2	0.31	0.50	0.29	4	1.8E-01	2.4E-03	4.3E-04
1709 Layton	0	2	3	2	0.32	0.50	0.29	4	1.9E-01	2.4E-03	4.5E-04
1731 Layton	0	2	3	1	0.32	0.50	0.29	4	1.9E-01	2.4E-03	4.5E-04
1753 Layton	0	2	2	1	0.31	0.50	0.29	4	1.8E-01	9.6E-04	1.7E-04
1775 Layton	0	2	3	1	0.32	0.50	0.29	4	1.9E-01	3.6E-03	6.8E-04
1797 Layton	0	2	2	1	0.31	0.50	0.29	4	1.8E-01	7.5E-04	1.3E-04
1815 Layton	1	0	1	3	0.42	0.50	0.29	4	2.4E-01	9.6E-04	2.3E-04
2391 Carman	1	1	1	2	0.56	0.50	0.29	4	3.2E-01	3.6E-03	1.2E-03
2379 Carman	2	1	0	3	0.94	0.50	0.29	4	5.5E-01	4.5E-03	2.5E-03
2360 Carman S.	3	0	3	3	1.25	0.50	0.29	4	7.2E-01	3.6E-03	2.6E-03
2360 Carman N.	2	2	3	1	1.12	0.50	0.29	4	6.5E-01	3.6E-03	2.3E-03
2372 Carman	2	1	3	3	0.99	0.50	0.29	4	5.7E-01	1.9E-03	1.1E-03
2386 Carman	2	0	3	2	0.84	0.50	0.29	4	4.9E-01	2.4E-04	1.2E-04
1839 Layton	3	0	3	2	1.24	0.50	0.29	4	7.2E-01	2.4E-04	1.7E-04
1847 Layton	3	0	3	2	1.24	0.50	0.29	4	7.2E-01	4.8E-04	3.5E-04
1855 Layton	3	0	3	3	1.25	0.50	0.29	4	7.2E-01	3.0E-04	2.2E-04
1863 Layton	4	1	1	2	1.76	0.50	0.29	4	1.0E+00	1.2E-03	1.2E-03
Hayseed/Layton Gully	4	1	2	2	1.77	0.50	0.29	4	1.0E+00	1.9E-03	2.0E-03
2448 Hayseed	4	1	1	2	1.76	0.50	0.29	4	1.0E+00	1.8E-03	1.8E-03
2454 Hayseed	5	1	1	2	2.16	0.50	0.29	4	1.3E+00	7.2E-04	9.0E-04
2462 Hayseed	4	1	1	1	1.76	0.50	0.29	4	1.0E+00	3.0E-03	3.1E-03
2468 Hayseed	2	0	3	0	0.84	0.50	0.29	4	4.9E-01	6.0E-04	2.9E-04
2474 Hayseed	3	0	3	1	1.24	0.50	0.29	4	7.2E-01	2.4E-04	1.7E-04
2480 Hayseed	2	0	1	1	0.82	0.50	0.29	4	4.7E-01	1.9E-03	9.1E-04
2486 Hayseed	3	0	1	2	1.22	0.50	0.29	4	7.1E-01	9.0E-04	6.4E-04
2125 Berkley	4	0	0	2	1.60	0.50	0.29	4	9.3E-01	1.9E-03	1.8E-03
2141 Berkley	4	0	0	3	1.60	0.50	0.29	4	9.3E-01	1.4E-03	1.3E-03
2157 Berkley	4	0	0	2	1.60	0.50	0.29	4	9.3E-01	1.9E-03	1.8E-03

Individuals Most At Risk (16 hrs/day)

If Houses >25°	If Houses >23°	If Houses >21°	If Houses <21°
3.7E-05	1.3E-05	1.3E-06	1.3E-07
4.6E-05	1.6E-05	1.6E-06	1.6E-07
1.9E-05	6.5E-06	6.5E-07	6.5E-08
3.7E-05	1.3E-05	1.3E-06	1.3E-07
3.7E-05	1.3E-05	1.3E-06	1.3E-07
1.9E-05	6.5E-06	6.5E-07	6.5E-08
3.7E-05	1.3E-05	1.3E-06	1.3E-07
2.3E-05	8.1E-06	8.1E-07	8.1E-08
5.6E-05	1.9E-05	1.9E-06	1.9E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
4.5E-04	1.6E-04	1.6E-05	1.6E-06
1.2E-04	4.1E-05	4.1E-06	4.1E-07
1.2E-04	4.1E-05	4.1E-06	4.1E-07
3.7E-04	1.3E-04	1.3E-05	1.3E-06
1.9E-04	6.5E-05	6.5E-06	6.5E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
1.2E-04	4.1E-05	4.1E-06	4.1E-07
3.7E-05	1.3E-05	1.3E-06	1.3E-07
9.3E-05	3.2E-05	3.2E-06	3.2E-07
5.6E-04	1.9E-04	1.9E-05	1.9E-06
7.4E-04	2.6E-04	2.6E-05	2.6E-06
2.8E-04	9.7E-05	9.7E-06	9.7E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
1.5E-03	5.2E-04	5.2E-05	5.2E-06
4.6E-04	1.6E-04	1.6E-05	1.6E-06
3.7E-05	1.3E-05	1.3E-06	1.3E-07
7.0E-05	2.4E-05	2.4E-06	2.4E-07
4.6E-05	1.6E-05	1.6E-06	1.6E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
7.4E-05	2.6E-05	2.6E-06	2.6E-07
2.8E-04	9.7E-05	9.7E-06	9.7E-07
5.8E-05	2.0E-05	2.0E-06	2.0E-07
7.4E-05	2.6E-05	2.6E-06	2.6E-07
2.8E-04	9.7E-05	9.7E-06	9.7E-07
3.5E-04	1.2E-04	1.2E-05	1.2E-06
2.8E-04	9.7E-05	9.7E-06	9.7E-07
2.8E-04	9.7E-05	9.7E-06	9.7E-07
1.5E-04	5.2E-05	5.2E-06	5.2E-07
1.9E-05	6.5E-06	6.5E-07	6.5E-08
1.9E-05	6.5E-06	6.5E-07	6.5E-08
3.7E-05	1.3E-05	1.3E-06	1.3E-07
2.3E-05	8.1E-06	8.1E-07	8.1E-08
9.3E-05	3.2E-05	3.2E-06	3.2E-07
1.5E-04	5.2E-05	5.2E-06	5.2E-07
1.4E-04	4.9E-05	4.9E-06	4.9E-07
5.6E-05	1.9E-05	1.9E-06	1.9E-07
2.3E-04	8.1E-05	8.1E-06	8.1E-07
4.6E-05	1.6E-05	1.6E-06	1.6E-07
1.9E-05	6.5E-06	6.5E-07	6.5E-08
1.5E-04	5.2E-05	5.2E-06	5.2E-07
7.0E-05	2.4E-05	2.4E-06	2.4E-07
1.5E-04	5.2E-05	5.2E-06	5.2E-07
1.1E-04	3.9E-05	3.9E-06	3.9E-07
1.5E-04	5.2E-05	5.2E-06	5.2E-07

DNV - Berkley Landslide Risk Assessment
Risk Estimates at Base of Escarpment

Address	# Houses >25°	# Houses >23°	# Houses >21°	# Houses 19-21°	House Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)	F (P_{slide})	Societal Risk (per year)
2175 Berkley	3	0	0	1	1.20	0.50	0.29	4	7.0E-01	7.7E-03	5.4E-03
2191 Berkley	2	0	0	2	0.80	0.50	0.29	4	4.7E-01	1.4E-02	6.7E-03
2205 Berkley	1	2	0	3	0.68	0.50	0.29	4	4.0E-01	4.8E-03	1.9E-03
2217 Berkley	0	2	1	1	0.30	0.50	0.29	4	1.7E-01	6.0E-03	1.0E-03
2223 Berkley	0	1	1	2	0.16	0.50	0.29	4	9.1E-02	1.9E-03	1.7E-04
2249 Berkley	0	0	1	2	0.02	0.50	0.29	4	9.7E-03	4.8E-03	4.7E-05
2251 Berkley	0	0	0	2	0.00	0.50	0.29	4	1.6E-03	1.9E-03	3.1E-06
2265 Berkley	0	0	0	1	0.00	0.50	0.29	4	8.1E-04	2.4E-03	1.9E-06
2279 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	9.6E-04	0.0E+00
2293 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	2.4E-03	0.0E+00
2307 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	1.2E-03	0.0E+00
2321 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	1.2E-03	0.0E+00
2335 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	1.2E-03	0.0E+00
2349 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	2.4E-03	0.0E+00
2363 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	1.8E-03	0.0E+00
2377 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	6.0E-03	0.0E+00
2391 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	6.0E-03	0.0E+00
2409 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	9.6E-03	0.0E+00
2425 Berkley	0	0	0	0	0.00	0.50	0.29	4	0.0E+00	1.9E-03	0.0E+00

0.064 (fatalities/year) 15.53 (years/fatality)

Individuals Most At Risk (16 hrs/day)

If Houses >25°	If Houses >23°	If Houses >21°	If Houses <21°
5.9E-04	2.1E-04	2.1E-05	2.1E-06
1.1E-03	3.9E-04	3.9E-05	3.9E-06
3.7E-04	1.3E-04	1.3E-05	1.3E-06
4.6E-04	1.6E-04	1.6E-05	1.6E-06
1.5E-04	5.2E-05	5.2E-06	5.2E-07
3.7E-04	1.3E-04	1.3E-05	1.3E-06
1.5E-04	5.2E-05	5.2E-06	5.2E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
7.4E-05	2.6E-05	2.6E-06	2.6E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
9.3E-05	3.2E-05	3.2E-06	3.2E-07
9.3E-05	3.2E-05	3.2E-06	3.2E-07
9.3E-05	3.2E-05	3.2E-06	3.2E-07
1.9E-04	6.5E-05	6.5E-06	6.5E-07
1.4E-04	4.9E-05	4.9E-06	4.9E-07
4.6E-04	1.6E-04	1.6E-05	1.6E-06
4.6E-04	1.6E-04	1.6E-05	1.6E-06
7.4E-04	2.6E-04	2.6E-05	2.6E-06
1.5E-04	5.2E-05	5.2E-06	5.2E-07

Estimates only apply in locations where houses are present

DNV - Berkley Landslide Risk Assessment
Risk Estimates at Crest of Escarpment

Address	Yard Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)	F (P_{slide})	Societal Risk (per year)
2477 Berton	0.2	0.01	0.5	4	4.0E-03	4.8E-04	1.9E-06
2475 Berton	0.2	0.01	0.5	4	4.0E-03	6.0E-04	2.4E-06
2469 Berton	0.2	0.01	0.5	4	4.0E-03	2.4E-04	9.6E-07
2465 Berton	0.2	0.01	0.5	4	4.0E-03	4.8E-04	1.9E-06
2461 Berton	0.2	0.01	0.5	4	4.0E-03	4.8E-04	1.9E-06
2441 Mowat	0.2	0.01	0.5	4	4.0E-03	2.4E-04	9.6E-07
2437 Mowat	0.2	0.01	0.5	4	4.0E-03	4.8E-04	1.9E-06
2433 Mowat	0.2	0.01	0.5	4	4.0E-03	3.0E-04	1.2E-06
2429 Mowat	0.2	0.01	0.5	4	4.0E-03	7.2E-04	2.9E-06
2425 Mowat	0.2	0.01	0.5	4	4.0E-03	2.4E-03	9.6E-06
1231 Lennox	0.67	0.01	0.5	4	1.3E-02	5.8E-03	7.7E-05
1275 Lennox	0.99	0.01	0.5	4	2.0E-02	1.5E-03	3.0E-05
1279 Lennox	0.67	0.01	0.5	4	1.3E-02	1.5E-03	2.0E-05
1305 Lennox	0.29	0.01	0.5	4	5.8E-03	4.8E-03	2.8E-05
1345 Lennox	0.29	0.01	0.5	4	5.8E-03	2.4E-03	1.4E-05
1383 Lennox	0.67	0.01	0.5	4	1.3E-02	2.4E-03	3.2E-05
1425 Lennox	0.4	0.01	0.5	4	8.0E-03	1.5E-03	1.2E-05
1477 Lennox	0.4	0.01	0.5	4	8.0E-03	4.8E-04	3.8E-06
1479 Lennox	0.4	0.01	0.5	4	8.0E-03	1.2E-03	9.6E-06
1491 Lennox	0.67	0.01	0.5	4	1.3E-02	7.2E-03	9.6E-05
1535 Lennox	0.67	0.01	0.5	4	1.3E-02	9.6E-03	1.3E-04
1557 Lennox	0.67	0.01	0.5	4	1.3E-02	3.6E-03	4.8E-05
1583 Lennox	0.99	0.01	0.5	4	2.0E-02	2.4E-03	4.8E-05
1593 Lennox	0.99	0.01	0.5	4	2.0E-02	1.9E-02	3.8E-04
2402 Swinburne	0.99	0.01	0.5	4	2.0E-02	6.0E-03	1.2E-04
2410 Swinburne	0.4	0.01	0.5	4	8.0E-03	4.8E-04	3.8E-06
2414 Swinburne	0.99	0.01	0.5	4	2.0E-02	9.0E-04	1.8E-05
1677 Layton	0.2	0.01	0.5	4	4.0E-03	6.0E-04	2.4E-06
1691 Layton	0.2	0.01	0.5	4	4.0E-03	2.4E-03	9.6E-06
1709 Layton	0.2	0.01	0.5	4	4.0E-03	2.4E-03	9.6E-06
1731 Layton	0.2	0.01	0.5	4	4.0E-03	2.4E-03	9.6E-06
1753 Layton	0.2	0.01	0.5	4	4.0E-03	9.6E-04	3.8E-06
1775 Layton	0.4	0.01	0.5	4	8.0E-03	3.6E-03	2.9E-05
1797 Layton	0.4	0.01	0.5	4	8.0E-03	7.5E-04	6.0E-06
1815 Layton	0.4	0.01	0.5	4	8.0E-03	9.6E-04	7.7E-06
2391 Carman	0.4	0.01	0.5	4	8.0E-03	3.6E-03	2.9E-05
2379 Carman	0.99	0.01	0.5	4	2.0E-02	4.5E-03	8.9E-05
2360 Carman S.	0.67	0.01	0.5	4	1.3E-02	3.6E-03	4.8E-05
2360 Carman N.	0.67	0.01	0.5	4	1.3E-02	3.6E-03	4.8E-05
2372 Carman	0.29	0.01	0.5	4	5.8E-03	1.9E-03	1.1E-05
2386 Carman	0.2	0.01	0.5	4	4.0E-03	2.4E-04	9.6E-07
1839 Layton	0.2	0.01	0.5	4	4.0E-03	2.4E-04	9.6E-07
1847 Layton	0.2	0.01	0.5	4	4.0E-03	4.8E-04	1.9E-06

Individuals Most At Risk (0.5 hrs/day)

Individual Risk (per year)
9.6E-07
1.2E-06
4.8E-07
9.6E-07
9.6E-07
4.8E-07
9.6E-07
6.0E-07
1.4E-06
4.8E-06
3.9E-05
1.5E-05
1.0E-05
1.4E-05
7.0E-06
1.6E-05
6.0E-06
1.9E-06
4.8E-06
4.8E-05
6.4E-05
2.4E-05
2.4E-05
1.9E-04
5.9E-05
1.9E-06
8.9E-06
1.2E-06
4.8E-06
4.8E-06
4.8E-06
1.9E-06
1.4E-05
3.0E-06
3.8E-06
1.4E-05
4.5E-05
2.4E-05
2.4E-05
5.6E-06
4.8E-07
4.8E-07
9.6E-07

DNV - Berkley Landslide Risk Assessment
Risk Estimates at Crest of Escarpment

Address	Yard Spatial ($P_{S:H}$)	Occupant Temporal ($P_{T:S}$)	Occupant Vulnerability (V)	Element Value (E)	N (Fatalities)	F (P_{slide})	Societal Risk (per year)	Individuals Most At Risk (0.5 hrs/day) Individual Risk (per year)
1855 Layton	0.2	0.01	0.5	4	4.0E-03	3.0E-04	1.2E-06	6.0E-07
1863 Layton	0.2	0.01	0.5	4	4.0E-03	1.2E-03	4.8E-06	2.4E-06
Hayseed/Layton Gully	0.2	0.01	0.5	4	4.0E-03	1.9E-03	7.7E-06	3.8E-06
2448 Hayseed	0.4	0.01	0.5	4	8.0E-03	1.8E-03	1.4E-05	7.2E-06
2454 Hayseed	0.29	0.01	0.5	4	5.8E-03	7.2E-04	4.2E-06	2.1E-06
2462 Hayseed	0.29	0.01	0.5	4	5.8E-03	3.0E-03	1.7E-05	8.7E-06
2468 Hayseed	0.99	0.01	0.5	4	2.0E-02	6.0E-04	1.2E-05	5.9E-06
2474 Hayseed	0.99	0.01	0.5	4	2.0E-02	2.4E-04	4.8E-06	2.4E-06
2480 Hayseed	0.67	0.01	0.5	4	1.3E-02	1.9E-03	2.6E-05	1.3E-05
2486 Hayseed	0.4	0.01	0.5	4	8.0E-03	9.0E-04	7.2E-06	3.6E-06
2125 Berkley	0.2	0.01	0.5	4	4.0E-03	1.9E-03	7.7E-06	3.8E-06
2141 Berkley	0.67	0.01	0.5	4	1.3E-02	1.4E-03	1.9E-05	9.6E-06
2157 Berkley	0.2	0.01	0.5	4	4.0E-03	1.9E-03	7.7E-06	3.8E-06
2175 Berkley	0.99	0.01	0.5	4	2.0E-02	7.7E-03	1.5E-04	7.6E-05
2191 Berkley	0.67	0.01	0.5	4	1.3E-02	1.4E-02	1.9E-04	9.6E-05
2205 Berkley	0.29	0.01	0.5	4	5.8E-03	4.8E-03	2.8E-05	1.4E-05
2217 Berkley	0.29	0.01	0.5	4	5.8E-03	6.0E-03	3.5E-05	1.7E-05
2223 Berkley	0.29	0.01	0.5	4	5.8E-03	1.9E-03	1.1E-05	5.6E-06
2249 Berkley	0.2	0.01	0.5	4	4.0E-03	4.8E-03	1.9E-05	9.6E-06
2251 Berkley	0.2	0.01	0.5	4	4.0E-03	1.9E-03	7.7E-06	3.8E-06
2265 Berkley	0.4	0.01	0.5	4	8.0E-03	2.4E-03	1.9E-05	9.6E-06
2279 Berkley	0.29	0.01	0.5	4	5.8E-03	9.6E-04	5.6E-06	2.8E-06
2293 Berkley	0.2	0.01	0.5	4	4.0E-03	2.4E-03	9.6E-06	4.8E-06
2307 Berkley	0.29	0.01	0.5	4	5.8E-03	1.2E-03	7.0E-06	3.5E-06
2321 Berkley	0.67	0.01	0.5	4	1.3E-02	1.2E-03	1.6E-05	8.0E-06
2335 Berkley	0.2	0.01	0.5	4	4.0E-03	1.2E-03	4.8E-06	2.4E-06
2349 Berkley	0.2	0.01	0.5	4	4.0E-03	2.4E-03	9.6E-06	4.8E-06
2363 Berkley	0.29	0.01	0.5	4	5.8E-03	1.8E-03	1.0E-05	5.2E-06
2377 Berkley	0.4	0.01	0.5	4	8.0E-03	6.0E-03	4.8E-05	2.4E-05
2391 Berkley	0.2	0.01	0.5	4	4.0E-03	6.0E-03	2.4E-05	1.2E-05
2409 Berkley	0.2	0.01	0.5	4	4.0E-03	9.6E-03	3.8E-05	1.9E-05
2425 Berkley	0.2	0.01	0.5	4	4.0E-03	1.9E-03	7.7E-06	3.8E-06

0.002 (fatalities/year)   459 (years/fatality)

DNV - Berkley Landslide Risk Assessment
Total Societal Loss of Life Risk Estimates

Address	N @ Base	N @ Crest	F (P_{slide})	N (Fatalities)	F for Graph	N for Graph	Societal Risk (per year)
2477 Berton	0.0E+00	4.0E-03	4.8E-04	4.0E-03	1.9E-06	1.0E+00	1.9E-06
2475 Berton	0.0E+00	4.0E-03	6.0E-04	4.0E-03	2.4E-06	1.0E+00	2.4E-06
2469 Berton	0.0E+00	4.0E-03	2.4E-04	4.0E-03	9.6E-07	1.0E+00	9.6E-07
2465 Berton	0.0E+00	4.0E-03	4.8E-04	4.0E-03	1.9E-06	1.0E+00	1.9E-06
2461 Berton	0.0E+00	4.0E-03	4.8E-04	4.0E-03	1.9E-06	1.0E+00	1.9E-06
2441 Mowat	0.0E+00	4.0E-03	2.4E-04	4.0E-03	9.6E-07	1.0E+00	9.6E-07
2437 Mowat	0.0E+00	4.0E-03	4.8E-04	4.0E-03	1.9E-06	1.0E+00	1.9E-06
2433 Mowat	0.0E+00	4.0E-03	3.0E-04	4.0E-03	1.2E-06	1.0E+00	1.2E-06
2429 Mowat	0.0E+00	4.0E-03	7.2E-04	4.0E-03	2.9E-06	1.0E+00	2.9E-06
2425 Mowat	0.0E+00	4.0E-03	2.4E-03	4.0E-03	9.6E-06	1.0E+00	9.6E-06
1231 Lennox	1.6E-02	1.3E-02	5.8E-03	3.0E-02	1.7E-04	1.0E+00	1.7E-04
1275 Lennox	1.7E-02	2.0E-02	1.5E-03	3.7E-02	5.5E-05	1.0E+00	5.5E-05
1279 Lennox	8.1E-03	1.3E-02	1.5E-03	2.2E-02	3.2E-05	1.0E+00	3.2E-05
1305 Lennox	8.9E-02	5.8E-03	4.8E-03	9.5E-02	4.6E-04	1.0E+00	4.6E-04
1345 Lennox	9.0E-02	5.8E-03	2.4E-03	9.6E-02	2.3E-04	1.0E+00	2.3E-04
1383 Lennox	1.6E-01	1.3E-02	2.4E-03	1.8E-01	4.3E-04	1.0E+00	4.3E-04
1425 Lennox	4.0E-01	8.0E-03	1.5E-03	4.0E-01	6.1E-04	1.0E+00	6.1E-04
1477 Lennox	7.1E-01	8.0E-03	4.8E-04	7.2E-01	3.4E-04	1.0E+00	3.4E-04
1479 Lennox	4.8E-01	8.0E-03	1.2E-03	4.8E-01	5.8E-04	1.0E+00	5.8E-04
1491 Lennox	2.6E-01	1.3E-02	7.2E-03	2.7E-01	2.0E-03	1.0E+00	2.0E-03
1535 Lennox	3.4E-01	1.3E-02	9.6E-03	3.5E-01	3.4E-03	1.0E+00	3.4E-03
1557 Lennox	3.4E-01	1.3E-02	3.6E-03	3.5E-01	1.3E-03	1.0E+00	1.3E-03
1583 Lennox	4.1E-01	2.0E-02	2.4E-03	4.3E-01	1.0E-03	1.0E+00	1.0E-03
1593 Lennox	4.1E-01	2.0E-02	1.9E-02	4.3E-01	8.3E-03	1.0E+00	8.3E-03
2402 Swinburne	3.3E-01	2.0E-02	6.0E-03	3.5E-01	2.1E-03	1.0E+00	2.1E-03
2410 Swinburne	3.3E-01	8.0E-03	4.8E-04	3.4E-01	1.6E-04	1.0E+00	1.6E-04
2414 Swinburne	9.3E-02	2.0E-02	9.0E-04	1.1E-01	1.0E-04	1.0E+00	1.0E-04
1677 Layton	1.8E-01	4.0E-03	6.0E-04	1.9E-01	1.1E-04	1.0E+00	1.1E-04
1691 Layton	1.8E-01	4.0E-03	2.4E-03	1.8E-01	4.4E-04	1.0E+00	4.4E-04
1709 Layton	1.9E-01	4.0E-03	2.4E-03	1.9E-01	4.6E-04	1.0E+00	4.6E-04
1731 Layton	1.9E-01	4.0E-03	2.4E-03	1.9E-01	4.6E-04	1.0E+00	4.6E-04
1753 Layton	1.8E-01	4.0E-03	9.6E-04	1.8E-01	1.8E-04	1.0E+00	1.8E-04
1775 Layton	1.9E-01	8.0E-03	3.6E-03	2.0E-01	7.0E-04	1.0E+00	7.0E-04
1797 Layton	1.8E-01	8.0E-03	7.5E-04	1.9E-01	1.4E-04	1.0E+00	1.4E-04
1815 Layton	2.4E-01	8.0E-03	9.6E-04	2.5E-01	2.4E-04	1.0E+00	2.4E-04
2391 Carman	3.2E-01	8.0E-03	3.6E-03	3.3E-01	1.2E-03	1.0E+00	1.2E-03
2379 Carman	5.5E-01	2.0E-02	4.5E-03	5.7E-01	2.6E-03	1.0E+00	2.6E-03
2360 Carman S.	7.2E-01	1.3E-02	3.6E-03	7.4E-01	2.7E-03	1.0E+00	2.7E-03
2360 Carman N.	6.5E-01	1.3E-02	3.6E-03	6.6E-01	2.4E-03	1.0E+00	2.4E-03
2372 Carman	5.7E-01	5.8E-03	1.9E-03	5.8E-01	1.1E-03	1.0E+00	1.1E-03
2386 Carman	4.9E-01	4.0E-03	2.4E-04	4.9E-01	1.2E-04	1.0E+00	1.2E-04
1839 Layton	7.2E-01	4.0E-03	2.4E-04	7.3E-01	1.7E-04	1.0E+00	1.7E-04

Summary Stats

16	Broadly Acceptable
37	ALARP Region
22	Unacceptable
75	

DNV - Berkley Landslide Risk Assessment
Total Societal Loss of Life Risk Estimates

Address	N @ Base	N @ Crest	F (P_{slide})	N (Fatalities)	F for Graph	N for Graph	Societal Risk (per year)
1847 Layton	7.2E-01	4.0E-03	4.8E-04	7.3E-01	3.5E-04	1.0E+00	3.5E-04
1855 Layton	7.2E-01	4.0E-03	3.0E-04	7.3E-01	2.2E-04	1.0E+00	2.2E-04
1863 Layton	1.0E+00	4.0E-03	1.2E-03	1.0E+00	1.2E-03	1.0E+00	1.2E-03
Hayseed/Layton Gully	1.0E+00	4.0E-03	1.9E-03	1.0E+00	1.9E-03	1.0E+00	2.0E-03
2448 Hayseed	1.0E+00	8.0E-03	1.8E-03	1.0E+00	1.8E-03	1.0E+00	1.8E-03
2454 Hayseed	1.3E+00	5.8E-03	7.2E-04	1.3E+00	7.2E-04	1.3E+00	9.0E-04
2462 Hayseed	1.0E+00	5.8E-03	3.0E-03	1.0E+00	3.0E-03	1.0E+00	3.1E-03
2468 Hayseed	4.9E-01	2.0E-02	6.0E-04	5.1E-01	3.0E-04	1.0E+00	3.0E-04
2474 Hayseed	7.2E-01	2.0E-02	2.4E-04	7.4E-01	1.8E-04	1.0E+00	1.8E-04
2480 Hayseed	4.7E-01	1.3E-02	1.9E-03	4.9E-01	9.3E-04	1.0E+00	9.3E-04
2486 Hayseed	7.1E-01	8.0E-03	9.0E-04	7.1E-01	6.4E-04	1.0E+00	6.4E-04
2125 Berkley	9.3E-01	4.0E-03	1.9E-03	9.3E-01	1.8E-03	1.0E+00	1.8E-03
2141 Berkley	9.3E-01	1.3E-02	1.4E-03	9.4E-01	1.4E-03	1.0E+00	1.4E-03
2157 Berkley	9.3E-01	4.0E-03	1.9E-03	9.3E-01	1.8E-03	1.0E+00	1.8E-03
2175 Berkley	7.0E-01	2.0E-02	7.7E-03	7.2E-01	5.5E-03	1.0E+00	5.5E-03
2191 Berkley	4.7E-01	1.3E-02	1.4E-02	4.8E-01	6.9E-03	1.0E+00	6.9E-03
2205 Berkley	4.0E-01	5.8E-03	4.8E-03	4.0E-01	1.9E-03	1.0E+00	1.9E-03
2217 Berkley	1.7E-01	5.8E-03	6.0E-03	1.8E-01	1.1E-03	1.0E+00	1.1E-03
2223 Berkley	9.1E-02	5.8E-03	1.9E-03	9.7E-02	1.9E-04	1.0E+00	1.9E-04
2249 Berkley	9.7E-03	4.0E-03	4.8E-03	1.4E-02	6.6E-05	1.0E+00	6.6E-05
2251 Berkley	1.6E-03	4.0E-03	1.9E-03	5.6E-03	1.1E-05	1.0E+00	1.1E-05
2265 Berkley	8.1E-04	8.0E-03	2.4E-03	8.8E-03	2.1E-05	1.0E+00	2.1E-05
2279 Berkley	0.0E+00	5.8E-03	9.6E-04	5.8E-03	5.6E-06	1.0E+00	5.6E-06
2293 Berkley	0.0E+00	4.0E-03	2.4E-03	4.0E-03	9.6E-06	1.0E+00	9.6E-06
2307 Berkley	0.0E+00	5.8E-03	1.2E-03	5.8E-03	7.0E-06	1.0E+00	7.0E-06
2321 Berkley	0.0E+00	1.3E-02	1.2E-03	1.3E-02	1.6E-05	1.0E+00	1.6E-05
2335 Berkley	0.0E+00	4.0E-03	1.2E-03	4.0E-03	4.8E-06	1.0E+00	4.8E-06
2349 Berkley	0.0E+00	4.0E-03	2.4E-03	4.0E-03	9.6E-06	1.0E+00	9.6E-06
2363 Berkley	0.0E+00	5.8E-03	1.8E-03	5.8E-03	1.0E-05	1.0E+00	1.0E-05
2377 Berkley	0.0E+00	8.0E-03	6.0E-03	8.0E-03	4.8E-05	1.0E+00	4.8E-05
2391 Berkley	0.0E+00	4.0E-03	6.0E-03	4.0E-03	2.4E-05	1.0E+00	2.4E-05
2409 Berkley	0.0E+00	4.0E-03	9.6E-03	4.0E-03	3.8E-05	1.0E+00	3.8E-05
2425 Berkley	0.0E+00	4.0E-03	1.9E-03	4.0E-03	7.7E-06	1.0E+00	7.7E-06

Note: Where total number of estimated fatalities was less than 1, slide frequency was multiplied by the expected number of fatalities to obtain the expected frequency of at least one fatality. These revised F-N pairs were plotted on the graph.

0.067 (fatalities/year)   15.02 (years/fatality)

F-N Pairs for Hypothetical Flow Slides Originating from Crest of Escarpment