KLOHN CRIPPEN

June 24, 2003

Ministry of Transportation
Thompson-Okanagan Region
1165 Battle Street, Rear Top Floor
Kamloops, British Columbia
V2C 2N4

Mr. Terry Harbicht, P.Eng., Project Manager

Dear Mr. Harbicht:

Consulting Services Contract 256CS0321
Hummingbird Creek Debris Flow – Decision Analysis

We are pleased to submit our report presenting our decision analysis of debris flow potential risk at Hummingbird Creek, near Sicamous, British Columbia. This work was conducted under authorization of Contract # 256CS0321.

We are available at your convenience to discuss the implementation of recommendations included in this report. We thank you for the opportunity to work on this challenging project.

Yours truly,

KLOHN CRIPPEN CONSULTANTS COLUMBIA LTD.

Neil K. Singh (Hemrajani), P.Eng.
Project Manager

NS:gs

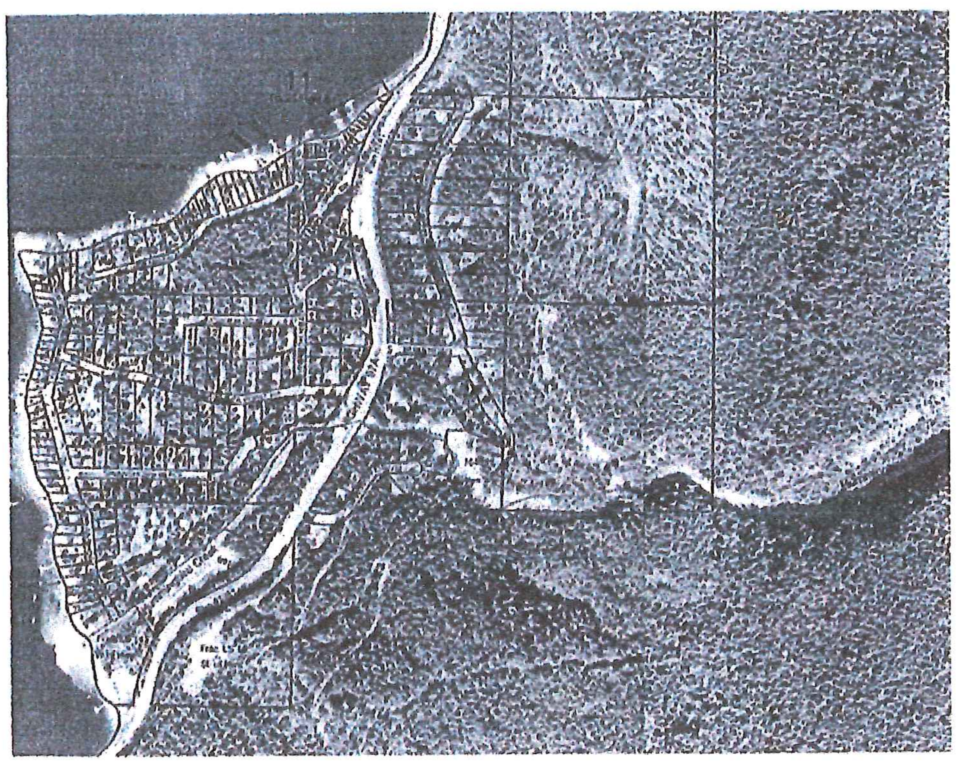
Suite 202, 542 Baker Street, Nelson, B.C., Canada V1L 4H9 • T (250) 505 5020 • F (250) 505 5030

British Columbia
Ministry of Transportation

British Columbia
Ministry of Community, Aboriginal and Women's Services

HUMMINGBIRD CREEK DEBRIS FLOW DECISION ANALYSIS

Final Report



G09143 01

June 2003

EXECUTIVE SUMMARY

On July 11, 1997, one of the largest non-volcanic debris flows in British Columbia history impacted Swansea Point, resulting in physical damage of over $4,000,000 (2003 $CAN), with one indirect death from heart attack. There is ongoing risk to Swansea Point from debris flows.

The Ministry of Transportation and Ministry of Community, Aboriginal and Women's Services retained Klohn Crippen Consultants Ltd. to review background information, review mitigation options and to conduct a decision analysis to select a mitigation option that will provide a reasonable level of protection to Swansea Point. The decision analysis framework consists of an evaluation of annualized total cost including both capital construction cost and risk cost. Costs include restitution of physical damage, clean-up and capital construction, but do not include environmental damages, bodily injury or loss of life, loss of use or loss of enjoyment, or litigation. The effects of debris flows were only considered at Swansea Point, not higher in the watershed. Risk of loss of life was assessed in separately from the cost-based decision analysis.

Klohn Crippen conducted a field visit, a review of background information including debris flow history and mitigative options, a review of hydrologic data and trends, and a review of cost data. A decision tree framework was built using the background information as inputs to evaluate the options.

A Failure Modes and Effects Analysis (FMEA) and Probabilistic Risk Analysis (PRA) were conducted. These analyses reduce the debris flow system into components that can be evaluated individually or systemically. The FMEA results in estimates of damage cost that are used in the PRA which uses probability distributions and cost inputs in a decision

tree to evaluate the probable annual cost resultant of each option. The key equation of this study is the evaluation of annualized total cost or:

$$C_T = C_C + C_R \tag{1}$$

Capital costs are based on conceptual designs of mitigative options and should be considered with a 25% to 40% contingency allowance if used for purposes beyond this decision analysis, such as for budgeting. The selected mitigation will need to proceed to detailed design prior to preparation of budget-level cost estimates. Risk costs are based on estimates of damage calibrated to the damage and cost of the 1997 debris flow event. Actual damage from future events will depend on local factors that cannot be accurately predicted. The total cost output is a relative comparison of three mitigation options. This comparison of cost assumes that principle stakeholders are not risk adverse to monetary factors.

The PRA relies on probabilities to quantify uncertainties. For this site, these probabilities are based on a combination of available data and subjective judgment. Judgmental probabilities rely on the amount and quality of information available and the experience of the assessor. Future evaluations of this site will change based on improved data and knowledge of the site characteristics.

Swansea Point, is located 10 km south of Sicamous on Highway 97A on the east shore of Mara Lake, built on an alluvial fan below the confluence of Mara and Hummingbird Creeks. The creeks are about 6 km in length with a combined catchment of 39 km^2, with steep headwater and transport segments and a flatter alluvial fan deposition area.

Review of rainfall and snowpack data from the nearby Salmon Arm and Enderby stations found that the 4- to 7-day rainfall was on the order of 30 to 80 year return period, the 3-month rainfall and the 9-month rain and snow accumulation were both of a 100 to 200 year return period. The rainfall trend-line has been increasing since 1900, and this trend is expected to increase through the 21st century. On this basis, the future frequency of debris flows is expected to increase.

Site bedrock (plutonic and metamorphic rock) has foliations, jointing, folding and faults throughout the region, with several lineations present in the Mara and Hummingbird catchments. Highly fractured rock serves as preferential seepage pathways for seepage. Surficial deposits include colluvial, fluvial, glaciofluvial, glaciolacustrine and morainal materials. Geologic processes, including rockfall, rockslides, debris slides, debris flows, soil and rock slumps and gully erosion modify the landscape. Both natural and man-made influences have caused slides. There is an ongoing risk of slope failures in or above the Mara and Hummingbird gullies.

The alluvial fan has formed from colluvial and alluvial processes over the last 10,000 years since glaciation. The mix of processes has created a complex geology with interlayers of high and low permeability layers. Water wells are expected to have widely varying yields due to local geologic variations.

Swansea Point includes approximately 270 lots with 90% developed as residences varying from 5th wheel trailers, to trailer parks to large single family homes. Utilities include gas, power, cable, and telephone. Development began in the early 1900's and current population is estimated at 500 to 600. Highway 97A crosses the eastern edge of the fan and there is a well-developed system of local roads. Forest harvesting and road building is ongoing in the watersheds.

The 1997 debris flow event of 92,000 m^3 is the only verified recorded event at Swansea Point. Damaging debris flows are defined in this report as events larger than 1,000 m^3. Other evidence of damaging debris flows includes five possible events identified in lake sediment cores, seven possible events identified by tree ring damage, three events identified by anecdote, and two to four events identified by air photograph interpretation of debris on the fan. Overall, there have been an estimated six to ten damaging debris flow or flood events in the last 75 years, or approximately eight to thirteen events per century, i.e., the annual probability of a damaging debris flow or flood event is 0.08 to 0.13. Future frequency is expected to increase due to hydrologic evidence and continued anthropogenic development.

Three debris flow frequency Scenarios were examined. Scenario 1 assumes a high frequency (0.17 annual probability) of damaging debris flows, Scenario 2 assumes a medium frequency (0.11 annual probability) and Scenario 3 assumes a lower frequency (0.08 annual probability). Six debris flow categories or event states were defined, classifying debris flows by size and three magnitude-recurrence relationships were derived for use in the high, medium and low frequency scenarios. Each magnitude-recurrence relationship was calibrated to the assumed annual probability of damaging event and checked against the actual fan accumulation rate of between 1,100 and 5,400 m^3 and meeting the requirement that events within Event State 4 recurred at between a 30 and 300 year interval, being the high and low frequency boundaries.

An acceptable threshold for debris flow hazard prior to subdivision approval is 1:10,000 (Cave, 1991). Swansea Point has a 1:6 to 1:15 annual probability of damaging debris flow (>1,000 m^3), with a 1:75 to 1:300 annual probability of a large (>50,000 m^3) debris flow. Boyer (2000) indicates that hazard at subdivisions with protective works should be at least 1:500 to 1:10,000. Mitigative measures at Swansea Point should reduce the annual probability of hazard to at least 1:500.

Mitigative measures could include passive or active options. Three options were selected for decision analysis, which represent minimum, intermediate and maximum capital cost, and provide a minimal, moderate and high reduction in risk respectively.

Option 1 includes Channel Improvements that reduce flood hazard but do not appreciably reduce risk from debris flow. Some channel improvements have been implemented but this work is currently on hold. Our opinion of probable cost of this option is $750,000 and this value was used for the decision analysis.

Option 2 includes a debris containment berm sized to contain 25,000 m^3, with associated training berms, retaining wall and outlet structures. Significant property acquisition would be required. This option may have the risk of diverting debris overflow into areas that it would not currently reach. Our opinion of probable cost of this option is $1,500,000.

Option 3 includes a debris containment berm sized to contain 150,000 m^3 with associated outlet structures and retaining wall. This option would require significant property acquisition. The Ministry of Transportation currently plans to upgrade the Highway 97A crossing. This proposed highway improvement may be incorporated into the Option 3 design, but additional study is required to verify the feasibility of combining these two projects. For the purpose of this decision analysis, the highway crossing cost savings is assumed to be additional irrespective of the mitigation option.

If the above opinions of cost are to be used for budgetary purposes, a contingency of 25% to 40% should be applied. At 33%, this would increase the cost estimates to approximately $1M for Option 1, $2M for Option 2 and $4M for Option 3. Decision analyses were conducted without application of contingency.

Other mitigative measures, including warning systems, forest management practices, check dams, impediments to flow, lateral or deflection berms, and creek channel linings were considered, and some aspects may be incorporated into the final selected mitigation option.

The FMEA examined the effects of direct and indirect impact on developments Swansea Point using DAN to predict the typical run-out distance of debris flows. Estimates of number of lots and homes impacted and the typical damage of debris flows from each of the six Event States were made. Six Damage States were defined to assist in evaluating the typical damage expected and in preparing a probability distribution of damage from average debris flow events. The damage probability distributions were varied until the end result, the expected damage cost was equal to the typical damage cost for Option 1, i.e., the situation with minimal mitigative measures. The probability of damages was reduced accordingly to reflect the reduction in expected damage costs with the implementation of mitigative Options 2 or 3. The expected damage cost becomes the risk cost in the decision matrix. Damage costs were calibrated against the actual cost of the 1997 debris flow.

The probability of the death of an individual (PDI) was calculated. The PDI does not predict the total number of deaths expected annually, but rather the increased risk of fatality to any given individual resident of Swansea Point, assuming a uniform application of hazard across the fan. In this regard, the PDI is considered a relative, not an absolute measure, of the risk of loss of life. It was found that the implementation of Option 2 would reduce the PDI risk by half and that Option 3 would reduce the risk by 75%. History indicates the risk of loss of life at Swansea Point is real and there is a strong likelihood of loss of life if no remediation is undertaken.

op. 1

Decision Trees were prepared for three Scenarios, High, Medium and Low Frequency, each evaluating three mitigative options, with six debris flow event states or classes, and six possible damage states from each debris flow. The summation of the end nodes represents the risk cost (C_R) of each option. The capital cost estimates were annualized by applying a discount rate of 4.5% and this capital cost (C_c) was added to the risk cost to prepare estimates of total annualized cost for each option within each scenario.

Option 3 was the lowest total cost in Scenario 1 (high frequency), and Option 2 was the lowest total cost in Scenario 2 (medium frequency) and Scenario 3 (low frequency). Option 1 is not recommended on the basis of annualized total cost.

The sensitivity of the decision analysis to the magnitude-recurrence frequency relationship (low, medium or high) was assessed by weighting the outcomes of each Scenario. The first blended scenario used an equal distribution of low/medium/high outcomes and the second blended scenario used a 20%/60%/20% blend of the low/medium/high outcomes. In the first blended Scenario, Option 2 is 5% lower cost than Option 3. In the second blend, Option 3 is 5% lower than Option 2. We conclude, in terms of lowest annualized total cost that Options 2 and 3 are essentially equal.

The sensitivity to the discount rate was also examined. The analysis is relatively insensitive to changes to the discount rate in the range of about 3.5% to 5%.

Option 3 has the added benefit of providing the greatest reduction in the Probability of the Death of an Individual. Option 3 would likely also reduce the debris flow hazard into the 1:500 to 1:10,000 range recommended for subdivision development with protective works and may allow incorporation of the MOT's planned highway culvert crossing upgrade for a further cost savings.

Development in high hazard areas on Swansea Point should not proceed without implementation of mitigative measures to reduce the risk. Ongoing forestry development in the Mara and Hummingbird watersheds should be carefully planned and designed so as to not worsen the hazard.